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Attorneys for Plaintiffs

UNITED STATES DISTRICT COURT
DISTRICT OF NEW JERSEY

EAGLE VIEW TECHNOLOGIES, INC., and PICTOMETRY INTERNATIONAL CORP.,	
Plaintiffs,	
v.	
XACTWARE SOLUTIONS, INC., and VERISK ANALYTICS, INC.,	
	Civil Action No. _________
Defendants.	

Plaintiffs Eagle View Technologies, Inc. ("Eagle View") and Pictometry International Corp. ("Pictometry") (collectively, "Plaintiffs"), by their undersigned attorneys, for their

Complaint against Defendants Xactware Solutions, Inc. ("Xactware") and Verisk Analytics, Inc. ("Verisk") (collectively, "Defendants"), hereby allege as follows:

NATURE OF ACTION

1. This is an action for patent infringement. Over the course of several years, Eagle View and its affiliate Pictometry have developed products that produce 3D models from aerial images of roofs, resulting in aerial roof reports that are extremely accurate and detailed. These reports are used, *inter alia*, to estimate the costs of roof repairs. Eagle View and Pictometry are market leaders in providing technologies relating to such reports in the construction and insurance markets. Xactware directly competes with Eagle View and Pictometry, including in the construction and insurance markets, with at least rooftop aerial measurement products, including Xactimate®, Roof InSight™, Property InSight™, and Aerial Sketch™ (collectively, "Accused Products"). Xactware is a wholly-owned subsidiary of Verisk, and Verisk has been and continues to be integrally involved in Xactware's operations. Plaintiffs Eagle View and Pictometry now bring this action to halt Defendants' respective infringement of seven patents, and obtain other relief as necessary. As more fully described below, each of Defendants Xactware and Verisk infringes each of United States Patent Nos. 8,078,436, 8,170,840, 8,209,152, 8,542,880, 8,818,770, 8,823,732, and 8,825,454 (collectively, "Patents-in-Suit") in connection with the Accused Products.

THE PARTIES

2. Plaintiff Eagle View Technologies, Inc. is a corporation organized and existing under the laws of the State of Washington, having a principal place of business at 3700 Monte Villa Parkway, Suite 200, Bothell, WA 98021. Eagle View launched in 2008, and was the first remote aerial roof measurement service. Eagle View has developed and continues to develop products that produce 3D models resulting in aerial roof and wall measurement reports. These reports are used, *inter alia*, to estimate the costs of roof repairs.

3. Plaintiff Pictometry International Corp. is a corporation organized and existing under the laws of the State of Delaware, having a principal place of business at 100 Town Centre Drive, Suite A, Rochester, NY 14623. Pictometry, which was founded in 1996, is an innovator of, among other things, aerial oblique image capture and processing technologies.

4. In January 2013, a merger between Eagle View and Pictometry resulted in the creation of a new company called EagleView Technology Corporation ("EVT"), which is comprised of Eagle View and Pictometry.

5. On information and belief, Defendant Xactware Solutions, Inc. is a corporation organized and existing under the laws of the State of Delaware, having a place of business at 545 Washington Boulevard, Jersey City, NJ 07310. Xactware directly competes with Eagle View and Pictometry, including in the construction and insurance markets, with at least the Accused Products.

6. On information and belief, Defendant Verisk Analytics, Inc. is a corporation organized and existing under the laws of the State of Delaware, having a principal place of business at 545 Washington Boulevard, Jersey City, NJ 07310. Xactware is a wholly-owned subsidiary of Verisk, and Verisk has been and continues to be integrally involved in Xactware's operations. According to Verisk's website, Xactware is a member of "The Verisk Family of Companies" (Ex. 1) and the President of Xactware, Jim Loveland, also is a Senior Vice President at Verisk (Ex. 2). According to records kept by the New Jersey Division of Revenue and Enterprise Services, Xactware maintains office space in the same building as Verisk, *i.e.*, 545 Washington Boulevard, Jersey City, NJ 07310. (Ex. 3).

PATENTS-IN-SUIT

7. Eagle View is the owner of the entire right, title, and interest in and to United States Patent No. 8,078,436 (the "'436 Patent"), entitled "Aerial Roof Estimation Systems and Methods," which was issued by the United States Patent and Trademark Office (USPTO) on December 13, 2011. A true and correct copy of the '436 Patent is attached hereto as Exhibit 4.

8. The '436 Patent is valid and enforceable.

9. Eagle View is the owner of the entire right, title, and interest in and to United States Patent No. 8,170,840 (the "'840 Patent"), entitled "Pitch Determination Systems and Methods for Aerial Roof Estimation," which was issued by the USPTO on May 1, 2012. A true and correct copy of the '840 Patent is attached hereto as Exhibit 5.

10. The '840 Patent is valid and enforceable.

11. Eagle View is the owner of the entire right, title, and interest in and to United States Patent No. 8,209,152 (the "'152 Patent"), entitled "Concurrent Display Systems and Methods for Aerial Roof Estimation," which was issued by the USPTO on June 26, 2012. A true and correct copy of the '152 Patent is attached hereto as Exhibit 6.

12. The '152 Patent is valid and enforceable.

13. Pictometry is the owner of the entire right, title, and interest in and to United States Patent No. 8,542,880 (the "'880 Patent"), entitled "System and Process for Roof Measurement Using Aerial Imagery," which was issued by the USPTO on September 24, 2013. A true and correct copy of the '880 Patent is attached hereto as Exhibit 7.

14. The '880 Patent is valid and enforceable.

15. Eagle View is the owner of the entire right, title, and interest in and to United States Patent No. 8,818,770 (the "'770 Patent"), entitled "Pitch Determination Systems and Methods for Aerial Roof Estimation," which was issued by the USPTO on August 26, 2014. A true and correct copy of the '770 Patent is attached hereto as Exhibit 8.

16. The '770 Patent is valid and enforceable.

17. Pictometry is the owner of the entire right, title, and interest in and to United States Patent No. 8,823,732 (the "'732 Patent"), entitled "Systems and Methods for Processing Images with Edge Detection and Snap-to Feature," which was issued by the USPTO on September 2, 2014. A true and correct copy of the '732 Patent is attached hereto as Exhibit 9.

18. The '732 Patent is valid and enforceable.

19. Eagle View is the owner of the entire right, title, and interest in and to United States Patent No. 8,825,454 (the "'454 Patent"), entitled "Concurrent Display Systems and

Methods for Aerial Roof Estimation," which was issued by the USPTO on September 2, 2014. A true and correct copy of the '454 Patent is attached hereto as Exhibit 10.

20. The '454 Patent is valid and enforceable.

JURISDICTION AND VENUE

21. This is an action for patent infringement arising under the provisions of the Patent Laws of the United States of America, Title 35, United States Code.

22. Subject matter jurisdiction over Plaintiffs' claims is conferred upon this Court by 28 U.S.C. §§ 1331 and 1338(a).

23. This Court has personal jurisdiction over Xactware because, *inter alia*, Xactware, on information and belief: (1) has substantial, continuous, and systematic contacts with this State; (2) is registered to do business in the State of New Jersey under entity ID # 0101006731 and has a registered agent for service of process in New Jersey (Ex. 3); (3) maintains a place of business in this State; (4) has solicited business in, transacted business within, and attempted to derive financial benefit from residents of New Jersey, on a substantial and not isolated basis; (5) has committed and continues to commit purposeful actions in this State that infringe the Patents-in-Suit; and (6) enjoys substantial income from such infringement in this State.

24. This Court has personal jurisdiction over Verisk because, *inter alia*, Verisk, on information and belief: (1) has substantial, continuous, and systematic contacts with this State; (2) maintains a principal place of business in this State; (3) has solicited business in, transacted business within, and attempted to derive financial benefit from residents of New Jersey, on a substantial and not isolated basis; (4) has committed and continues to commit purposeful actions in this State that infringe the Patents-in-Suit; and (5) enjoys substantial income from such infringement in this State.

25. Additionally, Verisk has previously consented to this Court's jurisdiction and availed itself of the protections afforded by this Court. *See, e.g.*, Defendant's Answer in *Austin v. Verisk Analytics, Inc. et al.*, Case No. 2:13-cv-04277.

26. Venue is proper in this Court under 28 U.S.C. §§ 1391 and 1400(b) because Xactware and Verisk have places of business in this District, have committed acts of infringement in this district, and are subject to personal jurisdiction in this district.

COUNT I – INFRINGEMENT OF THE ’436 PATENT BY XACTWARE

27. Plaintiffs reallege paragraphs 1-26 as if fully set forth herein.

28. The USPTO duly and legally issued the ‘436 Patent on December 13, 2011.

29. Xactware has directly and indirectly infringed and continues to directly and indirectly infringe the ‘436 Patent, in connection with rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™.

30. Xactware makes and uses rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™, within the United States, and as such, Xactware has directly infringed and continues to directly infringe, either literally or under the doctrine of equivalents, at least one claim of the ‘436 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(a).

31. On information and belief, Xactware has had knowledge of the ‘436 Patent since at least as early December 2014 in connection with Verisk’s intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View’s patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View’s patents, including the ‘436 Patent, prior to the termination of the EVT acquisition in December 2014.

32. On information and belief, Verisk has been and continues to be integrally involved in Xactware’s operations and as such, Xactware became aware of the ‘436 Patent through Verisk and the diligence Verisk performed in connection with its intended acquisition of EVT.

33. Xactware also has had knowledge of the ‘436 Patent since at least as early as May 22, 2012, when it submitted an Information Disclosure Statement (IDS) identifying the ‘436

Patent to the USPTO during the prosecution of its own U.S. Patent Application No. 13/397,325. (Ex. 11).

34. In addition to directly infringing the ‘436 Patent, Xactware has in the past and continues to indirectly infringe the ‘436 Patent by inducing direct infringement by others, such as end users of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™. As set forth above, Xactware knew or should have known that use of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™, by its end users infringes at least one claim of the ’436 Patent since at least as early as the first such infringing use of such products after May 22, 2012. Xactware knowingly induced such use of those products in a manner that infringes the ’436 Patent, including through at least promotional, advertising, and instructional materials, and Xactware had the requisite intent to encourage such infringement. As such, Xactware has indirectly infringed and continues to indirectly infringe at least one claim of the ‘436 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

35. Xactware’s infringement of the ’436 Patent has been and continues to be willful. Xactware has acted with knowledge of the ’436 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the ’436 Patent. For example, subsequent to being informed of the ’436 Patent, Xactware continued to make and use rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™, within the United States in a manner that infringes the ‘436 Patent. Xactware has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the ’436 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Xactware. Xactware’s infringement of the ’436 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

36. Xactware's acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Xactware the damages sustained by Eagle View as a result of Xactware's wrongful acts in an amount subject to proof at trial.

37. Xactware's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

38. This case is exceptional, entitling Eagle View to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT II – INFRINGEMENT OF THE '436 PATENT BY VERISK

39. Plaintiffs reallege paragraphs 1-38 as if fully set forth herein.

40. Verisk has indirectly infringed and continues to indirectly infringe the '436 Patent, in connection with Xactware's rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™.

41. On information and belief, Verisk has had knowledge of the '436 Patent since at least as early as December 2014 in connection with its intended acquisition of EVT. In January 2014, Verisk signed an agreement to acquire EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View's patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View's patents, including the '436 Patent, prior to the termination of the EVT acquisition in December 2014.

42. On information and belief, Verisk also has had knowledge of the '436 Patent since at least as early as May 22, 2012, when Xactware submitted an IDS identifying the '436 Patent to the USPTO during the prosecution of Xactware's U.S. Patent Application No. 13/397,325. (Ex. 11). On information and belief, Verisk has been and continues to be integrally involved in Xactware's operations and as such, stays apprised of Xactware's patent holdings and the prosecution of its patent applications.

43. Verisk has in the past and continues to indirectly infringe the '436 Patent by inducing direct infringement by Xactware, including Xactware's making and using rooftop aerial

measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™, within the United States. As set forth above, Verisk knew or should have known that Xactware's actions infringe the claims of the '436 Patent since at least as early as Xactware's first such act of direct infringement with respect to those products after May 22, 2012. Verisk knowingly induced Xactware's making and using of such products in a manner that infringes the '436 Patent, including through at least its involvement in and control over the development, support, sale, and distribution of these products (*e.g.*, through procuring aerial images to be used therein (*see* Ex. 12), through taking actions to broaden Xactware's customer base therefor (*see* Ex. 2), and in the marketing and promotion of these products (*e.g.*, through Verisk's website (*see* Exs. 13-15)), and Verisk had the requisite intent to encourage such infringement. Indeed, Jim Loveland is both a Senior Vice President at Verisk and Xactware's President, and has "overseen the release of many new [Xactware] products and services." (Ex. 2). Accordingly, Verisk has indirectly infringed and continues to indirectly infringe at least one claim of the '436 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

44. Verisk's infringement of the '436 Patent has been and continues to be willful. Verisk has acted with knowledge of the '436 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '436 Patent. For example, subsequent to being informed of the '436 Patent, Verisk continued to induce Xactware's making and using of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Property Insight™ in a manner that infringes the '436 Patent. Verisk has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the '436 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Verisk. Verisk's infringement of the '436 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

45. Verisk's acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Verisk the damages sustained by Eagle View as a result of Verisk's wrongful acts in an amount subject to proof at trial.

46. Verisk's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

47. This case is exceptional, entitling Eagle View to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT III – INFRINGEMENT OF THE '840 PATENT BY XACTWARE

48. Plaintiffs reallege paragraphs 1-47 as if fully set forth herein.

49. The USPTO duly and legally issued the '840 Patent on May 1, 2012.

50. Xactware has directly and indirectly infringed and continues to directly and indirectly infringe the '840 Patent, in connection with rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

51. Xactware makes and uses rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States, and as such, Xactware has directly infringed and continues to directly infringe, either literally or under the doctrine of equivalents, at least one claim of the '840 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(a).

52. On information and belief, Xactware has had knowledge of the '840 Patent since at least as early December 2014 in connection with Verisk's intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View's patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View's patents, including the '840 Patent, prior to the termination of the EVT acquisition in December 2014.

53. On information and belief, Verisk has been and continues to be integrally involved in Xactware's operations and as such, Xactware became aware of the '840 Patent

through Verisk and the diligence Verisk performed in connection with its intended acquisition of EVT.

54. On information and belief, Xactware also has had knowledge of the ‘840 Patent since May 22, 2012, when Xactware submitted an IDS identifying U.S. Patent Publication Number 2010/0110074, which corresponds to the ‘840 Patent, to the USPTO during the prosecution of its own U.S. Patent Application No. 13/397,325. (Ex. 11).

55. In addition to directly infringing the ‘840 Patent, Xactware has in the past and continues to indirectly infringe the ‘840 Patent by inducing direct infringement by others, such as end users of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™. As set forth above, Xactware knew or should have known that use of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, by its end users infringes at least one claim of the ’840 Patent since at least as early as the first such infringing use of such products after May 22, 2012. Xactware knowingly induced such use of those products in a manner that infringes the ’840 Patent, including through at least promotional, advertising, and instructional materials, and Xactware had the requisite intent to encourage such infringement. As such, Xactware has indirectly infringed and continues to indirectly infringe at least one claim of the ‘840 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

56. Xactware’s infringement of the ’840 Patent has been and continues to be willful. Xactware has acted with knowledge of the ’840 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the ’840 Patent. For example, subsequent to being informed of the ’840 Patent, Xactware continued to make and use rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States in a manner that infringes the ‘840 Patent. Xactware has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the ’840 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Xactware. Xactware’s infringement of

the ’840 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

57. Xactware’s acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Xactware the damages sustained by Eagle View as a result of Xactware’s wrongful acts in an amount subject to proof at trial.

58. Xactware’s acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

59. This case is exceptional, entitling Eagle View to an award of attorneys’ fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT IV – INFRINGEMENT OF THE ’840 PATENT BY VERISK

60. Plaintiffs reallege paragraphs 1-59 as if fully set forth herein.

61. Verisk has indirectly infringed and continues to indirectly infringe the ‘840 Patent, in connection with Xactware’s rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

62. On information and belief, Verisk has had knowledge of the ‘840 Patent since at least as early as December 2014 in connection with its intended acquisition of EVT. In January 2014, Verisk signed an agreement to acquire EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View’s patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View’s patents, including the ‘840 Patent, prior to the termination of the EVT acquisition in December 2014.

63. On information and belief, Verisk also has had knowledge of the ‘840 Patent since May 22, 2012, when Xactware submitted an IDS identifying U.S. Patent Publication Number 2010/0110074, which corresponds to the ‘840 Patent, to the USPTO during the prosecution of its own U.S. Patent Application No. 13/397,325. (Ex. 11). On information and belief, Verisk has been and continues to be integrally involved in Xactware’s operations and as such, stays apprised of Xactware’s patent holdings and the prosecution of its patent applications.

64. Verisk has in the past and continues to indirectly infringe the ‘840 Patent by inducing direct infringement by Xactware, including Xactware’s making and using rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States. As set forth above, Verisk knew or should have known that Xactware’s actions infringe the claims of the ’840 Patent since at least as early as Xactware’s first such act of direct infringement with respect to those products after May 22, 2012. Verisk knowingly induced Xactware’s making and using of such products in a manner that infringes the ’840 Patent, including through at least its involvement in and control over the development, support, sale, and distribution of these products (*e.g.*, through procuring aerial images to be used therein (*see* Ex. 12) and through taking actions to broaden Xactware’s customer base therefor (*see* Ex. 2), and in the marketing and promotion of these products (*e.g.*, through Verisk’s website (*see* Exs. 13-15)), and Verisk had the requisite intent to encourage such infringement. Indeed, Jim Loveland is both a Senior Vice President at Verisk and Xactware’s President, and has “overseen the release of many new [Xactware] products and services.” (Ex. 2). Accordingly, Verisk has indirectly infringed and continues to indirectly infringe at least one claim of the ‘840 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

65. Verisk’s infringement of the ’840 Patent has been and continues to be willful. Verisk has acted with knowledge of the ’840 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the ’840 Patent. For example, subsequent to being informed of the ’840 Patent, Verisk continued to induce Xactware’s making and using of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™ in a manner that infringes the ’840 Patent. Verisk has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the ’840 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Verisk. Verisk’s infringement of the ’840 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

66. Verisk's acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Verisk the damages sustained by Eagle View as a result of Verisk's wrongful acts in an amount subject to proof at trial.

67. Verisk's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

68. This case is exceptional, entitling Eagle View to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT V – INFRINGEMENT OF THE '152 PATENT BY XACTWARE

69. Plaintiffs reallege paragraphs 1-68 as if fully set forth herein.

70. The USPTO duly and legally issued the '152 Patent on June 26, 2012.

71. Xactware has directly and indirectly infringed and continues to directly and indirectly infringe the '152 Patent, in connection with rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

72. Xactware makes and uses rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States, and as such, Xactware has directly infringed and continues to directly infringe, either literally or under the doctrine of equivalents, at least one claim of the '152 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(a).

73. On information and belief, Xactware has had knowledge of the '152 Patent since at least as early December 2014 in connection with Verisk's intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View's patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View's patents, including the '152 Patent, prior to the termination of the EVT acquisition in December 2014.

74. On information and belief, Verisk has been and continues to be integrally involved in Xactware's operations and as such, Xactware became aware of the '152 Patent

through Verisk and the diligence Verisk performed in connection with its intended acquisition of EVT.

75. On information and belief, Xactware also has had knowledge of the ‘152 Patent since it issued on June 26, 2012. On May 22, 2012, Xactware submitted an IDS identifying U.S. Patent Publication Number 2010/0114537, which corresponds to the ‘152 Patent, to the USPTO during the prosecution of its own U.S. Patent Application No. 13/397,325. (Ex. 11).

76. In addition to directly infringing the ‘152 Patent, Xactware has in the past and continues to indirectly infringe the ‘152 Patent by inducing direct infringement by others, such as end users of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™. As set forth above, Xactware knew or should have known that use of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, by its end users infringes at least one claim of the ’152 Patent since at least as early the first such infringing use of such products after June 26, 2012. Xactware knowingly induced such use of those products in a manner that infringes the ’152 Patent, including through at least promotional, advertising, and instructional materials, and Xactware had the requisite intent to encourage such infringement. As such, Xactware has indirectly infringed and continues to indirectly infringe at least one claim of the ‘152 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

77. Xactware’s infringement of the ’152 Patent has been and continues to be willful. Xactware has acted with knowledge of the ’152 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the ’152 Patent. For example, subsequent to being informed of the ’152 Patent, Xactware continued to make and use rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States in a manner that infringes the ‘152 Patent. Xactware has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the ’152 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Xactware. Xactware’s infringement of

the ’152 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

78. Xactware’s acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Xactware the damages sustained by Eagle View as a result of Xactware’s wrongful acts in an amount subject to proof at trial.

79. Xactware’s acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

80. This case is exceptional, entitling Eagle View to an award of attorneys’ fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT VI – INFRINGEMENT OF THE ’152 PATENT BY VERISK

81. Plaintiffs reallege paragraphs 1-80 as if fully set forth herein.

82. Verisk has indirectly infringed and continues to indirectly infringe the ‘152 Patent, in connection with Xactware’s rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

83. On information and belief, Verisk has had knowledge of the ‘152 Patent since at least as early as December 2014 in connection with its intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View’s patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View’s patents, including the ‘152 Patent, prior to the termination of the EVT acquisition in December 2014.

84. On information and belief, Verisk also has had knowledge of the ‘152 Patent since it issued on June 26, 2012. On May 22, 2012, Xactware submitted an IDS identifying U.S. Patent Publication Number 2010/0114537, which corresponds to the ‘152 Patent, to the USPTO during the prosecution of its own U.S. Patent Application No. 13/397,325. (Ex. 11). On information and belief, Verisk has been and continues to be integrally involved in Xactware’s

operations and as such, stays apprised of Xactware's patent holdings and the prosecution of its patent applications.

85. Verisk has in the past and continues to indirectly infringe the '152 Patent by inducing direct infringement by Xactware, including Xactware's making and using rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States. As set forth above, Verisk knew or should have known that Xactware's actions infringe the claims of the '152 Patent since at least as early as Xactware's first such act of direct infringement with respect to those products after June 26, 2012. Verisk knowingly induced Xactware's making and using of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, in a manner that infringes the '152 Patent, including through at least its involvement in and control over the development, support, sale, and distribution of these products (*e.g.*, through procuring aerial images to be used therein (*see* Ex. 12), through taking actions to broaden Xactware's customer base therefor (*see* Ex. 2), and in the marketing and promotion of these products, including through Verisk's website (*see* Exs. 13-15)), and Verisk had the requisite intent to encourage such infringement. Indeed, Jim Loveland is both a Senior Vice President at Verisk and Xactware's President, and has "overseen the release of many new [Xactware] products and services." (Ex. 2). Accordingly, Verisk has indirectly infringed and continues to indirectly infringe at least one claim of the '152 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

86. Verisk's infringement of the '152 Patent has been and continues to be willful. Verisk has acted with knowledge of the '152 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '152 Patent. For example, subsequent to being informed of the '152 Patent, Verisk continued to induce Xactware's making and using of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, in a manner that infringes the '152 Patent. Verisk has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the '152 Patent. This objectively-defined risk was known

or is so obvious that it should have been known to Verisk. Verisk's infringement of the '152 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

87. Verisk's acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Verisk the damages sustained by Eagle View as a result of Verisk's wrongful acts in an amount subject to proof at trial.

88. Verisk's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

89. This case is exceptional, entitling Eagle View to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT VII – INFRINGEMENT OF THE '880 PATENT BY XACTWARE

90. Plaintiffs reallege paragraphs 1-89 as if fully set forth herein.

91. The USPTO duly and legally issued the '880 Patent on September 24, 2013.

92. Xactware has directly and indirectly infringed and continues to directly and indirectly infringe the '880 Patent, in connection with rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™.

93. Xactware makes and uses rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™, within the United States, and as such, Xactware has directly infringed and continues to directly infringe, either literally or under the doctrine of equivalents, at least one claim of the '880 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(a).

94. On information and belief, Xactware has had knowledge of the '880 Patent since at least as early December 2014 in connection with Verisk's intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Pictometry's patent holdings. EVT personnel had discussions with representatives of Verisk

concerning Pictometry's patents, including the '880 Patent, prior to the termination of the EVT acquisition in December 2014.

95. On information and belief, Verisk has been and continues to be integrally involved in Xactware's operations and as such, Xactware became aware of the '880 Patent through Verisk and the diligence Verisk performed in connection with its intended acquisition of EVT.

96. In addition to directly infringing the '880 Patent, Xactware has in the past and continues to indirectly infringe the '880 Patent by inducing direct infringement by others, such as end users of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™. As set forth above, Xactware knew or should have known that use of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™, by its end users infringes at least one claim of the '880 Patent since at least as early as the first such infringing use of such products after December 2014. Xactware knowingly induced such use of those products in a manner that infringes the '880 Patent, including through at least promotional, advertising, and instructional materials, and Xactware had the requisite intent to encourage such infringement. As such, Xactware has indirectly infringed and continues to indirectly infringe at least one claim of the '880 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

97. Xactware's infringement of the '880 Patent has been and continues to be willful. Xactware has acted with knowledge of the '880 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '880 Patent. For example, subsequent to being informed of the '880 Patent, Xactware continued to make and use rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™, within the United States in a manner that infringes the '880 Patent. Xactware has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the '880 Patent. This

objectively-defined risk was known or is so obvious that it should have been known to Xactware. Xactware's infringement of the '880 Patent has been and continues to be willful, entitling Pictometry to enhanced damages under 35 U.S.C. § 284.

98. Xactware's acts of infringement have caused damage to Pictometry, and Pictometry is entitled to recover from Xactware the damages sustained by Pictometry as a result of Xactware's wrongful acts in an amount subject to proof at trial.

99. Xactware's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Pictometry for which there is no adequate remedy at law.

100. This case is exceptional, entitling Pictometry to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT VIII – INFRINGEMENT OF THE '880 PATENT BY VERISK

101. Plaintiffs reallege paragraphs 1-100 as if fully set forth herein.

102. Verisk has indirectly infringed and continues to indirectly infringe the '880 Patent, in connection with Xactware's rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™.

103. On information and belief, Verisk has had knowledge of the '880 Patent since at least as early as December 2014 in connection with its intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Pictometry's patent holdings. EVT personnel had discussions with representatives of Verisk concerning Pictometry's patents, including the '880 Patent, prior to the termination of the EVT acquisition in December 2014.

104. Verisk has in the past and continues to indirectly infringe the '880 Patent by inducing direct infringement by Xactware, including Xactware's making and using rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™, within the United States. As set forth above, Verisk knew or should have known that Xactware's actions infringe the claims of the '880 Patent since at least as

early as Xactware's first such act of direct infringement with respect to those products after December 2014. Verisk knowingly induced Xactware's making and using of such products in a manner that infringes the '880 Patent, including through at least its involvement in and control over the development, support, sale, and distribution of these products (*e.g.*, through procuring aerial images to be used therein (*see* Ex. 12), through taking actions to broaden Xactware's customer base therefor (*see* Ex. 2), and in the marketing and promotion of these products, including through Verisk's website (*see* Exs. 13-15)), and Verisk had the requisite intent to encourage such infringement. Indeed, Jim Loveland is both a Senior Vice President at Verisk and Xactware's President, and has "overseen the release of many new [Xactware] products and services." (Ex. 2). Accordingly, Verisk has indirectly infringed and continues to indirectly infringe at least one claim of the '880 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

105. Verisk's infringement of the '880 Patent has been and continues to be willful. Verisk has acted with knowledge of the '880 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '880 Patent. For example, subsequent to being informed of the '880 Patent, Verisk continued to induce Xactware's making and using of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Roof InSight™ and/or Aerial Sketch™, in a manner that infringes the '880 Patent. Verisk has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the '880 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Verisk. Verisk's infringement of the '880 Patent has been and continues to be willful, entitling Pictometry to enhanced damages under 35 U.S.C. § 284.

106. Verisk's acts of infringement have caused damage to Pictometry, and Pictometry is entitled to recover from Verisk the damages sustained by Pictometry as a result of Verisk's wrongful acts in an amount subject to proof at trial.

107. Verisk's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Pictometry for which there is no adequate remedy at law.

108. This case is exceptional, entitling Pictometry to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT IX – INFRINGEMENT OF THE '770 PATENT BY XACTWARE

109. Plaintiffs reallege paragraphs 1-108 as if fully set forth herein.

110. The USPTO duly and legally issued the '770 Patent on August 26, 2014.

111. Xactware has directly and indirectly infringed and continues to directly and indirectly infringe the '770 Patent, in connection with rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

112. Xactware makes and uses rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States, and as such, Xactware has directly infringed and continues to directly infringe, either literally or under the doctrine of equivalents, at least one claim of the '770 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(a).

113. On information and belief, Xactware has had knowledge of the '770 Patent since at least as early December 2014 in connection with Verisk's intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View's patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View's patents, including the '770 Patent, prior to the termination of the EVT acquisition in December 2014.

114. On information and belief, Verisk has been and continues to be integrally involved in Xactware's operations and as such, Xactware became aware of the '770 Patent through Verisk and the diligence Verisk performed in connection with its intended acquisition of EVT.

115. In addition to directly infringing the ‘770 Patent, Xactware has in the past and continues to indirectly infringe the ‘770 Patent by inducing direct infringement by others, such as end users of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™. As set forth above, Xactware knew or should have known that use of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, by its end users infringes at least one claim of the ’770 Patent since at least as early as the first such infringing use of such products after December 2014. Xactware knowingly induced such use of those products in a manner that infringes the ’770 Patent, including through at least promotional, advertising, and instructional materials, and Xactware had the requisite intent to encourage such infringement. As such, Xactware has indirectly infringed and continues to indirectly infringe at least one claim of the ‘770 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

116. Xactware’s infringement of the ’770 Patent has been and continues to be willful. Xactware has acted with knowledge of the ’770 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the ’770 Patent. For example, subsequent to being informed of the ’770 Patent, Xactware continued to make and use rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States in a manner that infringes the ‘770 Patent. Xactware has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the ’770 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Xactware. Xactware’s infringement of the ’770 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

117. Xactware’s acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Xactware the damages sustained by Eagle View as a result of Xactware’s wrongful acts in an amount subject to proof at trial.

118. Xactware's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

119. This case is exceptional, entitling Eagle View to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT X – INFRINGEMENT OF THE '770 PATENT BY VERISK

120. Plaintiffs reallege paragraphs 1-119 as if fully set forth herein.

121. Verisk has indirectly infringed and continues to indirectly infringe the '770 Patent, in connection with Xactware's rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

122. On information and belief, Verisk has had knowledge of the '770 Patent since at least as early as December 2014 in connection with its intended acquisition of EVT. In January 2014, Verisk signed an agreement to acquire EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View's patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View's patents, including the '770 Patent, prior to the termination of the EVT acquisition in December 2014.

123. Verisk has in the past and continues to indirectly infringe the '770 Patent by inducing direct infringement by Xactware, including Xactware's making and using rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States. As set forth above, Verisk knew or should have known that Xactware's actions infringe the claims of the '770 Patent since at least as early as Xactware's first such act of direct infringement with respect to those products after December 2014. Verisk knowingly induced Xactware's making and using of such products in a manner that infringes the '770 Patent, including through at least its involvement in and control over the development, support, sale, and distribution of these products (*e.g.*, through procuring aerial images to be used therein (*see* Ex. 12), through taking actions to broaden Xactware's customer base therefor (*see* Ex. 2), and in the marketing and promotion of these products, including through Verisk's website

(*see* Exs. 13-15)), and Verisk had the requisite intent to encourage such infringement. Indeed, Jim Loveland is both a Senior Vice President at Verisk and Xactware's President, and has "overseen the release of many new [Xactware] products and services." (Ex. 2). Accordingly, Verisk has indirectly infringed and continues to indirectly infringe at least one claim of the '770 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

124. Verisk's infringement of the '770 Patent has been and continues to be willful. Verisk has acted with knowledge of the '770 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '770 Patent. For example, subsequent to being informed of the '770 Patent, Verisk continued to induce Xactware's making and using of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, in a manner that infringes the '770 Patent. Verisk has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the '770 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Verisk. Verisk's infringement of the '770 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

125. Verisk's acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Verisk the damages sustained by Eagle View as a result of Verisk's wrongful acts in an amount subject to proof at trial.

126. Verisk's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

127. This case is exceptional, entitling Eagle View to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT XI – INFRINGEMENT OF THE '732 PATENT BY XACTWARE

128. Plaintiffs reallege paragraphs 1-127 as if fully set forth herein.

129. The USPTO duly and legally issued the '732 Patent on September 2, 2014.

130. Xactware has directly and indirectly infringed and continues to directly and indirectly infringe the ‘732 Patent, in connection with rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

131. Xactware makes and uses rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States, and as such, Xactware has directly infringed and continues to directly infringe, either literally or under the doctrine of equivalents, at least one claim of the ‘732 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(a).

132. On information and belief, Xactware has had knowledge of the ‘732 Patent since at least as early December 2014 in connection with Verisk’s intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Pictometry’s patent holdings. EVT personnel had discussions with representatives of Verisk concerning Pictometry’s patents, including the ‘732 Patent, prior to the termination of the EVT acquisition in December 2014.

133. On information and belief, Verisk has been and continues to be integrally involved in Xactware’s operations and as such, Xactware became aware of the ‘732 Patent through Verisk and the diligence Verisk performed in connection with its intended acquisition of EVT.

134. In addition to directly infringing the ‘732 Patent, Xactware has in the past and continues to indirectly infringe the ‘732 Patent by inducing direct infringement by others, such as end users of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™. As set forth above, Xactware knew or should have known that use of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, by its end users infringes at least one claim of the ’732 Patent since at least as early as the first such infringing use of such products after December 2014. Xactware knowingly induced such use of those products in a manner that infringes the ’732 Patent, including through at least promotional, advertising, and instructional materials, and

Xactware had the requisite intent to encourage such infringement. As such, Xactware has indirectly infringed and continues to indirectly infringe at least one claim of the '732 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

135. Xactware's infringement of the '732 Patent has been and continues to be willful. Xactware has acted with knowledge of the '732 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '732 Patent. For example, subsequent to being informed of the '732 Patent, Xactware continued to make and use rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States in a manner that infringes the '732 Patent. Xactware has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the '732 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Xactware. Xactware's infringement of the '732 Patent has been and continues to be willful, entitling Pictometry to enhanced damages under 35 U.S.C. § 284.

136. Xactware's acts of infringement have caused damage to Pictometry, and Pictometry is entitled to recover from Xactware the damages sustained by Pictometry as a result of Xactware's wrongful acts in an amount subject to proof at trial.

137. Xactware's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Pictometry for which there is no adequate remedy at law.

138. This case is exceptional, entitling Pictometry to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT XII – INFRINGEMENT OF THE '732 PATENT BY VERISK

139. Plaintiffs reallege paragraphs 1-138 as if fully set forth herein.

140. Verisk has indirectly infringed and continues to indirectly infringe the '732 Patent, in connection with Xactware's rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

141. On information and belief, Verisk has had knowledge of the ‘732 Patent since at least as early as December 2014 in connection with its intended acquisition of EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Pictometry’s patent holdings. EVT personnel had discussions with representatives of Verisk concerning Pictometry’s patents, including the ‘732 Patent, prior to the termination of the EVT acquisition in December 2014.

142. Verisk has in the past and continues to indirectly infringe the ‘732 Patent by inducing direct infringement by Xactware, including Xactware’s making and using rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States. As set forth above, Verisk knew or should have known that Xactware’s actions infringe the claims of the ’732 Patent since at least as early as Xactware’s first such act of direct infringement with respect to those products after December 2014. Verisk knowingly induced Xactware’s making and using of such products in a manner that infringes the ’732 Patent, including through at least its involvement in and control over the development, support, sale, and distribution of these products (*e.g.*, through procuring aerial images to be used therein (*see* Ex. 12), through taking actions to broaden Xactware’s customer base therefor (*see* Ex. 2), and in the marketing and promotion of these products, including through Verisk’s website (*see* Exs. 13-15)), and Verisk had the requisite intent to encourage such infringement. Indeed, Jim Loveland is both a Senior Vice President at Verisk and Xactware’s President, and has “overseen the release of many new [Xactware] products and services.” (Ex. 2). Accordingly, Verisk has indirectly infringed and continues to indirectly infringe at least one claim of the ‘732 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

143. Verisk’s infringement of the ’732 Patent has been and continues to be willful. Verisk has acted with knowledge of the ’732 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the ’732 Patent. For example, subsequent to being informed of the ’732 Patent, Verisk continued to induce Xactware’s making and using of rooftop aerial measurement products, including but not limited to Xactimate® in

combination with Aerial Sketch™, in a manner that infringes the ’732 Patent. Verisk has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the ’732 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Verisk. Verisk’s infringement of the ’732 Patent has been and continues to be willful, entitling Pictometry to enhanced damages under 35 U.S.C. § 284.

144. Verisk’s acts of infringement have caused damage to Pictometry, and Pictometry is entitled to recover from Verisk the damages sustained by Pictometry as a result of Verisk’s wrongful acts in an amount subject to proof at trial.

145. Verisk’s acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Pictometry for which there is no adequate remedy at law.

146. This case is exceptional, entitling Pictometry to an award of attorneys’ fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT XIII – INFRINGEMENT OF THE ’454 PATENT BY XACTWARE

147. Plaintiffs reallege paragraphs 1-146 as if fully set forth herein.

148. The USPTO duly and legally issued the ‘454 Patent on September 2, 2014.

149. Xactware has directly and indirectly infringed and continues to directly and indirectly infringe the ‘454 Patent, in connection with rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

150. Xactware uses rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States, and as such, Xactware has directly infringed and continues to directly infringe, either literally or under the doctrine of equivalents, at least one claim of the ‘454 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(a).

151. On information and belief, Xactware has had knowledge of the ‘454 Patent since at least as early December 2014 in connection with Verisk’s intended acquisition of EVT.

Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View's patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View's patents, including the '454 Patent, prior to the termination of the EVT acquisition in December 2014.

152. On information and belief, Verisk has been and continues to be integrally involved in Xactware's operations and as such, Xactware became aware of the '454 Patent through Verisk and the diligence Verisk performed in connection with its intended acquisition of EVT.

153. In addition to directly infringing the '454 Patent, Xactware has in the past and continues to indirectly infringe the '454 Patent by inducing direct infringement by others, such as end users of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™. As set forth above, Xactware knew or should have known that use of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, by its end users infringes at least one claim of the '454 Patent since at least as early as the first such infringing use of such products after December 2014. Xactware knowingly induced such use of those products in a manner that infringes the '454 Patent, including through at least promotional, advertising, and instructional materials, and Xactware had the requisite intent to encourage such infringement. As such, Xactware has indirectly infringed and continues to indirectly infringe at least one claim of the '454 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

154. Xactware's infringement of the '454 Patent has been and continues to be willful. Xactware has acted with knowledge of the '454 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '454 Patent. For example, subsequent to being informed of the '454 Patent, Xactware continued to use rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States in a manner that infringes the '454 Patent. Xactware has disregarded and continues to disregard its infringement and/or an objectively high likelihood that

its actions constitute infringement of the ’454 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Xactware. Xactware’s infringement of the ’454 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

155. Xactware’s acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Xactware the damages sustained by Eagle View as a result of Xactware’s wrongful acts in an amount subject to proof at trial.

156. Xactware’s acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

157. This case is exceptional, entitling Eagle View to an award of attorneys’ fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

COUNT XIV – INFRINGEMENT OF THE ’454 PATENT BY VERISK

158. Plaintiffs reallege paragraphs 1-157 as if fully set forth herein.

159. Verisk has indirectly infringed and continues to indirectly infringe the ‘454 Patent, in connection with Xactware’s rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™.

160. On information and belief, Verisk has had knowledge of the ‘454 Patent since at least as early as December 2014 in connection with its intended acquisition of EVT. In January 2014, Verisk signed an agreement to acquire EVT. Verisk performed due diligence related to its intended acquisition of EVT, including with respect to Eagle View’s patent holdings. EVT personnel had discussions with representatives of Verisk concerning Eagle View’s patents, including the ‘454 Patent, prior to the termination of the EVT acquisition in December 2014.

161. Verisk has in the past and continues to indirectly infringe the ‘454 Patent by inducing direct infringement by Xactware, including Xactware’s using rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, within the United States. As set forth above, Verisk knew or should have known that

Xactware's actions infringe the claims of the '454 Patent since at least as early as Xactware's first such act of direct infringement with respect to those products after December 2014. Verisk knowingly induced Xactware's using of such products in a manner that infringes the '454 Patent, including through at least its involvement in and control over the development, support, sale, and distribution of these products (*e.g.*, through procuring aerial images to be used therein (*see* Ex. 12), through taking actions to broaden Xactware's customer base therefor (*see* Ex. 2), and in the marketing and promotion of these products, including through Verisk's website (*see* Exs. 13-15)), and Verisk had the requisite intent to encourage such infringement. Indeed, Jim Loveland is both a Senior Vice President at Verisk and Xactware's President, and has "overseen the release of many new [Xactware] products and services." (Ex. 2). Accordingly, Verisk has indirectly infringed and continues to indirectly infringe at least one claim of the '454 Patent under one or more subsections of 35 U.S.C. § 271, including § 271(b).

162. Verisk's infringement of the '454 Patent has been and continues to be willful. Verisk has acted with knowledge of the '454 Patent and without a reasonable basis for a good-faith belief that it would not be liable for infringement of the '454 Patent. For example, subsequent to being informed of the '454 Patent, Verisk continued to induce Xactware's using of rooftop aerial measurement products, including but not limited to Xactimate® in combination with Aerial Sketch™, in a manner that infringes the '454 Patent. Verisk has disregarded and continues to disregard its infringement and/or an objectively high likelihood that its actions constitute infringement of the '454 Patent. This objectively-defined risk was known or is so obvious that it should have been known to Verisk. Verisk's infringement of the '454 Patent has been and continues to be willful, entitling Eagle View to enhanced damages under 35 U.S.C. § 284.

163. Verisk's acts of infringement have caused damage to Eagle View, and Eagle View is entitled to recover from Verisk the damages sustained by Eagle View as a result of Verisk's wrongful acts in an amount subject to proof at trial.

164. Verisk's acts of infringement have caused, and unless restrained and enjoined, will continue to cause, irreparable injury and damage to Eagle View for which there is no adequate remedy at law.

165. This case is exceptional, entitling Eagle View to an award of attorneys' fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

PRAYER FOR RELIEF

WHEREFORE, Plaintiffs respectfully pray for the following relief:

A. For entry of judgment by this Court against Xactware and Verisk and in favor of Eagle View and Pictometry in all respects, including that Xactware and Verisk have and continue to directly infringe and/or indirectly infringe, by way of inducement, the '436, '840, '152, '880, '770, '732, and '454 Patents;

B. For an order permanently enjoining Xactware and Verisk, and their respective officers, directors, shareholders, agents, servants, employees, attorneys, all parent, subsidiary and affiliate corporations, their successors in interest and assigns, and all other entities and individuals acting in concert with it or on its behalf, including customers, from making, importing, using, offering for sale, and/or selling any product or service falling within the scope of any claim of the '436, '840, '152, '880, '770, '732, and '454 Patents, including Xactimate® in combination with Roof InSight™, Property InSight™, and/or Aerial Sketch™, or otherwise infringing any claim of the '436, '840, '152, '880, '770, '732, and '454 Patents;

C. Alternatively, in the event that an injunction does not issue, that this Court award a compulsory ongoing future royalty;

D. For damages arising from Xactware's and Verisk's infringement of the '436, '840, '152, '880, '770, '732, and '454 Patents, including lost profits suffered by Eagle View and Pictometry as a result of Xactware's and Verisk's infringement and in an amount not less than a reasonable royalty, together with pre-judgment and post-judgment interest;

E. That this Court declare Xactware's and Verisk's infringement to be willful and award increased damages in an amount not less than three times the damages assessed for

Xactware's and Verisk's infringement to Eagle View and Pictometry for the period of such willful infringement pursuant to 35 U.S.C.§ 284;

F. That this Court declare this to be an exceptional case pursuant to 35 U.S.C. § 285 and award Eagle View and Pictometry their attorneys' fees;

G. That Eagle View and Pictometry be awarded costs of court; and

H. For such other and further relief as the Court may deem just and proper.

DEMAND FOR JURY TRIAL

Pursuant to Fed. R. Civ. P. 38(b), Eagle View and Pictometry respectfully demand a jury trial on any and all issues triable as of right by a jury in this action.

Dated: September 23, 2015

CONNELL FOLEY LLP

s/*Liza M. Walsh*
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(212) 446-4800

RULE 11.2 CERTIFICATION

I hereby certify that, to the best of my knowledge, the matter in controversy is not the subject of any other pending or anticipated litigation in any court or arbitration proceeding, nor are there any non-parties known to Plaintiffs that should be joined to this action. In addition, I recognize a continuing obligation during the course of this litigation to file and to serve on all other parties and with the Court an amended certification if there is a change in the facts stated in this original certification.

Dated: September 23, 2015

CONNELL FOLEY LLP

s/Liza M. Walsh
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RULE 201.1 CERTIFICATION

I hereby certify that the above-captioned matter is not subject to compulsory arbitration in that the Plaintiffs seek, *inter alia*, injunctive relief.

Dated: September 23, 2015

CONNELL FOLEY LLP

s/*Liza M. Walsh*
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EXHIBIT 1

The Verisk Family of Companies

Follow the links for more information about Verisk's subsidiaries and business units:

(http://www.iso.com)

ISO (http://www.iso.com)
Data, analytics, and decision-support services for the property/casualty insurance industry

(http://www.3ecompany.com/)

3E Company (http://www.3ecompany.com/)
Data products and information services to help customers comply with environmental health and safety requirements

(http://www.aer.com)

Atmospheric and Environmental Research (AER) (http://www.aer.com)
Research and services that further understanding of the global environment and enable better decision ma in response to weather and climate-related risk

(http://www.air-worldwide.com)

AIR Worldwide (http://www.air-worldwide.com)
Analytical tools and software systems to help customers estimate and manage the risks associated with na and man-made catastrophes, weather, and climate

(http://www.argusinformation.com)

Argus Information & Advisory Services (http://www.argusinformation.com)
Benchmarking, scoring, analytics, and customized services for financial institutions and regulators

(http://www.iix.com/)

Insurance Information Exchange (iiX) (http://www.iix.com/)
Motor-vehicle reports, undisclosed driver reports, credit-score reports, and other underwriting information

(http://www.intellicorp.net/)

IntelliCorp (http://www.intellicorp.net/) Background checks, employment screening, and drug-testing products for pot employees and volunteers

(http://www.nerusa.com/)

National Equipment Register (NER) (http://www.nerusa.com/)
Information services to help owners of heavy construction and agricultural equipment — and their insurers recover stolen equipment

(http://www.veriskclimate.com)

Verisk Climate (http://www.veriskclimate.com)
Verisk Climate helps make society more resilient to the volatile natural environment.

(http://www.veriskhealth.com)

Verisk Health (http://www.veriskhealth.com)
Healthcare analytics and predictive modeling

(https://www.maplecroft.com/)

Verisk Maplecroft (https://www.maplecroft.com/)
Global risk analytics, research and strategic forecasting

Wood Mackenzie (http://www.woodmac.com/)
Commercial intelligence for the energy, metals and mining industries

(http://www.woodmac.com/)

Xactware (http://www.xactware.com/)
Software for estimating the cost of building and repair

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- P/C Insurance (/index.php?option=com_k2&view=item&layout=item&id=5747&Itemid=868)
- Healthcare (/index.php?option=com_k2&view=item&layout=item&id=2380&Itemid=870)
- Financial Services (/index.php?option=com_k2&view=item&layout=item&id=2379&Itemid=869)
- Supply Chain (/index.php?option=com_k2&view=item&layout=item&id=1278&Itemid=906)
- HR Departments (/index.php?option=com_k2&view=item&layout=item&id=5517&Itemid=894)
- Retail (/index.php?option=com_k2&view=item&layout=item&id=1568&Itemid=871)
- Commercial Real Estate (/index.php?option=com_k2&view=item&layout=item&id=2273&Itemid=911)
- Government Services (http://www.isogov.com/)
- Community Hazard Mitigation (http://www.isomitigation.com/)
- Climate Risk (http://www.veriskclimate.com/)

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EXHIBIT 2

Top

Verisk Analytics (/)
SERVE | ADD VALUE | INNOVATE

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$ INVESTORS (http://investor.verisk.com/) PRESS (/press-releases-verisk/2015.html) CONTACT (/contact-verisk.html)

LEADERSHIP | JIM LOVELAND — SENIOR VICE PRESIDENT — VERISK ANALYTICS, PRESIDENT — XACTWARE SOLUTIONS

Overview (/about-verisk.html)

Verisk Locations (/about-verisk/offices-directions/offices-directions.html)

Leadership (/about-verisk/leadership/verisk-leadership.html)

Honors and Awards (/about-verisk/honors-and-awards/honors-and-awards.html)

Corporate Social Responsibility (/csr/index.html)

Verisk Family of Companies (/about-verisk/verisk-family-of-companies/verisk-family-of-companies.html)

Verisk Strategic Alliances (/verisk-strategic-alliances.html)

Jim Loveland is a senior vice president of Verisk Analytics and president of Xactware Solutions, the leading provider estimating systems for the property insurance, remodeling, and restoration industries. The company's technology to include software estimating programs for PCs and tablet PCs, as well as online systems for replacement-cost calculations, estimate tracking, and data trending in real time.

Mr. Loveland is a group executive responsible for Verisk Insurance Solutions – Underwriting and Xactware. Verisk Insurance Solutions – Underwriting develops and delivers underwriting information and services for the property/cas insurance industry. The division has responsibility for Verisk's A-PLUS™, Coverage Verifier℠, LOCATION®, LOCATIC Analyst, QuickFill®, and 360Value® product lines, among others.

During Mr. Loveland's tenure as Xactware's president, the company has expanded business operations into several international markets, broadened its customer base into new vertical markets, joined the Verisk Analytics Family of Companies, and overseen the release of many new products and services. Today, Mr. Loveland leads a company wi more than 400 employees.

Mr. Loveland has been with Xactware since 1988. Before being appointed president, he was senior vice president of XactNet, the pricing, property-estimate network, and data-mining division of the business.

Mr. Loveland holds a bachelor of science degree in computer science from Brigham Young University and a master of business administration degr from the University of Utah. He serves on the boards of a number of charitable organizations. In 2011, Utah Business magazine named Mr. Loveland CEO of the Year.

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- Financial Services (/index.php?option=com_k2&view=item&layout=item&id=2379&Itemid=869)
- Supply Chain (/index.php?option=com_k2&view=item&layout=item&id=1278&Itemid=906)
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- Retail (/index.php?option=com_k2&view=item&layout=item&id=1568&Itemid=871)
- Commercial Real Estate (/index.php?option=com_k2&view=item&layout=item&id=2273&Itemid=911)
- Government Services (http://www.isogov.com/)
- Community Hazard Mitigation (http://www.isomitigation.com/)
- Climate Risk (http://www.veriskclimate.com/)

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EXHIBIT 3

New Jersey Business Gateway
Business Entity Information and Records Service
Business Id : 0101006731

Status Report For:	XACTWARE SOLUTIONS, INC.
Report Date:	8/12/2015
Confirmation Number:	5224703218

IDENTIFICATION NUMBER, ENTITY TYPE AND STATUS INFORMATION

Business ID Number:	0101006731
Business Type:	FOREIGN PROFIT CORPORATION
Status:	ACTIVE
Original Filing Date:	01/25/2010
Stock Amount:	N/A
Home Jurisdiction:	DE
Status Change Date:	NOT APPLICABLE

REVOCATION/SUSPENSION INFORMATION

DOR Suspension Start Date:	N/A
DOR Suspension End Date:	N/A
Tax Suspension Start Date:	N/A
Tax Suspension End Date:	N/A

ANNUAL REPORT INFORMATION

Annual Report Month:	JANUARY
Last Annual Report Filed:	10/14/2014
Year:	2015

AGENT/SERVICE OF PROCESS (SOP)INFORMATION

Agent:	KENNETH E. THOMPSON
Agent/SOP Address:	C/O INSURANCE SERVICES OFFICE, INC. 545 WASHINGTON BOULEVARD,JERSEY CITY,NJ,07310 1696
Address Status:	DELIVERABLE
Main Business Address:	1426 E. 750 NORTH, OREM, UT, 84097
Principal Business Address:	545 WASHINGTON BLVD.21ST FLOOR,JERSEY CITY,NJ,07310 1696

ASSOCIATED NAMES

New Jersey Business Gateway
Business Entity Information and Records Service
Business Id : 0101006731

Associated Name:	N/A
Type:	N/A

PRINCIPALS

Following are the most recently reported officers/directors (corporations), managers/members/managing members (LLCs), general partners (LPs), trustees/officers (non-profits).

Title:	PRESIDENT
Name:	LOVELAND,JAMES
Address:	1426 E. 750 NORTH, OREM, UT, 84097
Title:	VICE PRESIDENT
Name:	STEPHENSON ,SCOTT
Address:	545 WASHINGTON BLVD, JERSEY CITY, NJ, 07310
Title:	SECRETARY
Name:	THOMPSON,KENNETH
Address:	545 WASHINGTON BLVD, JERSEY CITY, NJ, 07310

FILING HISTORY -- CORPORATIONS, LIMITED LIABILITY COMPANIES, LIMITED PARTNERSHIPS AND LIMITED LIABILITY PARTNERSHIPS

To order copies of any of the filings below, return to the service page, https://www.njportal.com/DOR/businessrecords/Default.aspx and follow the instructions for obtaining copies. Please note that trade names are filed initially with the County Clerk(s) and are not available through this service. Contact the Division for instructions on how to order Trade Mark documents.

Charter Documents for Corporations, LLCs, LPs and LLPs

Original Filing (Certificate)Date:	2010

Changes and Amendments to the Original Certificate:

Filing Type	Year Filed
CHANGE OF AGENT AND OFFICE	2011
CHANGE OF AGENT AND OFFICE	2011

New Jersey Business Gateway
Business Entity Information and Records Service
Business Id : 0101006731

Annual Report filing with officer/member change	2014

Note:
Copies of some of the charter documents above, particularly those filed before June 1988 and recently filed documents (filed less than 20 work days from the current date), may not be available for online download.

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- For recent filings, allow 20 work days from the estimated filing date, revisit the service center at https://www.njportal.com/DOR/businessrecords/Default.aspx periodically, search for the business again and build a current list of its filings. Repeat this procedure until the document shows on the list of documents available for download.

The Division cannot provide information on filing requests that are in process. Only officially filed documents are available for download.

EXHIBIT 4

US008078436B2

(12) **United States Patent**
Pershing et al.

(10) **Patent No.: US 8,078,436 B2**
(45) **Date of Patent: Dec. 13, 2011**

(54) **AERIAL ROOF ESTIMATION SYSTEMS AND METHODS**

(75) Inventors: **Chris Pershing**, Bellevue, WA (US); **David P. Carlson**, Woodinville, WA (US)

(73) Assignee: **Eagle View Technologies, Inc.**, Redmond, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 532 days.

(21) Appl. No.: **12/253,092**

(22) Filed: **Oct. 16, 2008**

(65) **Prior Publication Data**

US 2009/0132436 A1 May 21, 2009

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/148,439, filed on Apr. 17, 2008.

(60) Provisional application No. 60/925,072, filed on Apr. 17, 2007.

(51) **Int. Cl.**
G06F 7/60 (2006.01)
G06F 17/10 (2006.01)

(52) **U.S. Cl.** **703/2**

(58) **Field of Classification Search** 703/2; 705/306, 705/313, 4
See application file for complete search history.

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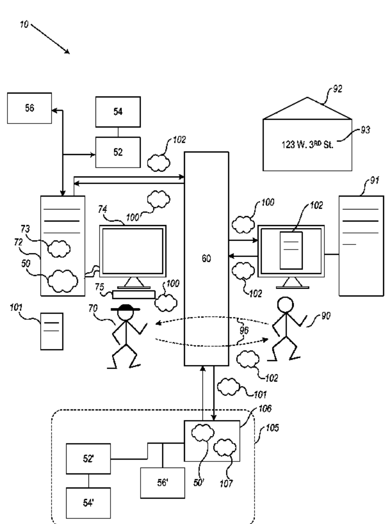
Primary Examiner — Dwin M Craig
Assistant Examiner — Bernard E Cothran
(74) *Attorney, Agent, or Firm* — Seed IP Law Group PLLC

(57) **ABSTRACT**

Methods and systems for roof estimation are described. Example embodiments include a roof estimation system, which generates and provides roof estimate reports annotated with indications of the size, geometry, pitch and/or orientation of the roof sections of a building. Generating a roof estimate report may be based on one or more aerial images of a building. In some embodiments, generating a roof estimate report of a specified building roof may include generating a three-dimensional model of the roof, and generating a report that includes one or more views of the three-dimensional model, the views annotated with indications of the dimensions, area, and/or slope of sections of the roof. This abstract is provided to comply with rules requiring an abstract, and it is submitted with the intention that it will not be used to interpret or limit the scope or meaning of the claims.

56 Claims, 13 Drawing Sheets



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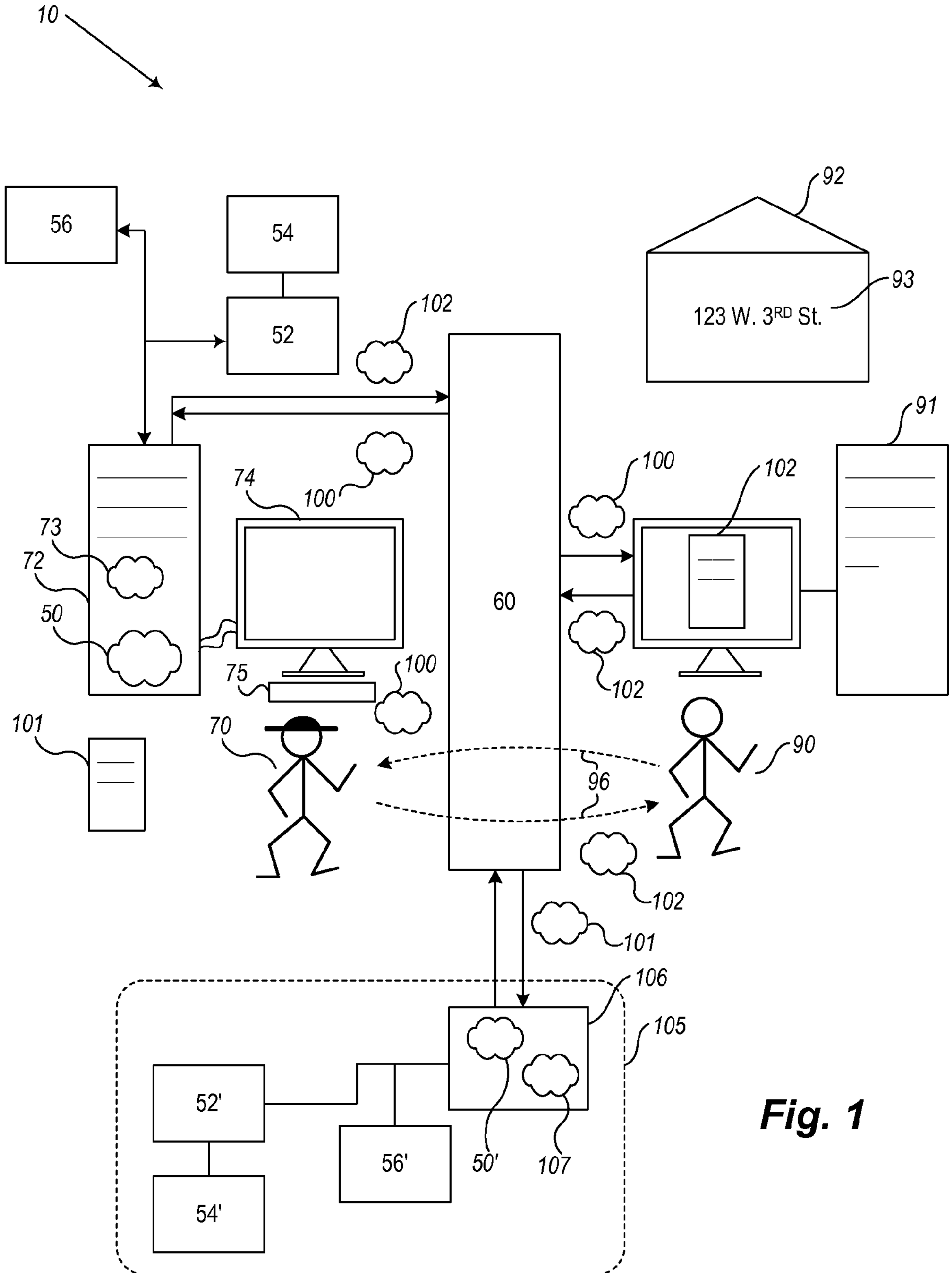

10
56
54
52
102
92
93
123 W. 3RD St.
91
100
102
74
100
73
72
50
60
75
100
102
101
70
90
96
102
101
106
105
52'
56'
50'
107
54'

Fig. 1

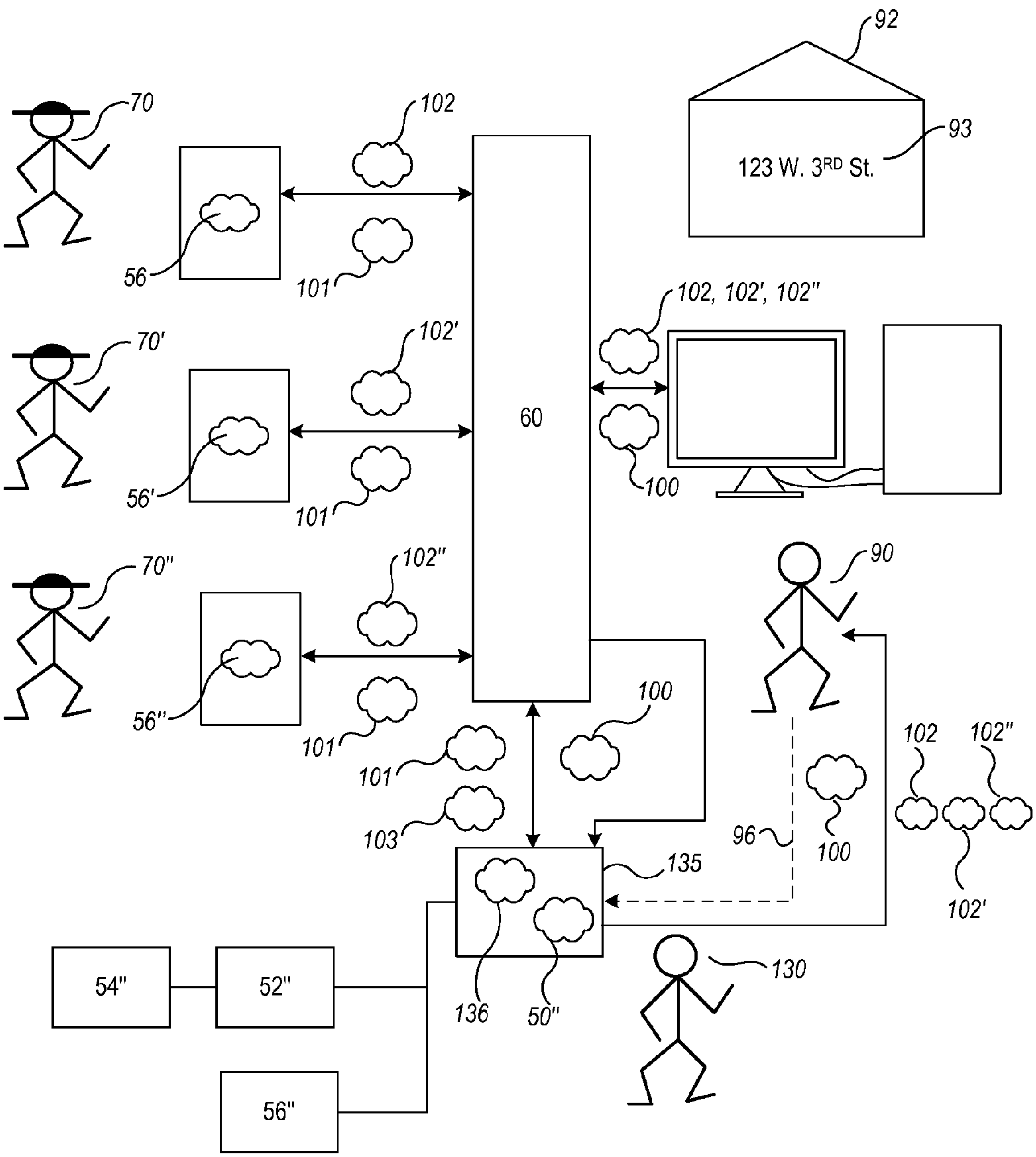

92
93
123 W. 3RD St.
70
102
56
101
60
102, 102', 102"
70'
102'
56'
101
100
70"
102"
90
56"
101
100
101
103
102
102"
96
100
135
102'
54"
52"
136
50"
130
56"

Fig. 2

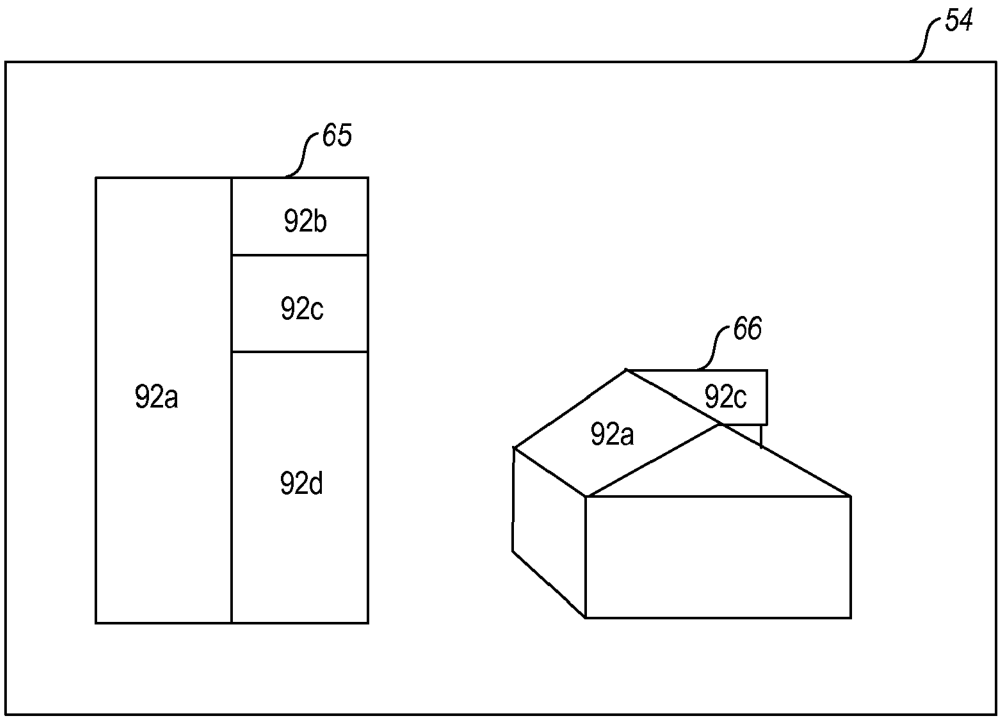


Fig. 3

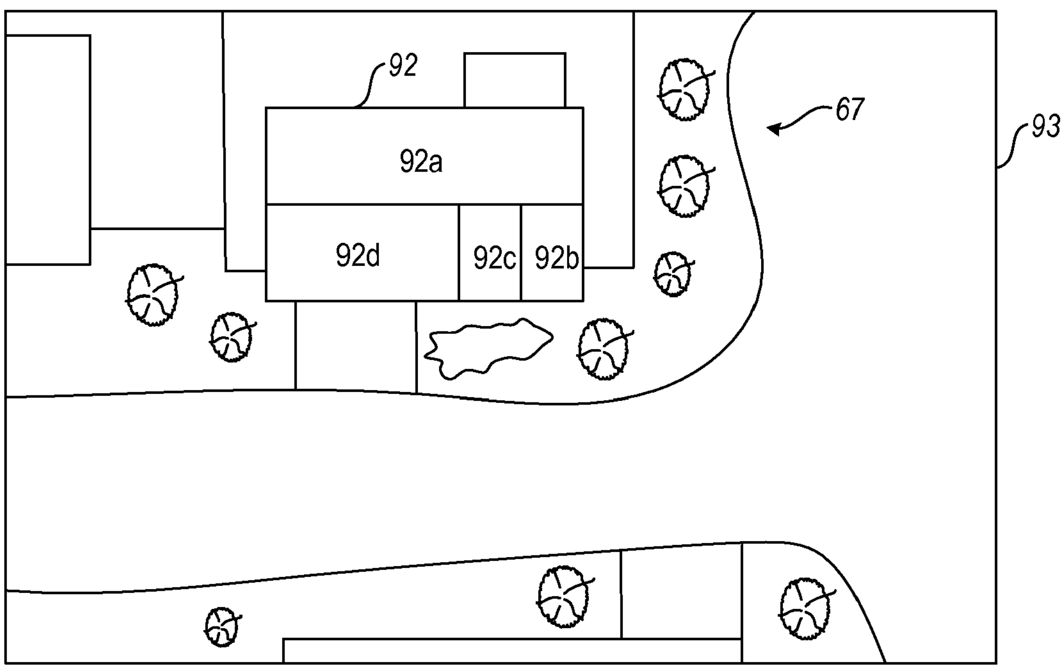


Fig. 4

1234 Main Street, Redmond, WA

Order: 2468

<Customer Name Here>

4/16/2008

103a

1234 Main Street, Redmond, WA

103b

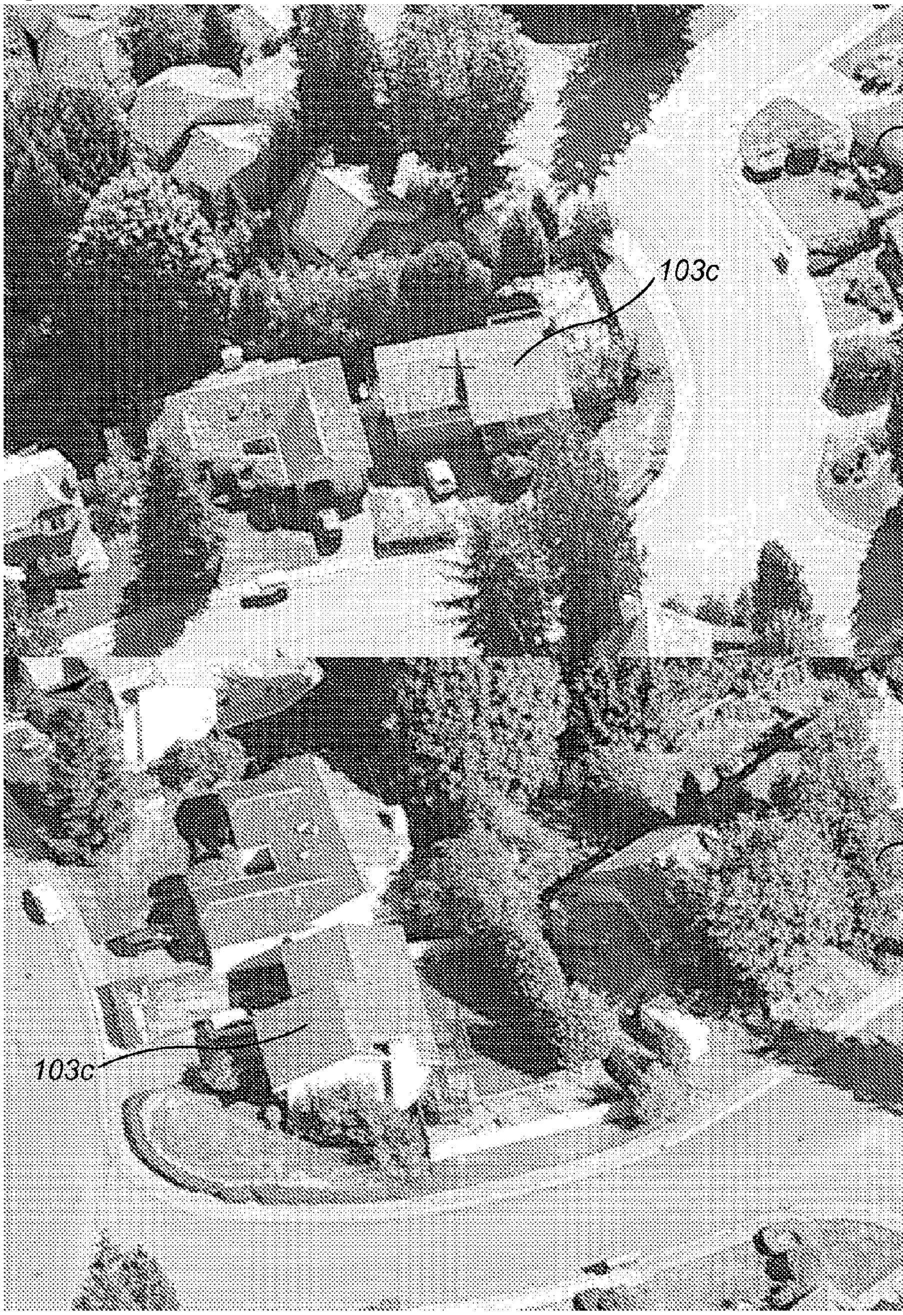
Order: 2468 Copyright (c) 2008 Eagle View Technologies, Inc. Page 1 of 6

103

Fig. 5A

1234 Main Street, Redmond, WA

Images:



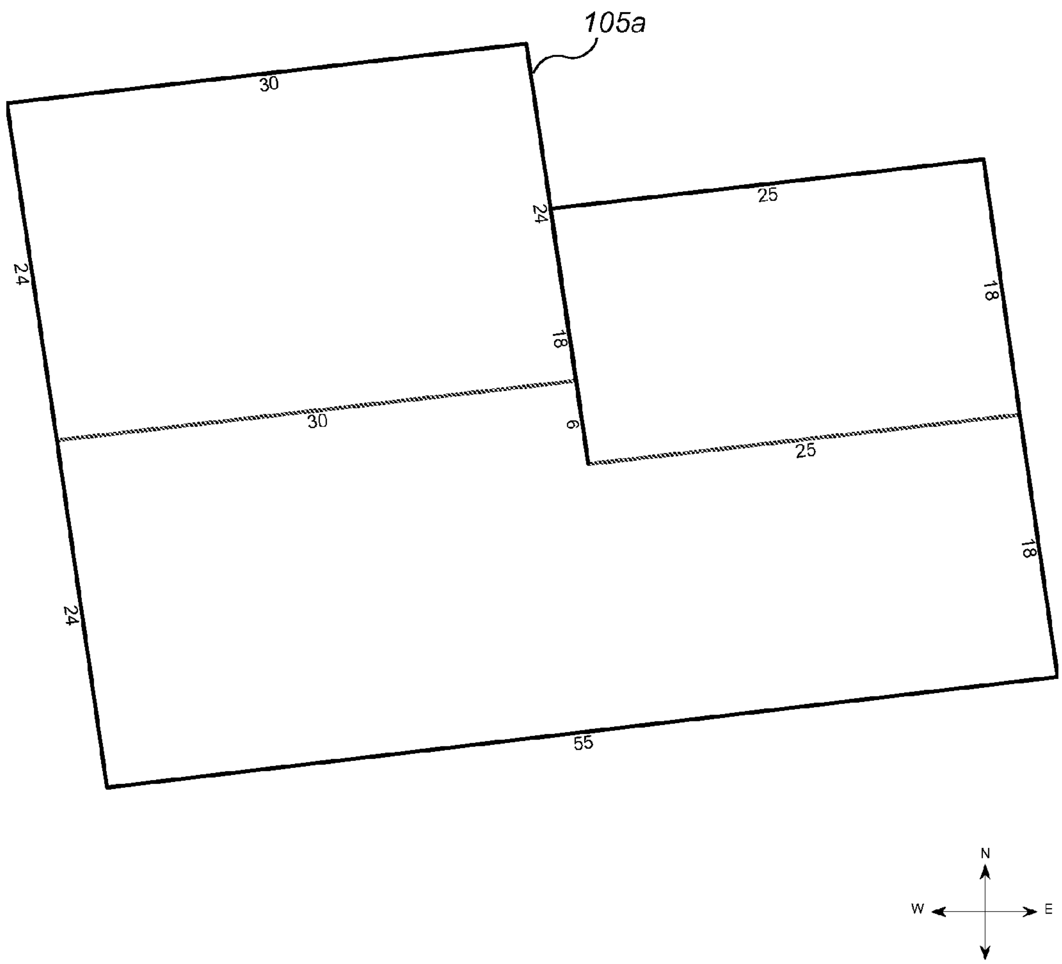
Order: 2468 Copyright (c) 2008 Eagle View Technologies, Inc. Page 2 of 6

104

Fig. 5B

1234 Main Street, Redmond, WA

Length Diagram:
All measurements are rounded to the nearest foot
Ridge Length = 55 ft [Red Lines]
Valley Length = 0 ft [Blue lines]



Order: 2468 Copyright (c) 2008 Eagle View Technologies, Inc. Page 3 of 6

105

Fig. 5C

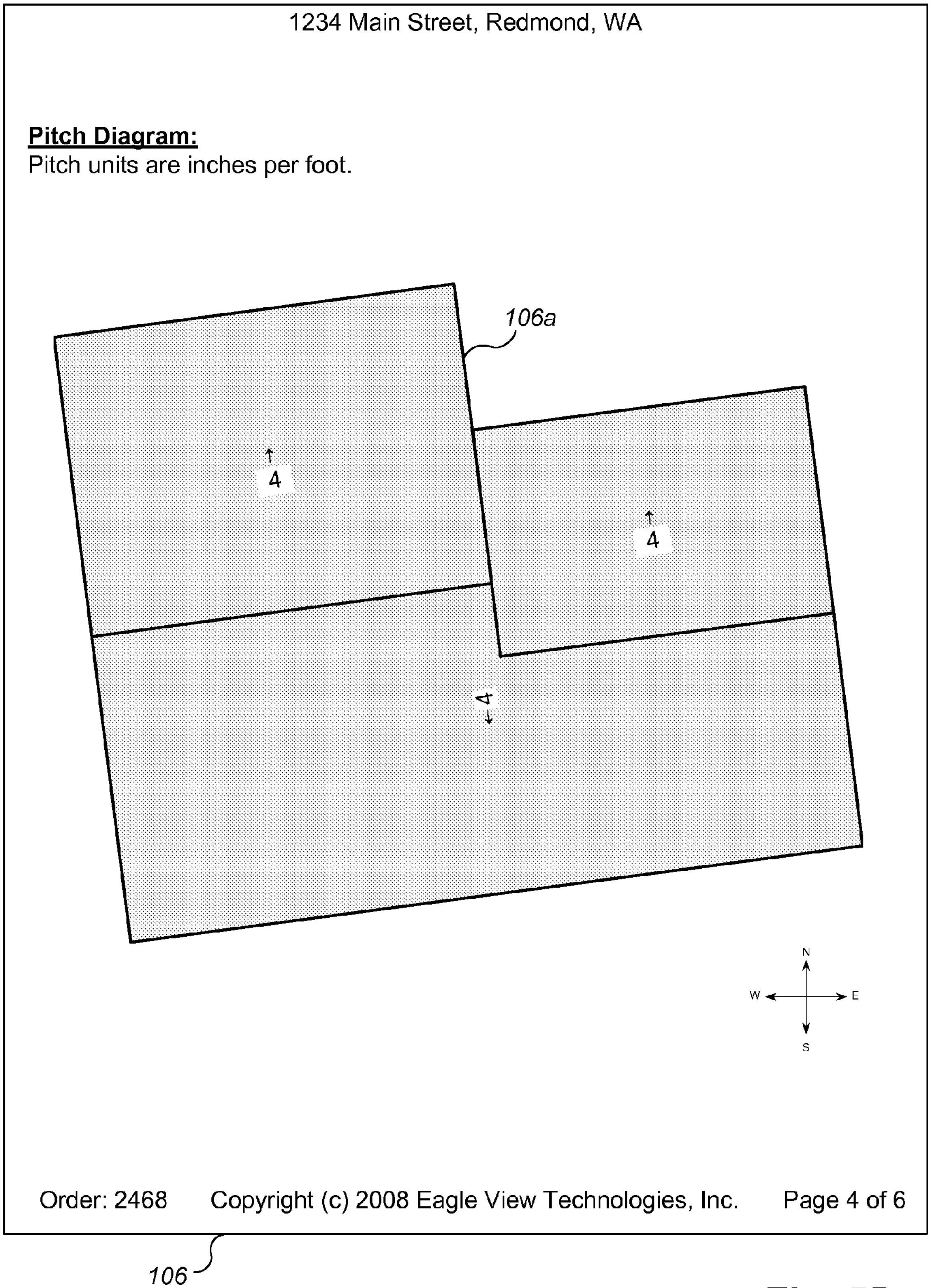

1234 Main Street, Redmond, WA
Pitch Diagram:
Pitch units are inches per foot.
106a
4
4
4
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 4 of 6
106

Fig. 5D

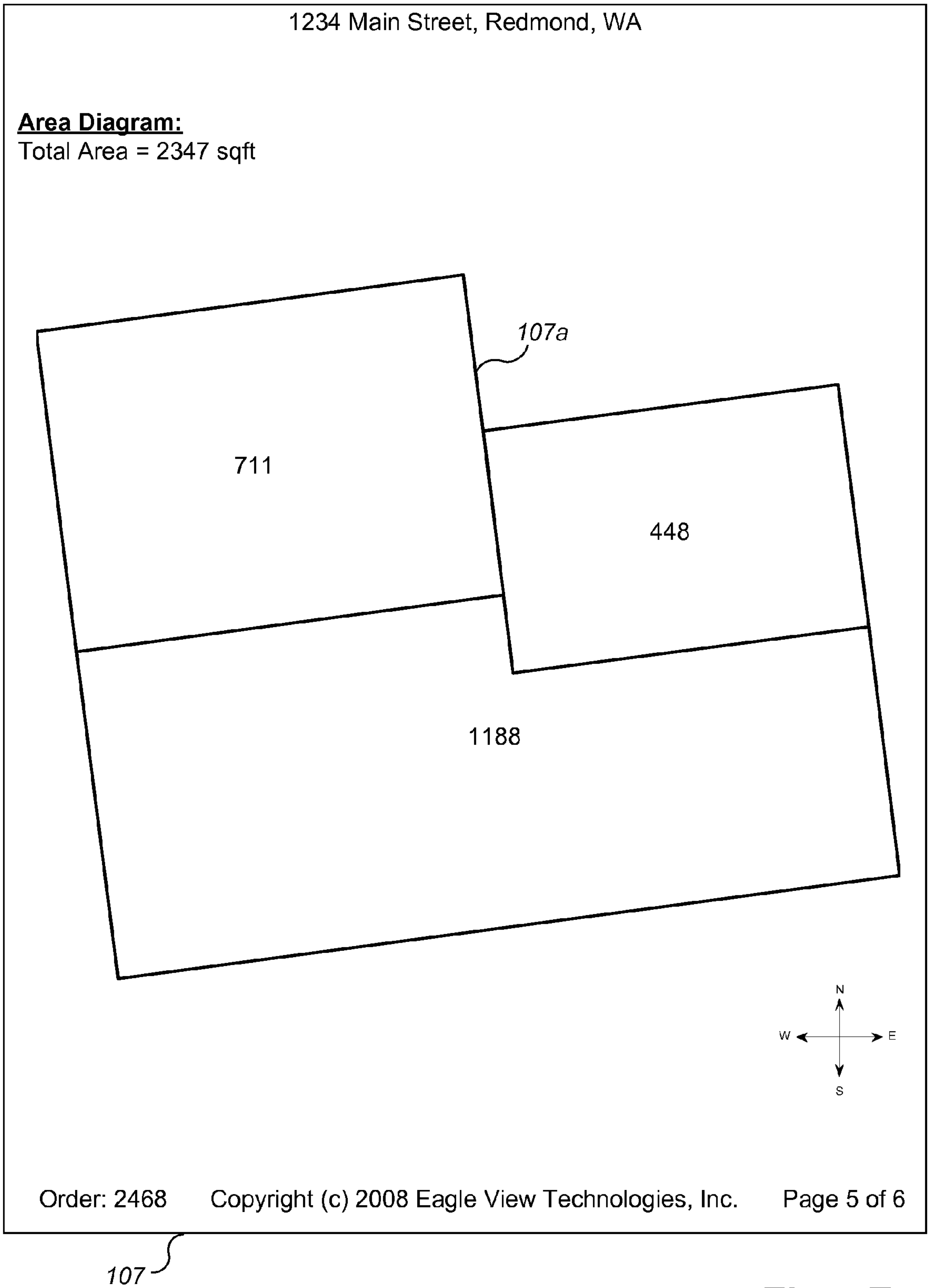

1234 Main Street, Redmond, WA
Area Diagram:
Total Area = 2347 sqft
107a
711
448
1188
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 5 of 6
107

Fig. 5E

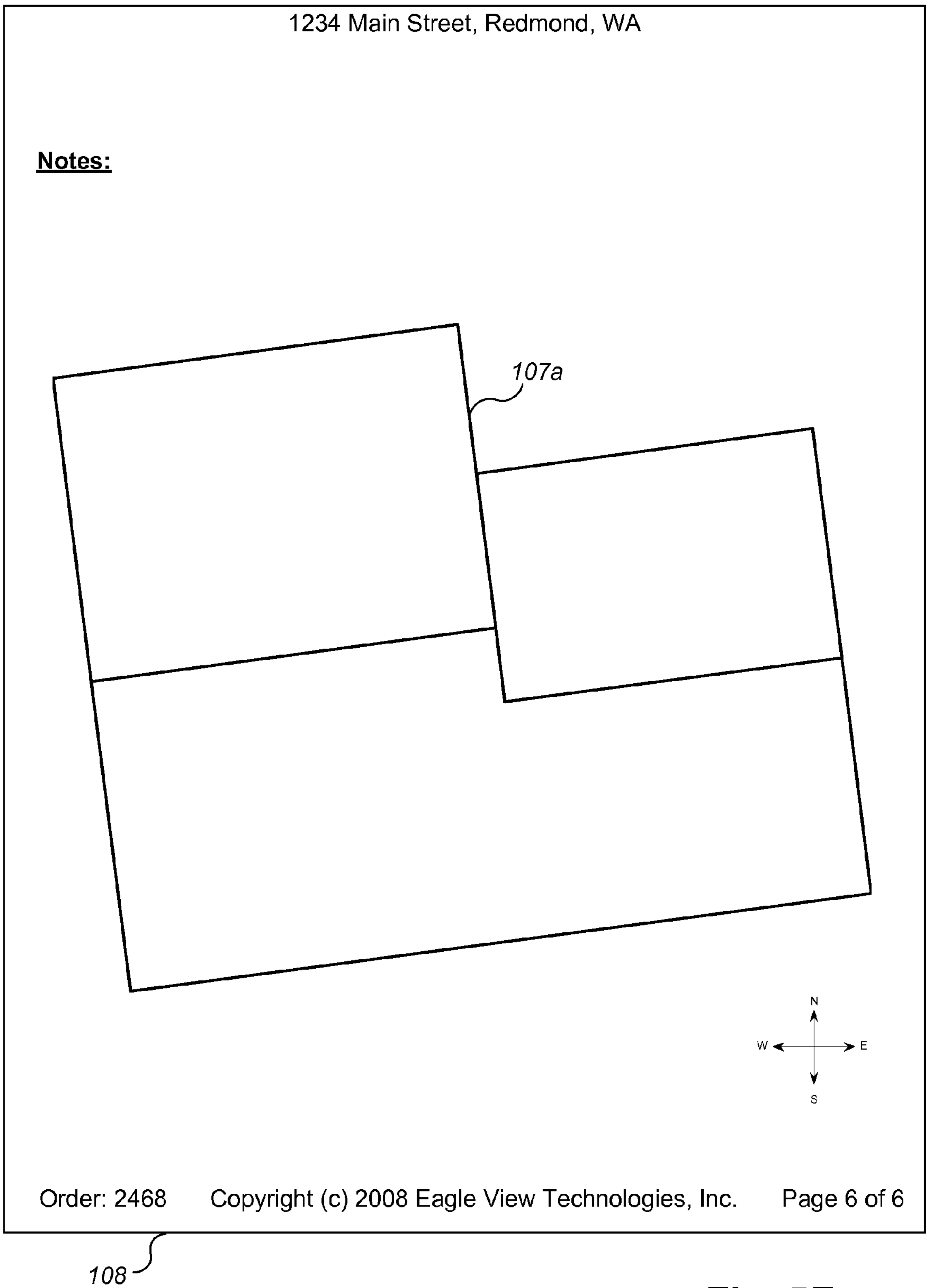
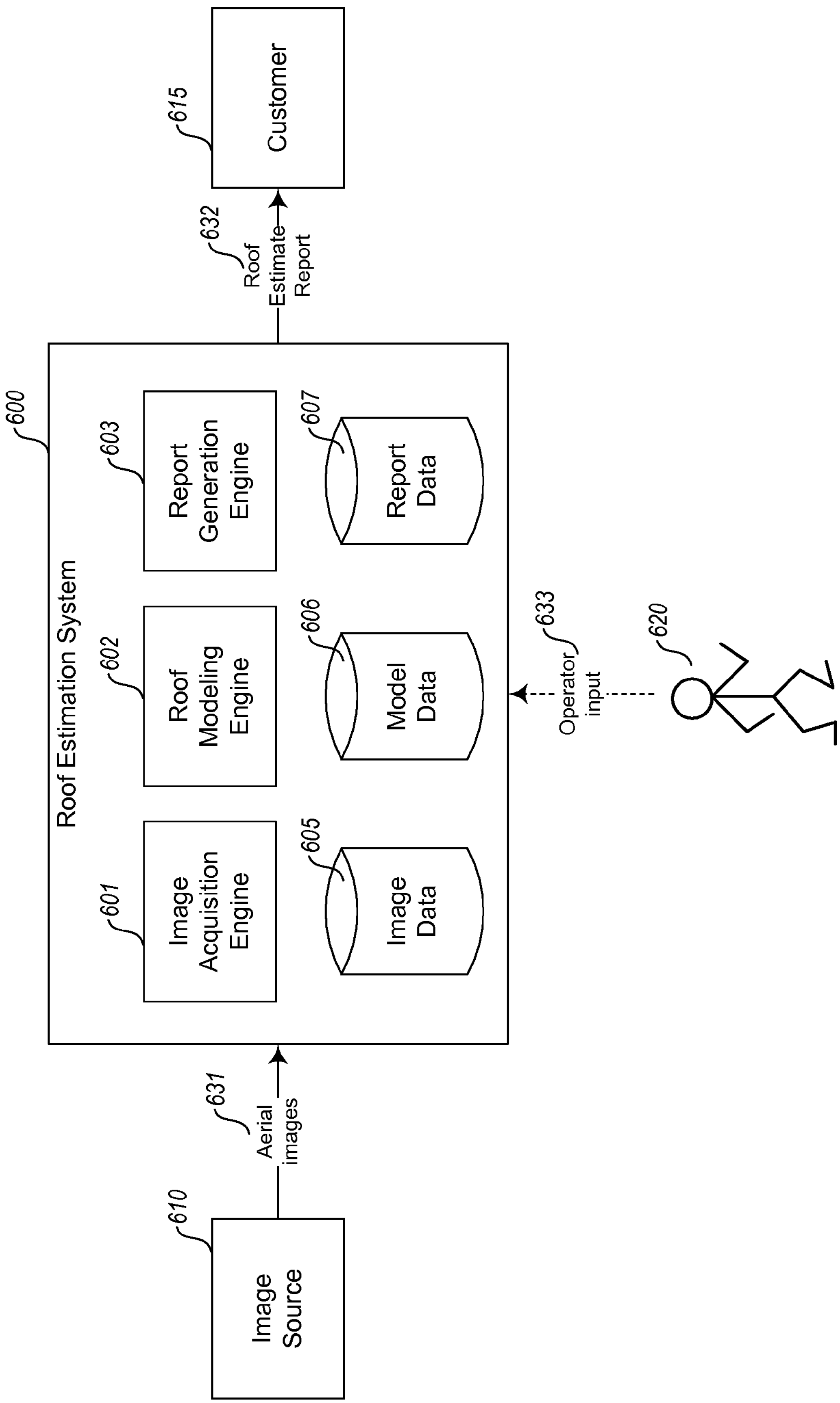
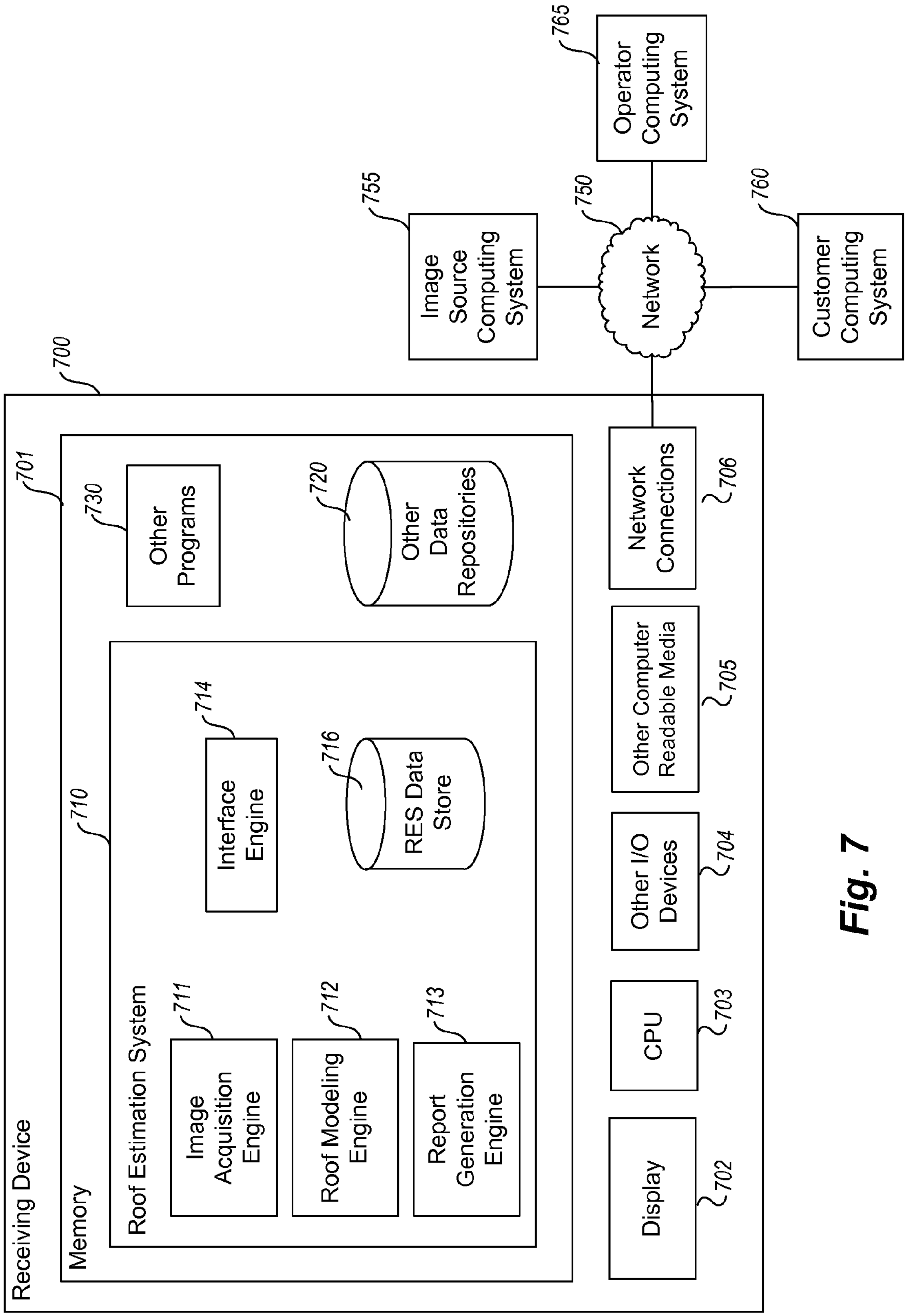

1234 Main Street, Redmond, WA
Notes:
107a
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 6 of 6
108

Fig. 5F

Fig. 6


600
Roof Estimation System
601
Image Acquisition Engine
602
Roof Modeling Engine
603
Report Generation Engine
605
Image Data
606
Model Data
607
Report Data
610
Image Source
631
Aerial images
615
Customer
632
Roof Estimate Report
633
Operator input
620



700
Receiving Device
701
Memory
710
Roof Estimation System
711
Image Acquisition Engine
712
Roof Modeling Engine
713
Report Generation Engine
714
Interface Engine
716
RES Data Store
730
Other Programs
720
Other Data Repositories
702
Display
703
CPU
704
Other I/O Devices
705
Other Computer Readable Media
706
Network Connections
750
Network
755
Image Source Computing System
760
Customer Computing System
765
Operator Computing System

Fig. 7

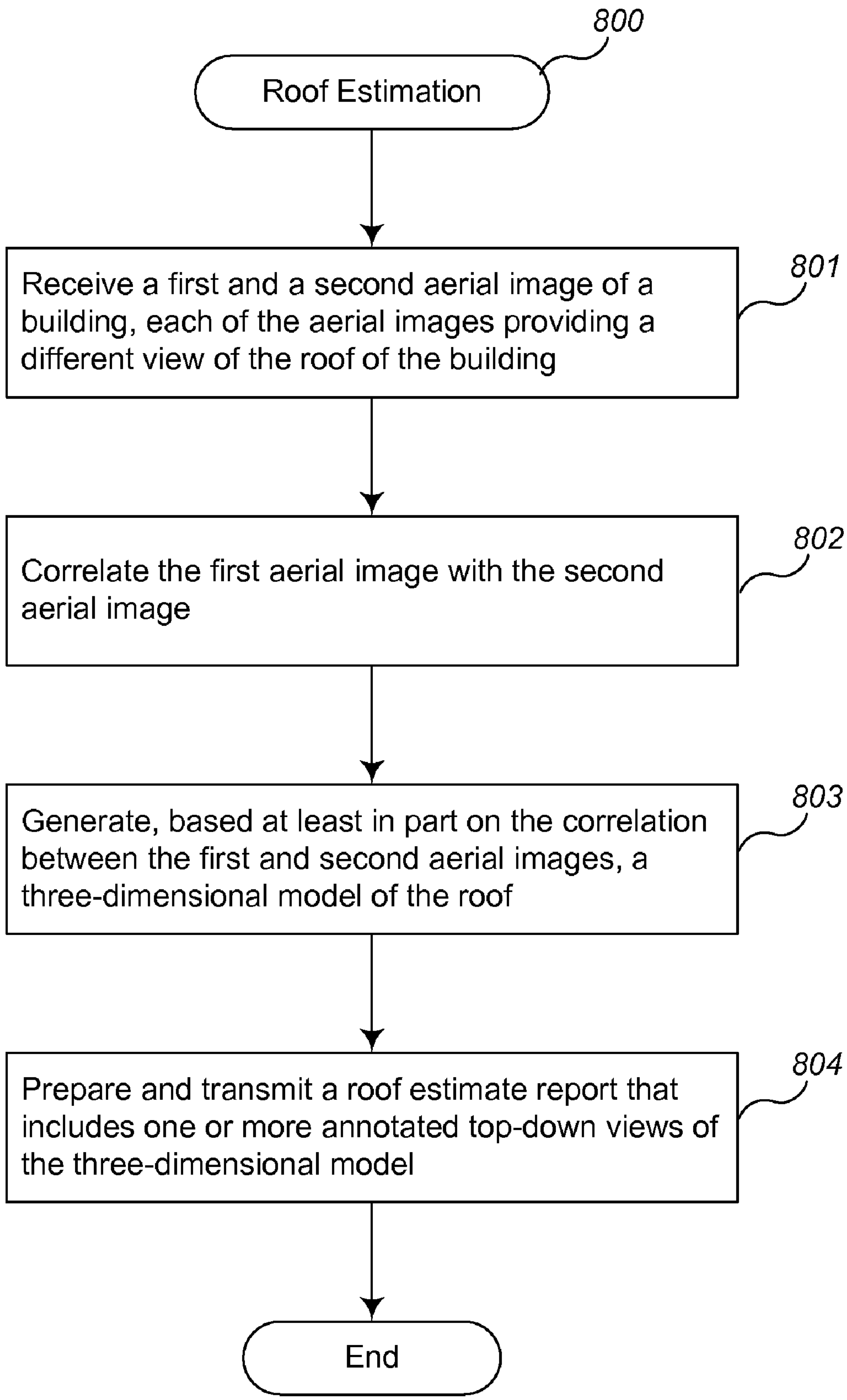

800
Roof Estimation
801
Receive a first and a second aerial image of a building, each of the aerial images providing a different view of the roof of the building
802
Correlate the first aerial image with the second aerial image
803
Generate, based at least in part on the correlation between the first and second aerial images, a three-dimensional model of the roof
804
Prepare and transmit a roof estimate report that includes one or more annotated top-down views of the three-dimensional model
End

Fig. 8

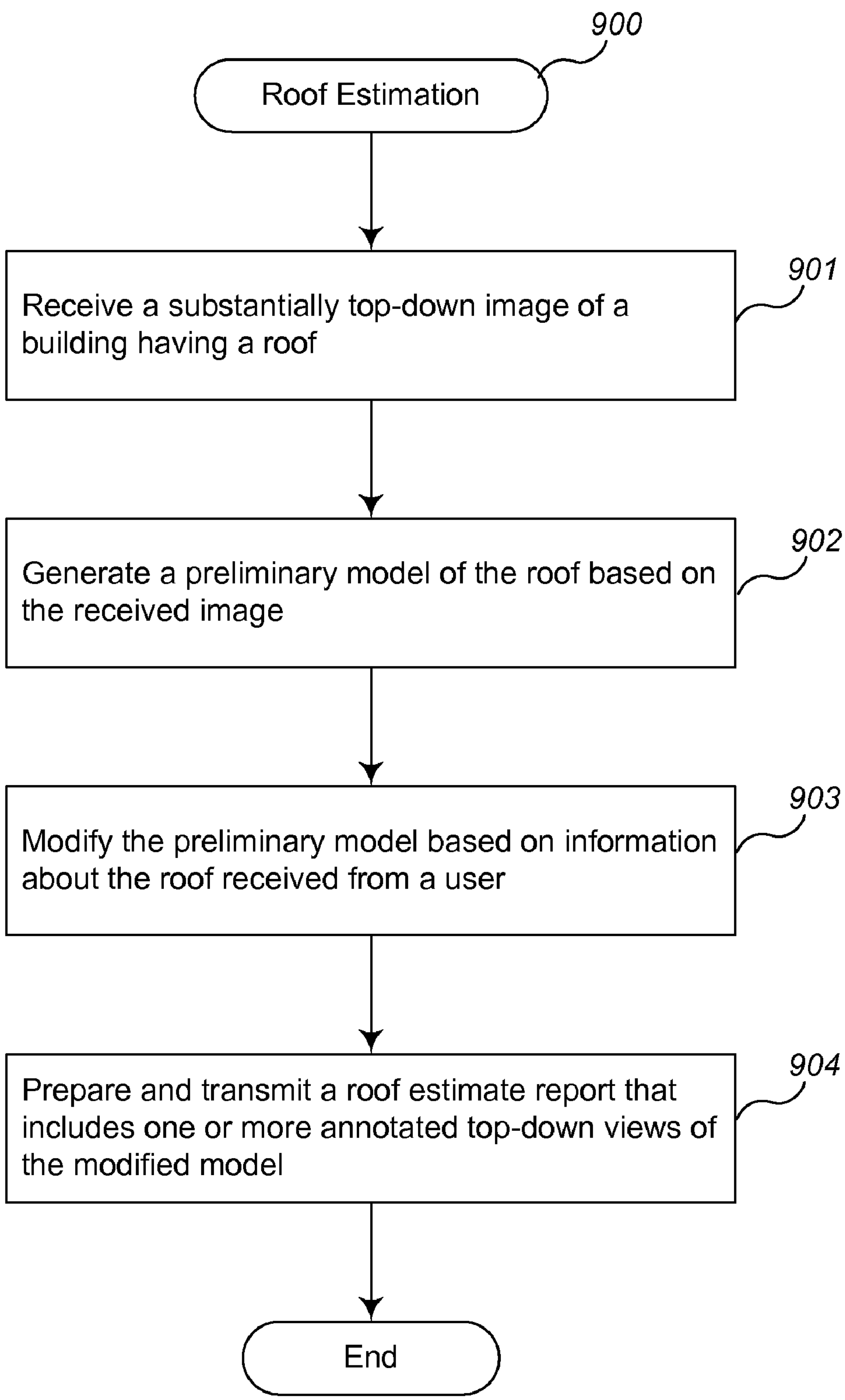

900
Roof Estimation
901
Receive a substantially top-down image of a building having a roof
902
Generate a preliminary model of the roof based on the received image
903
Modify the preliminary model based on information about the roof received from a user
904
Prepare and transmit a roof estimate report that includes one or more annotated top-down views of the modified model
End

Fig. 9

AERIAL ROOF ESTIMATION SYSTEMS AND METHODS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 12/148,439, filed on Apr. 17, 2008, which claims the benefit of U.S. Provisional Patent Application No. 60/925,072, filed on Apr. 17, 2007, each of which are incorporated herein by reference in their entireties.

BACKGROUND

1. Field of the Invention

This invention relates to systems and methods for estimating construction projects, and more particularly, to such systems and methods that allow estimates involving roofs on buildings to be created remotely.

2. Description of the Related Art

The information provided below is not admitted to be part of the present invention, but is provided solely to assist the understanding of the reader.

Homeowners typically ask several roofing contractors to provide written estimates to repair or replace a roof on a house. Heretofore, the homeowners would make an appointment with each roofing contractor to visit the house to determine the style of roof, take measurements, and to inspect the area around the house for access and cleanup. Using this information, the roofing contractor then prepares a written estimate and then timely delivers it to the homeowner. After receiving several estimates from different rooting contractors, the homeowner then selects one.

There are factors that impact a roofing contractor's ability to provide a timely written estimate. One factor is the size of the roof contractor's company and the location of the roofing jobs currently underway. Most roof contractors provide roofing services and estimates to building owners over a large geographical area. Larger roof contractor companies hire one or more trained individuals who travel throughout the entire area providing written estimates. With smaller roofing contractors, the owner or a key trained person is appointed to provide estimates. With both types of companies, roofing estimates are normally scheduled for buildings located in the same area on a particular day. If an estimate is needed suddenly at a distant location, the time for travel and the cost of commuting can be prohibitive. If the roofing contractor is a small company, the removal of the owner or key person on a current job site can be time prohibitive.

Another factor that may impact the roofing contractor's ability to provide a written estimate is weather and traffic.

Recently, solar panels have become popular. In order to install solar panels, the roof's slope, geometrical shape, and size as well as its orientation with respect to the sun all must be determined in order to provide an estimate of the number and type of solar panels required. Unfortunately, not all roofs on a building are proper size, geometrical shape, or orientation for use with solar panels.

SUMMARY

These and other objects are met by the system and method disclosed herein that allows a company that needs the sizes, dimensions, slopes and orientations of the roof sections on a building in order to provide a written estimate. A roof estimation system ("RES") that practices at least some of the techniques described herein may include a roof estimating software program and a location-linked, image file database. During use, the physical address or location information of a building is provided to the program, which then presents aerial images of roof sections on the building at the specific address location. An overhead aircraft, a balloon, or satellite may produce the aerial images. An image analysis and calibration is then performed either manually and/or via a software program that determines the geometry, the slopes, the pitch angles, and the outside dimensions of the roof sections. The images may also include the land surrounding the roof sections and building which the estimating company can use to factor in additional access or clean-up costs.

In a first embodiment of the roof estimation system, a roof estimation service is contacted by a potential customer requesting an estimate for repair or replacement of a roof on a building. The roof estimation service uses a local computer with an estimating software program loaded into its working memory to access an image file database located on the computer or on a remote server connected via a wide area network to the local computer. The image file database contains image files of various buildings. When a request for an estimate is received from a potential customer, the roof estimation service enters the customer's address into the software program and aerial images of the building are then presented to the roof estimation service. The roof estimation service then manually measures or uses a roof estimation software program to determine the slopes, dimensions, and other relevant geometric information of the roof sections on the buildings. From these determinations, the overall shape, slopes and square footage of the roof sections are determined and a report is produced. After the report has been prepared, the images are reviewed again for special access and cleanup tasks which can be added to the final estimate before transmission to the potential customer.

In another embodiment, the roof estimate software program and image file database, operated by a roof estimation service, are both stored on one or more a remote computers and accessed by a roof company, via a wide area network. The roof company uses an assigned user name and password to log onto the Web site and accessed the computer. After logging on, the roof company submits an address of a building, other relevant job related information, and a request for a report from the roof estimation service. The roof estimation service associated with the Web site uses the address information to obtain the images of the roof sections on the building(s) and uses the roof estimation software program and calibration module to determine the relevant geometry, pitch angles, dimensions, and surface areas of the building's roof. The roof estimation service then produces and sends a report to the roof company. The roof company then uses the report to prepare a final estimate that is then delivered to its potential customer.

In another embodiment, a roof estimating Web site is created designed to receive requests for roof estimates directly from potential customers in a region. The roof estimation service that operates the Web site is associated with various roof companies that provide roof-related services in the region serviced by the Web site. When a potential customer contacts the Web site and requests an estimate for a roof repair, replacement or installation of equipment, the potential's customer's name, address, and contact information is first submitted on the Web site. The estimation service representative enters the address of the building into the roof estimation software program. The aerial images of the buildings are then obtained and analyzed by the service representative to extract the relevant geometric information about the structures. A report containing the geometric information obtained

from the aerial images and other relevant project related information supplied by the potential customer are transmitted to roof companies associated with the estimation service. The roof company reviews the information then prepares an estimate which then can be uploaded to the roof estimating Web site server which then forwards the estimate to the potential customer, or sent from the roof company directly via email, fax or mail to the potential customer.

In another embodiment, a roof estimation service associated with the roof estimate Web site uses the image file database and roof estimate software to preemptively calculate and store the dimensions, areas, pitch angles, and other relevant geometric information about the buildings and structures located within a geographic region. This pre-calculated information can then be used by any of the previously mentioned embodiments to accelerate the process of obtaining roof estimates within that geographic region.

It should be understood, that the systems and methods described herein may be used by any individual or company that would find the calculation of the size, geometry, pitch and orientation of the roof of a building from aerial images of the building useful. Such companies may include roofing companies, solar panel installers, roof gutter installers, awning companies, HVAC contractors, general contractors, and insurance companies.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an illustration showing embodiments of a system and method for roof estimation.

FIG. **2** is an illustration showing another embodiment of a system and method for roof estimation.

FIG. **3** is an illustration showing the top and perspective view of a house for a particular address.

FIG. **4** is an aerial image of the home shown in FIG. **3** showing the areas and structures around the home.

FIGS. **5**A-**5**F are consecutive pages from a preliminary or final report sent to a potential customer prepared by the roofing company.

FIG. **6** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system.

FIG. **7** is an example block diagram of a computing system for practicing embodiments of a roof estimation system.

FIG. **8** is an example flow diagram of a first example roof estimation routine provided by an example embodiment.

FIG. **9** is an example flow diagram of a second example roof estimation routine provided by an example embodiment.

DETAILED DESCRIPTION

Referring to the accompanying Figures, there is described a roof estimation system ("RES") **10** and method that allows a roof estimation service **70** to provide a final estimate **102** to a potential customer **90** to install equipment or to repair or replace the roof on a building **92** using aerial images of the building **92**, as shown in FIG. **1**. The roof estimation service **70** may be any service that provides roof estimates to customers. In one embodiment, the roof estimation service **70** typically provides roof estimates to customers who are roof companies or other entities involved in the construction and/or repair of roofs, such as builders, contractors, etc. In another embodiment, the roof estimation service **70** is a roof company that is directly involved in the construction and/or repair of roofs, and that provides estimates to customers that are property owners, general contractors, etc. The system **10** includes an estimating software program **50** designed to receive an address for the building **92**. The software program **50** is linked to an aerial image file database **52** that contains aerial images files **54** of various building **92** in a region. The aerial image files **54** may be taken any available means, such as a manned or unmanned aircraft, a balloon, a satellite, etc. In some embodiments, the aerial image files may include images taken from a ground-based platform, such as a mobile ("street view") photography vehicle, a fixed position (e.g., a tower, nearby building, hilltop, etc.), etc. As shown in FIG. **3**, the image files **54** typically include at least one a top plan view **65** and a perspective view **66** of the building **92**. The roof of the building **92** includes multiple planar roof sections **92***a*-**92***d*.

As shown in FIG. **4**, the image files **54** may also include a wide angle image **67** showing the building **92** and the surrounding areas **93** around the building **92**.

Referring back to FIG. **1**, in one embodiment, an image analysis and calibration module **56** is linked to the software program **50** that enables the roof estimation service **70** to closely estimate the dimensions and slopes of the roofs of the buildings **92** shown in the views **65**, **66**. By simply inputting the customer's address into the software program **50**, the roof estimation service **70** is able view the customer's roof from the aerial image files **54** using a remote computer **72**, determine the dimensions and slopes of the roof sections that make up the roof, and prepare a preliminary report **101** which is then used to prepare a final estimate **102** that is then delivered to the potential customer **90**.

FIG. **1** is an illustration showing the system **10** used by a potential customer **90** requesting a roof estimate from a roof estimation service **70** that uses the system **10** described above. The potential customer **90** may be the building tenant, owner or insurance company. The roof estimation service **70** uses a computer **72** which may connect to a wide area network **60**. The customer **90** contacts the roof estimation service **70** via his or her computer **91** and the wide area network **60** or by a telecommunication network **96**, and requests a roof estimate **100** for his building **92** located at a public address **93**. (in this example, "123 W. 3rd St."). The roof estimation service **70** then processes the request **100** which leads to a final estimate **102** being delivered to the potential customer's computer **91** or via email, fax or postal service to the potential customer **90**.

There are several different ways the system **10** can be setup. FIG. **1** shows a first embodiment of the system **10** where the roof estimation service **70** operates a remote computer **72** with a display **74** and a keyboard **75** or similar input means, such as a mouse, joystick, track pad, etc. A roof estimating software program **50** is loaded into the working memory **73** of the remote computer **72**. The software program **50** is able to retrieve aerial images of buildings from the database **52** containing aerial images files **54** of buildings located in the region served by the roof estimation service **70**. In the first embodiment shown in FIG. **1**, the remote computer **72** is linked or connected to a database **52** containing aerial images files **54** of the buildings. The software program **50** includes a calibration module **56** that enables the roof estimation service **70** to determine the angles and dimensions of various roof sections shown in the images files **54**. After the angles and dimensions are determined, the combined square footage of the building **92** can be determined which is then used to create a preliminary report **101**. The roof estimation service **70** then reviews the wide angle image file **67** (see FIG. **4**) to determine if the building **92** has special access and clean up factors that may impact the final estimate **102**. Once the preliminary report **101** or the final estimate **102** is prepared by the roof estimation service **70**, one or both can be transmitted to the customer **90** via the wide area network **60**, the telecommunication network **96**, or by postal service.

Also shown in FIG. **1** is an alternative setup of the system **10** wherein a preliminary report **101** is prepared by a separate roof estimating entity **105** which is then forwarded to the roof estimation service **70** who then prepares the final estimate **102** and sends it to the customer **90**. The entity **105** includes a computer **106** with a roof estimating software program **50'** loaded into the working memory **107**. Like the software program **50** loaded into the roof contractor's computer **72** in the previous embodiment the software program **50'** is also able to retrieve aerial images of houses from a database **52'** containing aerial images files **54'** of houses located in the region served by the roof estimation service **70**. An optional calibration module **56'** may be provided which enables the entity **105** to determine the angles and linear dimensions of various roof sections on the house **92**.

When the system **10** is set up to include the estimating entity **105**, the customer **90** may first contact the roof estimation service **70**. The roof estimation service **70** may then contact the estimating entity **105** and forward the address of the building **92** thereto. The estimating entity **105** may then prepare the preliminary report **101** that is transmitted to the roof estimation service **70**. The roof estimation service **70** may then prepare the final report **102** and send it to the customer **90**. In other embodiments, interactions between the customer **90**, the roof estimation service **70**, and the estimating entity **105** may occur in different ways and/or orders. For example, the customer **90** may contact the estimating entity **105** directly to receive a final report **102**, which the customer **90** may then forward to one or more roof companies of their choosing.

FIG. **2** shows a third embodiment of the system **10** where the customer **90** contacts a roof estimating entity **130** who receives a request **100** from the customer **90** via the wide area network **60** or telecommunication network **96**. The roof estimating entity **130** prepares a preliminary report **101** which is then transmitted to various roof estimation services **70**, **70'**, **70"** associated with the entity **130**. Accompanying the preliminary report **101** may be the name and contact telephone number(s) or email address of the customer **90**. Each roof estimation service **70**, **70'**, **70"** reviews the preliminary report **101** and any associated images sent therewith and then prepares a final estimate **102**, **102'**, **102"**. The final estimate **102**, **102'**, **102"** is then mailed, emailed or faxed to the customer **90** or back to the estimating entity **130**. The estimating entity **130** then sends the final estimate **102**, **102'**, **102"** to the customer **90**. In this embodiment, the estimating entity **130** includes a computer **135** in which the roof estimating software program **50"** is loaded into its working memory **136** loaded and linked to the aerial image database **52"** containing image files **54"**. An optional calibration module **56"** may be loaded into the working memory **136** of the computer **135**.

FIGS. **5**A-**5**F are individual pages that make up a representative report. In FIG. **5**A, a cover page **103** that lists the address **103***a* of a building **103***c* and an overhead aerial image **103***b* of the building **103***c*. In FIG. **5**B, a second page **104** of the report is shown that shows two wide overhead perspective views **104***a* and **104***b* of the building **103***c* at the address with the surrounding areas more clearly shown. FIG. **5**C is the third page **105** of the report which shows a line drawing **105***a* of the building showing ridge and valley lines, dimensions and a compass indicator. FIG. **5**D is an illustration of the fourth page **106** of the report showing a line drawing **106***a* of the building showing the pitch of each roof section along with a compass indicator. The pitch in this example is given in inches, and it represents the number of vertical inches that the labeled planar roof section drops over 12 inches of horizontal run. The slope can be easily calculated from such a representation using basic trigonometry. The use of a numerical value of inches of rise per foot of run is a well known measure of slope in the roofing industry. A roof builder typically uses this information to assist in the repair and/or construction of a roof. Of course, other measures and/or units of slope may be utilized as well, including percent grade, angle in degrees, etc. FIG. **5**E is an illustration of the fifth page **107** of the report showing a line drawing **107***a* of the building showing the square footage of each roof section along with the total square foot area value. FIG. **5**F is an illustration of a sixth page **108** of the report showing a line drawing **108***a* of the building where notes or comments may be written.

Using the above roof estimation system, a detailed description of how the system may be used in one example embodiment is now provided.

First, a property of interest is identified by a potential customer of the roof estimation service **70**. The customer may be a property owner, a roof construction/repair company, a contractor, an insurance company, a solar panel installer, etc. The customer contacts the roof estimation service with the location of the property. Typically, this will be a street address. The roof estimation service **70** may then use a geo-coding provider, operated by the service **70** or some third party, to translate the location information (such as a street address) into a set of coordinates that can be used to query an aerial or satellite image database. Typically, the geo-coding provider will be used to translate the customer supplied street address into a set of longitude-latitude coordinates.

Next, the longitude-latitude coordinates of the property may be used to query an aerial and/or satellite imagery database in order to retrieve one or more images of the property of interest. It is important to note that horizontal (non-sloping) flat roofs only require a single image of the property. However, few roofs (especially those on residential buildings) are horizontally flat, and often contain one or more pitched sections. In such cases, two or more photographs are typically used in order for the service **70** to identify and measure all relevant sections and features of the roof.

Once the images of the roof section of the building are obtained, at least one of the images may be calibrated. During calibration, the distance in pixels between two points on the image is converted into a physical length. This calibration information is typically presented as a scale marker on the image itself, or as additional information supplied by the image database provider along with the requested image.

The image(s) and calibration information returned by the imagery database is entered or imported into measurement software of the service **70**.

Next, a set of reference points may be identified in each of the images. The service's **70** measurement software then uses these reference points and any acceptable algorithm to co-register the images and reconstruct the three-dimensional geometry of the object identified by the reference points. There are a variety of photo-grammetric algorithms that can be utilized to perform this reconstruction. One such algorithm used by the service **70** uses photographs taken from two or more view points to "triangulate" points of interest on the object in three-dimensional ("3D") space. This triangulation can be visualized as a process of projecting a line originating from the location of the photograph's observation point that passes through a particular reference point in the image. The intersection of these projected lines from the set of observation points to a particular reference point identifies the location of that point in 3D space. Repeating the process for all such reference points allows the software to build a 3D model of the structure.

The optimal choice of reconstruction algorithm depends on a number of factors such as the spatial relationships between the photographs, the number and locations of the reference points, and any assumptions that are made about the geometry and symmetry of the object being reconstructed. Several such algorithms are described in detail in textbooks, trade journals, and academic publications.

Once the reconstruction of the building is complete, the results may be reviewed for completeness and correctness. If necessary, an operator of the service's **70** software will make corrections to the reconstructed model.

Information from the reconstructed model may then be used to generate a report containing information relevant to the customer. The information in the report may include total square footage, square footage and pitch of each section of roof, linear measurements of all roof segments, identification and measurement of ridges and valleys, and different elevation views rendered from the 3D model (top, side, front, etc).

Using the above description, a method for estimating the size and the repair or replacement costs of a roof may include the following steps:

a. selecting a roof estimation system that includes a computer with a roof estimation software program loaded into its working memory, said roof estimation software uses aerial image files of buildings in a selected region and a calibration module that allows the size, geometry, and orientation of a roof section to be determined from said aerial image files;

b. submitting a request for a measurement of a roof of a building at a known location;

c. submitting the location information of a building with a roof that needs a size determination, a repair estimate, or replacement estimate;

d. entering the location information of said building and obtaining aerial image files of one or more roof sections used on a roof; and,

e. using said calibration module to determine the size, geometry and pitch of each said roof section.

In the above method, the entity requesting the measurement may be a roof construction/repair company, the building tenant, the building owner, an insurance company, etc.

FIG. **6** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system. In particular, FIG. **6** shows an example Roof Estimation System ("RES") **600** comprising an image acquisition engine **601**, a roof modeling engine **602**, a report generation engine **603**, image data **605**, model data **606**, and report data **607**. The RES **600** is communicatively coupled to an image source **610**, a customer **615**, and optionally an operator **620**. The RES **600** and its components may be implemented as part of a computing system, as will be further described with reference to FIG. **7**.

In the illustrated embodiment, the RES **600** performs some or all of the functions of the whole system described with reference to FIGS. **1** and **2**, and also additional functions as described below. For example, the RES **600** may perform one or more of the functions of the software program **50**, the roof estimating entity **105**, the aerial image file database **52**, and/or the calibration module **56**.

More specifically, in the illustrated embodiment of FIG. **6**, the RES **600** is configured to generate a roof estimate report **632** for a specified building, based on aerial images **631** of the building received from the image source **610**. The image source **610** may be any provider of images of the building for which a roof estimate is being generated. In one embodiment, the image source **610** includes a computing system that provides access to a repository of aerial images of one or more buildings. The image acquisition engine **601** obtains one or more aerial images of the specified building by, for example, providing an indicator of the location of the specified building (e.g., street address, GPS coordinates, lot number, etc.) to the image source **610**. In response, the image source **610** provides to the image acquisition engine **605** the one or more aerial images of the building. The image acquisition engine **601** then stores the received aerial images as image data **605**, for further processing by other components of the RES **600**. In some embodiments, the aerial images may include images obtain via one or more ground-based platforms, such as a vehicle-mounted camera that obtains street-level images of buildings, a nearby building, a hilltop, etc. In some cases, a vehicle-mounted camera may be mounted in an elevated position, such as a boom.

Next, the roof modeling engine **602** generates a model of the roof of the specified building. In the illustrated embodiment, the roof modeling engine **602** generates a three-dimensional model, although in other embodiments, a two-dimensional (e.g., top-down roof plan) may be generated instead or in addition. As noted above, a variety of automatic and semi-automatic techniques may be employed to generate a model of the roof of the building. In one embodiment, generating such a model is based at least in part on a correlation between at least two of the aerial images of the building. For example, the roof modeling engine **602** receives an indication of a corresponding feature that is shown in each of the two aerial images. In one embodiment, an operator **620**, viewing two or more images of the building, inputs an indication in at least some of the images, the indications identifying which points of the images correspond to each other for model generation purposes.

The corresponding feature may be, for example, a vertex of the roof of the building, the corner of one of the roof planes of the roof, a point of a gable or hip of the roof, etc. The corresponding feature may also be a linear feature, such as a ridge or valley line between two roof planes of the roof. In one embodiment, the indication of a corresponding feature on the building includes "registration" of a first point in a first aerial image, and a second point in a second aerial image, the first and second points corresponding the substantially the same point on the roof of the building. Generally, point registration may include the identification of any feature shown in both aerial images. Thus, the feature need not be a point on the roof of the building. Instead, it may be, for example, any point that is visible on both aerial images, such as on a nearby building (e.g., a garage, neighbor's building, etc.), on a nearby structure (e.g., swimming pool, tennis court, etc.), on a nearby natural feature (e.g., a tree, boulder, etc.), etc.

In some embodiments, the roof modeling engine **602** determines the corresponding feature automatically, such as by employing on one or more image processing techniques used to identify vertexes, edges, or other features of the roof. In other embodiments, the roof modeling engine **602** determines the corresponding feature by receiving, from the human operator **620** as operator input **633**, indications of the feature shown in multiple images of the building.

In addition, generating a 3D model of the roof of a building may include correcting one or more of the aerial images for various imperfections. For example, the vertical axis of a particular aerial image sometimes will not substantially match the actual vertical axis of its scene. This will happen, for example, if the aerial images were taken at different distances from the building, or at a different pitch, roll, or yaw angles of the aircraft from which the images were produced. In such cases, an aerial image may be corrected by providing the operator **620** with a user interface control operable to adjust the scale and/or relative angle of the aerial image to correct for such errors. The correction may be either applied directly to the aerial image, or instead be stored (e.g., as an offset) for use in model generation or other functions of the RES **600**.

Generating a 3D model of the roof of a building further includes the automatic or semi-automatic identification of features of the roof of the building. In one embodiment, one or more user interface controls may be provided, such that the operator **620** may indicate (e.g., draw, paint, etc.) various features of the roof, such as valleys, ridges, hips, vertexes, planes, edges, etc. As these features are indicated by the operator **620**, a corresponding 3D model may be updated accordingly to include those features. These features are identified by the operator based on a visual inspection of the images and by providing inputs that identify various features as valleys, ridges, hips, etc. In some cases, a first and a second image view of the roof (e.g., a north and east view) are simultaneously presented to the operator **620**, such that when the operator **620** indicates a feature in the first image view, a projection of that feature is automatically presented in the second image view. By presenting a view of the 3D model, simultaneously projected into multiple image views, the operator **620** is provided with useful visual cues as to the correctness of the 3D model and/or the correspondence between the aerial images.

In addition, generating a 3D model of the roof of a building may include determining the pitch of one or more of the sections of the roof. In some embodiments, one or more user interface controls are provided, such that the operator **620** may accurately determine the pitch of each of the one or more roof sections. An accurate determination of the roof pitch may be employed (by a human or the RES **600**) to better determine an accurate cost estimate, as roof sections having a low pitch are typically less costly surfaces to repair and/or replace.

The generated 3D model typically includes a plurality of planar roof sections that each correspond to one of the planar sections of the roof of the building. Each of the planar roof sections in the model has a number of associated dimensions and/or attributes, among them slope, area, and length of each edge of the roof section. Other information may include, whether a roof section edge is in a valley or on a ridge of the roof, the orientation of the roof section, and other information relevant to roof builder (e.g., roof and/or roof section perimeter dimensions and/or outlines). Once a 3D model has been generated to the satisfaction of the roof modeling engine **602** and/or the operator **620**, the generated 3D model is stored as model data **606** for further processing by the RES **600**. In one embodiment, the generated 3D model is then stored in a quality assurance queue, from which it is reviewed and possibly corrected by a quality control operator.

The report generation engine **603** generates a final roof estimate report based on a 3D model stored as model data **606**, and then stores the generated report as report data **607**. Such a report typically includes one or more plan (top-down) views of the 3D model, annotated with numerical values for the slope, area, and/or lengths of the edges of at least some of the plurality of planar roof sections of the 3D model of the roof. For example, the example report of FIGS. **5**A-**5**E includes multiple plan views of a generated 3D model of the house **103***c*. In particular, FIG. **5**C shows a first plan view of the 3D model, annotated with dimensions of the edges of each roof section. FIG. **5**D shows a second plan view of the same 3D model, annotated with the slope of each roof section. FIG. **5**E shows a third plan view of the same 3D model, annotated with the area of each roof section.

In some embodiments, generating a report includes labeling one or more views of the 3D model with annotations that

are readable to a human user. Some 3D models include a large number of small roof details, such as dormers or other sections, such that applying uniformly sized, oriented, and positioned labels to roof section views results in a visually cluttered diagram. Accordingly, various techniques may be employed to generate a readable report, including automatically determining an optimal or near-optimal label font size, label position, and/or label orientation, such that the resulting report may be easily read and understood by the customer **615**.

In addition, in some embodiments, generating a report includes automatically determining a cost estimate, based on specified costs, such as those of materials, labor, transportation, etc. For example, the customer **615** provides indications of material and labor costs to the RES **600**. In response, the report generation engine **603** generates a roof estimate report that includes a cost estimate, based on the costs provided by the customer **615** and the attributes of the particular roof, such as area, pitch, etc.

In one embodiment, the generated report is then provided to a customer. The generated report can be represented, for example, as an electronic file (e.g., a PDF file) or a paper document. In the illustrated example, roof estimate report **632** is transmitted to the customer **615**. The customer **615** may be or include any human, organization, or computing system that is the recipient of the roof estimate report **632**. The customer **615** may be a property owner, a property manager, a roof construction/repair company, a general contractor, an insurance company, a solar power panel installer, etc. Reports may be transmitted electronically, such as via a network (e.g., as an email, Web page, etc.) or by some shipping mechanism, such as the postal service, a courier service, etc.

In some embodiments, one or more of the 3D models stored as model data **606** are provided directly to the customer, without first being transformed into a report. For example, a 3D model may be exported as a data file, in any acceptable format, that may be consumed or otherwise utilized by some other computing system, such as computer-aided design ("CAD") tool, drawing program, etc.

FIG. **7** is an example block diagram of a computing system for practicing embodiments of a roof estimation system. FIG. **7** shows a computing system **700** that may be utilized to implement a Roof Estimation System ("RES") **710**. One or more general purpose or special purpose computing systems may be used to implement the RES **710**. More specifically, the computing system **700** may comprise one or more distinct computing systems present at distributed locations. In addition, each block shown may represent one or more such blocks as appropriate to a specific embodiment or may be combined with other blocks. Moreover, the various blocks of the RES **710** may physically reside on one or more machines, which use standard inter-process communication mechanisms (e.g., TCP/IP) to communicate with each other. Further, the RES **710** may be implemented in software, hardware, firmware, or in some combination to achieve the capabilities described herein.

In the embodiment shown, computing system **700** comprises a computer memory ("memory") **701**, a display **702**, one or more Central Processing Units ("CPU") **703**, Input/Output devices **704** (e.g., keyboard, mouse, CRT or LCD display, and the like), other computer-readable media **705**, and network connections **706**. The RES **710** is shown residing in memory **701**. In other embodiments, some portion of the contents, some of, or all of the components of the RES **710** may be stored on and/or transmitted over the other computer-readable media **705**. The components of the RES **710** preferably execute on one or more CPUs **703** and generate roof estimate reports, as described herein. Other code or programs **730** (e.g., a Web server, a database management system, and the like) and potentially other data repositories, such as data repository **720**, also reside in the memory **710**, and preferably execute on one or more CPUs **703**. Not all of the components in FIG. **7** are required for each implementation. For example, some embodiments embedded in other software do not provide means for user input, for display, for a customer computing system, or other components.

In a typical embodiment, the RES **710** includes an image acquisition engine **711**, a roof modeling engine **712**, a report generation engine **713**, an interface engine **714**, and a roof estimation system data repository **716**. Other and/or different modules may be implemented. In addition, the RES **710** interacts via a network **750** with an image source computing system **755**, an operator computing system **765**, and/or a customer computing system **760**.

The image acquisition engine **711** performs at least some of the functions of the image acquisition engine **601** described with reference to FIG. **6**. In particular, the image acquisition engine **711** interacts with the image source computing system **755** to obtain one or more images of a building, and stores those images in the RES data repository **716** for processing by other components of the RES **710**. In some embodiments, the image acquisition engine **711** may act as an image cache manager, such that it preferentially provides images to other components of the RES **710** from the RES data repository **716**, while obtaining images from the image source computing system **755** when they are not already present in the RES data repository **716**.

The roof modeling engine **712** performs at least some of the functions of the roof modeling engine **602** described with reference to FIG. **6**. In particular, the roof modeling engine **712** generates a 3D model based on one or more images of a building that are obtained from the RES data repository **716**. As noted, 3D model generation may be performed semi-automatically, based on at least some inputs received from the computing system **765**. In addition, at least some aspects of the 3D model generation may be performed automatically, based on image processing and/or image understanding techniques. After the roof modeling engine **712** generates a 3D model, it stores the generated model in the RES data repository **716** for further processing by other components of the RES **710**.

The report generation engine **713** performs at least some of the functions of the report generation engine **603** described with reference to FIG. **6**. In particular, the report generation engine **713** generates roof reports based on 3D models stored in the RES data repository **716**. Generating a roof report may include preparing one or more views of a given 3D model of a roof, annotating those views with indications of various characteristics of the model, such as dimensions of sections or other features (e.g., ridges, valleys, etc.) of the roof, slopes of sections of the roof, areas of sections of the roof, etc.

The interface engine **714** provides a view and a controller that facilitate user interaction with the RES **710** and its various components. For example, the interface engine **714** provides an interactive graphical user interface that can be used by a human user operating the operator computing system **765** to interact with, for example, the roof modeling engine **612**, to perform functions related to the generation of 3D models, such as point registration, feature indication, pitch estimation, etc. In other embodiments, the interface engine **714** provides access directly to a customer operating the customer computing system **760**, such that the customer may place an order for a roof estimate report for an indicated building location. In at least some embodiments, access to the functionality of the interface engine **714** is provided via a Web server, possibly executing as one of the other programs **730**.

In some embodiments, the interface engine **714** provides programmatic access to one or more functions of the RES **710**. For example, the interface engine **714** provides a programmatic interface (e.g., as a Web service, static or dynamic library, etc.) to one or more roof estimation functions of the RES **710** that may be invoked by one of the other programs **730** or some other module. In this manner, the interface engine **714** facilitates the development of third-party software, such as user interfaces, plug-ins, adapters (e.g., for integrating functions of the RES **710** into desktop applications, Web-based applications, embedded applications, etc.), and the like. In addition, the interface engine **714** may be in at least some embodiments invoked or otherwise accessed via remote entities, such as the operator computing system **765**, the image source computing system **755**, and/or the customer computing system **760**, to access various roof estimation functionality of the RES **710**.

The RES data repository **716** stores information related the roof estimation functions performed by the RES **710**. Such information may include image data **605**, model data **606**, and/or report data **607** described with reference to FIG. **6**. In addition, the RES data repository **716** may include information about customers, operators, or other individuals or entities associated with the RES **710**.

In an example embodiment, components/modules of the RES **710** are implemented using standard programming techniques. For example, the RES **710** may be implemented as a "native" executable running on the CPU **703**, along with one or more static or dynamic libraries. In other embodiments, the RES **710** is implemented as instructions processed by virtual machine that executes as one of the other programs **730**. In general, a range of programming languages known in the art may be employed for implementing such example embodiments, including representative implementations of various programming language paradigms, including but not limited to, object-oriented (e.g., Java, C++, C#, Visual Basic.NET, Smalltalk, and the like), functional (e.g., ML, Lisp, Scheme, and the like), procedural (e.g., C, Pascal, Ada, Modula, and the like), scripting (e.g., Perl, Ruby, Python, JavaScript, VBScript, and the like), declarative (e.g., SQL, Prolog, and the like).

The embodiments described above may also use well-known synchronous or asynchronous client-server computing techniques. However, the various components may be implemented using more monolithic programming techniques as well, for example, as an executable running on a single CPU computer system, or alternatively decomposed using a variety of structuring techniques known in the art, including but not limited to, multiprogramming, multithreading, client-server, or peer-to-peer, running on one or more computer systems each having one or more CPUs. Some embodiments execute concurrently and asynchronously, and communicate using message passing techniques. Equivalent synchronous embodiments are also supported by an RES implementation. Also, other functions could be implemented and/or performed by each component/module, and in different orders, and by different components/modules, yet still achieve the functions of the RES.

In addition, programming interfaces to the data stored as part of the RES **710**, such as in the RES data repository **716**, can be available by standard mechanisms such as through C, C++, C#, and Java APIs; libraries for accessing files, databases, or other data repositories; through scripting languages such as XML; or through Web servers, FTP servers, or other types of servers providing access to stored data. For example, the RES data repository **716** may be implemented as one or more database systems, file systems, memory buffers, or any other technique for storing such information, or any combination of the above, including implementations using distributed computing techniques.

Also, the example RES **710** can be implemented in a distributed environment comprising multiple, even heterogeneous, computer systems and networks. For example, in one embodiment, the image acquisition engine **711**, the roof modeling engine **712**, the report generation engine **713**, the interface engine **714**, and the data repository **716** are all located in physically different computer systems. In another embodiment, various modules of the RES **710** are hosted each on a separate server machine and are remotely located from the tables which are stored in the data repository **716**. Also, one or more of the modules may themselves be distributed, pooled or otherwise grouped, such as for load balancing, reliability or security reasons. Different configurations and locations of programs and data are contemplated for use with techniques of described herein. A variety of distributed computing techniques are appropriate for implementing the components of the illustrated embodiments in a distributed manner including but not limited to TCP/IP sockets, RPC, RMI, HTTP, Web Services (XML-RPC, JAX-RPC, SOAP, and the like).

Furthermore, in some embodiments, some or all of the components of the RES are implemented or provided in other manners, such as at least partially in firmware and/or hardware, including, but not limited to one or more application-specific integrated circuits (ASICs), standard integrated circuits, controllers (e.g., by executing appropriate instructions, and including microcontrollers and/or embedded controllers), field-programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs), and the like Some or all of the system components and/or data structures may also be stored (e.g., as software instructions or structured data) on a computer-readable medium, such as a hard disk, a memory, a network, or a portable media article to be read by an appropriate drive or via an appropriate connection. The system components and data structures may also be stored as data signals (e.g., by being encoded as part of a carrier wave or included as part of an analog or digital propagated signal) on a variety of computer-readable transmission mediums, which are then transmitted, including across wireless-based and wired/cable-based mediums, and may take a variety of forms (e.g., as part of a single or multiplexed analog signal, or as multiple discrete digital packets or frames). Such computer program products may also take other forms in other embodiments. Accordingly, embodiments of this disclosure may be practiced with other computer system configurations.

FIG. **8** is an example flow diagram of a first example roof estimation routine provided by an example embodiment. The illustrated routine **800** may be provided by, for example, execution of the roof estimation system **710** described with respect to FIG. **7**. The illustrated routine **800** generates a 3D model of a roof of a building, based on two or more aerial images of the building, and further prepares and transmits a roof estimate report based on the 3D model.

More specifically, the routine begins at step **801** where it receives a first and a second aerial image of a building, each of the aerial images providing a different view of the roof of the building. The aerial images may be received from, for example, the image source computing system **755** and/or from the RES data repository **716** described with reference to FIG. **7**. As discussed above, aerial images may be originally created by cameras mounted on airplanes, balloons, satellites, etc. In some embodiments, images obtained from ground-based platforms (e.g., vehicle-mounted cameras) may be used instead or in addition.

In step **802**, the routine correlates the first aerial image with the second aerial image. In some embodiments, correlating the aerial images may include registering pairs of points on the first and second aerial images, each pair of points corresponding to substantially the same point on the roof depicted in each of the images. Correlating the aerial images may be based at least in part on input received from a human operator and/or automatic image processing techniques.

In step **803**, the routine generates, based at least in part on the correlation between the first and second aerial images, a three-dimensional model of the roof. The three-dimensional model of the roof may include a plurality of planar roof sections that each have a corresponding slope, area, and perimeter. Generating the three-dimensional model may be based at least in part indications of features of the roof, such as valleys, ridges, edges, planes, etc. Generating the three-dimensional model may also be based at least in part on input received from a human operator (e.g., indications of roof ridges and valleys) and/or automatic image processing techniques.

In step **804**, the routine prepares (e.g., generates, determines, produces, etc.) and transmits a roof estimate report that includes one or more annotated top-down views of the three-dimensional model. In some embodiments, the annotations include numerical values indicating the slope, area, and lengths of the edges of the perimeter of at least some of the plurality of planar roof sections of the three-dimensional model of the roof. The roof estimate report may be an electronic file that includes images of the building and/or its roof, as well as line drawings of one or more views of the three-dimensional model of the building roof. Preparing the report may include annotating the report with labels that are sized and oriented in a manner that preserves and/or enhances readability of the report. For example, labels on a particular line drawing may be sized based at least in part on the size of the feature (e.g., roof ridge line) that they are associated with, such that smaller features are annotated with smaller labels so as to preserve readability of the line drawing by preventing or reducing the occurrence of labels that overlap with other portions (e.g., lines, labels, etc.) of the line drawing. The roof estimate report may be transmitted to various destinations, such as directly to a customer or computing system associated with that customer, a data repository, and/or a quality assurance queue for inspection and/or improvement by a human operator.

After step **804**, the routine ends. In other embodiments, the routine may instead return to step **801**, to generate another roof estimate report for another building. Note that the illustrated routine may be performed interactively, such as based at least in part on one or more inputs received from a human operator, or in batch mode, such as for performing automatic, bulk generation of roof estimate reports.

FIG. **9** is an example flow diagram of a second example roof estimation routine provided by an example embodiment. The illustrated routine **900** may be provided by, for example, execution of the roof estimation system **710** described with respect to FIG. **7**. The illustrated routine **900** generates a roof estimate report based on a single aerial image and additional information received from a user, such as information about the pitch of various roof sections.

In step **901**, the routine receives a substantially top-down aerial image of a building having a roof. Such an aerial image may be obtained from, for example, a satellite or aircraft.

In step **902**, the routine generates a preliminary model of the roof based on the received aerial image. The preliminary roof model may be a two-dimensional ("flat") model that includes information about the perimeter of the roof and at least some of its corresponding planar roof sections. Such a preliminary roof model may include estimates of various dimensions of the roof, such as edge lengths and/or section areas. In some cases, the preliminary roof model does not include information related to the pitch of various roof sections.

In step **903**, the routine modifies the preliminary model based on additional information about the roof received from a user. For example, the preliminary model may be presented to a user (e.g., a customer, an operator, etc.), by displaying a representation of the model, such as a line drawing. In response, the user provides the routine with pitch information and/or feature identification (e.g., of ridges and/or valleys), etc. Such user-supplied information is then incorporated into the preliminary roof model to obtain a modified (refined) roof model. In some cases, the user supplies the additional information via a Web-base interface that provides access to the routine.

In step **904**, the routine prepares and transmits a roof estimate report that includes one or more annotated views of the modified model. As discussed above, the annotations may include numerical values indicating the slope, area, and lengths of the edges of the perimeter of at least some of the roof sections of the roof. After step **904**, the routine ends.

The routines **800** and **900** may be used in conjunction to advantageously offer customers roof estimate reports at differing price points. For example, routine **800** can be utilized as part of a "premium" service that offers a customer with a more accurate roof estimate report for minimal effort on the customer's part. Routine **900** can be utilized as part of an "economy" service that offers a customer a less accurate roof estimate report at a lower price, but that may be further refined with additional effort from the customer.

From the foregoing it will be appreciated that, although specific embodiments have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the present disclosure. For example, the methods, systems, and techniques for generating and providing roof estimate reports discussed herein are applicable to other architectures other than the illustrated architecture or a particular roof estimation system implementation. Also, the methods and systems discussed herein are applicable to differing network protocols, communication media (optical, wireless, cable, etc.) and devices (such as wireless handsets, electronic organizers, personal digital assistants, portable email machines, game machines, pagers, navigation devices such as GPS receivers, etc.). Further, the methods and systems discussed herein may be utilized by and/or applied to other contexts or purposes, such as by or for solar panel installers, roof gutter installers, awning companies, HVAC contractors, general contractors, and/or insurance companies.

The invention claimed is:

1. A computing system for generating a roof estimate report, the computing system comprising:

a memory;

a roof estimation module that is stored on the memory and that is configured, when executed, to:

receive a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building;

correlate the first aerial image with the second aerial image;

generate, based at least in part on the correlation between the first and second aerial images, a three-dimensional model of the roof that includes a plurality of planar roof sections that each have a corresponding slope, area, and edges; and

generate and transmit a roof estimate report that includes one or more top plan views of the three-dimensional model annotated with numerical values that indicate the corresponding slope, area, and length of edges of at least some of the plurality of planar roof sections using at least two different indicia for different types of roof properties.

2. The computing system of claim **1** wherein the roof estimation module is further configured to correlate the first and second aerial images by receiving an indication of one or more corresponding points on the building shown in each of the first and second aerial images.

3. The computing system of claim **1** wherein the roof estimation module is further configured to generate the three-dimensional model by receiving an indication of at least one of a ridgeline of the roof, a valley of the roof, an edge of the roof, a hip of the roof, and a gable of the roof.

4. The computing system of claim **1** wherein the roof estimation module is further configured to receive the first and second aerial image from an image source computing system.

5. The computing system of claim **1** wherein the roof estimation module is further configured to generate the roof estimate report by generating an electronic file that includes an image of the building along with line drawings of the one or more top plan views of the three-dimensional model.

6. The method of claim **1** wherein transmitting the roof estimate report includes initiating printing of the one or more top plan views of the three-dimensional model.

7. The computing system of claim **1** wherein the different types of roof properties include different roof measurements, and the at least two different indicia include at least one of: length, slope, and area.

8. The computing system of claim **7** wherein the length is located adjacent to a line representing a segment, the slope is located next to an arrow indicating direction of the slope and the area is located within a section having the area.

9. The computing system of claim **1** wherein the different types of roof properties include different roof features, and the at least two different indicia include different graphical representations of the different roof features.

10. The computing system of claim **1** wherein the different types of roof properties include a ridge line and a valley line and the at least two different indicia include one color of a line associated with a ridge and a different color of a line associated with a valley.

11. The computing system of claim **1** wherein the different types of roof properties include at least one of: a roof section, a roof segment, a roof valley, a ridge, a roof size, a roof geometry, a roof measurement, a roof dimension, slope, length and area.

12. The computing system of claim **1** wherein the at least two different indicia include at least one of: different line color, different line weight, different visual characteristics of a line, different characters, different color of characters, different visual characteristics of characters, different measurements, different visual characteristics of measurements, different placement of measurements with respect to lines, different symbols, different visual characteristics of symbols and different placement of measurements with respect to symbols.

13. The computing system of claim **1** wherein the different types of roof properties include a ridge length and a valley length and the at least two different indicia include one color of a line associated with a ridge and a different color of a line associated with a valley.

14. The computing system of claim **13** wherein the one color of the line associated with the ridge is red and the different color of the line associated with the valley is blue.

15. The computing system of claim **1** wherein the different types of roof properties include a ridge and the at least two different indicia include a ridge length indicia, wherein the ridge length indicia is a ridge line with a numerical value adjacent thereto.

16. The computing system of claim **1** wherein the different types of roof properties include a valley and the at least two different indicia include a valley length indicia, wherein the valley length indicia is a valley line with a numerical value adjacent thereto.

17. The computing system of claim **1** wherein the different types of roof properties include a slope and the at least two different indicia include a slope indicia, wherein the slope indicia is an arrow in a direction of the slope with a numerical value adjacent thereto.

18. A computer-implemented method for generating a roof estimate, the method comprising:

receiving a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building;

correlating the first aerial image with the second aerial image;

generating, based at least in part on the correlation between the first and second aerial images, a three-dimensional model of the roof that includes a plurality of planar roof sections that each have a corresponding slope, area, and edges; and

transmitting a roof estimate report that includes one or more top plan views of the three-dimensional model annotated with numerical indications of at least one of the slope, area, and lengths of the edges of the plurality of planar roof sections, wherein the roof estimate report includes at least two different indicia for different types of roof properties.

19. The method of claim **18** wherein identifying the building includes receiving a street address of the building.

20. The method of claim **18** wherein correlating the first and second aerial images includes receiving an indication of one or more corresponding points shown in each of the first and second aerial images.

21. The method of claim **20** wherein receiving the indication of the corresponding point includes receiving the indication from a user.

22. The method of claim **18** wherein generating the three-dimensional model includes receiving an indication of at least one of a ridgeline of the roof, a valley of the roof, an edge of the roof, a hip of the roof, and a gable of the roof.

23. The method of claim **18**, further comprising generating the roof estimate report, the roof estimate report being a data file that includes an image of the building along with line drawings of the one or more top plan views of the three-dimensional model.

24. The method of claim **18** wherein transmitting the roof estimate report includes transmitting a data file that includes the one or more top plan views of the three-dimensional model.

25. The method of claim **18** wherein the different types of roof properties include different roof measurements, and the at least two different indicia include at least one of: length, slope, and area.

26. The method of claim **25** wherein the length is located adjacent to a line representing a segment, the slope is located next to an arrow indicating direction of the slope and the area is located within a section having the area.

27. The method of claim **18** wherein the different types of roof properties include different roof features, and the at least two different indicia include different graphical representations of the different roof features.

28. The method of claim **18** wherein the different types of roof properties include a ridge line and a valley line and the at least two different indicia include one color of a line associated with a ridge and a different color of a line associated with a valley.

29. The method of claim **18** wherein the different types of roof properties include at least one of: a roof section, a roof segment, a roof valley, a ridge, a roof size, a roof geometry, a roof measurement, a roof dimension, slope, length and area.

30. The method of claim **18** wherein the at least two different indicia include at least one of: different line color, different line weight, different visual characteristics of a line, different characters, different color of characters, different visual characteristics of characters, different measurements, different visual characteristics of measurements, different placement of measurements with respect to lines, different symbols, different visual characteristics of symbols and different placement of measurements with respect to symbols.

31. The method of claim **18** wherein the different types of roof properties include a ridge length and a valley length and the at least two different indicia include one color of a line associated with a ridge and a different color of a line associated with a valley.

32. The method of claim **31** wherein the one color of the line associated with the ridge is red and the different color of the line associated with the valley is blue.

33. The method of claim **18** wherein the different types of roof properties include a ridge and the at least two different indicia include a ridge length indicia, wherein the ridge length indicia is a ridge line with a numerical value adjacent thereto.

34. The method of claim **18** wherein the different types of roof properties include a valley and the at least two different indicia include a valley length indicia, wherein the valley length indicia is a valley line with a numerical value adjacent thereto.

35. The method of claim **18** wherein the different types of roof properties include a slope and the at least two different indicia include a slope indicia, wherein the slope indicia is an arrow in a direction of the slope with a numerical value adjacent thereto.

36. A non-transitory computer-readable storage medium whose contents enable a computing system to generate a roof estimate report for a building having a roof, by performing a method comprising:

receiving one or more images of the building;

generating, based on the one or more images of the building, a model of the roof that includes a plurality of planar roof sections that each have a corresponding area and edges; and

transmitting a roof estimate report that includes one or more views of the model, the report being annotated with numerical indications of the area and lengths of the edges of at least some of the plurality of planar roof sections, wherein the roof estimate report includes at least two different indicia for different types of roof properties.

37. The non-transitory computer-readable storage medium of claim **36** wherein generating the model includes generating a three-dimensional model based on a correlation between two of the one or more images.

38. The non-transitory computer-readable storage medium of claim **36** wherein the method further comprises generating the roof estimate report, the roof estimate report including annotated line drawings of each of the one or more views of the model.

39. The non-transitory computer-readable storage medium of claim **36** wherein the one or more images of the building are images obtained from at least one of an aircraft, satellite, and ground-based platform, and wherein the one or more views of the model are top-down line drawing views of the model.

40. The non-transitory computer-readable storage medium of claim **36** wherein generating the model of the roof includes automatically identifying at least some features of the roof for inclusion in the model.

41. The non-transitory computer-readable storage medium of claim **36** wherein the contents are instructions that when executed cause the computing system to perform the method.

42. The non-transitory computer-readable storage medium of claim **36** wherein the method further comprises transmitting to a remote computing system a computer-readable data file that includes a representation of the model.

43. The non-transitory computer-readable storage medium of claim **36** wherein generating the model of the roof includes generating a two-dimensional model of the roof based on a single image that provides a substantially top-down view of the roof.

44. The non-transitory computer-readable storage medium of claim **43** further comprising:

presenting the model to a customer; and

modifying the model of the roof based on input received from the customer, the input indicating a slope corresponding to one of the plurality of planar roof sections, wherein transmitting the roof estimate report includes generating a roof estimate report based on the modified model.

45. The non-transitory computer-readable storage medium of claim **43** further comprising:

modifying the model of the roof based on input received from a customer, the input identifying a ridge or valley of the roof, wherein transmitting the roof estimate report includes generating a roof estimate report based on the modified model.

46. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include different roof measurements, and the at least two different indicia include at least one of: length, slope, and area.

47. The non-transitory computer-readable storage medium of claim **46** wherein the length is located adjacent to a line representing a segment, the slope is located next to an arrow indicating direction of the slope and the area is located within a section having the area.

48. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include different roof features, and the at least two different indicia include different graphical representations of the different roof features.

49. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include a ridge line and a valley line and the at least two different indicia include one color of a line associated with a ridge and a different color of a line associated with a valley.

50. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include at least one of: a roof section, a roof segment, a roof valley, a ridge, a roof size, a roof geometry, a roof measurement, a roof dimension, slope, length and area.

51. The non-transitory computer-readable storage medium of claim **36** wherein the at least two different indicia include at least one of: different line color, different line weight, different visual characteristics of a line, different characters, different color of characters, different visual characteristics of characters, different measurements, different visual characteristics of measurements, different placement of measurements with respect to lines, different symbols, different visual characteristics of symbols and different placement of measurements with respect to symbols.

52. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include a ridge length and a valley length and the at least two different indicia include one color of a line associated with a ridge and a different color of a line associated with a valley.

53. The non-transitory computer-readable storage medium of claim **52** wherein the one color of the line associated with the ridge is red and the different color of the line associated with the valley is blue.

54. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include a ridge and the at least two different indicia include a ridge length indicia, wherein the ridge length indicia is a ridge line with a numerical value adjacent thereto.

55. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include a valley and the at least two different indicia include a valley length indicia, wherein the valley length indicia is a valley line with a numerical value adjacent thereto.

56. The non-transitory computer-readable storage medium of claim **36** wherein the different types of roof properties include a slope and the at least two different indicia include a slope indicia, wherein the slope indicia is an arrow in a direction of the slope with a numerical value adjacent thereto.

* * * * *

US008078436C1

(12) EX PARTE REEXAMINATION CERTIFICATE (11th)

Ex Parte Reexamination Ordered under 35 U.S.C. 257

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Pershing et al. (45) **Certificate Issued: Aug. 27, 2014**

(54) **AERIAL ROOF ESTIMATION SYSTEMS AND METHODS**

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(73) Assignee: **Eagle View Technologies, Inc.**, Redmond, WA (US)

Supplemental Examination Request:
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(51) **Int. Cl.**

G06F 7/60	(2006.01)
G06F 17/10	(2006.01)
G06Q 30/02	(2012.01)
G06T 17/20	(2006.01)

(52) **U.S. Cl.**
CPC ***G06Q 30/02*** (2013.01); ***G06T 17/20*** (2013.01); ***G06Q 30/0283*** (2013.01); *G06T 2200/08* (2013.01)
USPC **703/2**

(58) **Field of Classification Search**
None
See application file for complete search history.

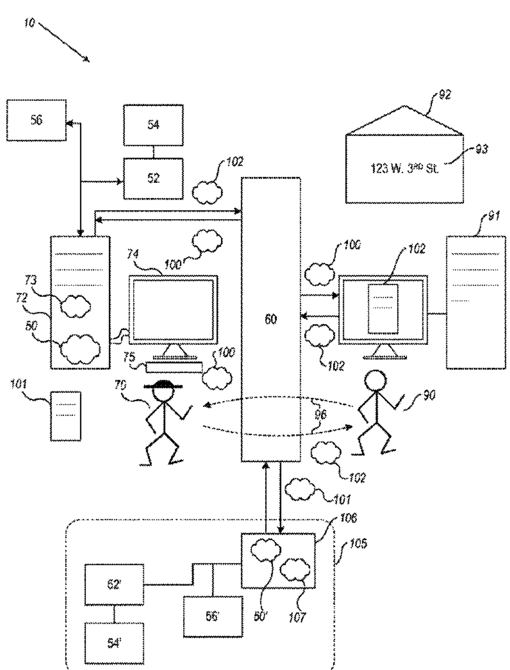
(56) **References Cited**

To view the complete listing of prior art documents cited during the supplemental examination proceeding and the resulting reexamination proceeding for Control Number 96/000,004, please refer to the USPTO's public Patent Application Information Retrieval (PAIR) system under the Display References tab.

Primary Examiner — Jason Proctor

(57) **ABSTRACT**

Methods and systems for roof estimation are described. Example embodiments include a roof estimation system, which generates and provides roof estimate reports annotated with indications of the size, geometry, pitch and/or orientation of the roof sections of a building. Generating a roof estimate report may be based on one or more aerial images of a building. *The slope and orientation images are typically oblique perspective views and top plan views of the buildings in the area.* In some embodiments, generating a roof estimate report of a specified building roof may include generating a three-dimensional model of the roof, and generating a report that includes one or more views of the three-dimensional model, the views annotated with indications of the dimensions, area, and/or slope of sections of the roof. This abstract is provided to comply with rules requiring an abstract, and it is submitted with the intention that it will not be used to interpret or limit the scope or meaning of the claims.



EX PARTE REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

Claims **43-45** are cancelled.

Claims **1**, **18**, **36**, **37** and **41** are determined to be patentable as amended.

Claims **2-17**, **19-35**, **38-40**, **42** and **46-56**, dependent on an amended claim, are determined to be patentable.

New claims **57-66** are added and determined to be patentable.

1. A computing system for generating a roof estimate report, the computing system comprising:

a memory;

a roof estimation module that is stored on the memory and that is configured, when executed, to:

receive a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building, *wherein the first aerial image provides a top plan view of the roof and the second aerial image provides an oblique perspective view of the roof, and are not a stereoscopic pair*;

correlate the first aerial image with the second aerial image;

generate, based at least in part on the correlation between the first and second aerial images, a three-dimensional model of the roof that includes a plurality of planar roof sections that each have a corresponding slope, area, and edges; and

generate and transmit a roof estimate report that includes one or more top plan views of the three-dimensional model annotated with numerical values that indicate the corresponding slope, area, and length of edges of at least some of the plurality of planar roof sections using at least two different indicia for different types of roof properties.

18. A computer-implemented method for generating a roof estimate, the method comprising:

receiving a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building *wherein the first aerial image provides a top plan view of the roof and the second aerial image provides a view of the roof that is other than a top plan view and neither of the two images are part of a stereoscopic pair*;

correlating the first aerial image with the second aerial image;

generating, based at least in part on the correlation between the first and second aerial images, a three-dimensional model of the roof that includes a plurality of planar roof sections that each have a corresponding slope, area, and edges; and

transmitting a roof estimate report that includes one or more top plan views of the three-dimensional model annotated with numerical indications of at least one of the slope, area, and lengths of the edges of the plurality of planar roof sections, wherein the roof estimate report includes at least two different indicia for different types of roof properties.

36. A non-transitory computer-readable storage medium whose contents*, which are computer executable instructions stored on the non-transitory computer-readable storage medium, when executed by a computer processor of a computing system,* enable **[**a**]** *the* computing system to generate a roof estimate report for a building having a roof, by **[**performing**]** *causing, when executed by the computer processor of the computing system, the computing system to perform* a method comprising:

receiving **[**one**]** *two* or more images of the building, *wherein at least one of the two or more images provides an oblique perspective view of the roof and one of the images provides a top plan view of the roof;*

receiving an indication of pairs of points on the two or more images, each pair of points corresponding to substantially the same point on the roof depicted in each of the two or more images;

generating, based on the **[**one**]** *two* or more images of the building, a *three- dimensional* model of the roof that includes a plurality of planar roof sections that each have a corresponding area and edges*, wherein the generating, based on the two or more images of the building, the model of the roof includes generating the model of the roof based on the receiving the indication of the pairs of points on the two or more images of the building*; and

transmitting a roof estimate report that includes one or more views of the model, the report being annotated with numerical indications of the area and lengths of the edges of at least some of the plurality of planar roof sections, wherein the roof estimate report includes at least two different indicia for different types of roof properties.

37. The non-transitory computer-readable storage medium of claim **36** wherein generating the model *of the roof based on the receiving the indication of the pairs of points on the two or more images* includes*:*

correlating two of the two or more images by registering the pairs of points; and

generating **[**a**]** *the* three-dimensional model based on **[**a**]** *the* correlation between *the* two of the **[**one**]** *two* or more images.

41. The non-transitory computer-readable storage medium of claim **36** wherein the contents are instructions that when executed cause the computing system to perform *the receiving two or more images step of* the method *by causing, when executed by the computer processor of the computing system, the computing system to provide access to a repository of aerial images of one or more buildings*.

57. The method according to 18 wherein the second aerial image provides an oblique perspective view of the roof.

58. A computer-implemented method for generating a roof estimate, the method comprising:

receiving a first aerial image of a building having a type of view of the roof that is a top plan view of the roof;

receiving a second aerial image of the building having a type of view of the roof that is a perspective oblique view of the roof;

receiving a third aerial image having a type of view of the roof that is an oblique perspective from a different direc-

tion than the second aerial image, each of the aerial images providing a different view of the roof of the building;

correlating the first aerial image with the second aerial image and third aerial images;

generating, based at least in part on the correlation between the first, second and third aerial images, a three-dimensional model of the roof that includes a plurality of planar roof sections that each have a corresponding slope, area, and edges; and

transmitting a roof estimate report that includes one or more top plan views of the three-dimensional model annotated with numerical indications of at least one of the slope, area, and lengths of the edges of the plurality of planar roof sections, wherein the roof estimate report includes at least two different indicia for different types of roof properties.

59. The method of claim 58 wherein the different types of roof properties include a ridge line and a valley line and the at least two different indicia include one color of a line conveying the meaning of a roof ridge and a different color of a line conveying the meaning of roof valley.

60. A computer-implemented method for generating a roof estimate, the method comprising:

receiving a first aerial image of a building;

receiving a second aerial image of the building having the roof;

receiving a third aerial image of the building, each of the aerial images providing a different view of the roof of the building;

correlating the first aerial image with the second aerial image and third aerial image;

generating, based at least in part on the correlation between the first, second and third aerial images, a three-dimensional model of the roof that includes a plurality of planar roof sections that each have a corresponding slope, area, and edges; and

generating and transmitting a roof estimate report that includes one or more top plan views of the three-dimensional model annotated with numerical indications of at least one of the slope, area, and lengths of the edges of the plurality of planar roof sections, wherein the roof estimate report includes at least two different indicia for different types of roof properties.

61. The method of claim 60 wherein the correlating the first aerial image with the second and third aerial image includes receiving an indication of pairs of points on each of the images corresponding to substantially the same point on the roof depicted in each of the images.

62. The method of claim 61 wherein the correlating the first aerial image with the second and third aerial image further includes registering the pairs of points and the generating the three-dimensional model includes generating the three-dimensional model based on the registering of the pairs of points.

63. A computer-implemented method for generating a roof estimate, the method comprising:

receiving a request for a roof estimate report for the roof of the building;

receiving location information regarding the building;

receiving a first aerial image of the building having the roof;

receiving a second aerial image of the building having the roof, the first and second images of the roof being independent of each in the views provided of the roof, each of the aerial images providing a different view of the roof of the building;

correlating the first aerial image with the second aerial image;

generating, based at least in part on the correlation between the first and second aerial images, a three-dimensional model of the roof that includes a plurality of planar roof sections that each have a corresponding pitch, area, and edges;

determining a pitch of a plurality of sections of the roof;

determining a direction of the pitch for each of the plurality of sections of the roof for which a pitch was determined;

generating a roof estimate report that includes a top plan views of the three-dimensional model annotated with numerical indications of the determined pitch and the direction of the pitch;

displaying on at least one top plan view a graphical indication of the pitch value of the respective roof sections that conveys the pitch value;

determining a ridge line and a valley line of the roof;

displaying on at least one top plan view a ridge line in which the property of it being a ridge line is conveyed by it being displayed in a first color and a valley line in which the property of it being a valley line is convey by it being in a second color, different from the first color; and

transmitting the generated roof report.

64. The method of claim 63 further comprising:

displaying on at least one top plan view of the roof a graphical indication of the pitch direction of the respective roof sections that conveys the direction of the pitch.

65. The method of claim 63 wherein the top plan view showing the pitch value is a different top plan view than the one showing the ridge line and the valley line.

66. The method of claim 65 wherein the correlating the first aerial image with the second aerial image further includes registering pairs of points and the generating the three-dimensional model includes generating the three-dimensional model based on the registering of the pairs of points.

* * * * *

EXHIBIT 5
Part 1

US008170840B2

(12) **United States Patent**
Pershing

(10) **Patent No.: US 8,170,840 B2**
(45) **Date of Patent: *May 1, 2012**

(54) **PITCH DETERMINATION SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION**

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(73) Assignee: **Eagle View Technologies, Inc.**, Redmond, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 362 days.

This patent is subject to a terminal disclaimer.

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(22) Filed: **May 15, 2009**

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G06F 17/50 (2006.01)

(52) **U.S. Cl.** **703/1**

(58) **Field of Classification Search** 703/1
See application file for complete search history.

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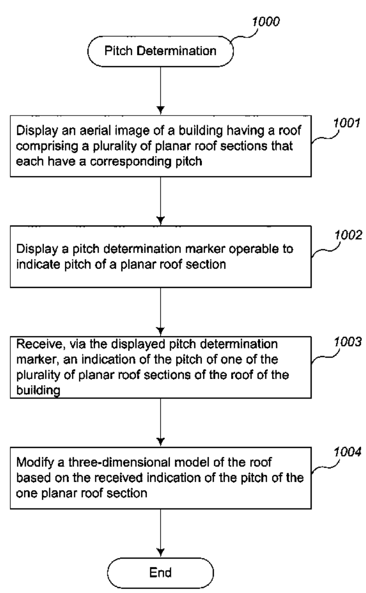
Primary Examiner — Dwin M Craig
Assistant Examiner — Andre Pierre Louis
(74) *Attorney, Agent, or Firm* — Seed IP Law Group PLLC

(57) **ABSTRACT**

User interface systems and methods for roof estimation are described. Example embodiments include a roof estimation system that provides a user interface configured to facilitate roof model generation based on one or more aerial images of a building roof. In one embodiment, roof model generation includes image registration, image lean correction, roof section pitch determination, wire frame model construction, and/or roof model review. The described user interface provides user interface controls that may be manipulated by an operator to perform at least some of the functions of roof model generation. In one embodiment, the user interface provides user interface controls that facilitate the determination of pitch of one or more sections of a building roof. This abstract is provided to comply with rules requiring an abstract, and it is submitted with the intention that it will not be used to interpret or limit the scope or meaning of the claims.

28 Claims, 29 Drawing Sheets



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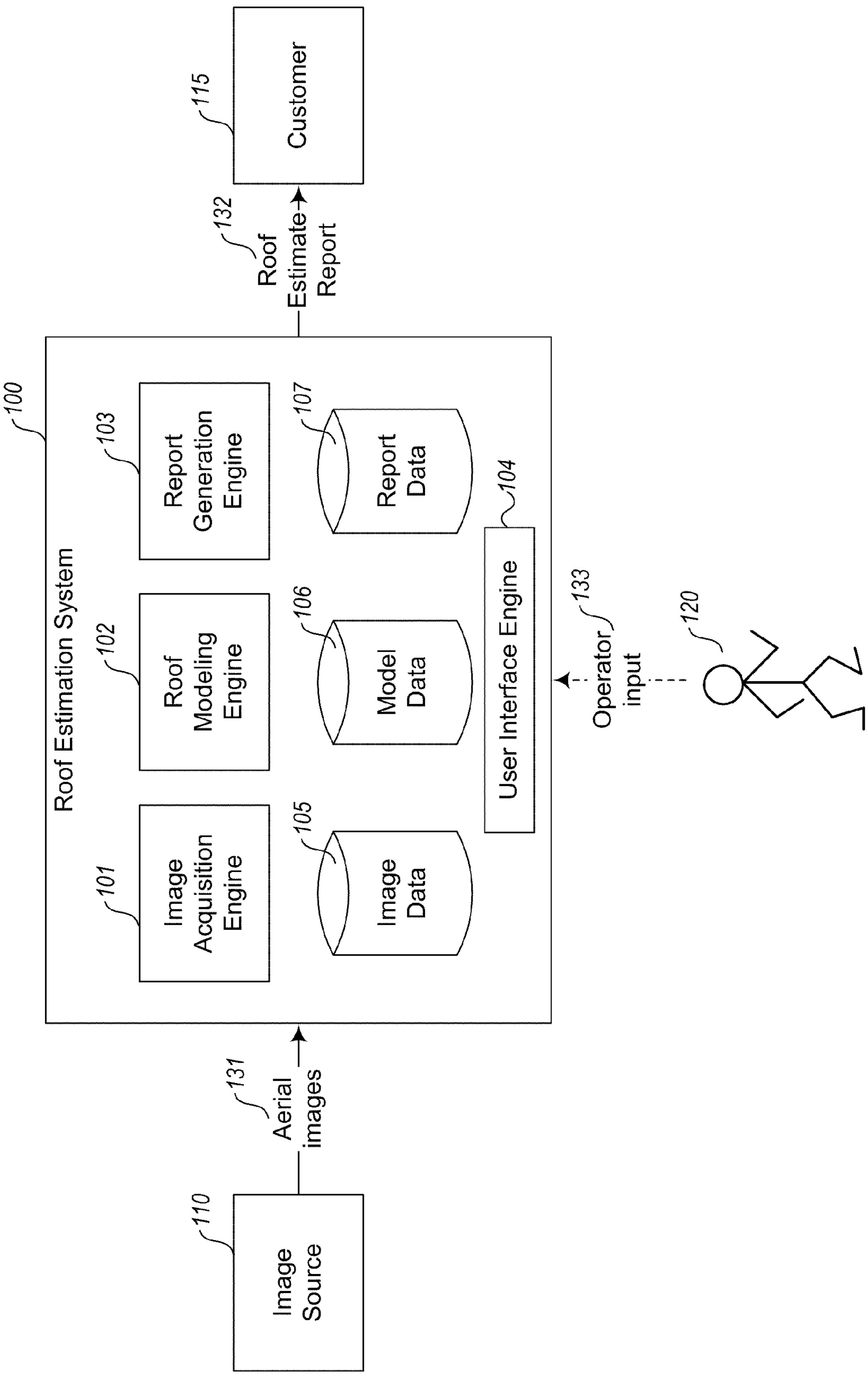


Image Source
110
Aerial images
131
Roof Estimation System
100
Image Acquisition Engine
101
Roof Modeling Engine
102
Report Generation Engine
103
Image Data
105
Model Data
106
Report Data
107
User Interface Engine
104
Operator input
133
120
Roof Estimate Report
132
Customer
115

Fig. 1

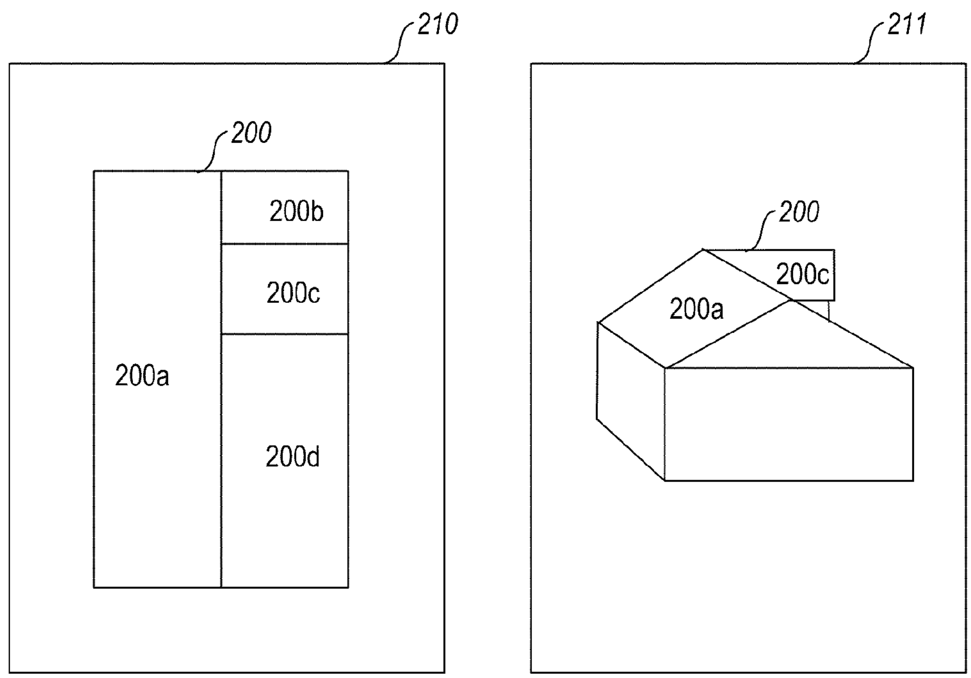

210
200
200b
200c
200a
200d
211
200
200c
200a

Fig. 2A

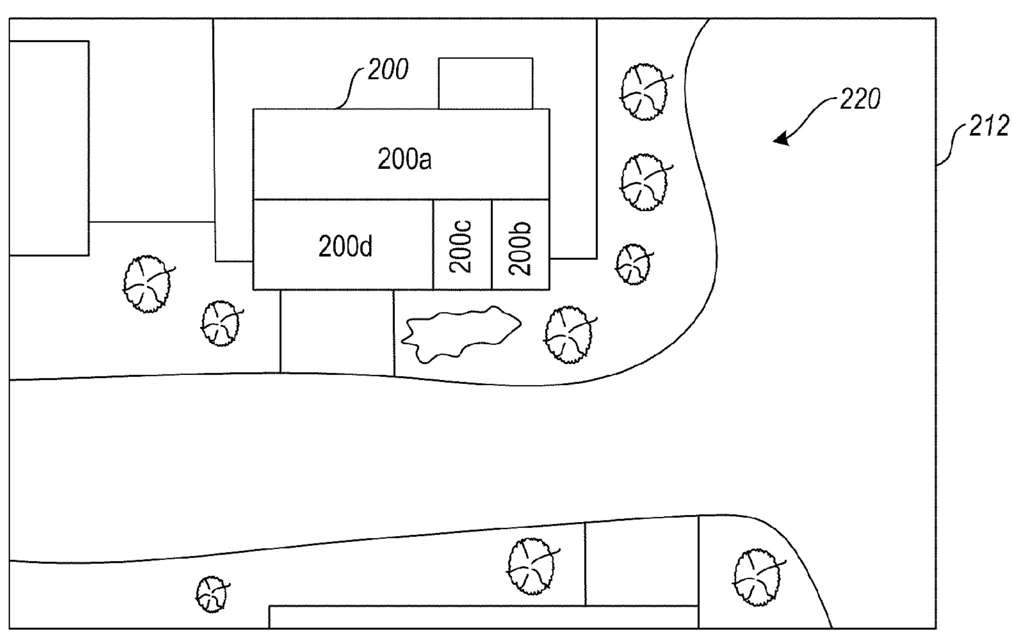

200
200a
200d
200c
200b
220
212

Fig. 2B

1234 Main Street, Redmond, WA

Order: 2468

<Customer Name Here>

4/16/2008

301a

1234 Main Street, Redmond, WA

301b

Order: 2468 Copyright (c) 2008 Eagle View Technologies, Inc. Page 1 of 6

301

Fig. 3A

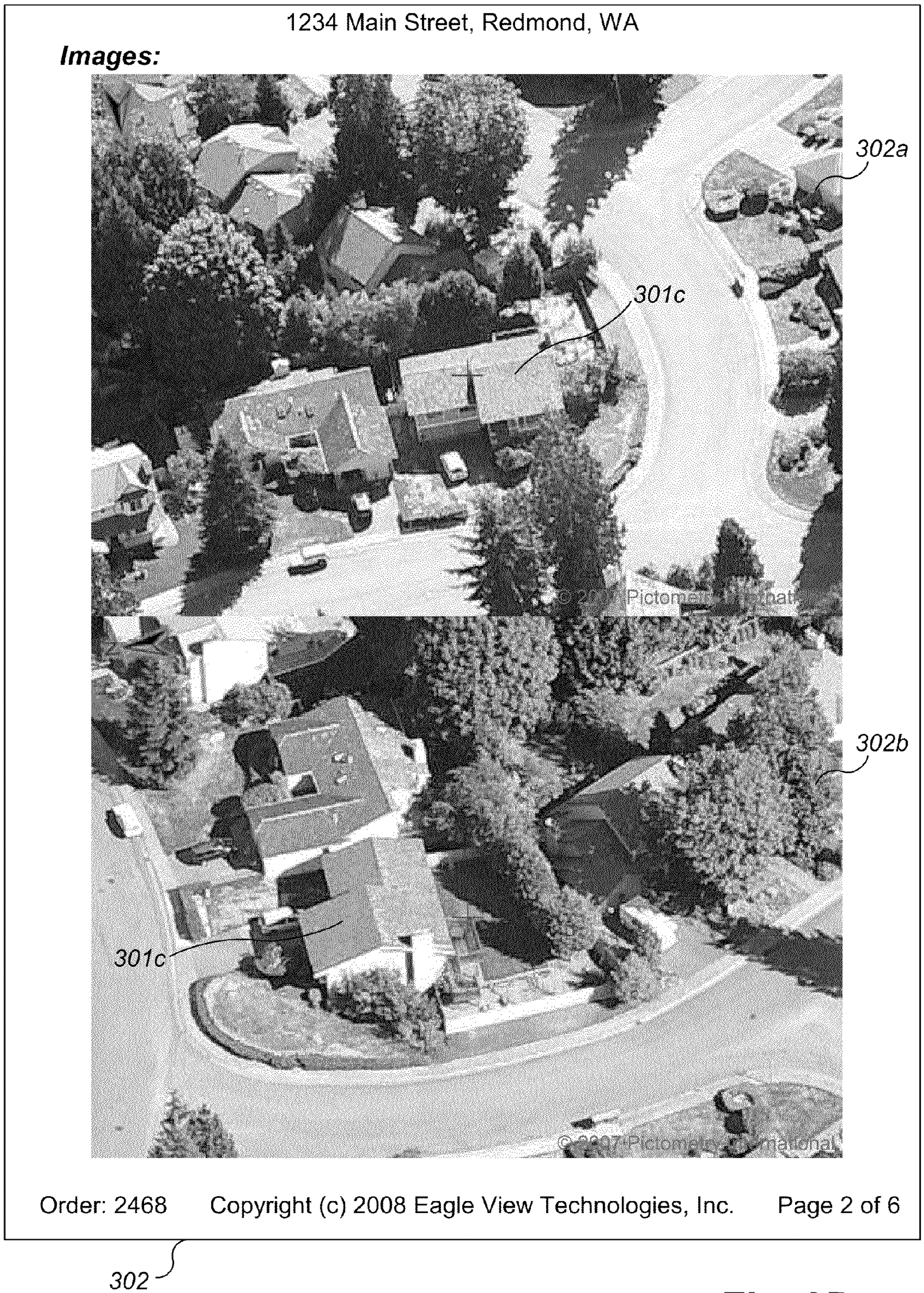

1234 Main Street, Redmond, WA
Images:
302a
301c
302b
301c
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 2 of 6
302

Fig. 3B

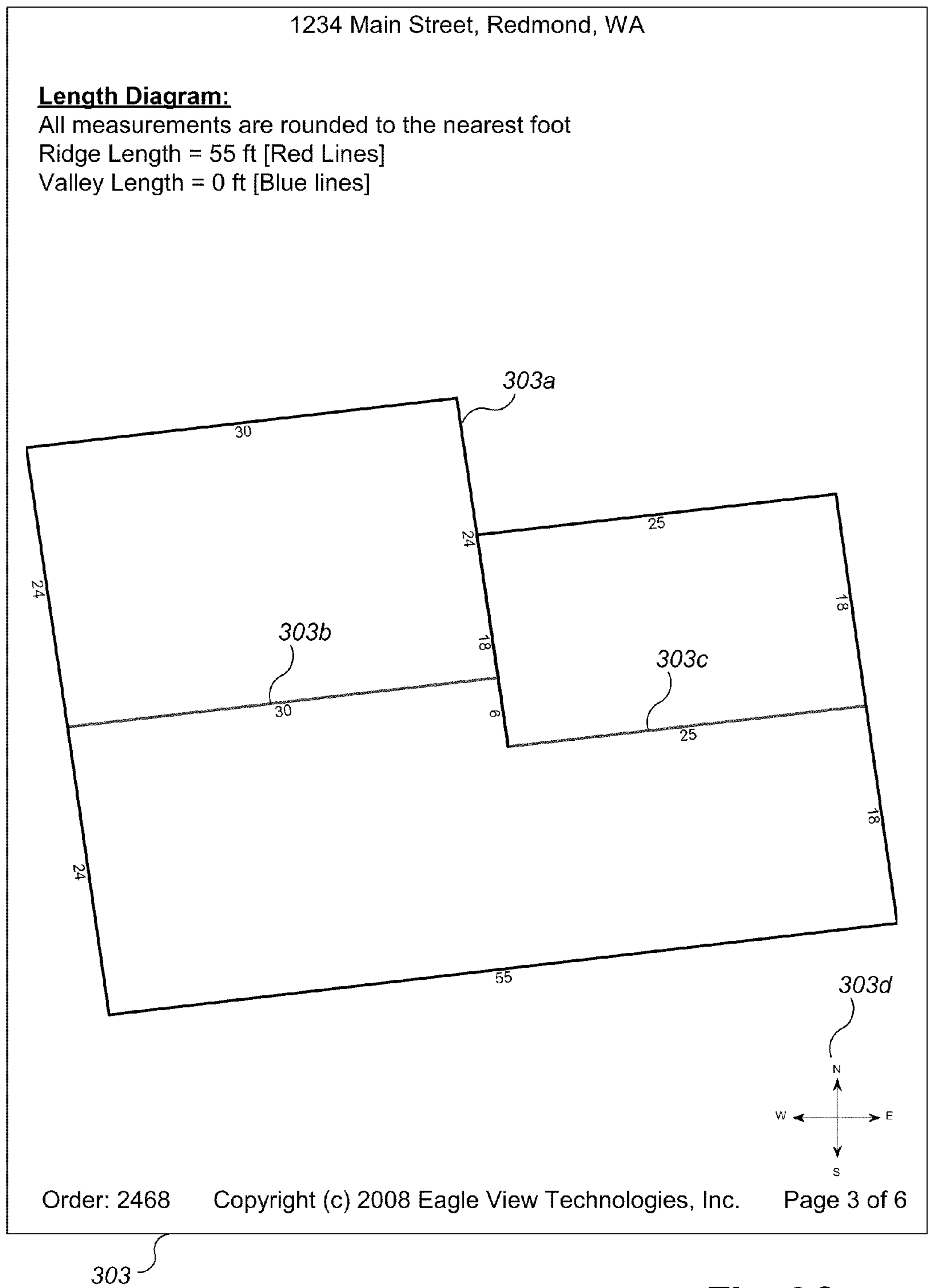

1234 Main Street, Redmond, WA
Length Diagram:
All measurements are rounded to the nearest foot
Ridge Length = 55 ft [Red Lines]
Valley Length = 0 ft [Blue lines]
303a
30
25
24
24
18
303b
18
303c
30
6
25
24
18
55
303d
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 3 of 6
303

Fig. 3C

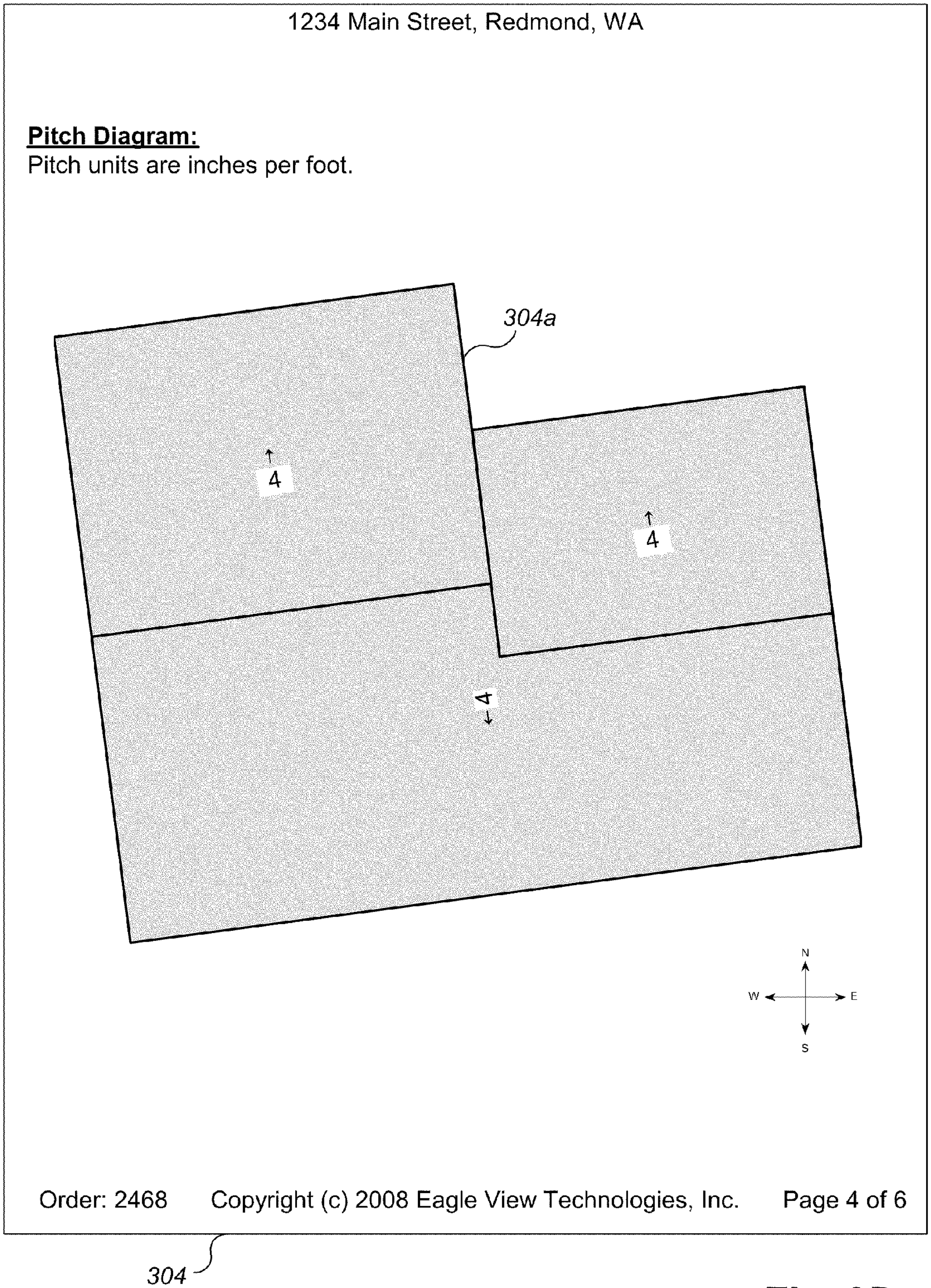

1234 Main Street, Redmond, WA
Pitch Diagram:
Pitch units are inches per foot.
304a
4
4
4
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 4 of 6
304

Fig. 3D

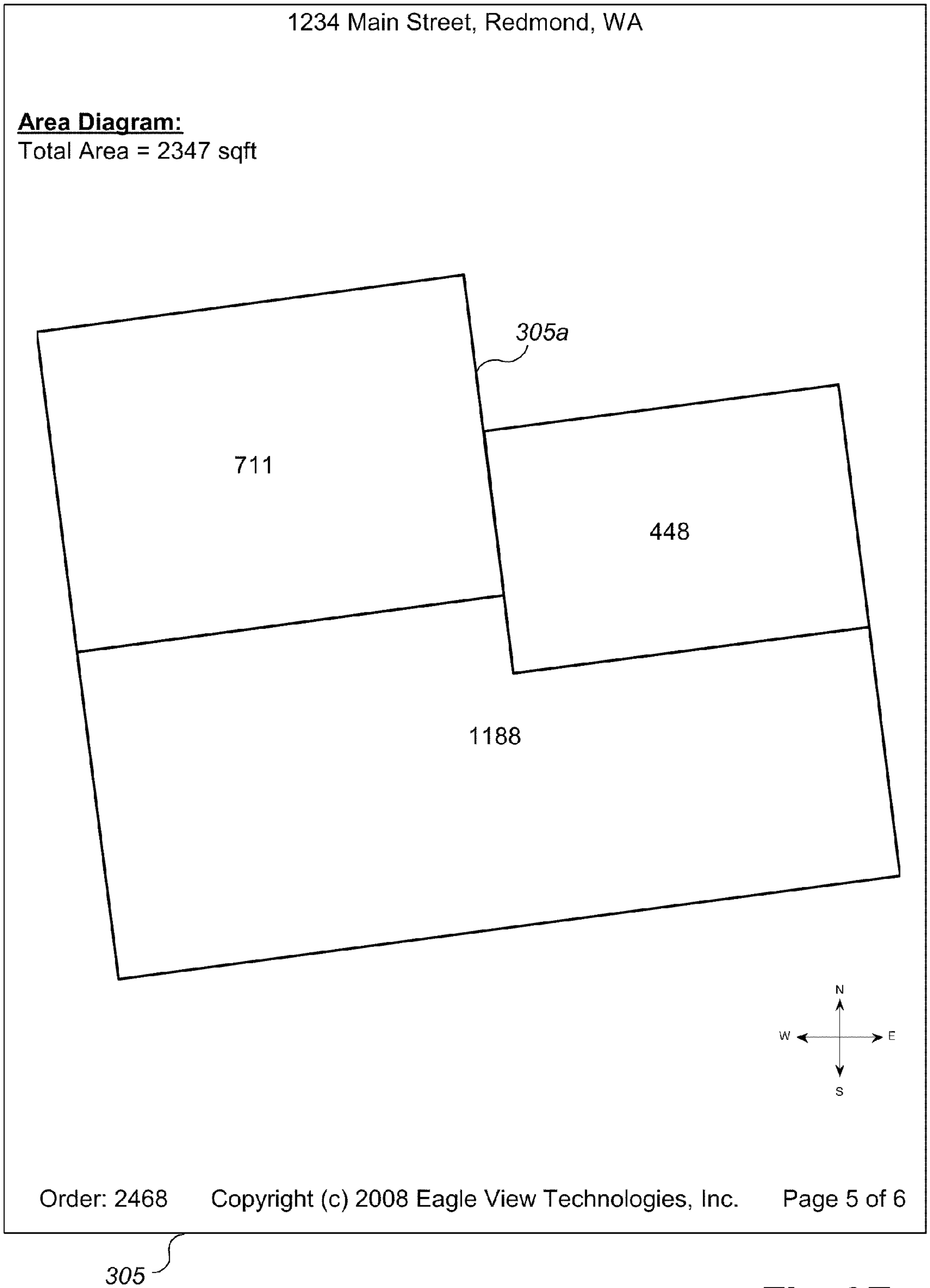
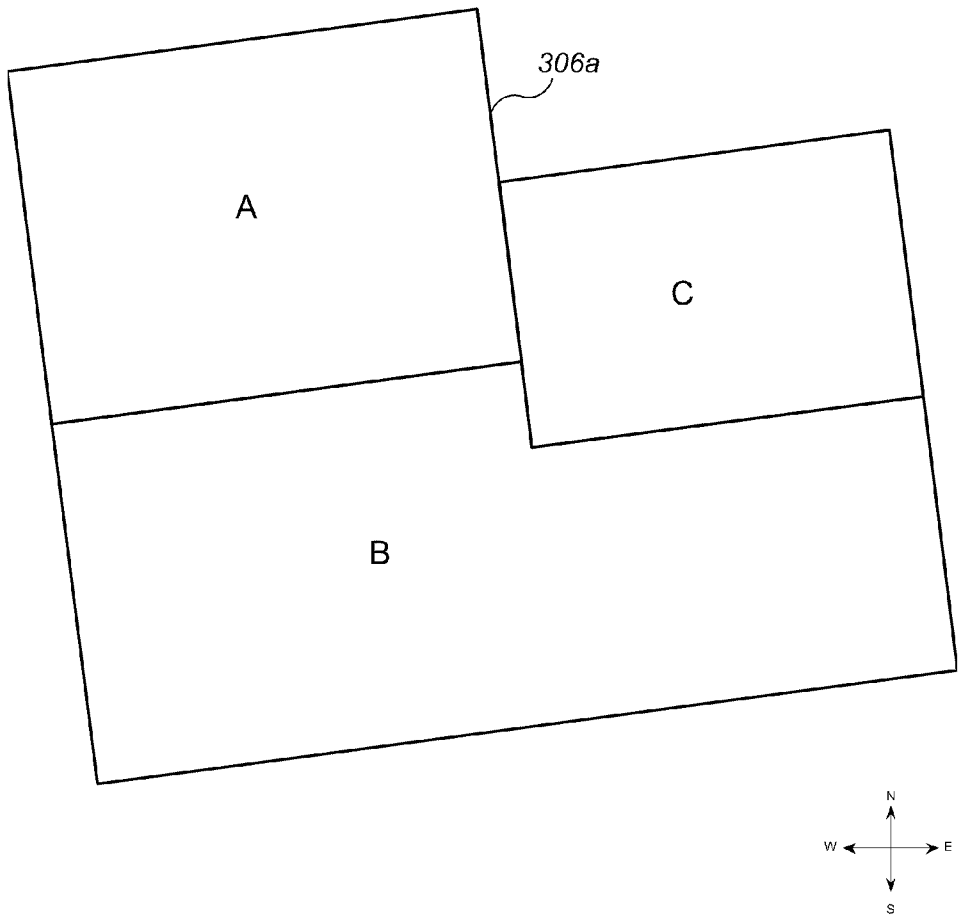

1234 Main Street, Redmond, WA
Area Diagram:
Total Area = 2347 sqft
305a
711
448
1188
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 5 of 6
305

Fig. 3E

1234 Main Street, Redmond, WA

Notes:



Order: 2468 Copyright (c) 2008 Eagle View Technologies, Inc. Page 6 of 6

306

Fig. 3F

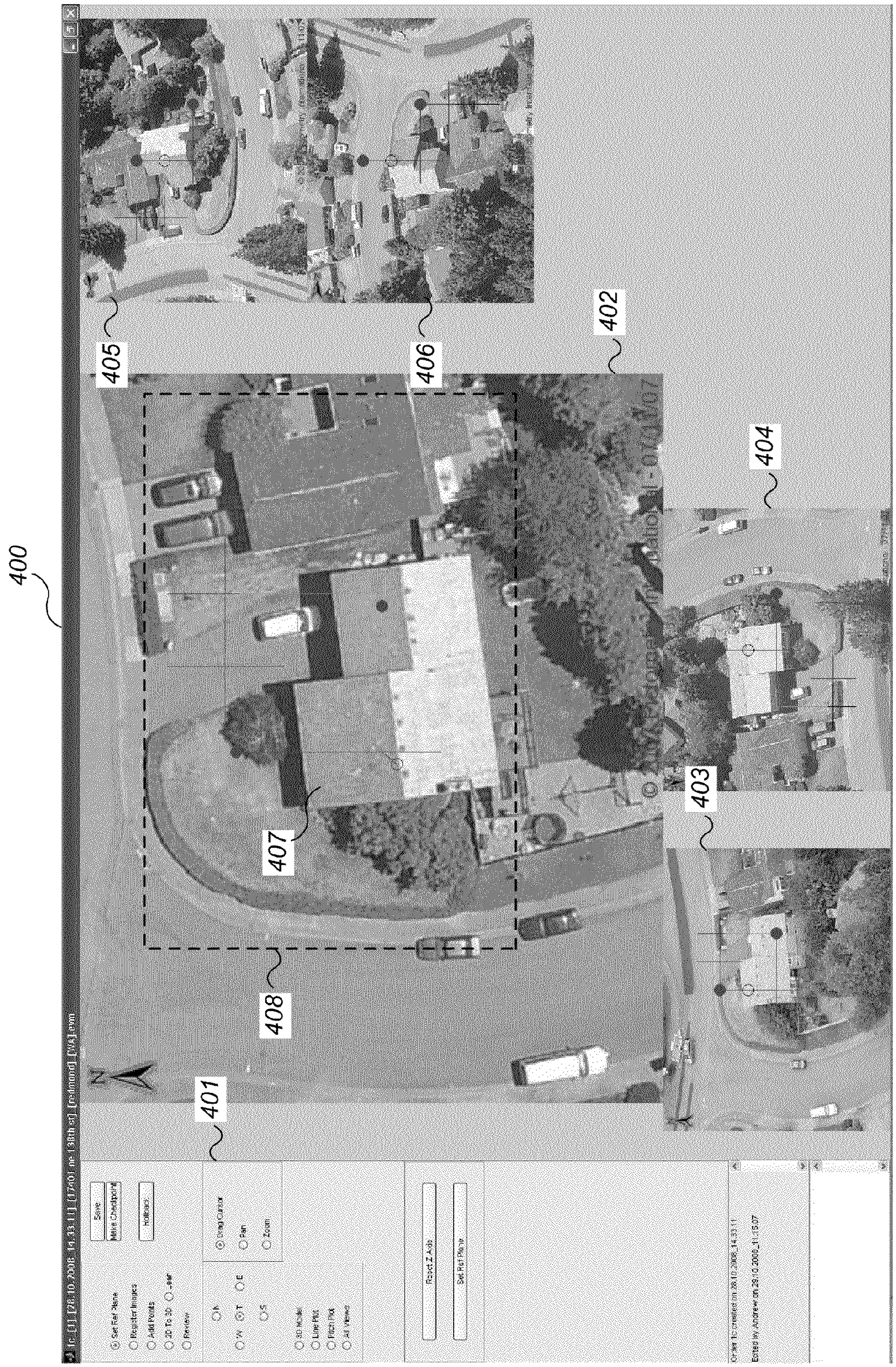


Fig. 4A

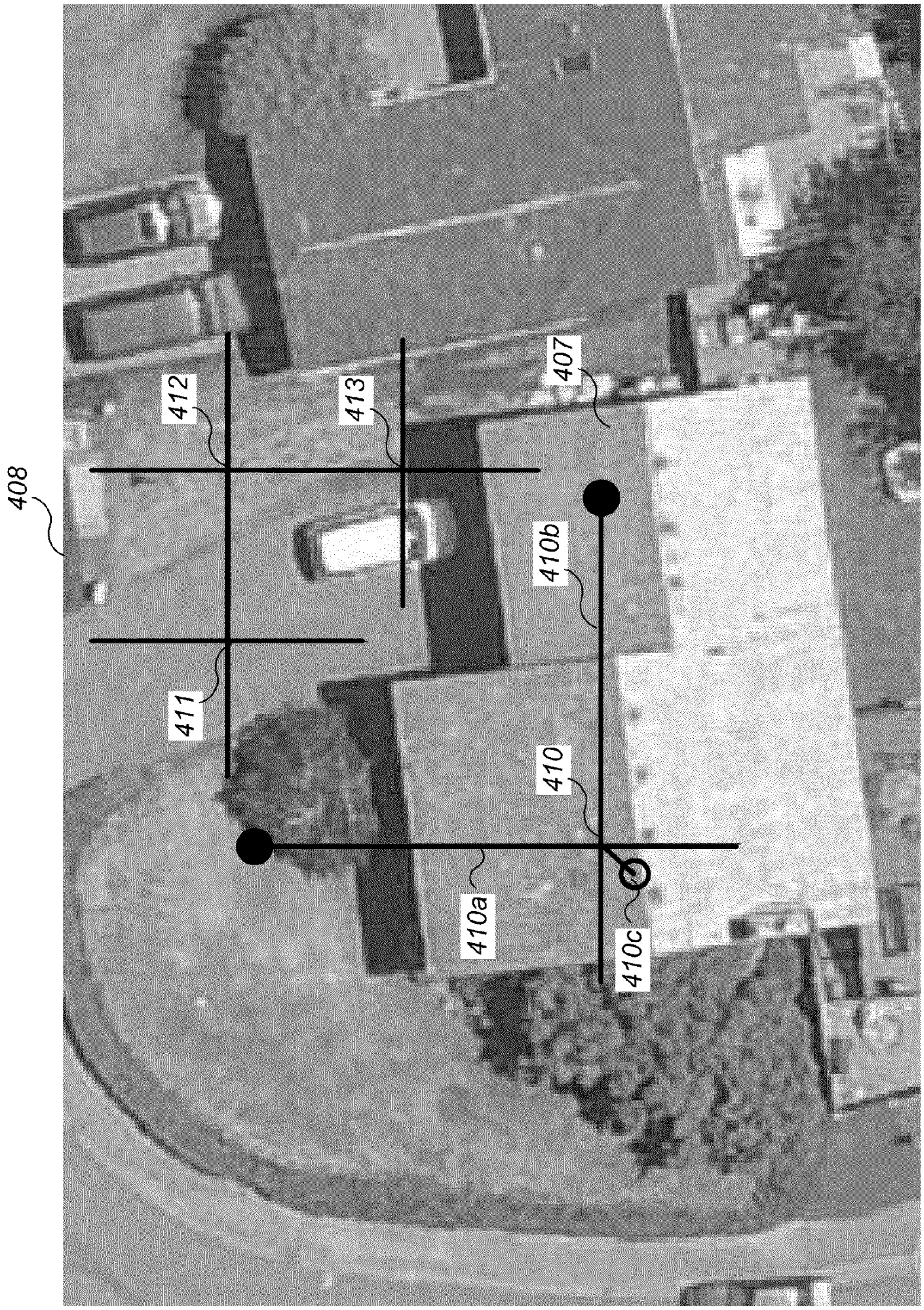


Fig. 4B

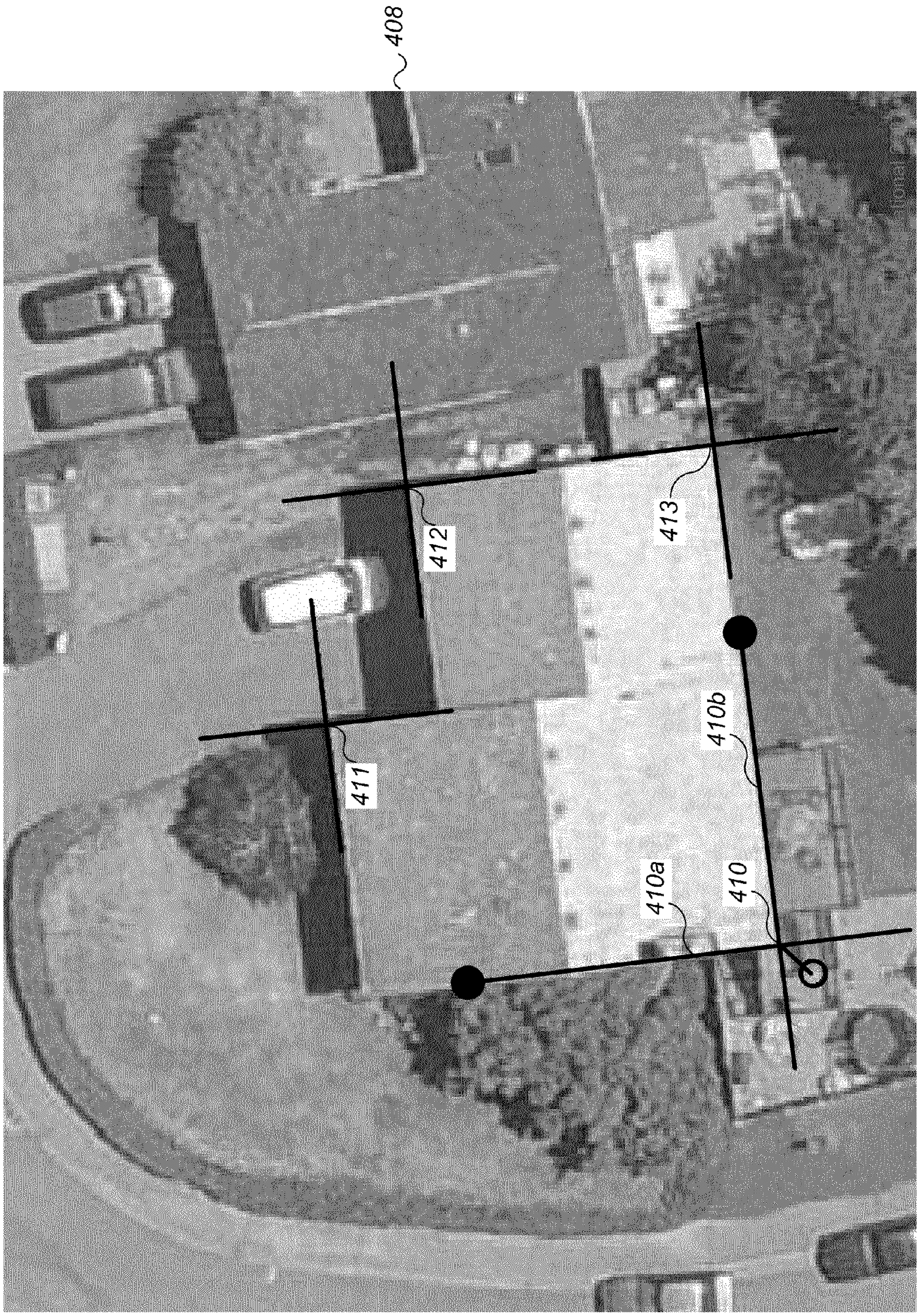


Fig. 4C

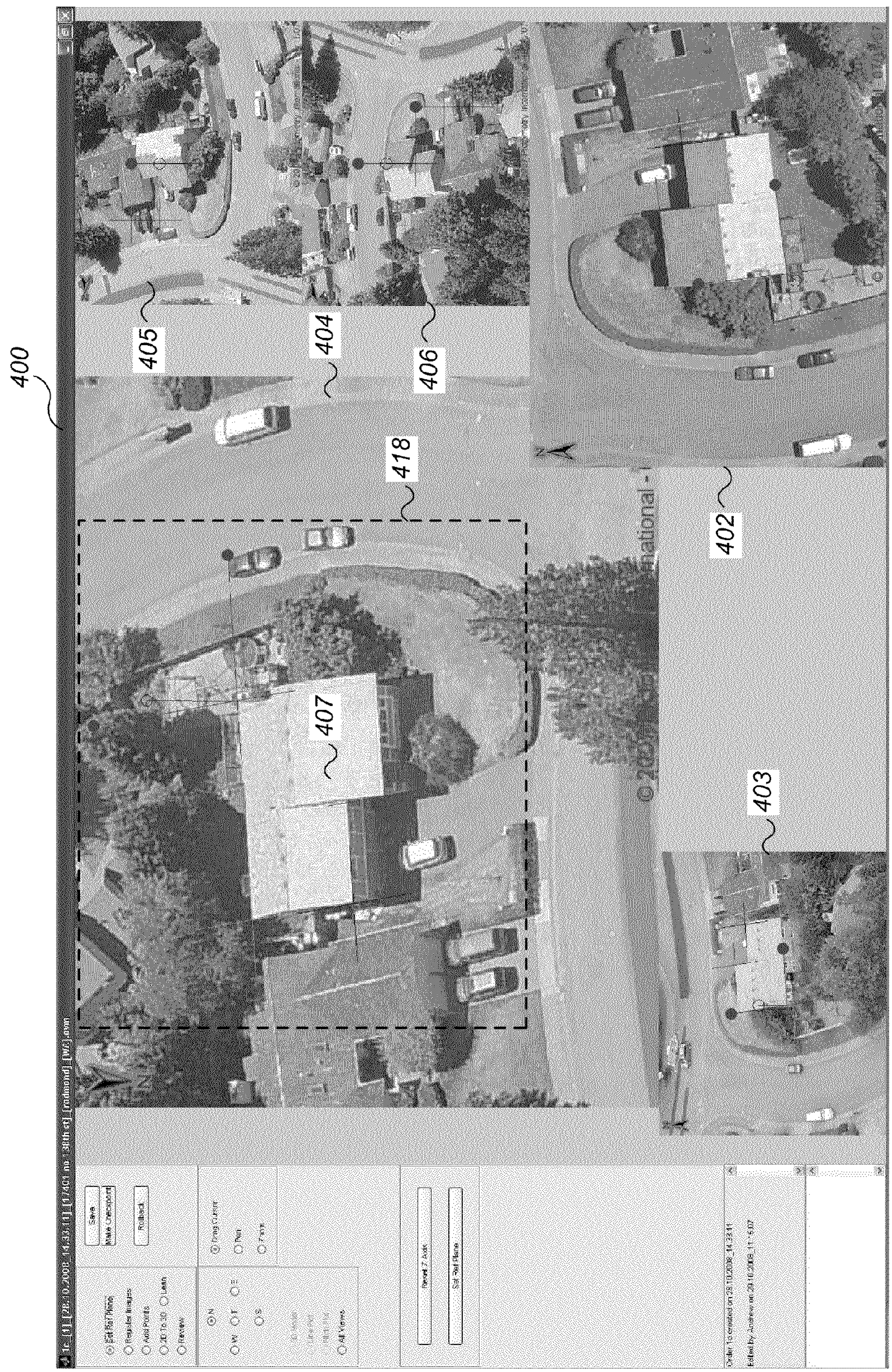


Fig. 4D

EXHIBIT 5
Part 2

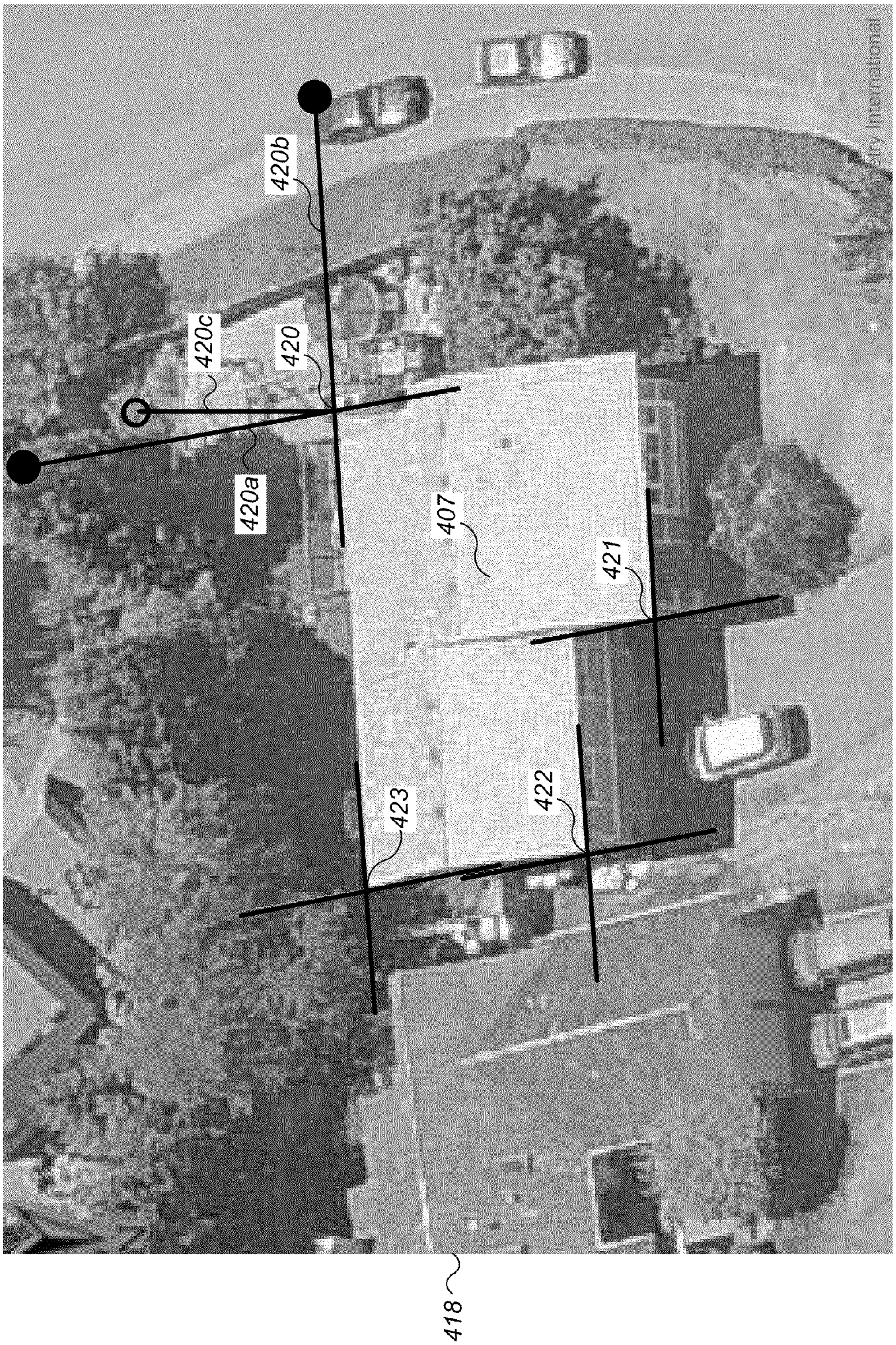


Fig. 4E

Fig. 4F

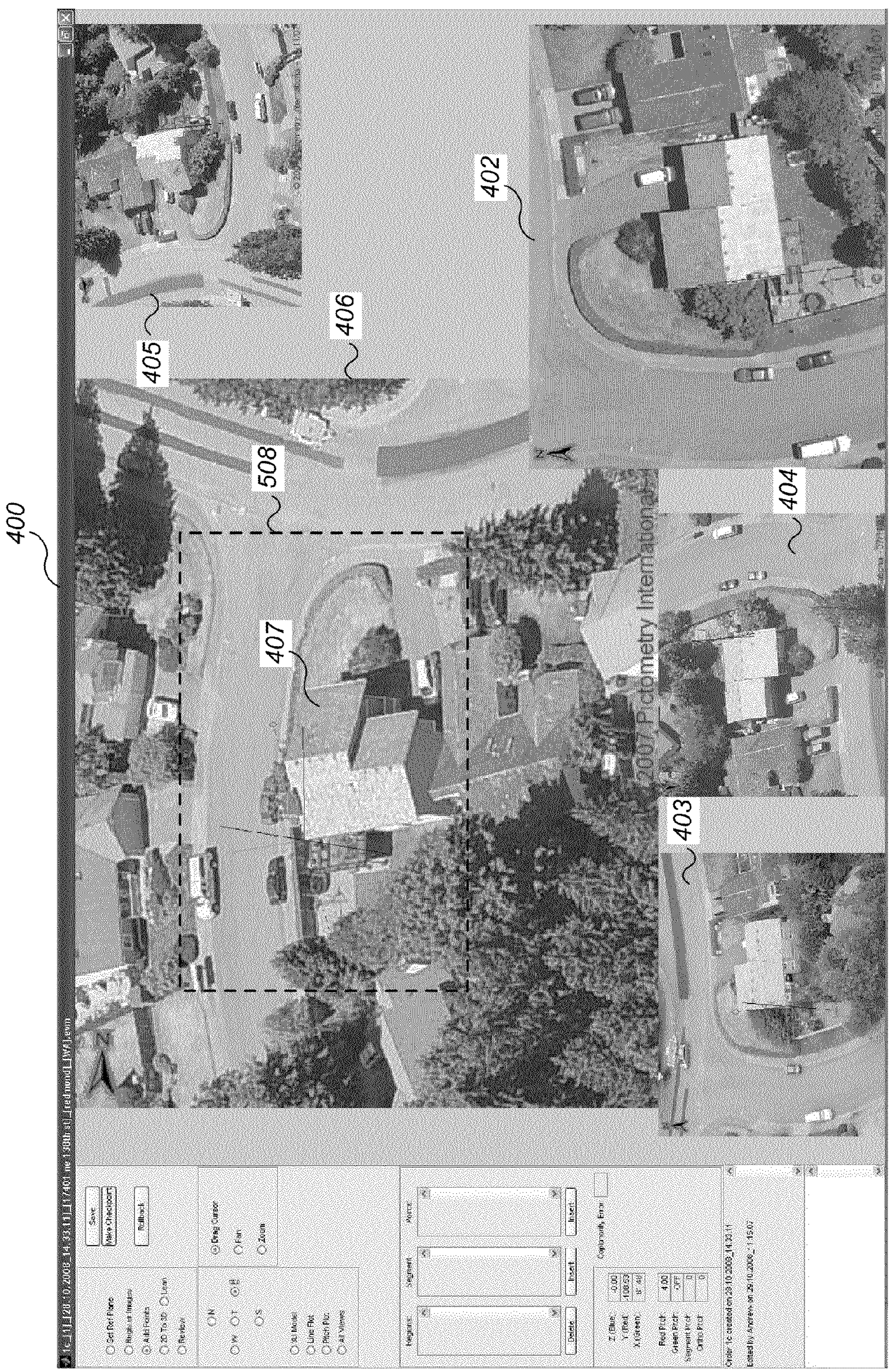

400
402
403
404
405
406
407
508
2007 Pictometry International

Fig. 5A

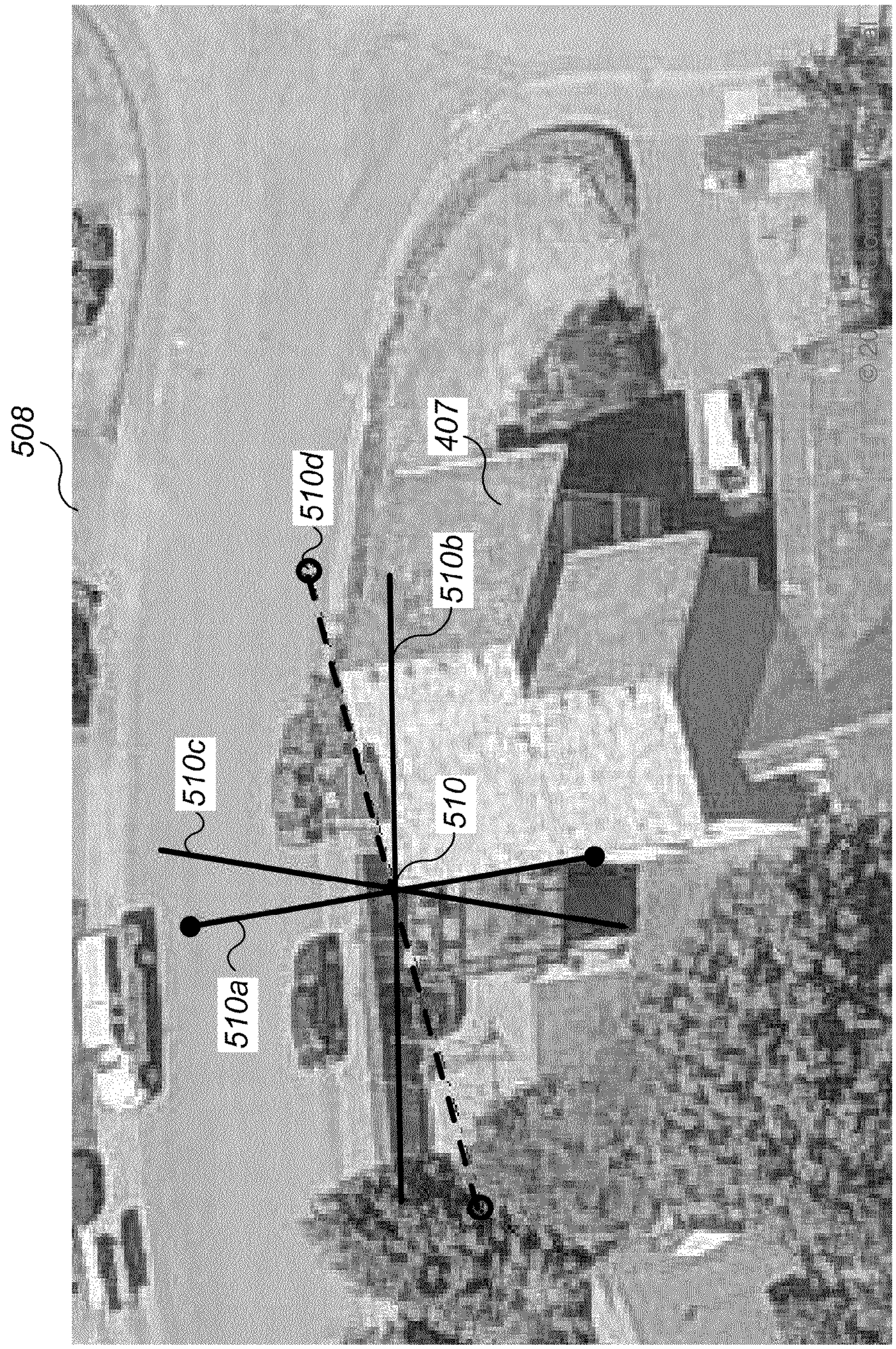


Fig. 5B

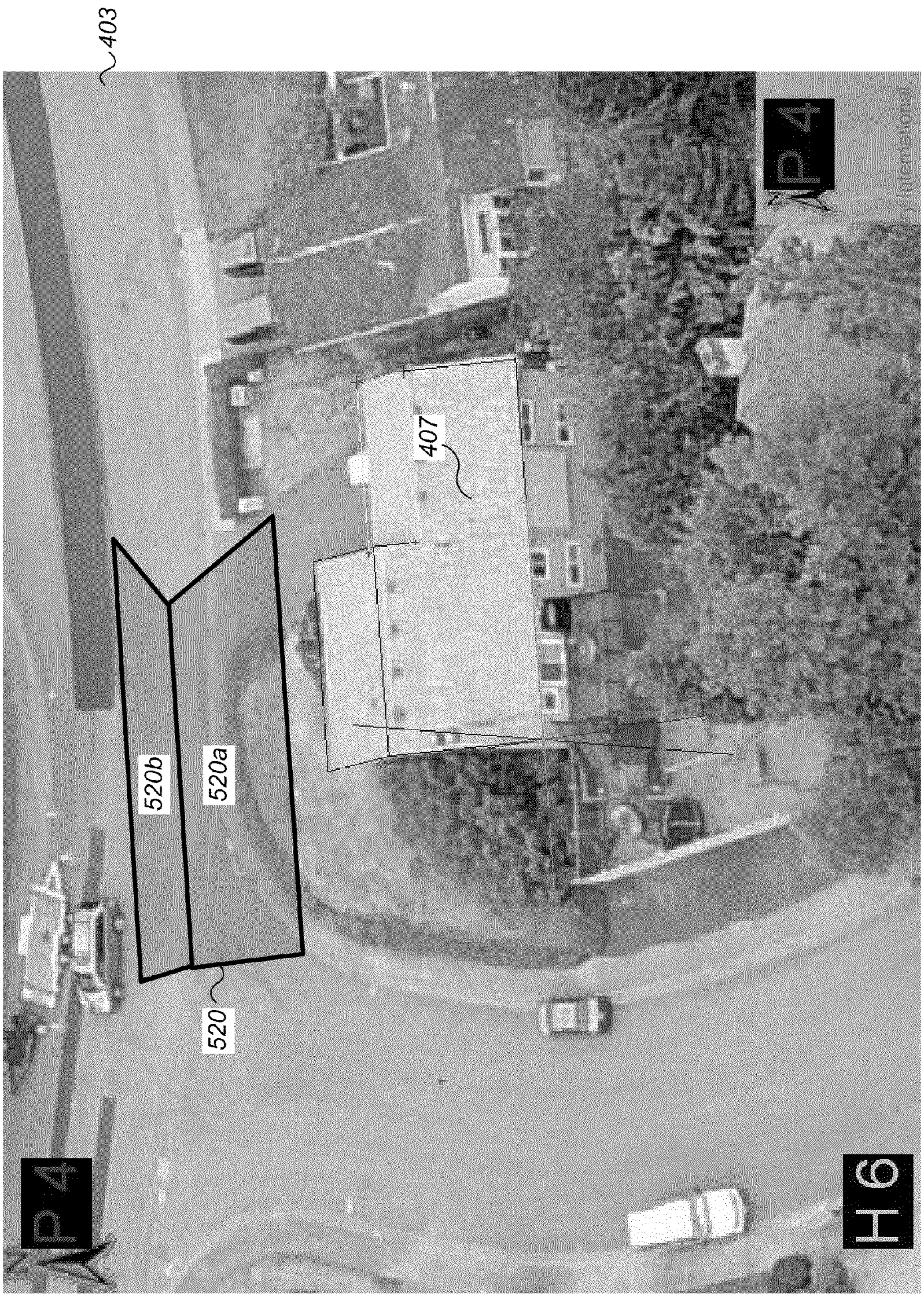


Fig. 5C

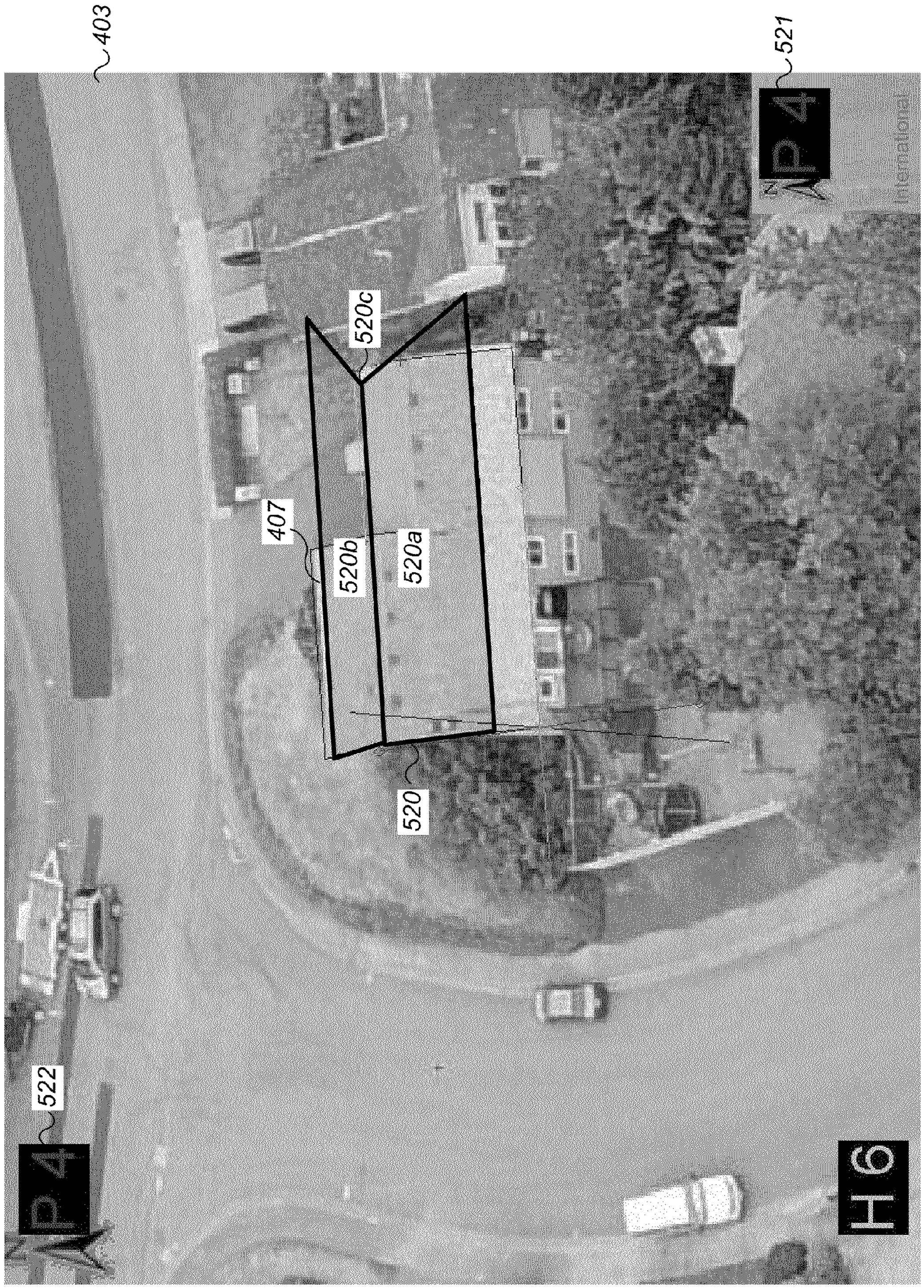


Fig. 5D

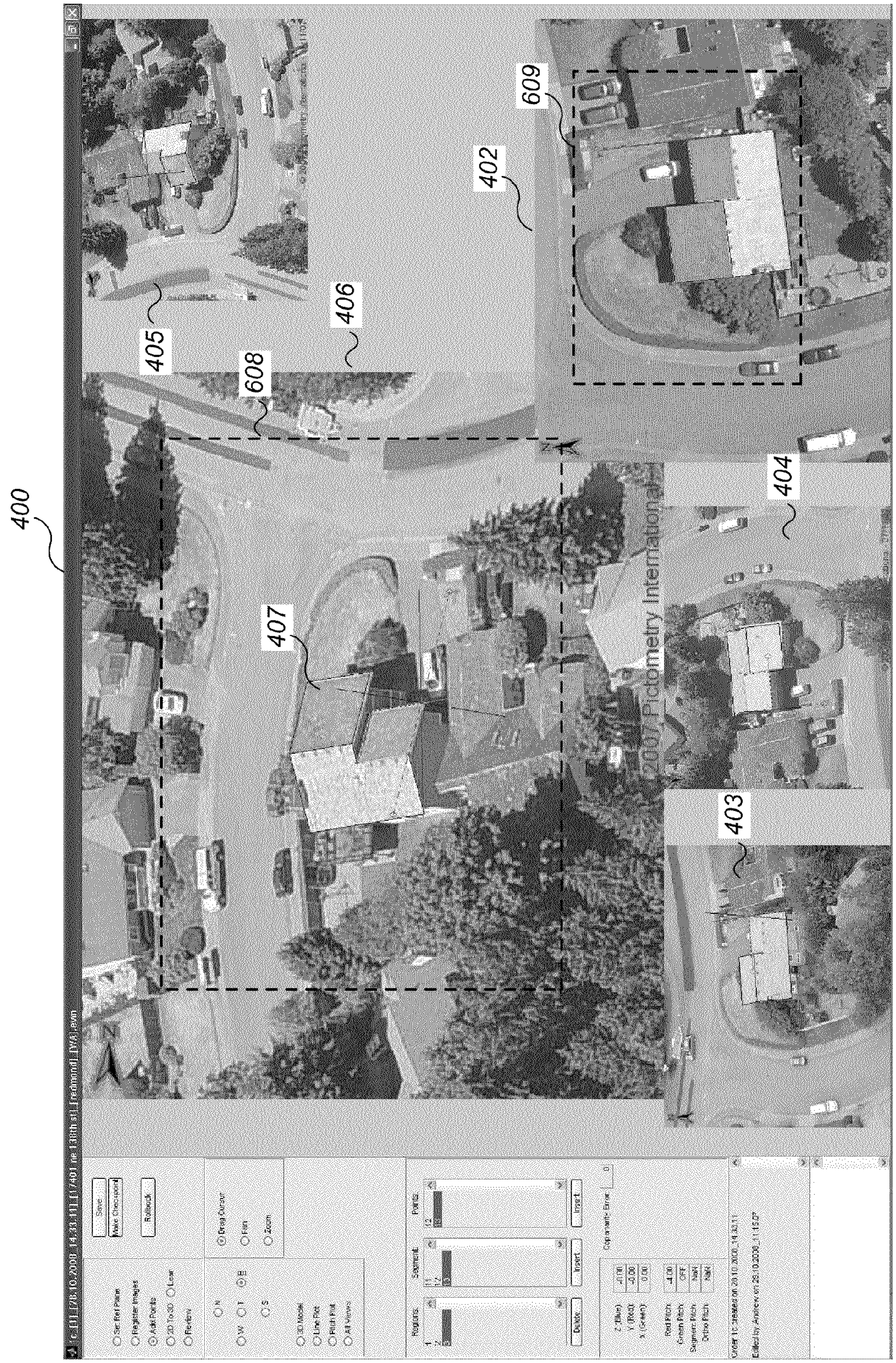

400
402
403
404
405
406
407
608
609
2007 Pictometry International

Fig. 6A

EXHIBIT 5
Part 3

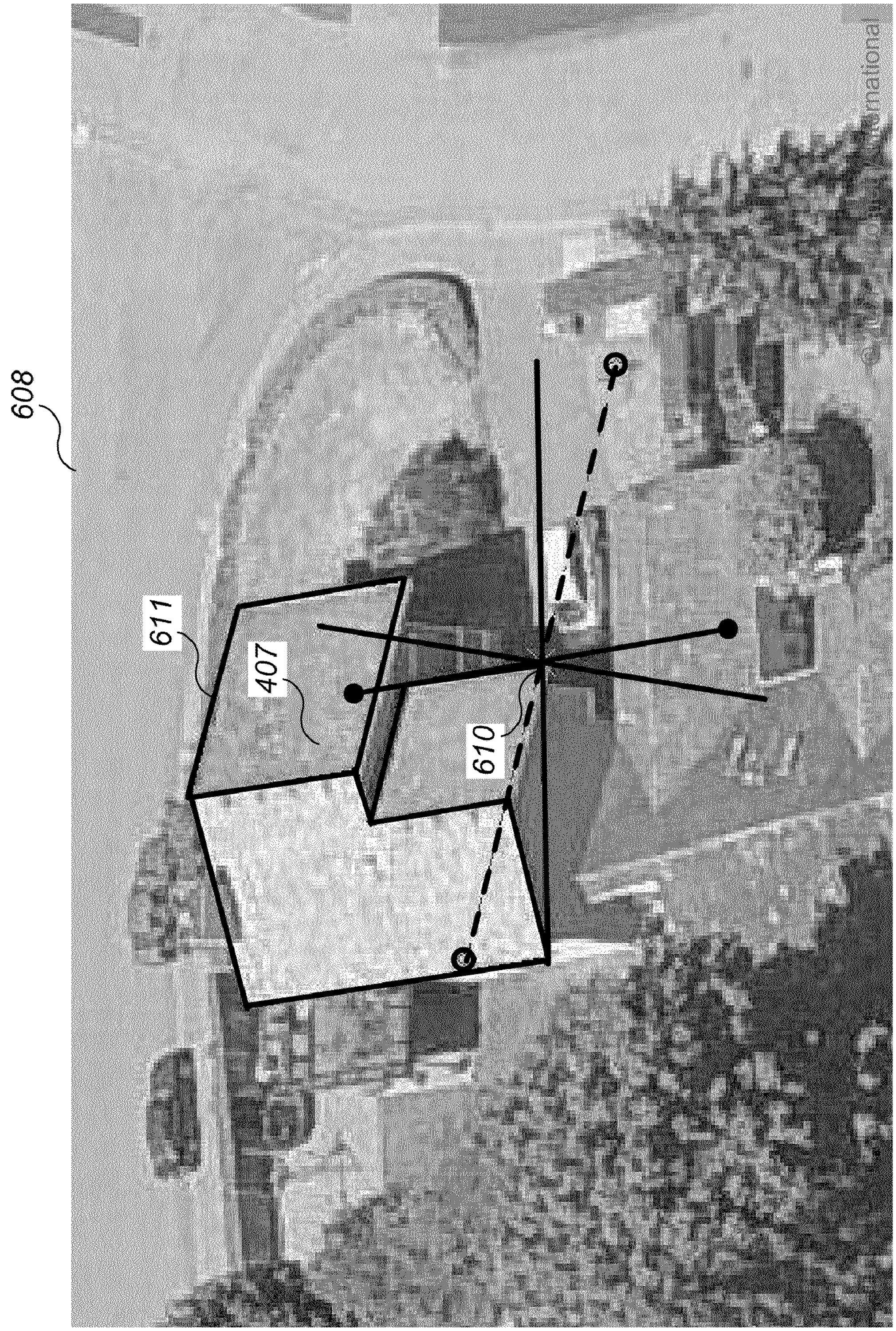


Fig. 6B

Fig. 6C

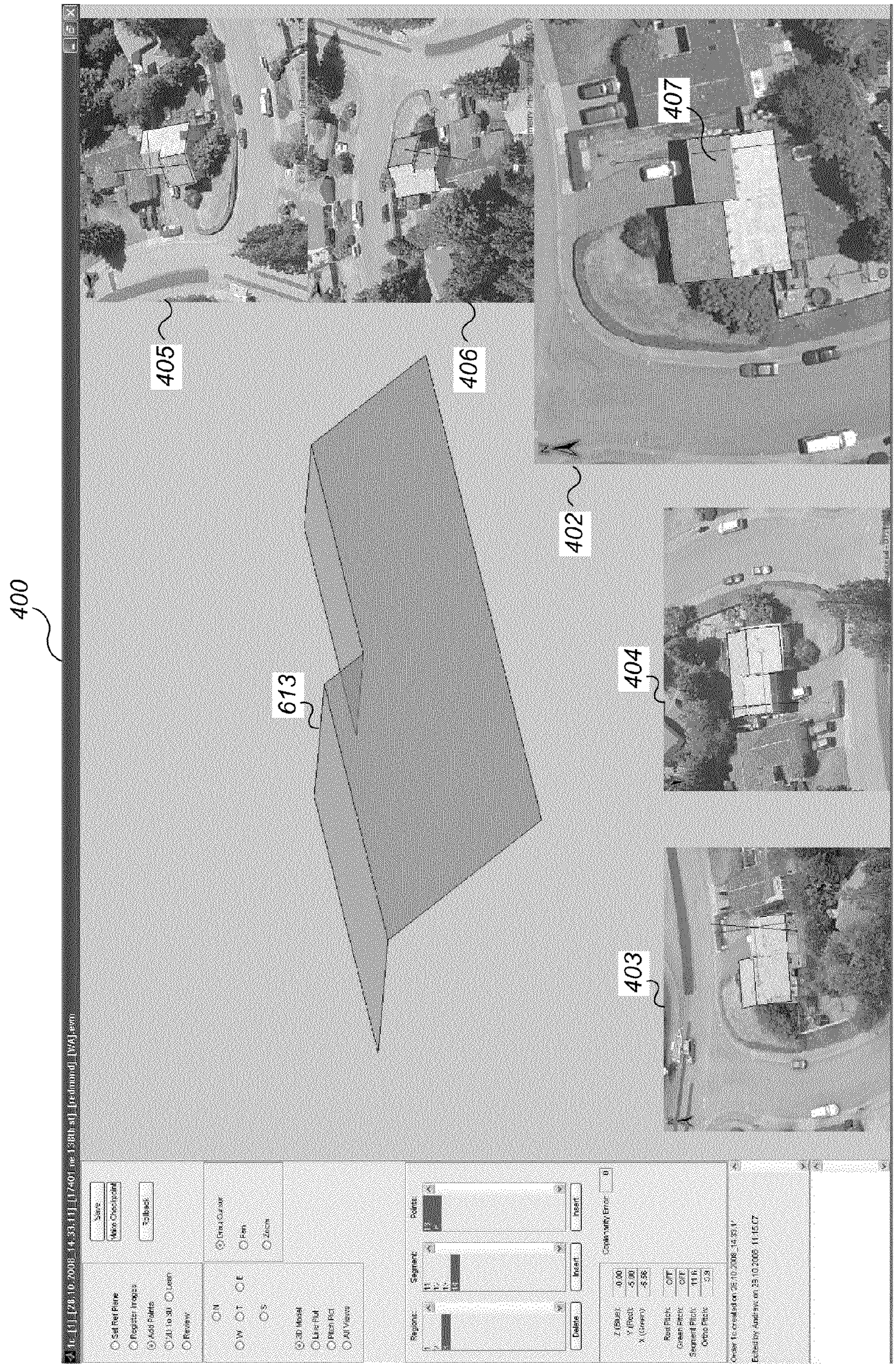


Fig. 6D

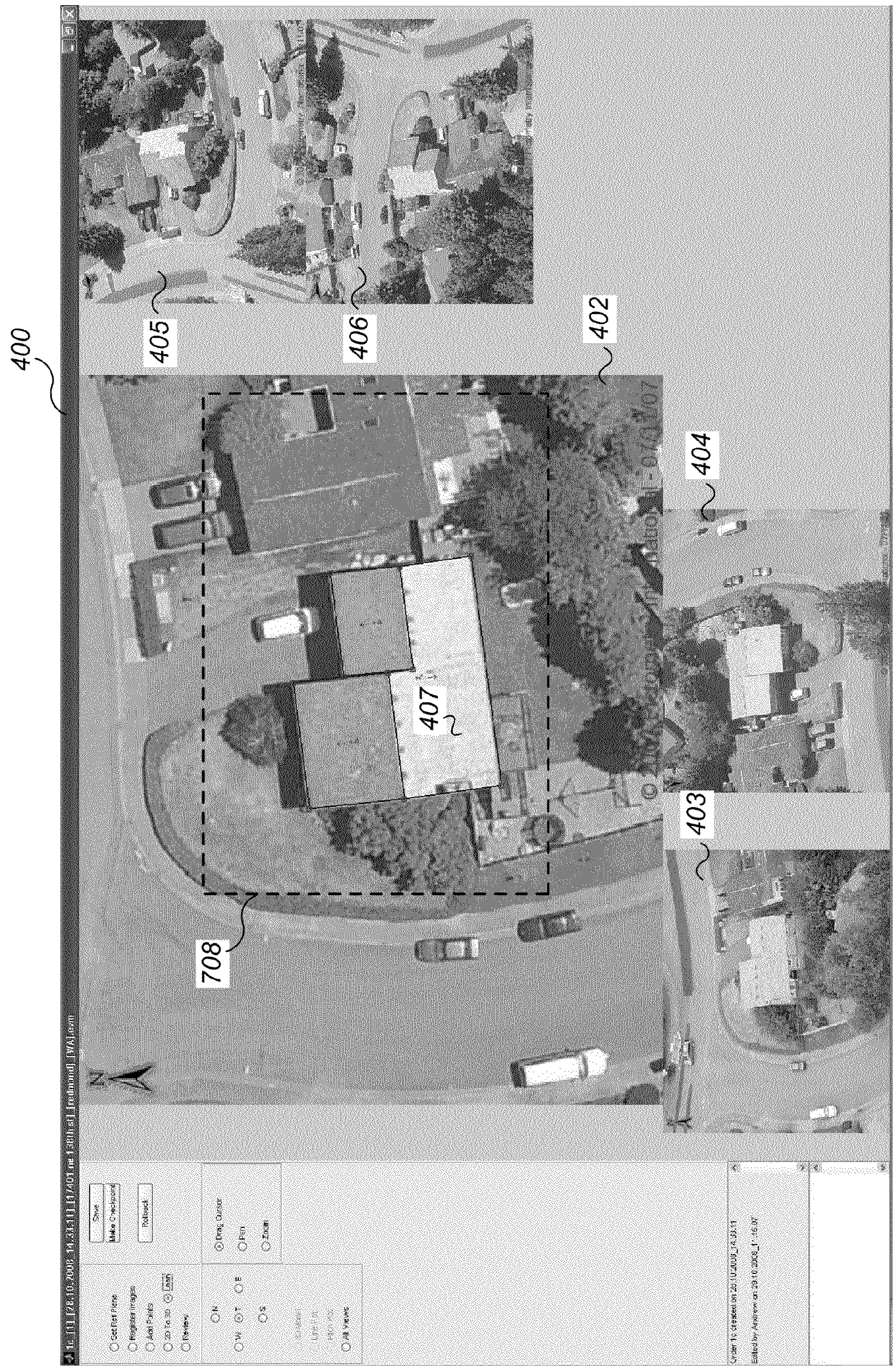


Fig. 7A

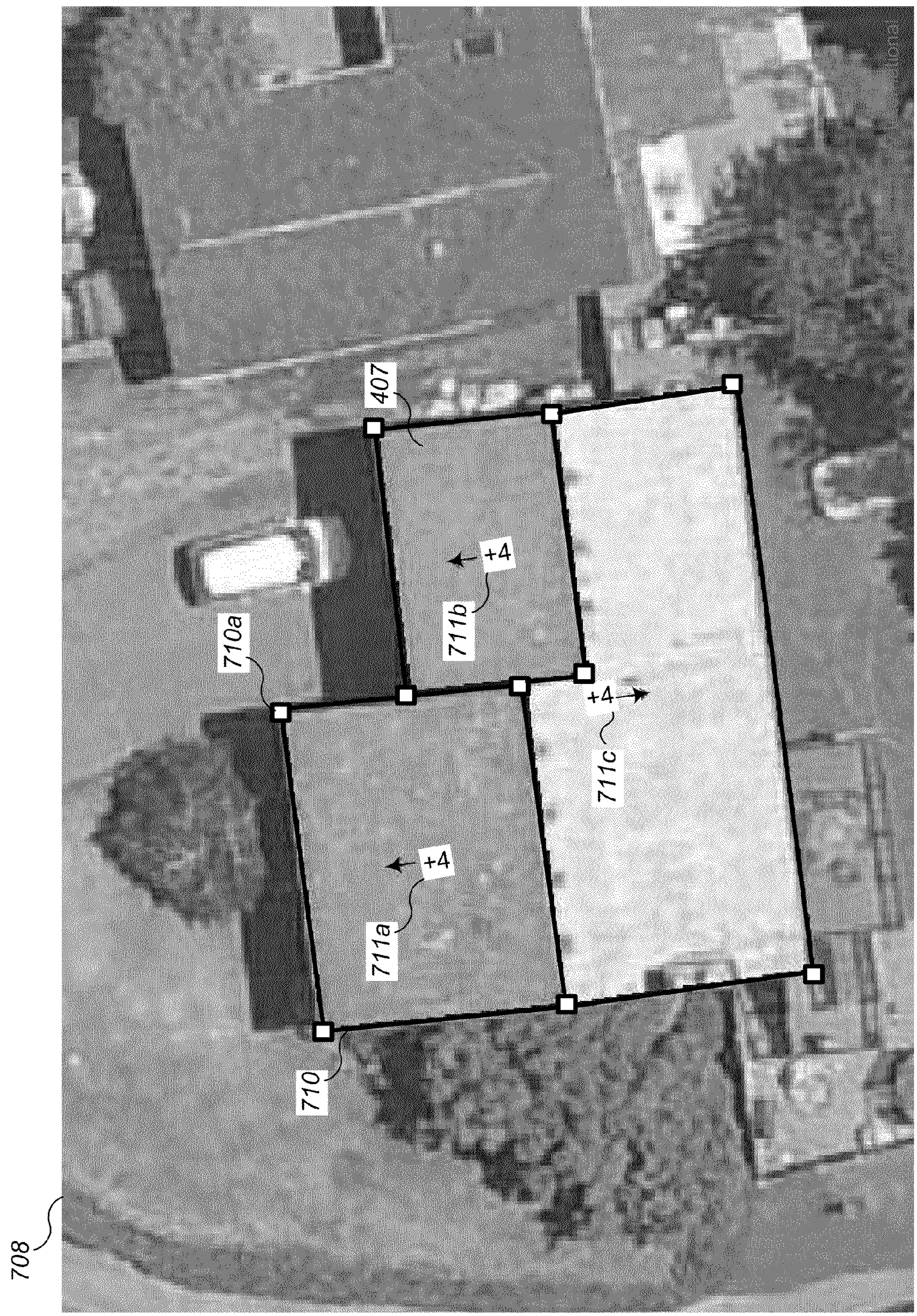


Fig. 7B

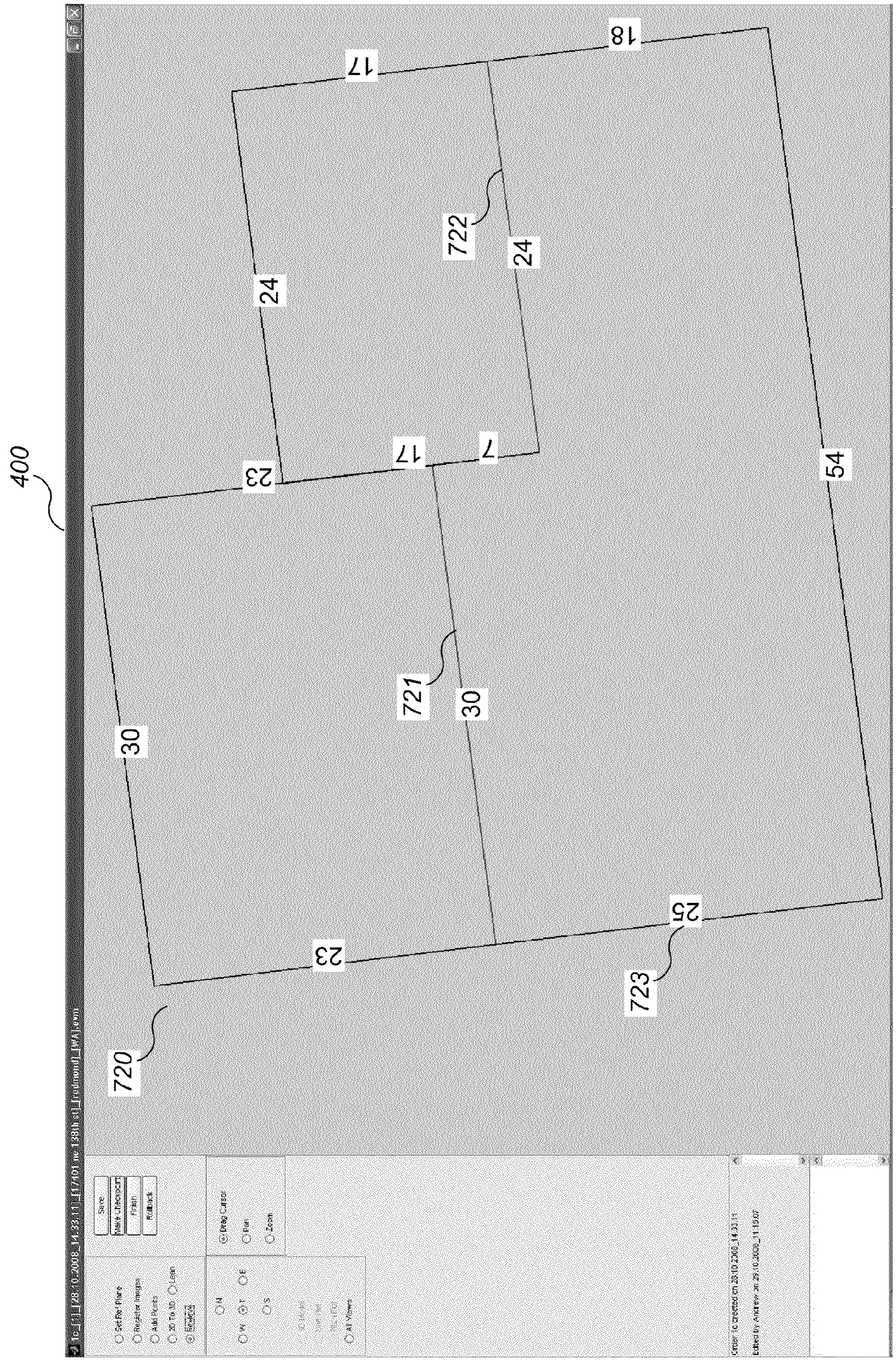
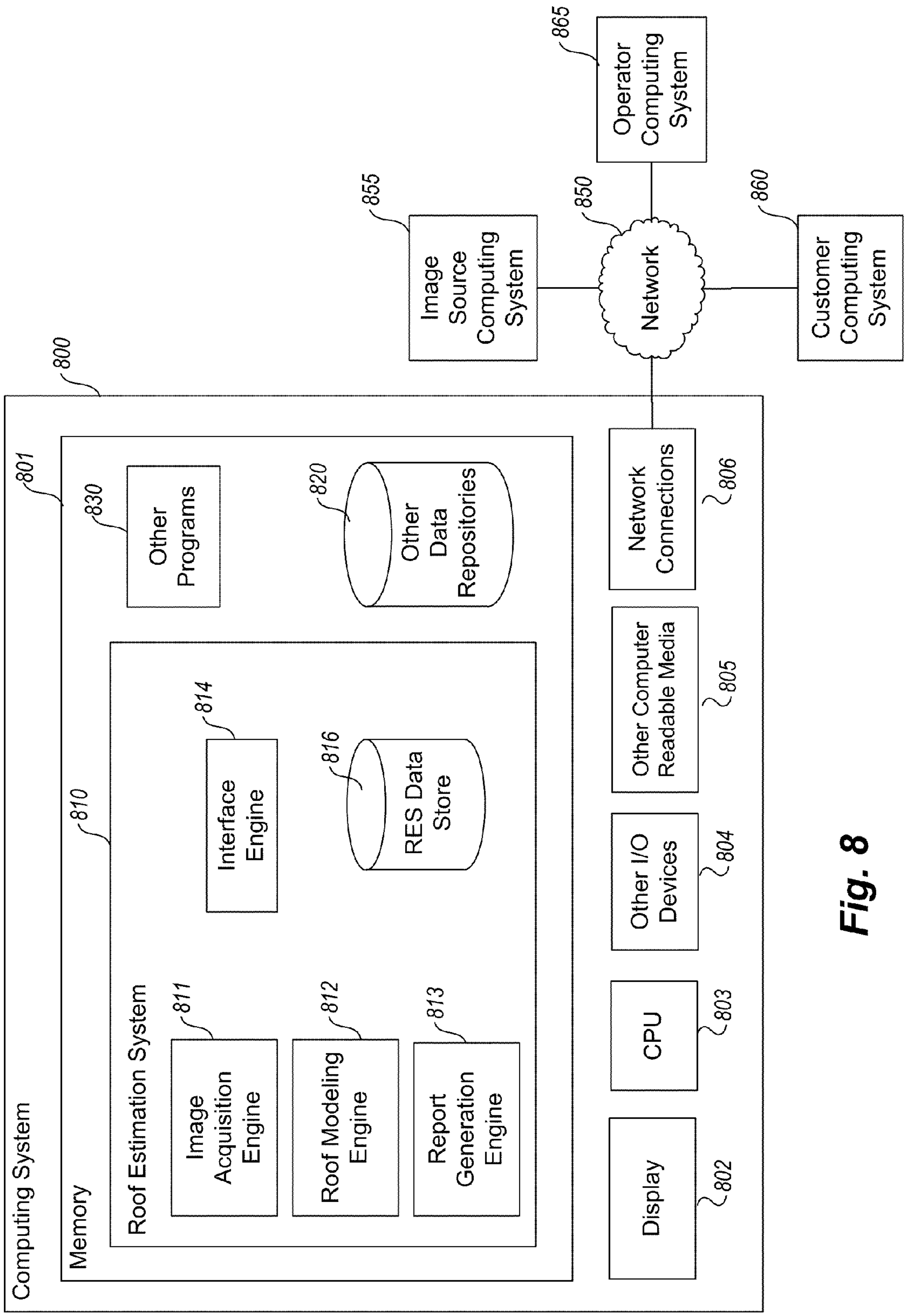


Fig. 7C



Computing System
800
Memory
801
Roof Estimation System
810
Image Acquisition Engine
811
Roof Modeling Engine
812
Report Generation Engine
813
Interface Engine
814
RES Data Store
816
Other Programs
830
Other Data Repositories
820
Display
802
CPU
803
Other I/O Devices
804
Other Computer Readable Media
805
Network Connections
806
Network
850
Image Source Computing System
855
Customer Computing System
860
Operator Computing System
865

Fig. 8

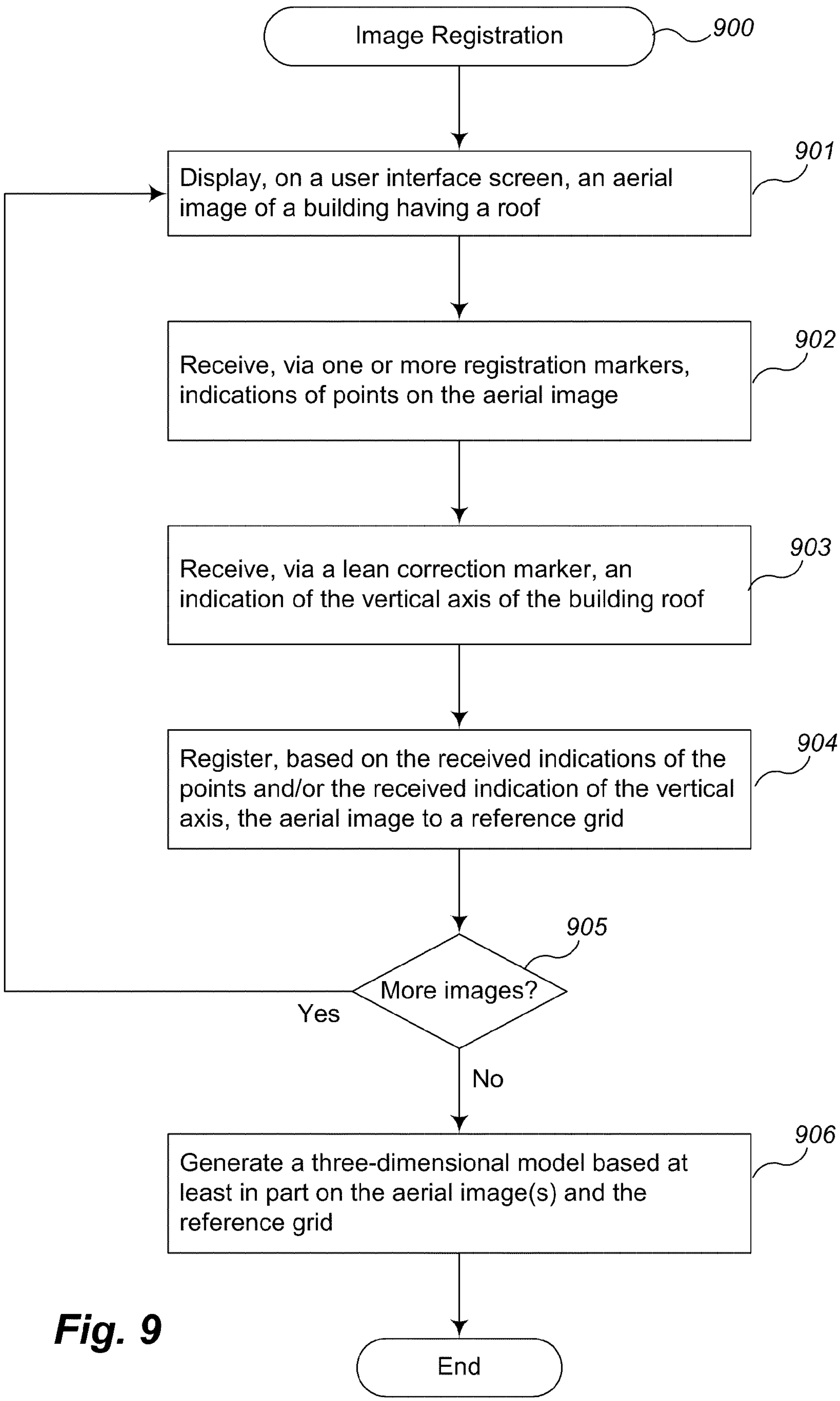


Image Registration
900
Display, on a user interface screen, an aerial image of a building having a roof
901
Receive, via one or more registration markers, indications of points on the aerial image
902
Receive, via a lean correction marker, an indication of the vertical axis of the building roof
903
Register, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid
904
More images?
905
Yes
No
Generate a three-dimensional model based at least in part on the aerial image(s) and the reference grid
906
End

Fig. 9

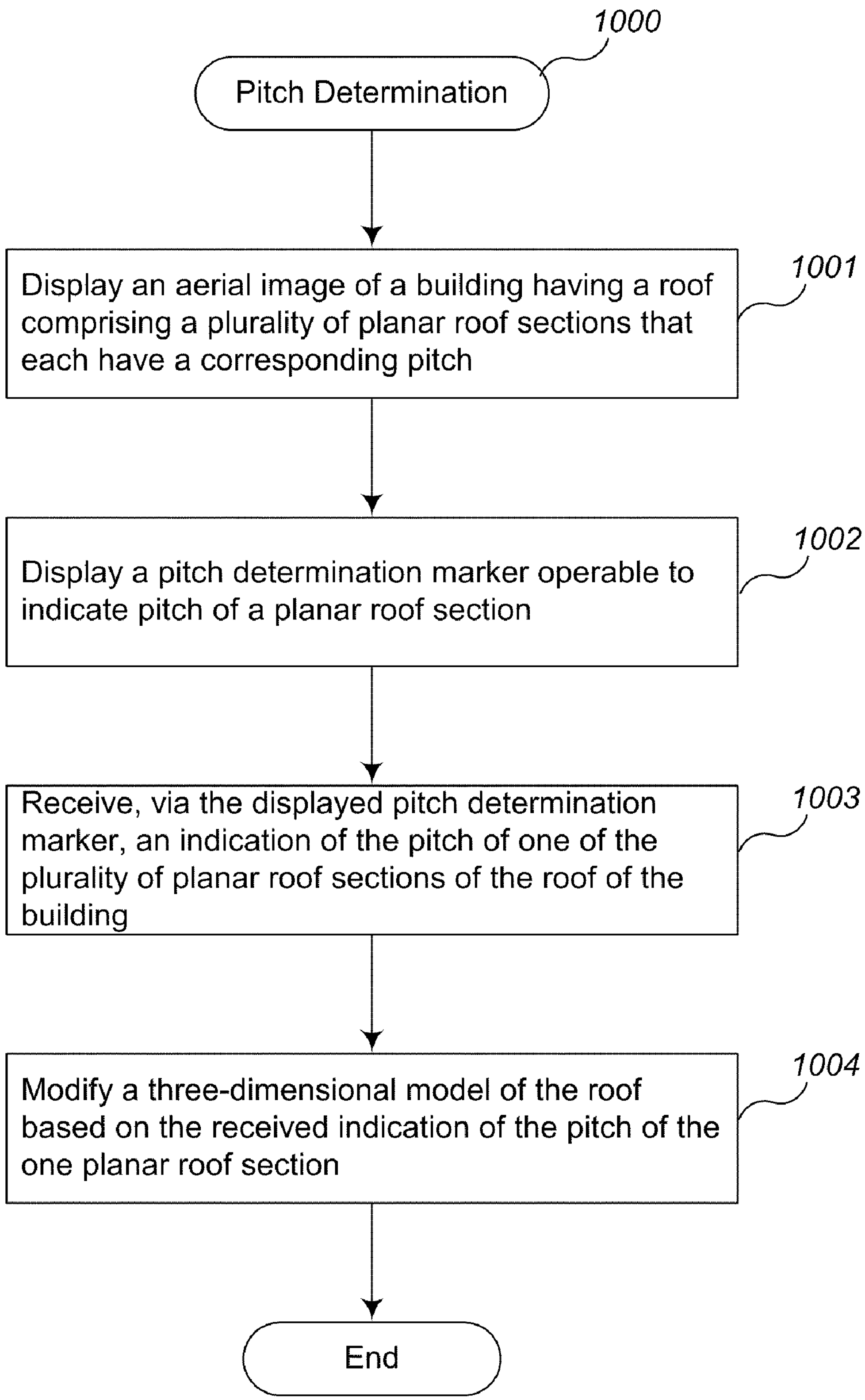

1000
Pitch Determination
Display an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch
1001
Display a pitch determination marker operable to indicate pitch of a planar roof section
1002
Receive, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building
1003
Modify a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section
1004
End

Fig. 10

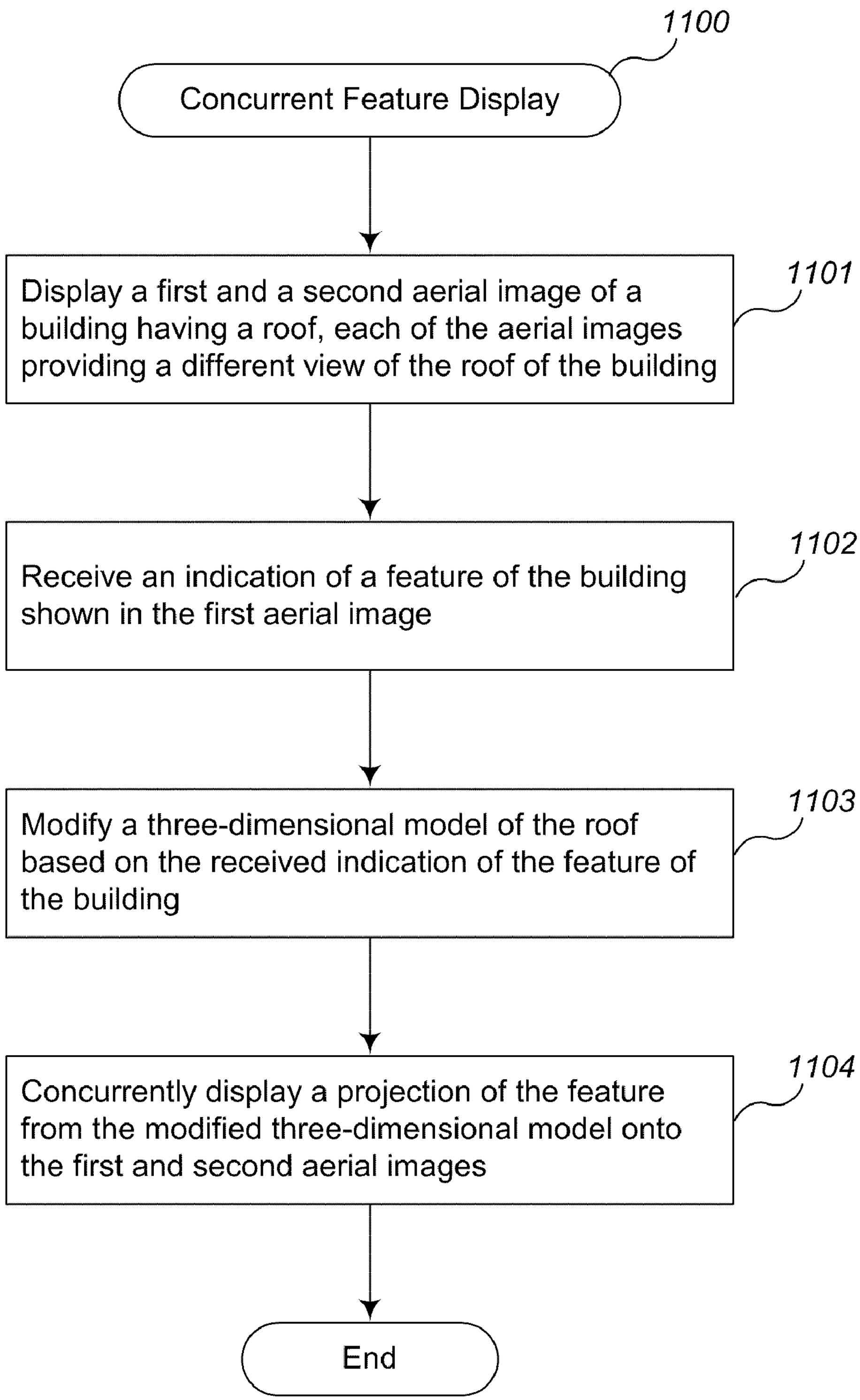

1100
Concurrent Feature Display
1101
Display a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building
1102
Receive an indication of a feature of the building shown in the first aerial image
1103
Modify a three-dimensional model of the roof based on the received indication of the feature of the building
1104
Concurrently display a projection of the feature from the modified three-dimensional model onto the first and second aerial images
End

Fig. 11

PITCH DETERMINATION SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 61/197,904, entitled "USER INTERFACE SYSTEMS AND METHODS FOR ROOF ESTIMATION," filed Oct. 31, 2008, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field of the Invention

This invention relates to systems and methods for estimating construction projects, and more particularly, to such systems and methods for determining roof measurement information based on one or more aerial images of a roof of a building.

2. Description of the Related Art

The information provided below is not admitted to be part of the present invention, but is provided solely to assist the understanding of the reader.

Homeowners typically ask several roofing contractors to provide written estimates to repair or replace a roof on a house. Heretofore, the homeowners would make an appointment with each roofing contractor to visit the house to determine the style of roof, take measurements, and to inspect the area around the house for access and cleanup. Using this information, the roofing contractor then prepares a written estimate and then timely delivers it to the homeowner. After receiving several estimates from different rooting contractors, the homeowner then selects one.

There are factors that impact a roofing contractor's ability to provide a timely written estimate. One factor is the size of the roof contractor's company and the location of the roofing jobs currently underway. Most roof contractors provide roofing services and estimates to building owners over a large geographical area. Larger roof contractor companies hire one or more trained individuals who travel throughout the entire area providing written estimates. With smaller roofing contractors, the owner or a key trained person is appointed to provide estimates. With both types of companies, roofing estimates are normally scheduled for buildings located in the same area on a particular day. If an estimate is needed suddenly at a distant location, the time for travel and the cost of commuting can be prohibitive. If the roofing contractor is a small company, the removal of the owner or key person on a current job site can be time prohibitive.

Another factor that may impact the roofing contractor's ability to provide a written estimate is weather and traffic.

Recently, solar panels have become popular. In order to install solar panels, the roof's slope, geometrical shape, and size as well as its orientation with respect to the sun all must be determined in order to provide an estimate of the number and type of solar panels required. Unfortunately, not all roofs on a building are proper size, geometrical shape, or orientation for use with solar panels.

SUMMARY

These and other objects are met by the systems and methods disclosed herein that determine and provide roof measurement information about the sizes, dimensions, slopes and orientations of the roof sections of a building roof. Roof measurement information may be used to generate a roof estimate report that provides and graphically shows this information. A roof estimation system that practices at least some of the techniques described herein may include an image acquisition engine, a roof modeling engine, and a report generation engine. The roof estimation system is configured to generate a model of a roof of a building, based on one or more aerial images. In addition, the roof estimation system is configured to determine roof measurement information and generate a roof estimate report based on the generated model and/or the determined roof measurement information.

In some embodiments, the roof estimation system includes a user interface engine which provides access to at least some of the functions of the roof estimation system. In one embodiment, the user interface engine provides interactive user interface components operable by an operator to perform various functions related to generating a model of a roof of a building, including image registration, lean correction, pitch determination, feature identification, and model review and/or correction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system.

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. (Also shows lean correction.)

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment.

FIGS. **7**A-**7**C are screen displays illustrating roof model review in an example embodiment.

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment.

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment.

DETAILED DESCRIPTION

Embodiments described herein provide enhanced computer- and network-based methods, techniques, and systems for estimating construction projects based on one or more images of a structure. Example embodiments provide a Roof Estimation System ("RES") that is operable to provide a roof estimate report for a specified building, based on one or more aerial images of the building. In one embodiment, a customer of the RES specifies the building by providing an address of the building. The RES then obtains one or more aerial images showing at least portions of the roof of the building. Next, the RES generates a model of the roof of the building, which is then utilized to determine roof measurement information. The roof measurement information may include measurements such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc. The model of the roof and/or the roof measurement information is then used to generate a roof estimate report. The

roof estimate report includes one or more line drawings of the roof of the building, which are annotated with information about the roof, such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc.

Some embodiments of the roof estimation system include an interactive user interface configured to provide access to one or more of the functions of the roof estimation system. In one embodiment, the roof estimation system includes user interface controls that facilitate image registration, image lean correction, roof model generation, pitch determination, and roof model review. Image registration includes aligning, based at least in part on operator inputs, one or more images of a building roof to a set of reference points within a single three-dimensional ("3D") grid that is shared between the one or more images. Roof model generation includes generating a 3D model of a roof, based at least in part on operator inputs specifying various features and/or dimensional attributes of the roof. Roof model generation may further include the determination of the pitches of various planar sections of a roof. Roof model review includes display of a model of a roof, possibly in conjunction with one or more images of the roof, so that an operator may review the model for accuracy and possibly make adjustments and/or corrections to the roof model. In other embodiments, all or some of the functions of the roof estimation system may be performed automatically. For example, image registration may include automatically identifying building features for the placement of reference markers. Further, roof model generation may include automatically recognizing features, dimensional attributes, and/or pitches of various planar roof sections of the roof.

The described user interface is also configured to concurrently display roof features onto multiple images of a roof. For example, in the context of roof model generation, an operator may indicate a roof feature, such as an edge or a corner of a section of the roof, in a first image of the roof. As the roof estimation system receives the indication of the roof feature, the user interface concurrently displays that feature in one or more other images of the roof, so that the operator may obtain feedback regarding the accuracy of the roof model, the image registration, etc.

In the following, FIGS. **1-3** provide an overview of the operation of an example roof estimation system. FIGS. **4-7** provide additional details related an example interactive user interface provided by one embodiment of the roof estimation system. FIGS. **8-11** provide details related to roof estimation system implementation techniques.

1. Roof Estimation System Overview

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system. In particular, FIG. **1** shows an example Roof Estimation System ("RES") **100** comprising an image acquisition engine **101**, a roof modeling engine **102**, a report generation engine **103**, image data **105**, model data **106**, and report data **107**. The RES **100** is communicatively coupled to an image source **110**, a customer **115**, and optionally an operator **120**. The RES **100** and its components may be implemented as part of a computing system, as will be further described with reference to FIG. **8**.

More specifically, in the illustrated embodiment of FIG. **1**, the RES **100** is configured to generate a roof estimate report **132** for a specified building, based on aerial images **131** of the building received from the image source **110**. The image source **110** may be any provider of images of the building for which a roof estimate is being generated. In one embodiment, the image source **110** includes a computing system that provides access to a repository of aerial images of one or more buildings. In addition, the aerial images **131** may include images obtained via manned or unmanned aircraft (e.g., airplane, helicopter, blimp, drone, etc.), satellite, etc. Furthermore, the aerial images **131** may include images obtain via one or more ground-based platforms, such as a vehicle-mounted camera that obtains street-level images of buildings, a nearby building, a hilltop, etc. In some cases, a vehicle-mounted camera may be mounted in an elevated position, such as a boom. Example aerial images are described further with reference to FIGS. **2**A-**2**B.

The image acquisition engine **101** obtains one or more aerial images of the specified building by, for example, providing an indicator of the location of the specified building (e.g., street address, GPS coordinates, lot number, etc.) to the image source **110**. In response, the image source **110** provides to the image acquisition engine **101** the one or more aerial images of the building. The image acquisition engine **101** then stores the received aerial images as image data **105**, for further processing by other components of the RES **100**. Obtaining aerial images of a specified building may include various forms of geo-coding, performed by the image acquisition engine **101** and/or the image source **110**. In one embodiment, the image source geo-codes a provided street address into latitude and longitude coordinates, which are then used to look up (e.g., query a database) aerial images of the provided street address.

Next, the roof modeling engine **102** generates a model of the roof of the specified building. In the illustrated embodiment, the roof modeling engine **102** generates a three-dimensional ("3D") model, although in other embodiments, a two-dimensional (e.g., top-down roof plan) may be generated instead or in addition. Generating a model of the roof may generally include image calibration, in which the distance between two pixels on a given image is converted into a physical length. Image calibration may be performed automatically, such as based on meta-information provided along with the aerial images **131**.

A variety of automatic and semi-automatic techniques may be employed to generate a model of the roof of the building. In one embodiment, generating such a model is based at least in part on a correlation between at least two of the aerial images of the building. For example, the roof modeling engine **102** receives an indication of a corresponding feature that is shown in each of the two aerial images. In one embodiment, an operator **120**, viewing two or more images of the building, inputs an indication in at least some of the images, the indications identifying which points of the images correspond to each other for model generation purposes.

The corresponding feature may be, for example, a vertex of the roof of the building, the corner of one of the roof planes of the roof, a point of a gable or hip of the roof, etc. The corresponding feature may also be a linear feature, such as a ridge or valley line between two roof planes of the roof. In one embodiment, the indication of a corresponding feature on the building includes "registration" of a first point in a first aerial image, and a second point in a second aerial image, the first and second points corresponding the substantially the same point on the roof of the building. Generally, point registration may include the identification of any feature shown in both aerial images. Thus, the feature need not be a point on the roof of the building. Instead, it may be, for example, any point that is visible on both aerial images, such as on a nearby building (e.g., a garage, neighbor's building, etc.), on a nearby structure (e.g., swimming pool, tennis court, etc.), on a nearby natural feature (e.g., a tree, boulder, etc.), etc.

In some embodiments, the roof modeling engine **102** determines the corresponding feature automatically, such as by

employing on one or more image processing techniques used to identify vertexes, edges, or other features of the roof. In other embodiments, the roof modeling engine **102** determines the corresponding feature by receiving, from the human operator **120** as operator input **133**, indications of the feature shown in multiple images of the building.

In one example embodiment, the RES **100** generates a model of the roof of the building in the following manner. First, a set of reference points are be identified in each of the images. These reference points are identified by the operator **120** utilizing a suitable input device, such as a mouse or joystick. The roof modeling engine **102** then uses these reference points and any acceptable algorithm to co-register the images and reconstruct the three-dimensional geometry of the object identified by the reference points. There are a variety of photogrammetric algorithms that can be utilized to perform this reconstruction. One such algorithm used by the RES **100** uses photographs taken from two or more view points to "triangulate" points of interest on the object in three-dimensional ("3D") space. This triangulation can be visualized as a process of projecting a line originating from the location of the photograph's observation point that passes through a particular reference point in the image. The intersection of these projected lines from the set of observation points to a particular reference point identifies the location of that point in 3D space. Repeating the process for all such reference points allows the software to determine a 3D volume suitable for building a 3D model of the structure. The choice of reconstruction algorithm depends on a number of factors such as the spatial relationships between the photographs, the number and locations of the reference points, and any assumptions that are made about the geometry and symmetry of the object being reconstructed. Several such algorithms are described in detail in textbooks, trade journals, and academic publications.

In addition, generating a model of the roof of a building may include correcting one or more of the aerial images for various imperfections. For example, the vertical axis of a particular aerial image sometimes will not substantially match the actual vertical axis of its scene. This will happen, for example, if the aerial images were taken at different distances from the building, or at a different pitch, roll, or yaw angles of the aircraft from which the images were produced. In such cases, an aerial image may be corrected by providing the operator **120** with a user interface control operable to adjust the scale and/or relative angle of the aerial image to correct for such errors. The correction may be either applied directly to the aerial image, or instead be stored (e.g., as an offset) for use in model generation or other functions of the RES **100**.

Generating a model of the roof of a building further includes the automatic or semi-automatic identification of features of the roof of the building. In one embodiment, one or more user interface controls may be provided, such that the operator **120** may indicate (e.g., draw, paint, etc.) various features of the roof, such as valleys, ridges, hips, vertexes, planes, edges, etc. As these features are indicated by the operator **120**, a corresponding three-dimensional ("3D") model may be updated accordingly to include those features. These features are identified by the operator based on a visual inspection of the images and by providing inputs that identify various features as valleys, ridges, hips, etc. In some cases, a first and a second image view of the roof (e.g., a north and east view) are simultaneously presented to the operator **120**, such that when the operator **120** indicates a feature in the first image view, a projection of that feature is automatically presented in the second image view. By presenting a view of the 3D model, simultaneously projected into multiple image views, the operator **120** is provided with useful visual cues as to the correctness of the 3D model and/or the correspondence between the aerial images.

In addition, generating a model of the roof of a building may include determining the pitch of one or more of the sections of the roof. In some embodiments, one or more user interface controls are provided, such that the operator **120** may accurately determine the pitch of each of the one or more roof sections. An accurate determination of the roof pitch may be employed (by a human or the RES **100**) to better determine an accurate cost estimate, as roof sections having a low pitch are typically less costly surfaces to repair and/or replace.

The generated model typically includes a plurality of planar roof sections that each correspond to one of the planar sections of the roof of the building. Each of the planar roof sections in the model has a number of associated dimensions and/or attributes, among them slope, area, and length of each edge of the roof section. Other information may include any information relevant to a roof builder or other entity having an interest in construction of, or installation upon, the roof. For example, the other information may include identification of valleys, ridges, rakes, eaves, or hip ridges of the roof and/or its sections; roof and/or roof section perimeter dimensions and/or outlines; measurements of step heights between different roof levels (e.g., terraces); bearing and/or orientation of each roof section; light exposure and/or shadowing patterns due to chimneys, other structures, trees, latitude, etc.; roofing material; etc? Once a 3D model has been generated to the satisfaction of the roof modeling engine **102** and/or the operator **120**, the generated 3D model is stored as model data **106** for further processing by the RES **100**. In one embodiment, the generated 3D model is then stored in a quality assurance queue, from which it is reviewed and possibly corrected by a quality control operator.

The report generation engine **103** generates a final roof estimate report based on a model stored as model data **106**, and then stores the generated report as report data **107**. Such a report typically includes one or more plan (top-down) views of the model, annotated with numerical values for the slope, area, and/or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof. The report may also include information about total area of the roof, identification and measurement of ridges and/or valleys of the roof, and/or different elevation views rendered from the 3D model (top, side, front, etc). An example report is illustrated and discussed with respect to FIGS. **3**A-**3**E, below.

In some embodiments, generating a report includes labeling one or more views of the model with annotations that are readable to a human user. Some models include a large number of small roof details, such as dormers or other sections, such that applying uniformly sized, oriented, and positioned labels to roof section views results in a visually cluttered diagram. Accordingly, various techniques may be employed to generate a readable report, including automatically determining an optimal or near-optimal label font size, label position, and/or label orientation, such that the resulting report may be easily read and understood by the customer **115**.

In addition, in some embodiments, generating a report includes automatically determining a cost estimate, based on specified costs, such as those of materials, labor, transportation, etc. For example, the customer **115** provides indications of material and labor costs to the RES **100**. In response, the report generation engine **103** generates a roof estimate report that includes a cost estimate, based on the costs provided by the customer **115** and the attributes of the particular roof, such as area, pitch, etc.

In one embodiment, the generated report is then provided to a customer. The generated report can be represented, for example, as an electronic file (e.g., a PDF file) or a paper document. In the illustrated example, roof estimate report **132** is transmitted to the customer **115**. The customer **115** may be or include any human, organization, or computing system that is the recipient of the roof estimate report **132**. For example, the customer **115** may be a property owner, a property manager, a roof construction/repair company, a general contractor, an insurance company, a solar power panel installer, a climate control (e.g., heating, ventilation, and/or air conditioning) system installer, a roof gutter installer, an awning installer, etc. Reports may be transmitted electronically, such as via a network (e.g., as an email, Web page, etc.) or by some shipping mechanism, such as the postal service, a courier service, etc.

In some embodiments, one or more of the models stored as model data **106** are provided directly to the customer or other computing system, without first being transformed into a report. For example, a model and/or roof measurement information based thereon may be exported and/or transmitted as a data file, in any suitable format, that may be consumed or otherwise utilized by some other computing system, such as a computer-aided design ("CAD") tool, a drawing program, a labor and material estimation software, a project management/estimation software, etc.

The RES **100** may be operated by various types of entities. In one embodiment, the RES **100** is operated by a roof estimation service that provides roof estimate reports to customers, such as roofing contractors, in exchange for payment. In another embodiment, the RES **100** is operated by a roof construction/repair company, to generate roof estimate reports that are used internally and/or provided to customers, such as property owners.

In addition, the RES **100** may be operated in various ways. In one embodiment, the RES **100** executes as a desktop computer application that is operated by the operator **120**. In another embodiment, the RES **100** executes as a network-accessible service, such as by a Web server, that may be operated remotely by the operator **120** and/or the customer **115**. Additional details regarding the implementation of an example roof estimation system are provided with respect to FIG. **8**, below.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address. In the illustrated example, the aerial images are represented as stylized line drawings for clarity of explanation. As noted above, such aerial images may be acquired in various ways. In one embodiment, an aircraft, such as an airplane or helicopter is utilized to take photographs while flying over one or more properties. Such aircraft may be manned or unmanned. In another embodiment, a ground-based vehicle, such as a car or truck, is utilized to take photographs (e.g., "street view" photographs) while driving past one or more properties. In such an embodiment, a camera may be mounted on a boom or other elevating member, such that images of building roofs may be obtained. In another embodiment, photographs may be taken from a fixed position, such as a tall building, hilltop, tower, etc.

In particular, FIG. **2**A shows a top plan (top-down) aerial image **210** of a building **200**. The roof of the building **200** includes multiple planar roof sections **200***a*-**200***d*. FIG. **2**A also shows a second aerial image **211** providing a perspective (oblique) view of the building **200**. The roof sections **200***a* and **200***c* are also visible in image **211**.

FIG. **2**B shows a top-down, wide angle image **212** of the building **200**. The image **212** includes details of the surrounding areas **220** of the building **220**. Information about the surrounding areas **220** of the building **220** are in some embodiments used to determine additional cost factors related to a roof estimate. For example, the cleanup of, or access to, a worksite at building **220** may be complicated by various factors, including a substantial amount of landscaping; steeply sloped building sites; proximity to environmentally sensitive areas; etc. In such cases, the roof estimation system may automatically increase a cost factor in a corresponding roof estimate report.

In some embodiments, an aerial image has corresponding meta-information. Such meta-information may include details about the type of camera used (e.g., focal length, exposure, etc.), the position of the camera (e.g., GPS coordinates of the aircraft at the time the image was captured), the orientation of the camera (e.g., the angle of the camera), the time and/or date the image was captured, etc.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system. As discussed with respect to FIG. **1**, a roof estimate report is generated by the roof estimation system based on one or more aerial images of a building. The roof estimate report may be based on a computer model (e.g., a 3D model) of the roof, and includes one or more views of the model. In this example, the various views of the model are presented as annotated line drawings, which provide information about the roof, such as the roof section areas, roof section edge lengths, roof section pitches, etc. The roof estimate report may be in an electronic format (e.g., a PDF file) and/or paper format (e.g., a printed report). In some embodiments, the roof estimate report may be in a format that may be consumed by a computer-aided design program.

FIG. **3**A shows a cover page **301** of the report and includes the address **301***a* of a building **301***c* and an overhead aerial image **301***b* of the building **301***c*.

FIG. **3**B shows a second page **302** of the report and includes two wide perspective (oblique) views **302***a* and **302***b* of the building **301***c* at the address with the surrounding areas more clearly shown.

FIG. **3**C shows a third page **303** of the report and includes a line drawing **303***a* of the building roof showing ridge lines **303***b* and **303***c*, and a compass indicator **303***d*. In addition, a building roof having valleys would result in a line drawing including one or more valley lines. The ridge and/or valley lines may be called out in particular colors. For example, ridge lines **303***b* and **303***c* may be illustrated in red, while valley lines may be illustrated in blue. The line drawing **303***a* is also annotated with the dimensions of the planar sections of the building roof. In this case, the dimensions are the lengths of the edges of the planar roof sections.

FIG. **3**D shows a fourth page **304** of the report and includes a line drawing **304***a* of the building roof showing the pitch of each roof section along with a compass indicator. The pitch in this example is given in inches, and it represents the number of vertical inches that the labeled planar roof section drops over 12 inches of horizontal run. The slope can be easily calculated from such a representation using basic trigonometry. The use of a numerical value of inches of rise per foot of run is a well known measure of slope in the roofing industry. A roof builder typically uses this information to assist in the repair and/or construction of a roof. Of course, other measures and/or units of slope may be utilized as well, including percent grade, angle in degrees, etc.

FIG. **3**E shows a fifth page **305** of the report and includes a line drawing **305***a* of the building roof showing the square footage of each roof section along with the total square foot area value. Of course, other units of area may be used as well,

such as square meters or the number of "squares" of roofing material required for covering each roof section.

FIG. **3**F shows a fifth page **306** of the report and includes a line drawing **306***a* of the building roof where notes or comments may be written. The line drawing **306***a* includes a label for each roof section (shown here as "A", "B", "C"), such that comments may be conveniently related to specific roof sections.

In other embodiments, more or less information may be provided, or the illustrated information may be arranged in different ways. For example, the report may be provided in electronic form, such as a PDF file or a computer aided design software format. In some embodiments, the report may be "active" or editable, such that the user of the report may make changes to the report, based on on-site observations.

2. Roof Estimation System User Interface

FIGS. **4**A-**4**F, **5**A-**5**D, **6**A-**6**D, and **7**A-**7**C describe an example interactive user interface provided by one embodiment of the roof estimation system. As noted, the RES **100** described with reference to FIG. **1** includes a user interface engine **104** that is configured to provide access to one or more functions of the RES **100**, including image registration (described with respect to FIGS. **4**A-**4**F), roof pitch determination (described with respect to FIGS. **5**A-**5**D), roof model construction (described with reference to FIGS. **6**A-**6**D), and roof model review (described with respect to FIGS. **7**A-**7**C).

A. Image Registration

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. In particular, FIG. **4**A shows a user interface screen **400** that is utilized by an operator to generate a three dimensional model of a roof of a building. The user interface screen **400** shows a roof modeling project in an initial state, after the operator has specified an address of a building and after images of the building have been obtained and loaded into the roof estimation system.

The user interface screen **400** includes a control panel **401** and five images **402**-**406** of a building roof **407**. The control panel **401** includes user selectable controls (e.g., buttons, check boxes, menus, etc.) for various roof modeling tasks, such as setting reference points for the images, setting the vertical (Z) axis for the images, switching between different images, saving the model, and the like. Each of the images **402**-**406** provides a different view of the building roof **407**. In particular, images **402**-**406** respectively provide substantially top-down, south, north, west, and east views of the building roof **407**. Each image **402**-**406** includes four marker controls (also called "reference points" or "registration markers") that are used by the operator to set reference points in the image for purposes of image registration. The registration markers will be described further with respect to an enlargement of image portion **408** described with respect to FIGS. **4**B-**4**C, below.

FIGS. **4**B-**4**C show an enlarged view of image portion **408** during the process of image registration for image **402**, which provides a top-down view of the building roof **407**. As shown in FIG. **4**B, image portion **408** includes the building roof **407** and registration markers **410**-**413**. The markers **410**-**413** are interactive user interface controls that can be directly manipulated (e.g., moved, rotated, etc.) by the operator in order to specify points to use for purposes of image registration. In particular, image registration includes determining a transformation between each of one or more images and a uniform 3D reference grid. The uniform 3D reference grid is used as a coordinate system for a 3D model of the roof. By registering multiple images to the reference grid, an operator may indicate a roof feature on an image (such as a roof edge), which may then be translated from the coordinate system of the image to the coordinate system of the reference grid, for purposes of including of the indicated feature in the 3D model.

Marker **410** is an origin marker control, and includes arms **410***a*-**410***c*. Arms **410***a* and **410***b* are horizontal arms that are utilized to specify the X and Y axes (e.g., the horizontal plane) of the reference grid. Arm **410***c* is a vertical arm that may be utilized to specify the Z axis (e.g., the vertical axis) of the reference grid. The use of the vertical arm to specify the Z axis will be further described with respect to FIG. **4**E, below.

Typically, markers **410**-**413** are color coded, such that they may be distinguished from one another. For example, marker **411**-**413** may be respectively colored red, blue, and green. Origin marker **410** has a different appearance than markers **411**-**413**, so may be of any color. In other embodiments, markers **411**-**413** may be distinguished in other ways, such as by utilizing different sized dashed lines, different line thicknesses, etc. In still other embodiments, markers are not distinguished any way from each other, such as by being of uniform shape, color, etc.

FIG. **4**C shows image portion **408** with markers **410**-**413** after they have been placed by an operator. Typically, registration markers are placed at four spatially distributed corners of the roof. As shown in FIG. **4**C, the operator has placed markers **410**-**413** at four different corners of the building roof **407**. In particular, the operator first placed the origin marker **410** at the lower left corner of the building roof **407**, and has adjusted (e.g., rotated) the arms **410***a* and **410***b* to align with the major horizontal axes of the roof. By adjusting the arms **410***a* and **410***b* of the origin marker **410**, the rotational orientation of markers **411**-**413** is automatically adjusted by the roof estimation system. Next, the operator places markers **411**-**413** on some other corners of the roof. In general, the operator can place registration marker over any roof feature, but roof corners are typically utilized because they are more easily identified by the operator. After the operator is satisfied with the placement of markers **410**-**413**, the operator typically registers a next image of the building roof **407**, as will be described next.

FIGS. **4**D-**4**F illustrate image registration for image **404**, which provides a north view of the building roof **407**. In particular, FIG. **4**D shows the user interface screen **400** described with reference to FIG. **4**A. Here, image **402** has been minimized, while image **404** has been enlarged so that the operator may register that image by placing markers on image **404**, as will be described below with respect to an enlarged view of image portion **418**.

FIG. **4**E shows an enlarged view of image portion **418** during the process of image registration for image **404**. Image portion **418** includes the building roof **407** and registration markers **420**-**423**. Markers **420**-**423** respectively correspond to markers **410**-**413** described above. In particular, marker **420** is an origin marker control that includes arms **420***a*-**420***c*. Arms **420***a* and **420***b* are horizontal arms that are utilized to specify the X and Y axes of the reference grid. Arm **420***c* is a vertical arm that may be utilized to specify the Z axis of the reference grid.

In the example of FIG. **4**E, the operator has moved each of markers **420**-**423** to a corner of the roof **407**. Note that the markers **420**-**423** are moved to roof corners that correspond to those selected by the operator with markers **410**-**413**, as described with reference to FIG. **4**C. In particular, origin marker **420** has been moved to the corner of the roof **407** selected with origin marker **410** in image **408**; marker **421** has been moved to the corner selected with marker **411** in image **408**; marker **422** has been moved to the corner selected with

marker **412** in image **408**; and marker **423** has been moved to the corner selected with marker **413** in image **408**. In addition, markers **420-423** have been rotated, by operator rotation of the origin marker **420**, to align with the major axes of the roof **407**.

As noted, the operator can utilize the origin marker **420** to specify the vertical axis of the reference grid. In particular, the operator can adjust (e.g., by dragging with a mouse or other pointing device) arm **420***c* of marker **420** to specify the vertical (Z) axis of the image. In some cases, aerial images may include some amount of lean, due to the orientation of the aircraft during image capture. For example, pitch, yaw, or roll of an aircraft during the course of image capture may result in images that are misaligned with respect to the vertical axis of the building and its roof. Typically, an operator may adjust arm **420***c* to line up with a feature of a building or roof that is known to be substantially vertical, such as a wall of a house or a chimney. Then, based on the angle of arm **420***c* with respect to the vertical axis of the image, the roof estimation system can determine a correction between the reference grid and the image.

FIG. **4**F shows an enlarged view of image portion **418** after registration of image **404**. Once the operator has placed and adjusted markers **420-423**, the operator may direct (e.g., by clicking a button) the roof estimation system to register the image to the reference grid, based on the positions and orientations of markers **420-423**. Once the roof estimation system registers the image, it provides the operator with feedback so that the operator may determine the correctness or accuracy of the registration.

In the example of FIG. **4**F, the operator has directed the roof estimation system to register image **404**, and the roof estimation system has updated image portion **418** with registration indicators **430-433**. Registration indicators **430-433** provide the operator with feedback so that the operator may judge the accuracy of the registration of image **404**.

Registration indicator **430** is an origin registration indicator that includes two arms **430***a*-**430***b* and three reference grid indicators **430***c*-**430***e*, shown as dashed lines. The reference grid indicators **430***c*-**430***e* show the vertical axis (**430***c*) and the two horizontal axes (**430***d* and **430***e*) of the reference grid determined based on the placement and orientation of the markers **420-423**. Arms **430***a* and **430***b* correspond to the placement of arms **420***a*-**420***c* of origin marker **420**. If the arms **430***a* and **430***b* do not substantially align with the corresponding reference grid indicators **430***e* and **430***d*, then the determined reference grid is out of alignment with the specified axes of the house. Typically, an operator will return to the view of FIG. **4**E to make adjustments to origin marker, such as adjusting one or more of the vertical or horizontal axes, in order to refine the registration of the image. Although the arms **430***a*-**430***b* and the reference grid indicators **430***c*-**430***e* are here illustrated as solid and dashed lines, in other embodiments they may be color coded. For example, arms **430***a*-**430***b* may be red, while reference grid indicators **430***c*-**430***e* may be blue.

Registration indicators **431-433** provide the operator with information regarding the accuracy of the placement of markers **421-423**. In particular, each registration indicator **431-433** includes a solid crosshairs and a reference indicator, shown for example as a dashed line **432***a*. The crosshair of a registration indicator corresponds to the placement of a marker. For example, the crosshairs of registration indicator **431** corresponds to the placement of marker **421** in FIG. **4**E. If the reference indicator intersects the center (or substantially near the center) of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is accurate. On the other hand, if the reference indicator does not intersect the center of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is inaccurate. Typically, such an inaccuracy arises when the placement of markers in the top view of the roof does not agree with (correspond to) the placement of corresponding markers in another view of the roof. In such cases, the operator can return to the view of FIG. **4**C or **4**E to adjust the position of one or more markers.

After registering image **404**, the operator will proceed to register additional images of the building roof **407** utilizing a process similar to that described above. In this example, the operator will register images **403**, **405**, and **406**. Although the operator is here described as registering a total of five images, in other cases more or fewer images may be registered.

B. Roof Model Construction

FIGS. **5**A-**5**D and **6**A-**6**C generally illustrate aspects of the process of roof model generation based on multiple registered images. In particular, these figures illustrate the construction of a roof model by an operator. Model generation/construction may include identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. Each identified roof feature is incorporated by the roof estimation system into a 3D model of the roof, based on a translation between an image in which the feature is identified and the reference grid, as determined by the process described with reference to FIGS. **4**A-**4**F, above.

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment. In particular, FIG. **5**A shows the user interface screen **400** after images **402-406** have been registered. In this example, the operator is using a pitch determination control (also called a "pitch determination marker" or "pitch determination tool") to specify the pitch of a planar roof section of the building roof **407** visible in image **406**. The pitch determination control will be further described in FIG. **5**B, below, with respect to an enlargement of image portion **508**.

FIG. **5**B shows an enlarged view of image portion **508** during the process of pitch determination for image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **5**B, the image portion **508** includes the building roof **407** and a pitch determination marker **510** (also called a "protractor tool"). The pitch determination marker **510** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**.

The pitch determination marker **510** includes arms **510***a*-**510***d*. Arms **510***a*-**510***c* are axes, which are automatically aligned, based on the registration of image **406**, with the major (X, Y, and Z) axes of the building roof. Arm **510***d* is a "protractor" arm that is adjustable by the operator to specify roof pitch.

The marker **510** is typically first moved by the operator to a convenient location on the building roof **407**, usually corner of a planar section of the roof **407**. Next, the operator adjusts arm **510***d* so that is substantially aligns with the sloped edge of the planar roof section. Then, the roof estimation system determines the pitch of the roof section, based on the configuration of the marker **510** with respect to the image and the reference grid.

After specifying the pitch of a planar roof section, the operator will typically specify other information about the planar roof section, such as its outline, as will be described with reference to FIGS. **6**A-**6**D. Note that as the operator provides additional information about the geometry of the

roof **407**, the roof estimation system may automatically determine the pitch and/or other features of at least some of the other planar roof sections, based on the provided geometric information and/or assumptions about roof symmetry or other standard architectural practices.

FIG. **5**C shows a second type of pitch determination marker being used in the context of image **403** which provides a south perspective view of the building roof **407**. The illustrated pitch determination marker may be used in addition to, or instead of, the pitch determination marker **510** described with respect to FIGS. **5**A-**5**B, above. In particular, FIG. **5**C shows a pitch determination marker **520** (also called an "envelope tool") that includes surfaces **520***a* and **520***b*. The pitch determination marker **520** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**. In particular, the pitch determination marker **520** may be moved and/or adjusted so that it appears to lie substantially atop two adjacent planar sections of roof **407**.

FIG. **5**D shows the pitch determination marker **520** after the operator has used it to specify the pitch of two sections of roof **407**. Here, the operator has moved the marker **520** to a position in which the spine of the marker **520** is substantially aligned with the ridge line of roof **407**. Then, the operator has adjusted the angle of the surfaces **520***a* and **520***b* so that they appear to lie substantially atop corresponding sections of roof **407**. Then, the roof estimation system determines the pitch of the roof sections, based on the configuration of the marker **520** with respect to the image and the reference grid. Also illustrated are pitch indicators **521** and **522**. Pitch indicator **521** corresponds to the measured pitch of surface **520***a*, and pitch indicator **522** corresponds to the measured pitch of surface **520***b*. As the operator adjusts the angle of surfaces **520***a* and/or **520***b*, the corresponding pitch indicators **521**-**522** are automatically updated to reflect the determined pitch. In this example, the pitch of both surfaces is given as 4 inches of rise per foot of run.

The envelope pitch determination marker **520** may be adjusted in other ways, to specify pitches for types of roofs other than the gabled roof shown in image **403**. For example, when measuring pitch of roof sections that form a roof hip, point **520***c* may be manipulated by the operator, such as by dragging it to the left or right, to adjust the shape of the surfaces **520***a* and **520***b*, so that the surfaces align with the edges formed by the intersection of the sections that form the roof hip.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment. In particular, FIGS. **6**A-**6**D illustrate the construction of a three dimensional wire frame model of a building roof, based on the specification of roof features by an operator. In addition, FIGS. **6**A-**6**D illustrate the concurrent display of operator specified roof features in multiple views of a building roof.

FIG. **6**A shows the user interface screen **400** after images **402**-**406** have been registered, and after roof pitches have been determined. In this example, the operator is specifying sections of roof **407**, visible in image **406**, that are to be added to a 3D wire frame model of the roof **407** maintained by the roof estimation system. The specification of roof sections will be further described with reference to enlarged portion **608** of image **406** in FIG. **6**B, below. In addition, as the operator specifies roof sections in image **406**, the roof estimation system concurrently displays the specified roof sections in each of the other images **402**-**405**. The concurrent display of operator specified roof features will be further described with reference to enlarged portion **609** of image **402** in FIG. **6**C, below.

FIG. **6**B is an enlarged view of image portion **608** during the process of wire frame model construction in the context of image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **6**B, the image portion **608** includes the building roof **407**, drawing tool **610**, and wire frame **611**. The drawing tool **610** (also called a "drawing marker" or a "drawing control") is an interactive user interface control that can be directly manipulated by the operator in order to specify roof features, such as edges, ridges, valleys, corners, etc. In the illustrated embodiment, the operator uses the drawing tool **610** to trace or outline planar sections of the roof **407**, leading to the generation of wire frame **611**. The drawing tool **610** may be used to establish a series of connected line segments that result in a closed polygon representing a planar roof section. As the operator specifies a planar roof section in this manner, the roof estimation system determines, based on the image and the reference grid, the geometry of the planar roof section, and includes (adds) the specified planar roof section in a 3D model that corresponds to roof **407**.

FIG. **6**C is an enlarged view of image portion **609** illustrating the concurrent display of operator specified roof features, in the context of image **402**, which provides a top plan view of the building roof **407**. As the operator specifies roof sections as described with respect to FIG. **6**B, the roof estimation system concurrently displays the specified roof features in one or more of the other images displayed by the user interface screen **400**. More specifically, image portion **609** includes building roof **407** and wire frame **612**. Wire frame **612** corresponds to wire frame **611** constructed by the operator with reference to FIG. **6**B, except that wire frame **612** is automatically displayed as a projection from the 3D model into the top-down view of image **402**. Changes that the operator makes to wire frame **611** are concurrently displayed by the roof estimation system as wire frame **612** in image portion **609**. For example, if a new planar roof section is added by the operator to wire frame **611**, the new planar roof section is automatically displayed in wire frame **612**. By concurrently displaying operator identified features in multiple views of building roof **407**, the operator obtains feedback regarding the correctness and/or accuracy of the 3D model or other aspects of the model generation process, such as image registration and pitch determination.

Generally, the roof estimation system can be configured to concurrently display any operator-identified features, such as corners, ridges, valleys, planar sections, and the like, in multiple views of a building.

Furthermore, the concurrently displayed wire frame **612** is an interactive user interface element, in that the operator can make changes to the wire frame **612**, which are then concurrently displayed in wire frame **611**. Wire frames similar to those described above are also projected by the roof estimation system into images **403**, **404**, and **405** displayed by the user interface screen **400**. In this manner, the operator can switch between various images of the building roof **407**, making refinements to the 3D model by adjusting the wire frame in whichever image is more convenient and/or provides a more suitable perspective/view of the model.

FIG. **6**D shows the user interface screen **400** during construction of a 3D model of the building roof **407**. In particular, the user interface **400** includes a shaded wire frame **613** representation of the 3D model constructed as described above. In this view, the operator can review the wire frame **613** in isolation from any images to determine whether the

wire frame **613** accurately represents the building roof **407**. The wire frame **613** is an interactive user interface component, in that it can be directly manipulated (e.g., moved, rotated, resized, etc.). In some embodiments, manipulating the wire frame **613**, such as by changing its shape, results in corresponding changes in the underlying 3D model.

C. Roof Model Review

FIGS. **7A**-**7C** are screen displays illustrating roof model review in an example embodiment. In particular, FIGS. **7A**-**7C** illustrate various techniques to facilitate the review of a roof model by an operator. Reviewing the roof model may include reviewing roof section pitches (e.g., to determine whether they conform to the building roof and/or standard construction practices), reviewing the shape and/or location of the roof model (e.g., to determine whether it substantially conforms to the building roof), etc.

FIG. **7A** shows the user interface screen **400** after the operator has constructed a model of the roof **407** using one or more of the images **402**-**406**. In this example, a wire frame has been projected onto (superimposed upon) image **402** and annotated with roof section pitches, as will be described further with respect to enlarged portion **708** of image **402** in FIG. **7B**, below.

FIG. **7B** is an enlarged view of image portion **708** during the process of roof model review in the context of image **402**, which provides a substantially top plan view of the building roof **407**. As shown in FIG. **7B**, the image portion **708** includes a wire frame **710** and labels **711***a*-**711***c* that indicate pitches of corresponding sections of roof **407**. The wire frame **710** and the illustrated pitches are determined by the roof estimation system based on the pitch determination described with respect to FIGS. **5A**-**5D**, above, and the operator's specification of the wire frame model described with respect to FIGS. **6A**-**6D**, above.

The wire frame **710** includes multiple vertexes connected by line segments. Each vertex includes a handle, such as handle **710***a*. The handles may be directly manipulated (individually or in groups) by the operator to make adjustments/modifications to the wire frame **710**. For example, when an operator drags handle **710***a* to a new location, the ends of the two line segments connected to handle **710***a* will also move to the new location.

FIG. **7C** is an alternative view of the 3D model of roof **407** during the process of roof model review. In FIG. **7C**, the user interface screen **400** includes a wire frame **720** representation of the 3D model of the roof **407**. The wire frame **720** consists of multiple line segments corresponding to edges of planar roof sections. Each line segment is annotated with a label, such as label **723**, indicating the determined length of the corresponding roof section edge. Furthermore, some of the line segments indicate that they correspond to a particular roof feature. For example, line segments **721** and **722** may be colored (e.g., red) so as to indicate that they correspond to roof ridges. Other line segments may be differently colored (e.g., blue) so as to indicate a correspondence to roof valleys or other features. In addition, the wire frame **720** may be directly manipulated by the operator in order to make adjustments to the underlying model of the roof **407**. For example, the operator could increase or decrease the length of line segment **721**, resulting in a change in the corresponding feature of the 3D model of roof **407**.

Note that although the operator is shown, in FIGS. **5**-**7** above, operating upon a total of five images, in other cases, fewer images may be used. For example, in some cases fewer images may be available, or some images may provide obstructed views of the building roof, such as due to tree cover, neighboring buildings, etc.

3. Implementation Techniques

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system. FIG. **8** shows a computing system **800** that may be utilized to implement a Roof Estimation System ("RES") **810**. One or more general purpose or special purpose computing systems may be used to implement the RES **810**. More specifically, the computing system **800** may comprise one or more distinct computing systems present at distributed locations. In addition, each block shown may represent one or more such blocks as appropriate to a specific embodiment or may be combined with other blocks. Moreover, the various blocks of the RES **810** may physically reside on one or more machines, which use standard inter-process communication mechanisms (e.g., TCP/IP) to communicate with each other. Further, the RES **810** may be implemented in software, hardware, firmware, or in some combination to achieve the capabilities described herein.

In the embodiment shown, computing system **800** comprises a computer memory ("memory") **801**, a display **802**, one or more Central Processing Units ("CPU") **803**, Input/Output devices **804** (e.g., keyboard, mouse, joystick, track pad, CRT or LCD display, and the like), other computer-readable media **805**, and network connections **806**. The RES **810** is shown residing in memory **801**. In other embodiments, some portion of the contents, some of, or all of the components of the RES **810** may be stored on and/or transmitted over the other computer-readable media **805**. The components of the RES **810** preferably execute on one or more CPUs **803** and generate roof estimate reports, as described herein. Other code or programs **830** (e.g., a Web server, a database management system, and the like) and potentially other data repositories, such as data repository **820**, also reside in the memory **801**, and preferably execute on one or more CPUs **803**. Not all of the components in FIG. **8** are required for each implementation. For example, some embodiments embedded in other software do not provide means for user input, for display, for a customer computing system, or other components.

In a typical embodiment, the RES **810** includes an image acquisition engine **811**, a roof modeling engine **812**, a report generation engine **813**, an interface engine **814**, and a roof estimation system data repository **816**. Other and/or different modules may be implemented. In addition, the RES **810** interacts via a network **850** with an image source computing system **855**, an operator computing system **865**, and/or a customer computing system **860**.

The image acquisition engine **811** performs at least some of the functions of the image acquisition engine **101** described with reference to FIG. **1**. In particular, the image acquisition engine **811** interacts with the image source computing system **855** to obtain one or more images of a building, and stores those images in the RES data repository **816** for processing by other components of the RES **810**. In some embodiments, the image acquisition engine **811** may act as an image cache manager, such that it preferentially provides images to other components of the RES **810** from the RES data repository **816**, while obtaining images from the image source computing system **855** when they are not already present in the RES data repository **816**. In other embodiments, images may be obtained in an "on demand" manner, such that they are provided, either by the image acquisition engine **811** or the image source computing system **855**, directly to modules of the RES **810** and/or the operator computing system **865**, without intervening storage in the RES data repository **816**.

The roof modeling engine **812** performs at least some of the functions of the roof modeling engine **102** described with reference to FIG. **1**. In particular, the roof modeling engine **812** generates a model based on one or more images of a building that are obtained from the RES data repository **816** or directly from the image source computing system **855**. As noted, model generation may be performed semi-automatically, based on at least some inputs received from the computing system **865**. In addition, at least some aspects of the model generation may be performed automatically, based on image processing and/or image understanding techniques. After the roof modeling engine **812** generates a model, it stores the generated model in the RES data repository **816** for further processing by other components of the RES **810**.

The report generation engine **813** performs at least some of the functions of the report generation engine **103** described with reference to FIG. **1**. In particular, the report generation engine **813** generates roof reports based on models stored in the RES data repository **816**. Generating a roof report may include preparing one or more views of a given 3D model of a roof, annotating those views with indications of various characteristics of the model, such as dimensions of sections or other features (e.g., ridges, valleys, etc.) of the roof, slopes of sections of the roof, areas of sections of the roof, etc. In some embodiments, the report generation engine **813** facilitates transmission of roof measurement information that may or may not be incorporated into a roof estimate report. For example, the roof generation engine **813** may transmit roof measurement information based on, or derived from, models stored in the RES data repository **816**. Such roof measurement information may be provided to, for example, third-party systems that generate roof estimate reports based on the provided information.

The interface engine **814** provides a view and a controller that facilitate user interaction with the RES **810** and its various components. For example, the interface engine **814** implements a user interface engine **104** described with reference to FIG. **1**. Thus, the interface engine **814** provides an interactive graphical user interface that can be used by a human user operating the operator computing system **865** to interact with, for example, the roof modeling engine **812**, to perform functions related to the generation of models, such as point registration, feature indication, pitch estimation, etc. In other embodiments, the interface engine **814** provides access directly to a customer operating the customer computing system **860**, such that the customer may place an order for a roof estimate report for an indicated building location. In at least some embodiments, access to the functionality of the interface engine **814** is provided via a Web server, possibly executing as one of the other programs **830**.

In some embodiments, the interface engine **814** provides programmatic access to one or more functions of the RES **810**. For example, the interface engine **814** provides a programmatic interface (e.g., as a Web service, static or dynamic library, etc.) to one or more roof estimation functions of the RES **810** that may be invoked by one of the other programs **830** or some other module. In this manner, the interface engine **814** facilitates the development of third-party software, such as user interfaces, plug-ins, adapters (e.g., for integrating functions of the RES **810** into desktop applications, Web-based applications, embedded applications, etc.), and the like. In addition, the interface engine **814** may be in at least some embodiments invoked or otherwise accessed via remote entities, such as the operator computing system **865**, the image source computing system **855**, and/or the customer computing system **860**, to access various roof estimation functionality of the RES **810**.

The RES data repository **816** stores information related the roof estimation functions performed by the RES **810**. Such information may include image data **105**, model data **106**, and/or report data **107** described with reference to FIG. **1**. In addition, the RES data repository **816** may include information about customers, operators, or other individuals or entities associated with the RES **810**.

In an example embodiment, components/modules of the RES **810** are implemented using standard programming techniques. For example, the RES **810** may be implemented as a "native" executable running on the CPU **803**, along with one or more static or dynamic libraries. In other embodiments, the RES **810** is implemented as instructions processed by virtual machine that executes as one of the other programs **830**. In general, a range of programming languages known in the art may be employed for implementing such example embodiments, including representative implementations of various programming language paradigms, including but not limited to, object-oriented (e.g., Java, C++, C#, Matlab, Visual Basic .NET, Smalltalk, and the like), functional (e.g., ML, Lisp, Scheme, and the like), procedural (e.g., C, Pascal, Ada, Modula, and the like), scripting (e.g., Perl, Ruby, Python, JavaScript, VBScript, and the like), declarative (e.g., SQL, Prolog, and the like).

The embodiments described above may also use well-known synchronous or asynchronous client-server computing techniques. However, the various components may be implemented using more monolithic programming techniques as well, for example, as an executable running on a single CPU computer system, or alternatively decomposed using a variety of structuring techniques known in the art, including but not limited to, multiprogramming, multithreading, client-server, or peer-to-peer, running on one or more computer systems each having one or more CPUs. Some embodiments execute concurrently and asynchronously, and communicate using message passing techniques. Equivalent synchronous embodiments are also supported by an RES implementation. Also, other functions could be implemented and/or performed by each component/module, and in different orders, and by different components/modules, yet still achieve the functions of the RES.

In addition, programming interfaces to the data stored as part of the RES **810**, such as in the RES data repository **816**, can be available by standard mechanisms such as through C, C++, C#, and Java APIs; libraries for accessing files, databases, or other data repositories; through scripting languages such as XML; or through Web servers, FTP servers, or other types of servers providing access to stored data. For example, the RES data repository **816** may be implemented as one or more database systems, file systems, memory buffers, or any other technique for storing such information, or any combination of the above, including implementations using distributed computing techniques.

Also, the example RES **810** can be implemented in a distributed environment comprising multiple, even heterogeneous, computer systems and networks. For example, in one embodiment, the image acquisition engine **811**, the roof modeling engine **812**, the report generation engine **813**, the interface engine **814**, and the data repository **816** are all located in physically different computer systems. In another embodiment, various modules of the RES **810** are hosted each on a separate server machine and are remotely located from the tables which are stored in the data repository **816**. Also, one or more of the modules may themselves be distributed, pooled or otherwise grouped, such as for load balancing, reliability or security reasons. Different configurations and locations of programs and data are contemplated for use with techniques

of described herein. A variety of distributed computing techniques are appropriate for implementing the components of the illustrated embodiments in a distributed manner including but not limited to TCP/IP sockets, RPC, RMI, HTTP, Web Services (XML-RPC, JAX-RPC, SOAP, and the like).

Furthermore, in some embodiments, some or all of the components of the RES are implemented or provided in other manners, such as at least partially in firmware and/or hardware, including, but not limited to one or more application-specific integrated circuits (ASICs), standard integrated circuits, controllers (e.g., by executing appropriate instructions, and including microcontrollers and/or embedded controllers), field-programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs), and the like Some or all of the system components and/or data structures may also be stored (e.g., as software instructions or structured data) on a computer-readable medium, such as a hard disk, a memory, a network, or a portable media article to be read by an appropriate drive or via an appropriate connection. The system components and data structures may also be stored as data signals (e.g., by being encoded as part of a carrier wave or included as part of an analog or digital propagated signal) on a variety of computer-readable transmission mediums, which are then transmitted, including across wireless-based and wired/cable-based mediums, and may take a variety of forms (e.g., as part of a single or multiplexed analog signal, or as multiple discrete digital packets or frames). Such computer program products may also take other forms in other embodiments. Accordingly, embodiments of this disclosure may be practiced with other computer system configurations.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment. The illustrated routine **900** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **900** facilitates image registration based upon operator indicated registration points and/or image lean corrections.

More specifically, the routine begins in step **901**, where it displays, on a user interface screen, an aerial image of a building having a roof. As part of the user interface screen, the routine also displays user interface controls such as markers that may be used by an operator for purposes of image registration and/or lean correction, as described with reference to FIG. **4**A, above.

In step **902**, the routine receives, via one or more registration markers, indications of one or more points on the aerial image. The registration markers are manipulated by the operator to specify points on the aerial image, as described with reference to FIGS. **4**A-**4**E. Typically, the points are visually identifiable features, such as corners of the roof of the building. For example, if the roof has four corners (e.g., a northwest, southwest, northeast, and southwest corner) the operator may place one registration marker on each of the four corners as shown in the aerial image. Then, the positions (e.g., coordinates on the aerial image) of the markers are transmitted to the routine for use in registering the aerial image, as described below.

In step **903**, the routine receives, via a lean correction marker, an indication of the vertical axis of the building roof. In at least some cases, the aerial image of the building is out of alignment with respect to the vertical axis of the building. This may be caused, for example, by pitch, roll, and/or yaw experienced by the aircraft during the process of photographing the building. To correct for such misalignment, the lean correction marker is manipulated by the operator to indicate a vertical axis of the building. Typically, the operator aligns the lean correction marker with known, substantially vertical feature of the building, such as a chimney, wall corner, etc., as described with reference to FIG. **4**E, above. After the operator has aligned the lean correction marker, the position (e.g., angle of the marker, coordinates of the endpoints of the marker, etc.) of the lean correction marker is transmitted to the routine for use in registering the aerial image, as described below.

Particular benefits may be obtained from lean correction performed in the context of an overhead, or "top down," view. An "overhead lean" occurs when the camera is not directly overhead with respect to the building when the photo is taken. In some cases, leans in excess of 5 degrees have been observed in "top down" photos. Furthermore, unlike oblique, perspective views, a top-down lean is typically less likely to include a convenient visual marker that provides sufficient angle to assess the lean direction and magnitude, such as the edge of the building or a tall chimney. An overhead lean affects the perceived location of the roof lines in a top down view. This effect is amplified as the pitch of the roof increases and/or as the vertical separation between disconnected roof sections increases. Without lean correction, superimposing a wire frame over the visible ridgelines (and other features of a building that reside at different elevations) may produce asymmetries in otherwise symmetric structures. Further, an absence of lean correction may introduce errors in pitch estimation, as the wire frame may not appear consistent between top and oblique view points. More specifically, without top view lean correction, the positions for the roof lines in an otherwise correct (i.e., accurate with respect to the actual geometry of the roof) wire frame will typically not line up on the visible roof lines in the overhead reference photo. This often leads the user (or software) to either introduce errors by incorrectly drawing the wire frame to the image lines or perform a subjective determination of where and how to shift the wire frame lines off the image lines to produce a correct model. Top view lean correction allows the roof estimation system to trace to, or substantially to, the actual roof lines seen in the top image while still producing an accurate wire frame model.

Image misalignment may be specified in other ways. For example, in other embodiments, the operator may instead rotate the image to a position in which the building appears to be in a substantially vertical position. Then, the angle of rotation of the image may be transmitted to the routine for use in registering the aerial image.

In step **904**, the routine registers, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid. Registering the image to a reference grid may include determining a transformation between the reference grid and the image, based on the indicated points and/or the indicated vertical axis. Determining such a transformation may be based on other information as well, such as meta-information associated with the aerial image. In some embodiments, the aerial image has corresponding meta-information that includes image capture conditions, such as camera type, focal length, time of day, camera position (e.g., latitude, longitude, and/or elevation), etc.

In step **905**, the routine determines whether there are additional aerial images to be registered, and if so, returns to step **901**, else proceeds to step **906**. During execution of the loop of steps **901-905**, the operator typically indicates, for each registration marker, the same feature (e.g., corner) of the roof as shown in each of multiple images, such that the routine can register the multiple images to a single, uniform reference grid. Upon completion of the registration process, the routine has determined a uniform coordinate system for the multiple

aerial images, for use during other phases of model construction, such as pitch determination or feature identification.

In step **906**, the routine generates a three-dimensional model based at least in part on the aerial image(s) and the reference grid. As discussed above with reference to FIGS. **5**A-**5**D and **6**A-**6**D, model generation includes identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. In other embodiments, the routine performs other functions with the registered images, such as storing them for later use (e.g., by an automated model generation module), transmitting them to another computing (e.g., for use in a third-party design application), etc. After step **906**, the routine ends.

Note that in at least some embodiments, aspects of the routine **900** may be performed in an automated manner. For example, operations discussed above as being performed by an operator, such as the determination of the location of image registration points of step **902** and/or the indication of lean of step **903**, may be performed by automated image processing techniques.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment. The illustrated routine **1000** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1000** facilitates the determination of the pitch of a section of a roof, by displaying a pitch determination marker and modifying a 3D model of a roof based on an indication of roof pitch received via the pitch determination marker.

More specifically, the routine begins at step **1001** where it displays an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch. The aerial image is displayed in the context of a user interface screen, such as is described with reference to FIGS. **4**A-**6**C, above. The aerial images may be received from, for example, the image source computing system **855** and/or from the RES data repository **816** described with reference to FIG. **8**. As discussed above, aerial images may be originally created by cameras mounted on airplanes, balloons, satellites, etc. In some embodiments, images obtained from ground-based platforms (e.g., vehicle-mounted cameras) may be used instead or in addition.

In step **1002**, the routine displays a pitch determination marker operable to indicate pitch of a planar roof section. The pitch determination marker may be, for example, a pitch determination marker **510** ("protractor tool") or **520** ("envelope tool"), such as are respectively described with respect to FIGS. **5**B and **5**C, above. The routine displays the pitch determination marker by, for example, presenting it on a user interface screen displayed on a computer monitor or other display device. The pitch determination marker is a direct manipulation user interface control, in that an operator may manipulate it (e.g., adjust an angle, change its shape, alter its position, etc.) in order to indicate pitch of a planar roof section. Additional details regarding pitch determination controls are provided with respect to FIGS. **5**A-**5**D, above.

In step **1003**, the routine receives, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building. Receiving an indication of the pitch includes receiving an indication (e.g., via an event, callback, etc.) that the marker has been manipulated by the operator, and then determining an angle based on the shape and/or position of the marker. In some embodiments, such an indication may be received on an event driven basis, such as every time the marker is manipulated in some manner. In other embodiments, the routine may poll the marker from time to time to determine its current state. In addition, the operator may explicitly indicate that the current state of the marker is to be transmitted to the routine, such as by pressing a button or other indication.

In step **1004**, the routine modifies a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section. Modifying the 3D model of the roof includes associating the indicated pitch with a portion of the model corresponding to the one planar roof section. For example, the 3D model may include one or more data structures representing planar roof sections, and the indicated pitch may be included as part of the data structure representing the one planar roof section. In some embodiments, the 3D model may not at this point include representations of the planar roof sections, such as because the operator has not yet specified them. In such a case, the routine may store the indicated pitch in association with the location and orientation at which the pitch was specified by the operator, as determined from the aerial image. Then, at a later time, when the operator specifies a roof section that has the same orientation as the stored pitch and that includes or is near the stored location, the roof estimation system can store the indicated pitch in association with the specified roof section.

After step **1004**, the routine ends. In other embodiments, the routine may instead return to step **1001**, to determine the pitch for another planar roof section (of the same or different roof).

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment. The illustrated routine **1100** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1100** concurrently displays operator indicated features in multiple aerial images of a building roof.

More specifically, the routine begins in step **1101**, where it displays a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building. The aerial images are displayed in the context of a user interface screen, such as is described with reference to FIGS. **6**A-**6**C, above.

In step **1102**, the routine receives an indication of a feature of the building shown in the first aerial image. The indication is typically received via a user interface control, such as a drawing tool or marker, upon its manipulation by an operator. For example, the operator may manipulate a drawing tool in order to specify one or more features of the building roof, such as a corner on the roof, an edge of the roof, an outline of a section of the roof, etc. In one embodiment, the operator utilizes a drawing tool to indicate roof section corner points and roof section edges connecting those corner points. Additional details regarding feature indication are provided with respect to FIGS. **6**A-**6**C, above.

In step **1103**, the routine modifies a three-dimensional model of the roof based on the received indication of the feature of the building. Modifying the 3D model may include adding or updating the indicated feature to a wire frame model of the roof. For example, if the indicated feature is a roof section corner point, the corner point will be added to the 3D model, along with the location (e.g., the X, Y, and Z position of the point) of the point. The location of the point is automatically determined based on a translation of the position of the point in the image to a point in the uniform reference grid associated with the image. If the indicated feature is a roof section edge, the edge will be added to the 3D model, such as by associating the edge with two points corresponding to the end points of the edge. Higher-level features can also be indicated. For example, a planar roof section may be indicated by "closing" a sequence of two or more connected line segments, to create a closed polygon that represents the outline or perimeter of the planar roof section.

In step **1104**, the routine concurrently displays a projection of the feature from the modified three-dimensional model onto the first and second aerial images. In one embodiment, displaying the feature from the modified three-dimensional model includes projecting the three-dimensional model onto both the first and second aerial images. For example, if the first image (for which the indicated feature was received) provides a west view of the building, and the second image provides an east view of the building, the routine will concurrently display a projection of the indicated feature from the 3D model onto both the first and second images. The projection of the indicated feature into the second image is based at least in part on a translation from the position of the feature in the reference grid to a position in the second image. In addition, the concurrent display onto two or more images occurs at substantially the same time (within a short time interval, at times that are substantially coincident) as the indication of the feature of the building in step **1102**, giving the operator the illusion that as they are indicating a feature in the first image, the feature is being simultaneously projected into the second image.

After step **1104**, the routine ends. In other embodiments, the routine may instead return to step **1101**, to perform an interactive loop of steps **1101-1104** with the operator, so that the routine can concurrently display multiple features as they are indicated by the operator. Note that in such an embodiment, each iteration of the loop of steps **1101-1104** may be performed at near real-time speeds, so as to provide a fluid, interactive model generation experience for the operator enabling the operator to drag, draw, or otherwise indicate/manipulate features in a first image and view the results of their work concurrently projected into a second image.

All of the above U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, including but not limited to U.S. Provisional Patent Application No. 61/197,904, entitled "USER INTERFACE SYSTEMS AND METHODS FOR ROOF ESTIMATION," filed Oct. 31, 2008, are incorporated herein by reference, in their entireties.

From the foregoing it will be appreciated that, although specific embodiments have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the present disclosure. For example, the methods, systems, and techniques for generating and providing roof estimate reports discussed herein are applicable to other architectures other than the illustrated architecture or a particular roof estimation system implementation. Also, the methods and systems discussed herein are applicable to differing network protocols, communication media (optical, wireless, cable, etc.) and devices (such as wireless handsets, electronic organizers, personal digital assistants, portable email machines, game machines, pagers, navigation devices such as GPS receivers, etc.). Further, the methods and systems discussed herein may be utilized by and/or applied to other contexts or purposes, such as by or for solar panel installers, roof gutter installers, awning companies, HVAC contractors, general contractors, and/or insurance companies.

The invention claimed is:

1. A computer-implemented method for generating a roof estimate report, the method comprising:

displaying an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch;

displaying a pitch determination marker operable to indicate pitch of a planar roof section, wherein the pitch determination marker is overlaid on the aerial image of the building having the roof;

receiving, based on the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building; and

modifying a model of the roof based on the received indication of the pitch of the one planar roof section.

2. The method of claim **1** wherein the pitch determination marker is adjustable to specify pitch of a planar roof section.

3. The method of claim **1** further comprising:

transmitting roof measurement information based on the modified model of the roof, the roof measurement information including a measure of the pitch of the one planar roof section.

4. The method of claim **1** wherein modifying the model of the roof includes associating the indicated pitch with a portion of the model of the roof that corresponds to the one planar roof section of the roof of the building.

5. The method of claim **1** further comprising:

displaying a wireframe rendering of the modified model superimposed on the aerial image of the building.

6. The method of claim **5** wherein displaying the wireframe rendering occurs in response to the receiving of the indicated pitch.

7. The method of claim **1** wherein the pitch determination marker includes an adjustable protractor tool having a member that is adjustable to indicate an angle.

8. The method of claim **1** wherein the pitch determination marker includes an envelope tool having two surfaces that are adjustable to indicate an angle.

9. The method of claim **1** wherein modifying the model of the roof includes modifying a three-dimensional model of the roof.

10. A computing system for generating a roof estimate report, the computing system comprising:

a memory;

a roof estimation module that is stored on the memory and that is configured, when executed, to:

display an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch;

display a pitch determination marker operable to indicate pitch of a planar roof section, wherein the pitch determination marker is overlaid on the aerial image of the building having the roof;

receive, based on the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building;

modify a model of the roof based on the received indication of the pitch of the one planar roof section; and

provide roof measurement information based on the model of the roof, the roof measurement information including a measure of the pitch of the one planar roof section.

11. The computing system of claim **10** wherein the roof estimation module is further configured to transmit a roof estimate report based on the provided roof measurement information.

12. The computing system of claim **10** wherein the pitch determination marker includes at least one of an adjustable protractor tool and an envelope tool.

13. The computing system of claim **10** wherein the roof estimation module includes an interactive roof modeling user interface.

14. The computing system of claim **10** wherein the roof estimation module is further configured to display the pitch determination marker as part of an interactive user interface.

15. The computing system of claim **10** wherein the model of the roof is a three-dimensional model of the roof.

16. A non-transitory computer-readable storage medium whose contents enable a computing system to generate a roof estimate report for a building having a roof, by performing a method comprising:

displaying an aerial image of a building having a roof comprising a planar roof section that has a corresponding pitch;

displaying a pitch determination marker operable to indicate pitch of the planar roof section, wherein the pitch determination marker is overlaid on the aerial image of the building having the roof;

receiving, based on the displayed pitch determination marker, an indication of the pitch of the planar roof section; and

modifying a model of the roof based on the received indication of the pitch of the planar roof section.

17. The non-transitory computer-readable storage medium of claim **16** wherein the pitch determination marker is adjustable to specify pitch of a planar roof section.

18. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises:

generating a roof estimate report based on the modified model of the roof; and

transmitting the generated roof estimate report.

19. The non-transitory computer-readable storage medium of claim **18** wherein the transmitted roof estimate report includes a line drawing of the roof of the house labeled with a measure of the pitch of the planar roof section.

20. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises:

determining roof measurement information based on the modified model of the roof, the roof measurement information including a measure of the pitch of the planar roof section; and

transmitting the determined roof measurement information.

21. The non-transitory computer-readable storage medium of claim **16** wherein modifying the model of the roof includes modifying a model of the roof by associating the indicated pitch with a portion of the model of the roof that corresponds to planar roof section of the roof of the building.

22. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises:

displaying a wireframe rendering of the modified model superimposed on the aerial image of the building.

23. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises:

registering, based on operator indicated features, multiple aerial images to a reference grid corresponding to the model.

24. The non-transitory computer-readable storage medium of claim **23** wherein registering multiple images includes:

displaying a marker operable to specify a point on the aerial image;

receiving, via the marker, an indication of a point on the aerial image; and

registering, based on the received indication of the point, the aerial image to the reference grid.

25. The non-transitory computer-readable storage medium of claim **24** wherein registering the aerial image to the reference grid includes determining a transformation between the aerial image and the reference grid.

26. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises:

correcting lean of the aerial image with respect to a vertical axis of a reference grid corresponding to the model.

27. The non-transitory computer-readable storage medium of claim **26** wherein correcting misalignment of the aerial image includes:

displaying a lean correction marker operable to indicate a vertical axis of the aerial image;

receiving, via the lean correction marker, an indication of the vertical axis of the aerial image; and

registering, based on the received indication of the vertical axis, the aerial image to the reference grid.

28. The non-transitory computer-readable storage medium of claim **16** wherein modifying the model of the roof includes modifying a three-dimensional model of the roof.

* * * * *

EXHIBIT 6

US008209152B2

(12) **United States Patent**
Pershing

(10) **Patent No.: US 8,209,152 B2**
(45) **Date of Patent: *Jun. 26, 2012**

(54) **CONCURRENT DISPLAY SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION**

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(73) Assignee: **EagleView Technologies, Inc.**, Redmond, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 412 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/467,250**

(22) Filed: **May 15, 2009**

(65) **Prior Publication Data**

US 2010/0114537 A1 May 6, 2010

Related U.S. Application Data

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(51) **Int. Cl.**
G06F 17/50 (2006.01)

(52) **U.S. Cl.** **703/1**

(58) **Field of Classification Search** 703/1
See application file for complete search history.

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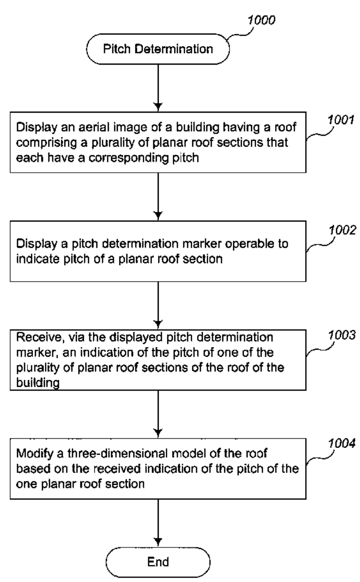
Primary Examiner — Dwin M Craig
Assistant Examiner — Andre Pierre Louis
(74) *Attorney, Agent, or Firm* — Seed IP Law Group PLLC

(57) **ABSTRACT**

User interface systems and methods for roof estimation are described. Example embodiments include a roof estimation system that provides a user interface configured to facilitate roof model generation based on one or more aerial images of a building roof. In one embodiment, roof model generation includes image registration, image lean correction, roof section pitch determination, wire frame model construction, and/or roof model review. The described user interface provides user interface controls that may be manipulated by an operator to perform at least some of the functions of roof model generation. The user interface is further configured to concurrently display roof features onto multiple images of a roof. This abstract is provided to comply with rules requiring an abstract, and it is submitted with the intention that it will not be used to interpret or limit the scope or meaning of the claims.

25 Claims, 29 Drawing Sheets



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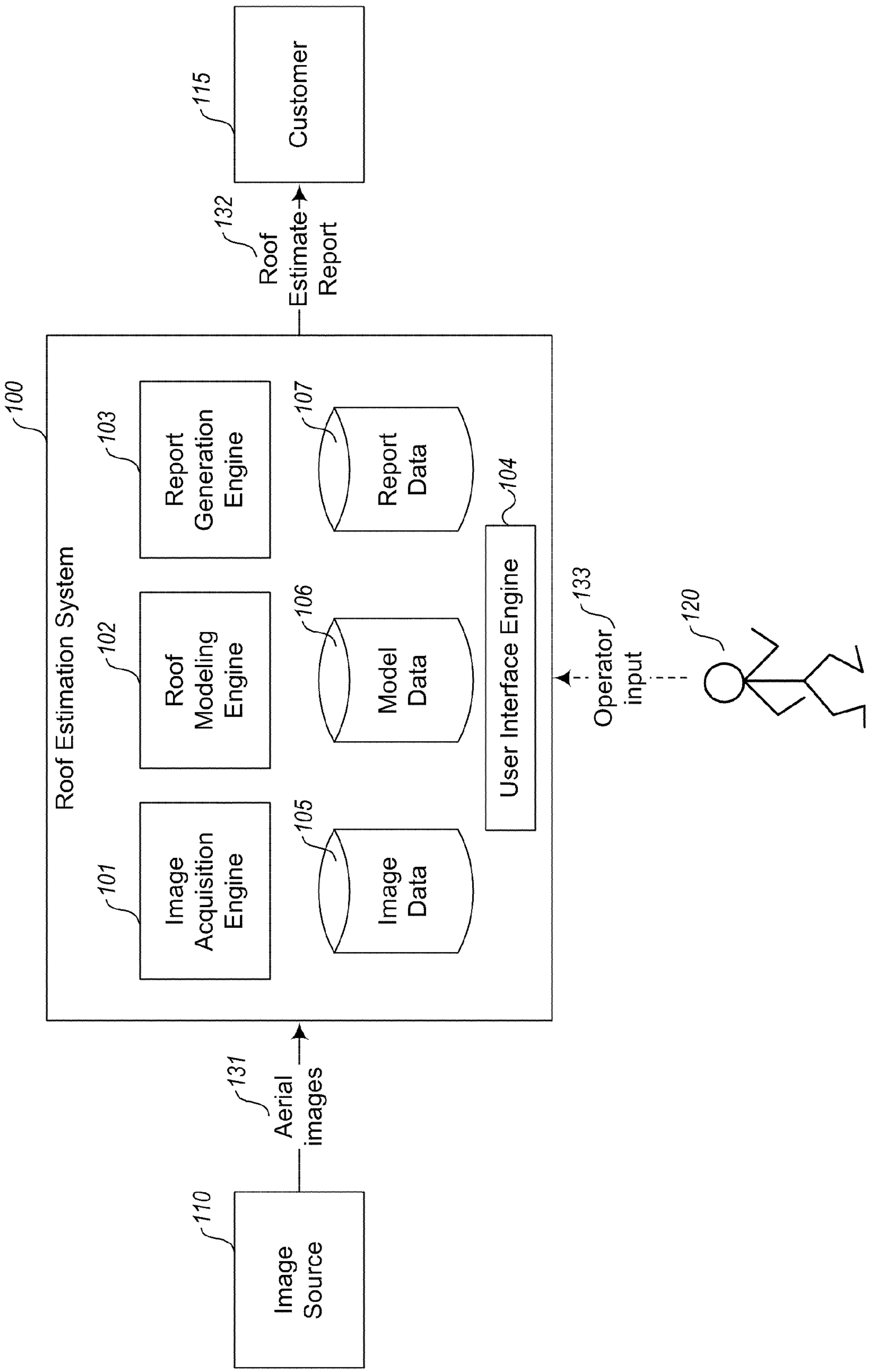

Image Source
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Aerial images
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Roof Estimation System
100
Image Acquisition Engine
101
Roof Modeling Engine
102
Report Generation Engine
103
Image Data
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Model Data
106
Report Data
107
User Interface Engine
104
Operator input
133
120
Roof Estimate Report
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Customer
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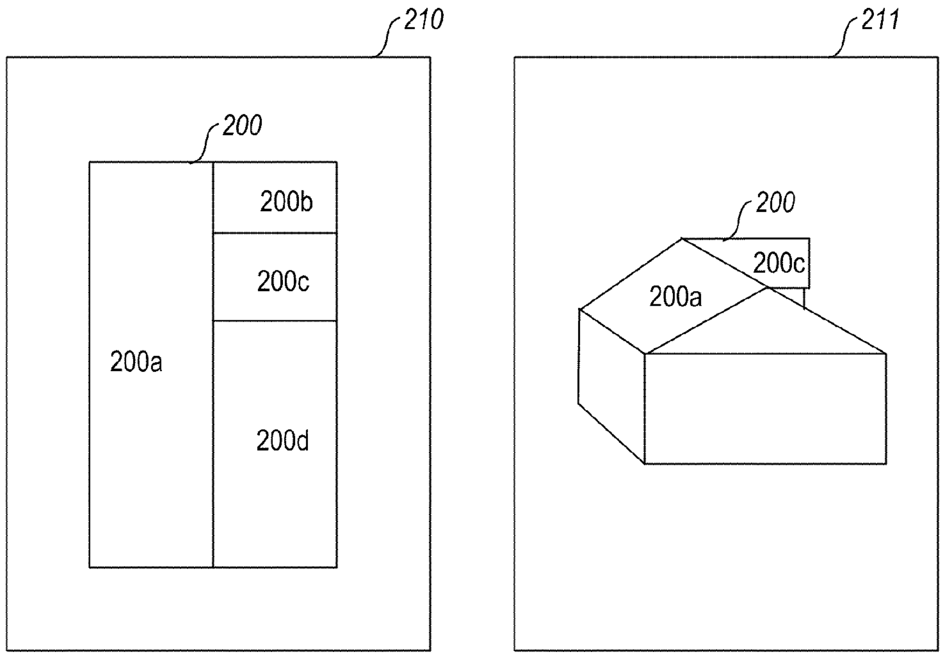
Fig. 1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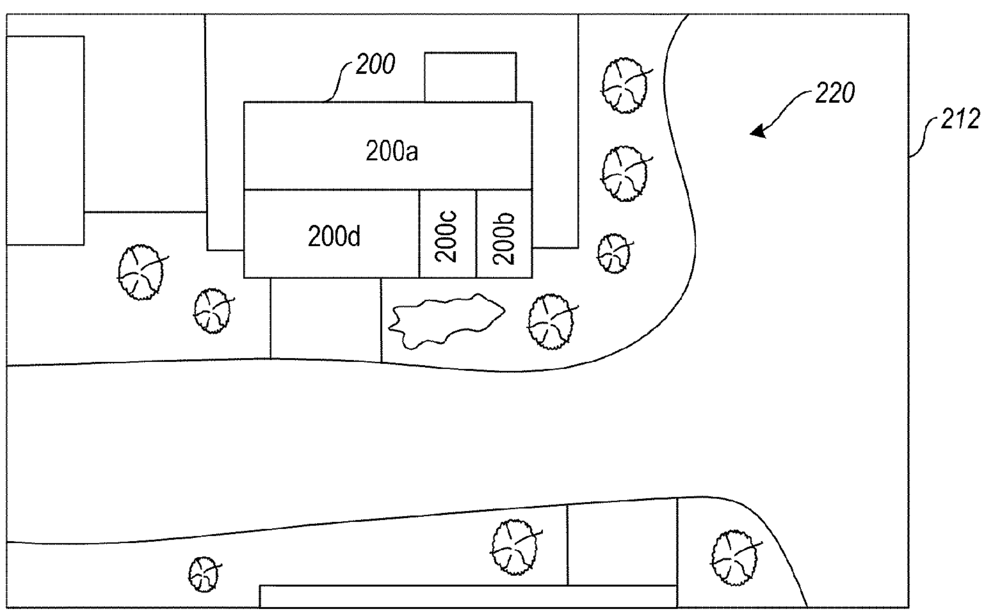
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Fig. 2B

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Order: 2468

<Customer Name Here>

4/16/2008

301a

1234 Main Street, Redmond, WA

301b

Order: 2468 Copyright (c) 2008 Eagle View Technologies, Inc. Page 1 of 6

301

Fig. 3A

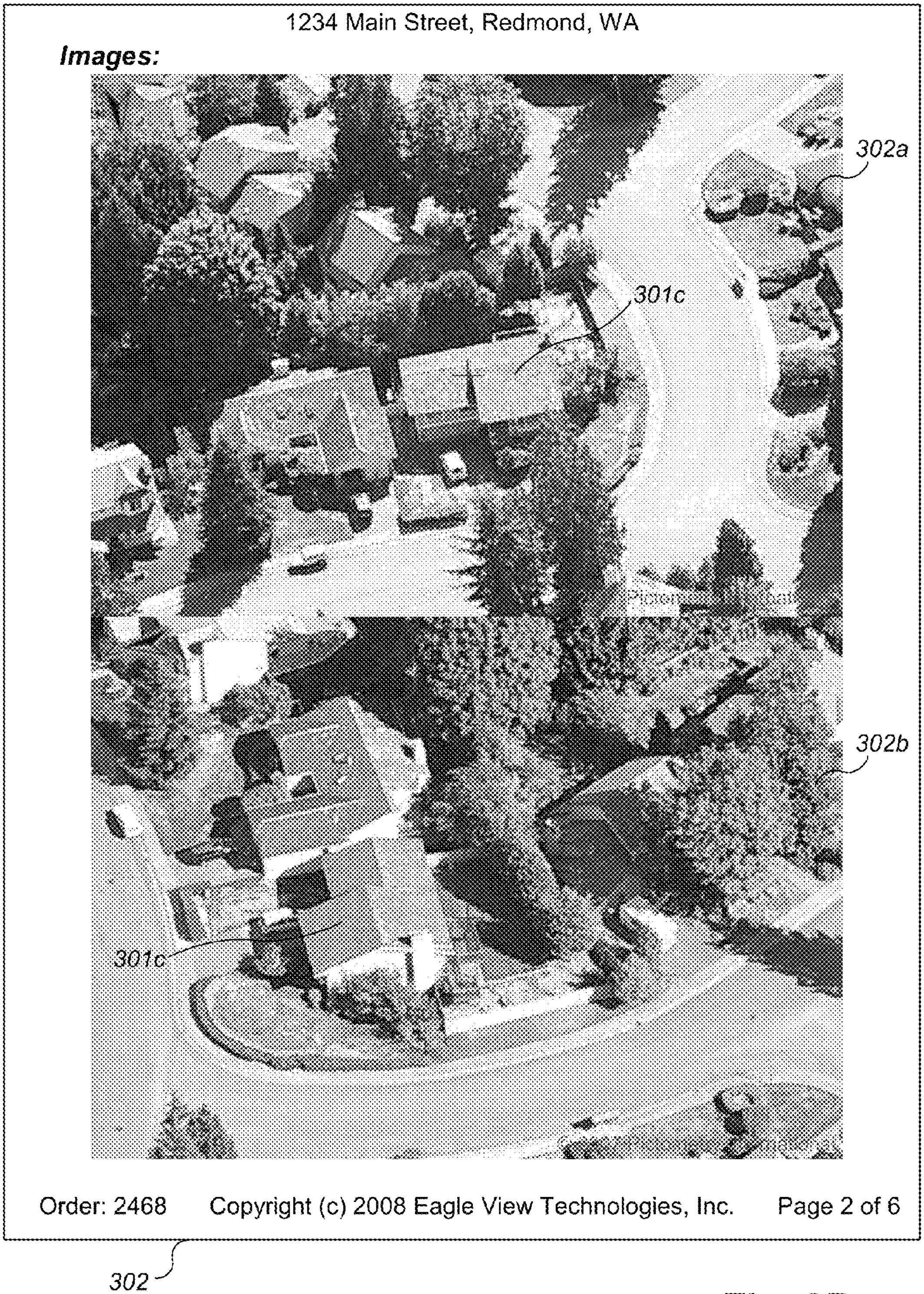
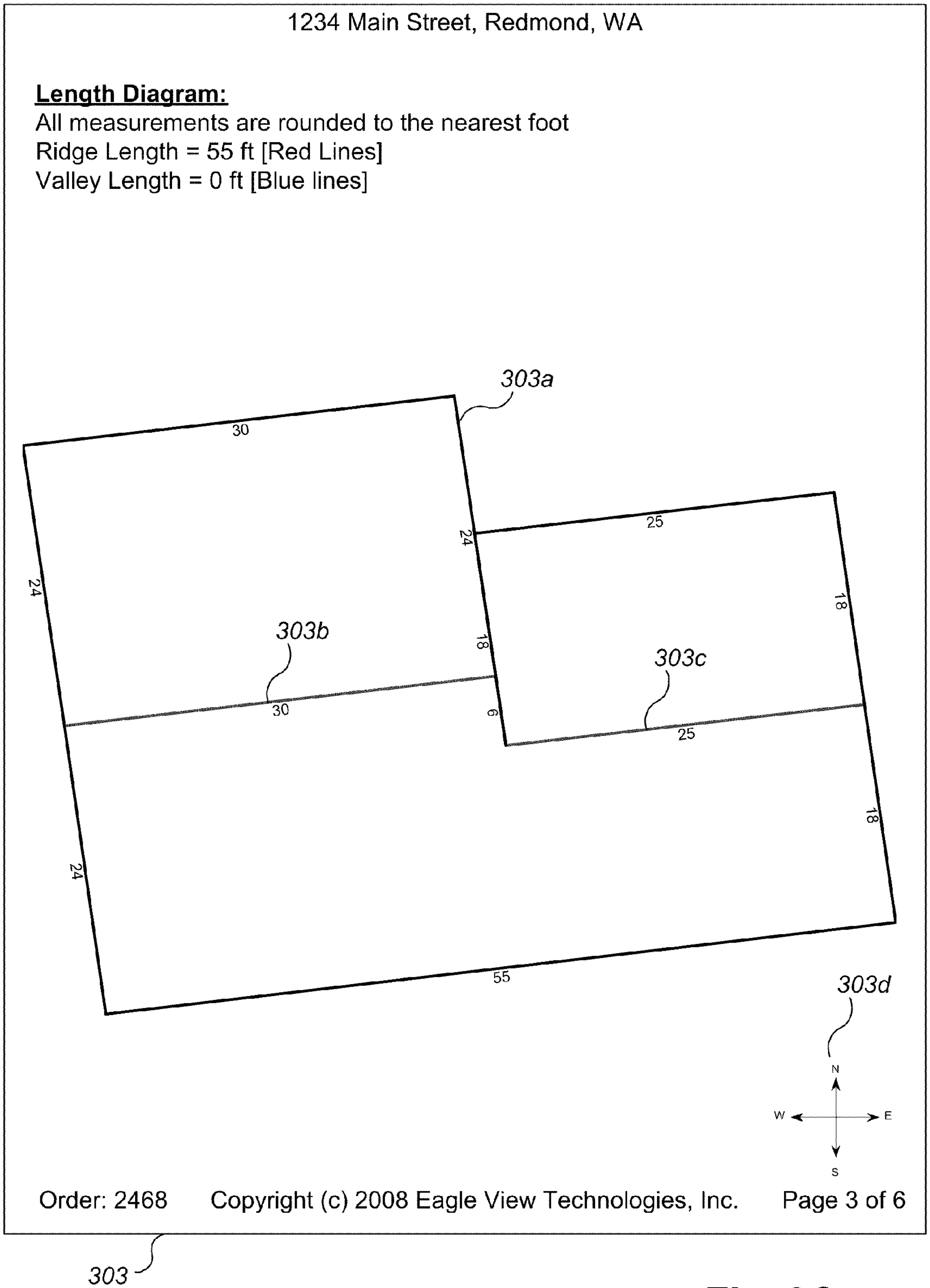

1234 Main Street, Redmond, WA
Images:
302a
301c
302b
301c
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 2 of 6
302

Fig. 3B


1234 Main Street, Redmond, WA
Length Diagram:
All measurements are rounded to the nearest foot
Ridge Length = 55 ft [Red Lines]
Valley Length = 0 ft [Blue lines]
303a
30
25
24
24
18
303b
18
303c
30
6
25
18
24
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303d
N
W
E
S
Order: 2468
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Page 3 of 6
303

Fig. 3C

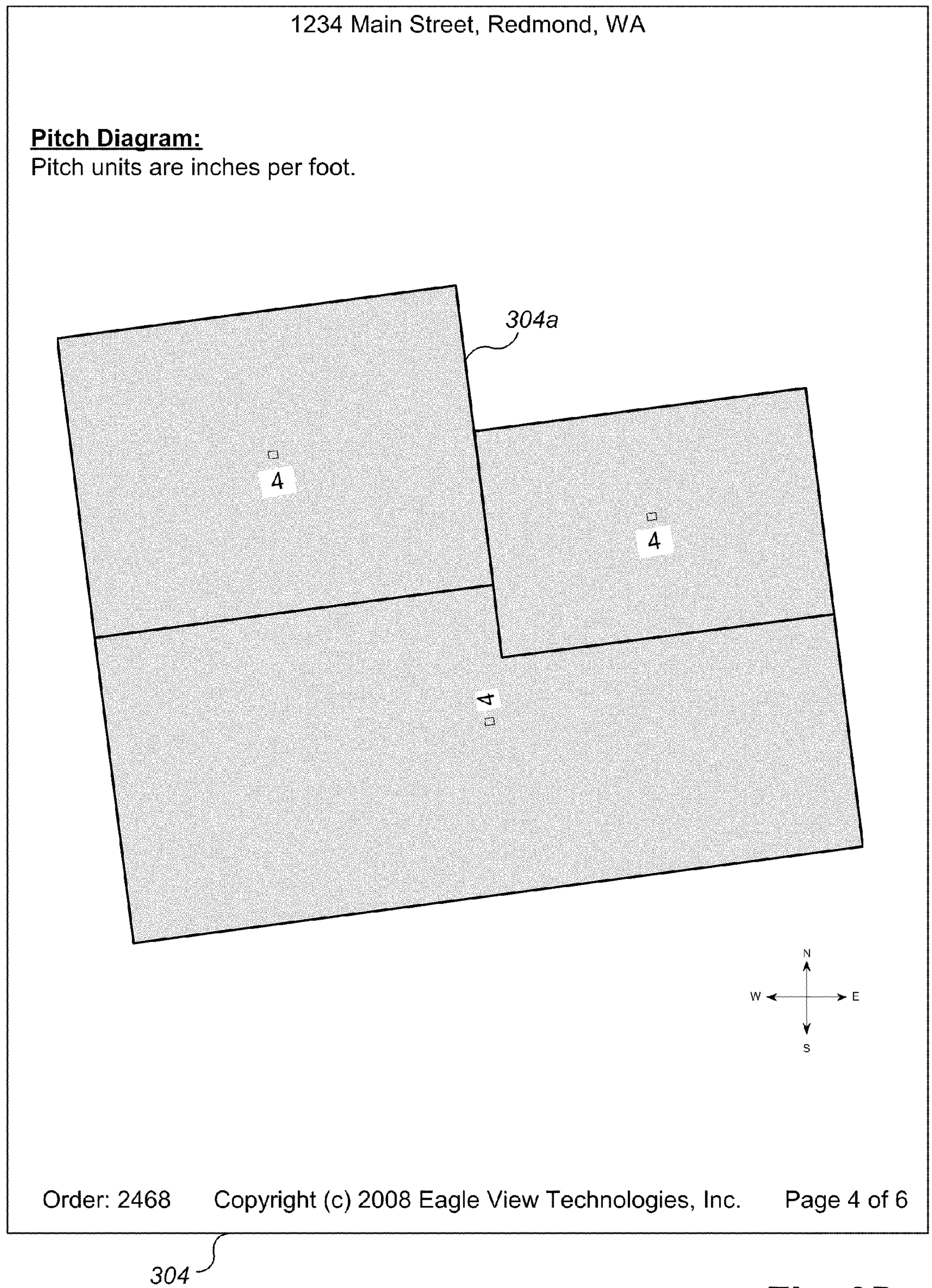
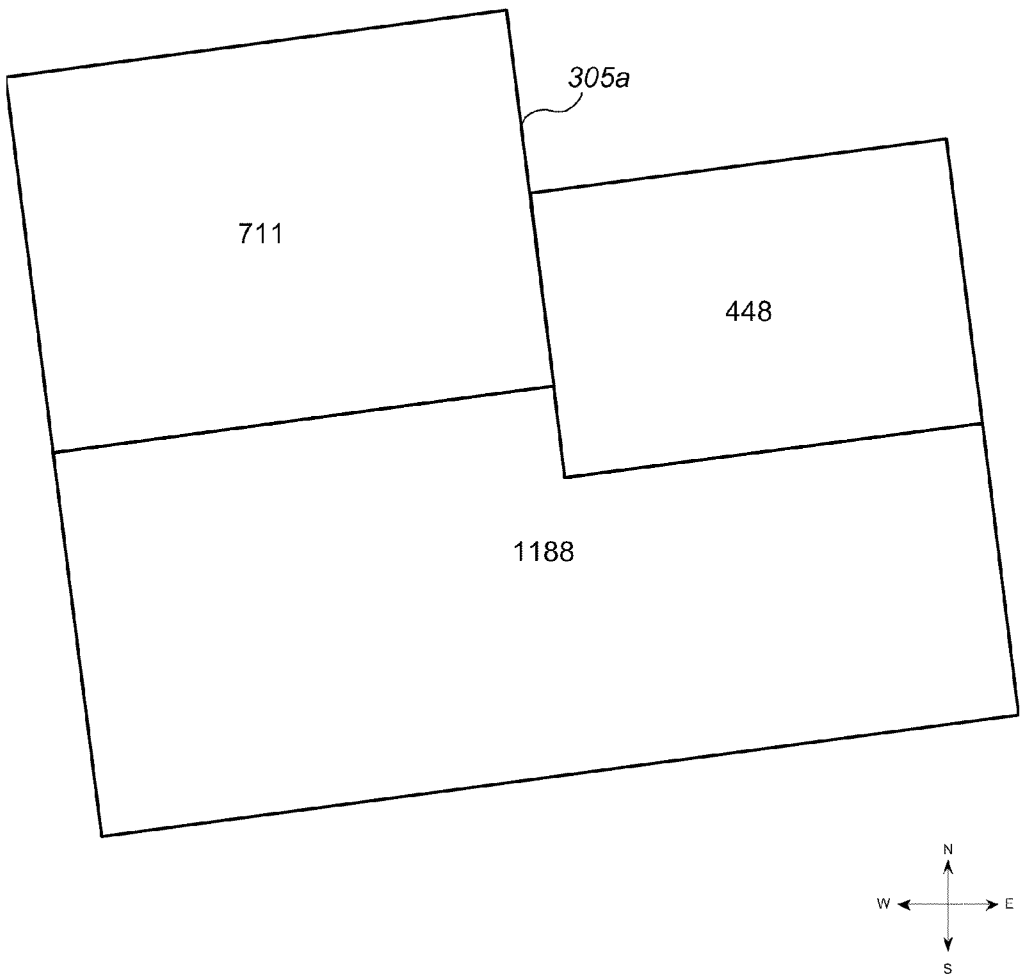

1234 Main Street, Redmond, WA
Pitch Diagram:
Pitch units are inches per foot.
304a
4
4
4
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 4 of 6
304

Fig. 3D

1234 Main Street, Redmond, WA

Area Diagram:
Total Area = 2347 sqft



Order: 2468 Page 5 of 6

305

Fig. 3E

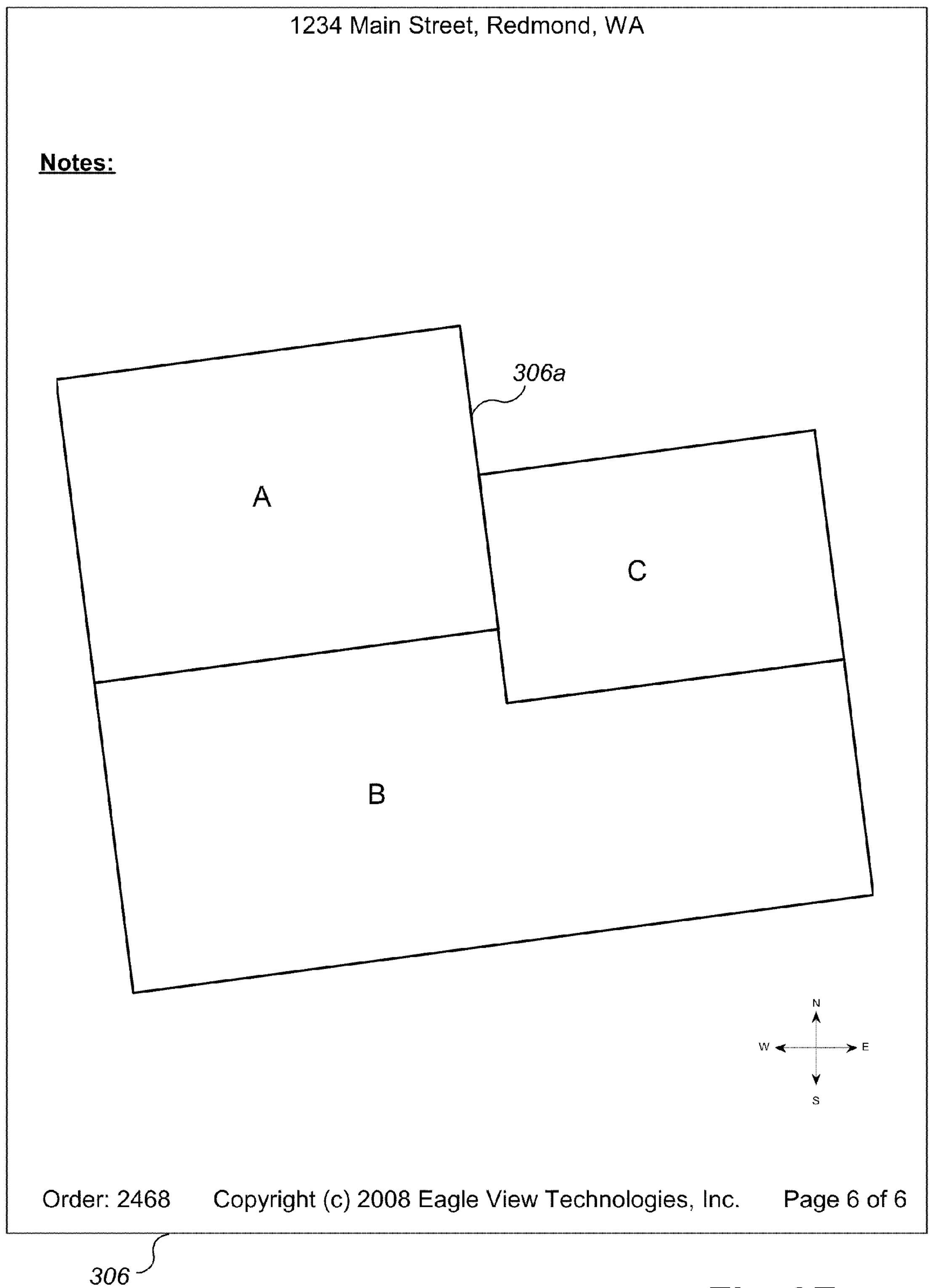

1234 Main Street, Redmond, WA
Notes:
306a
A
C
B
N
W
E
S
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 6 of 6
306

Fig. 3F

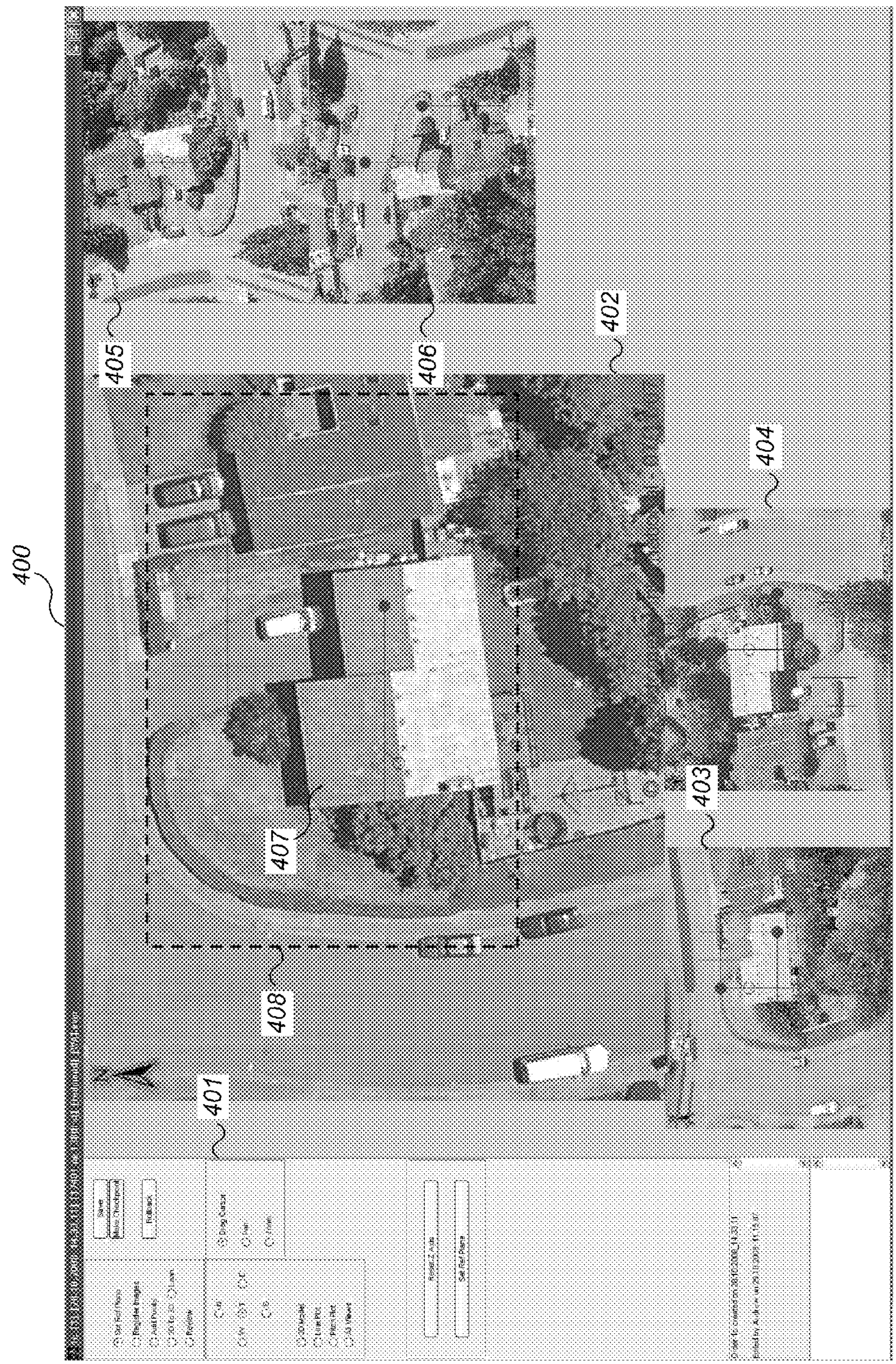


Fig. 4A

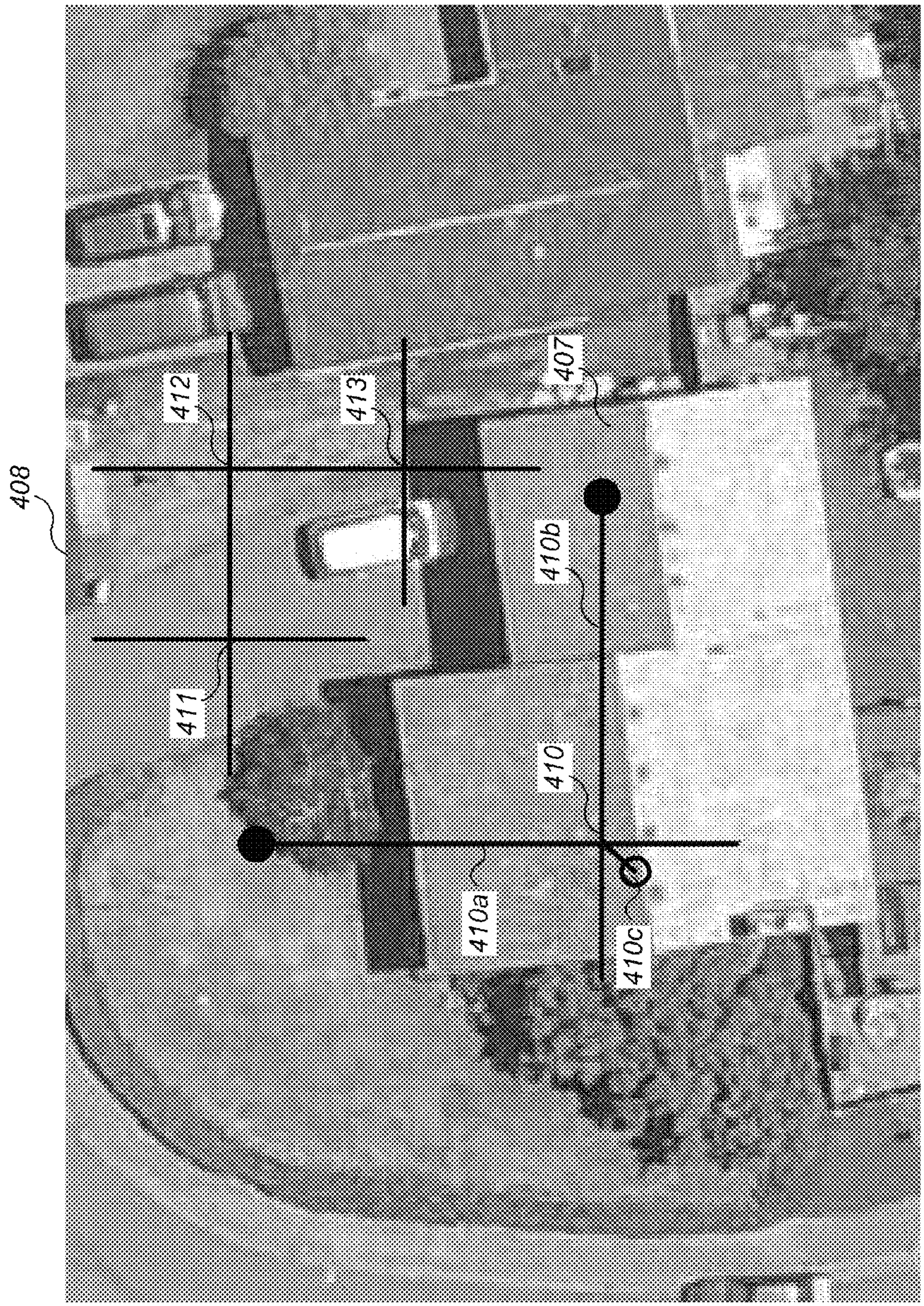


Fig. 4B

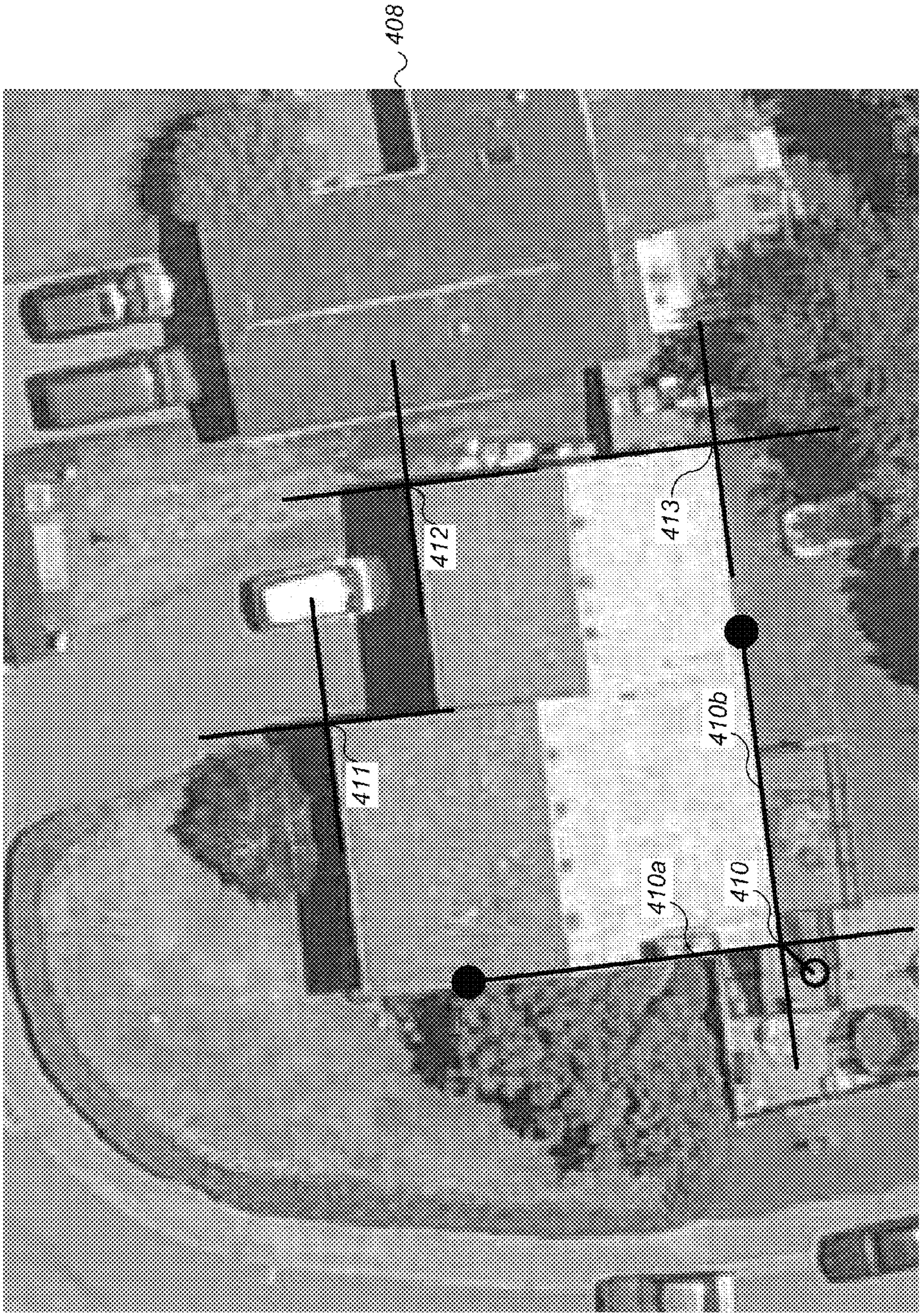


Fig. 4C

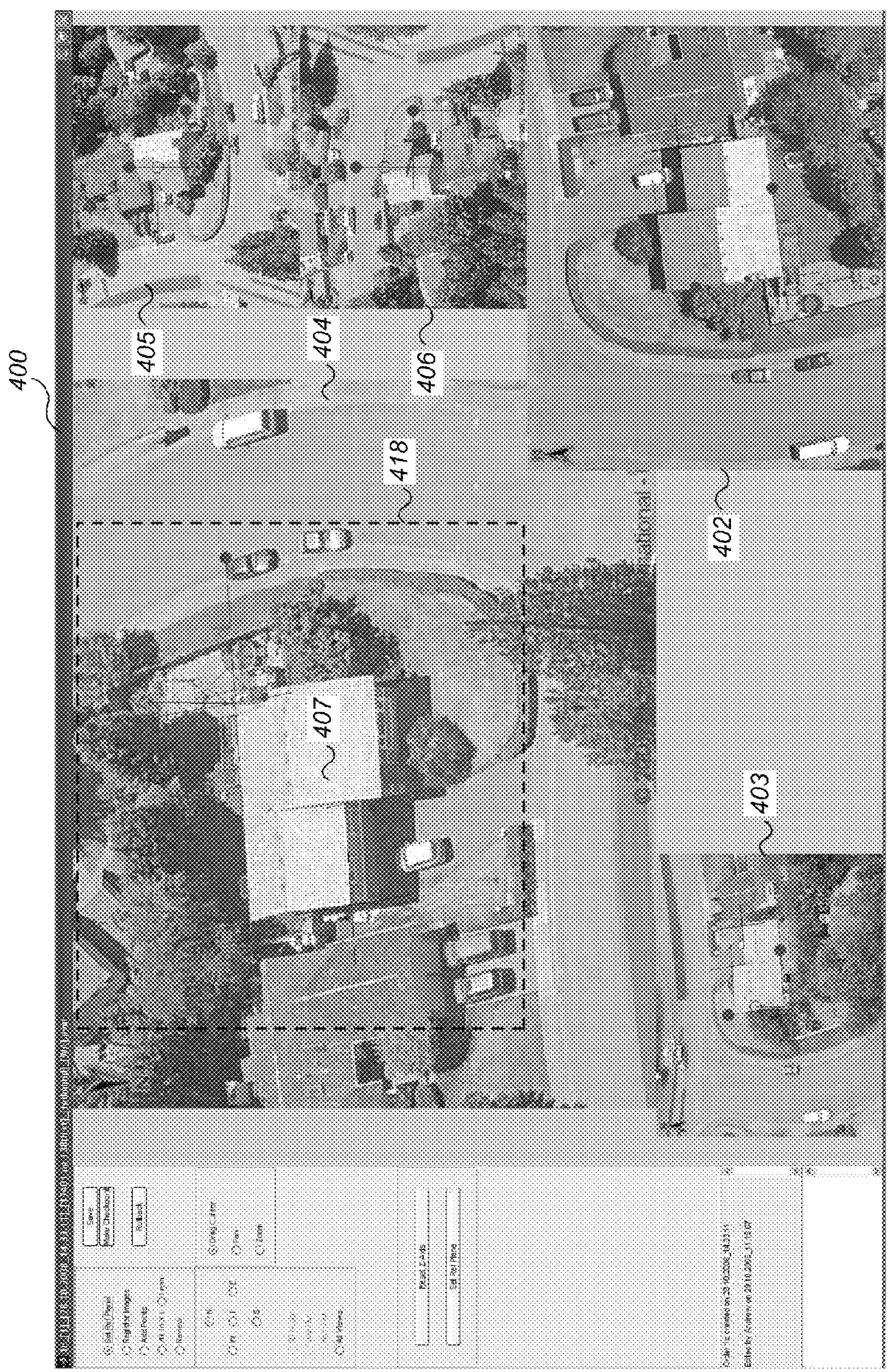


Fig. 4D

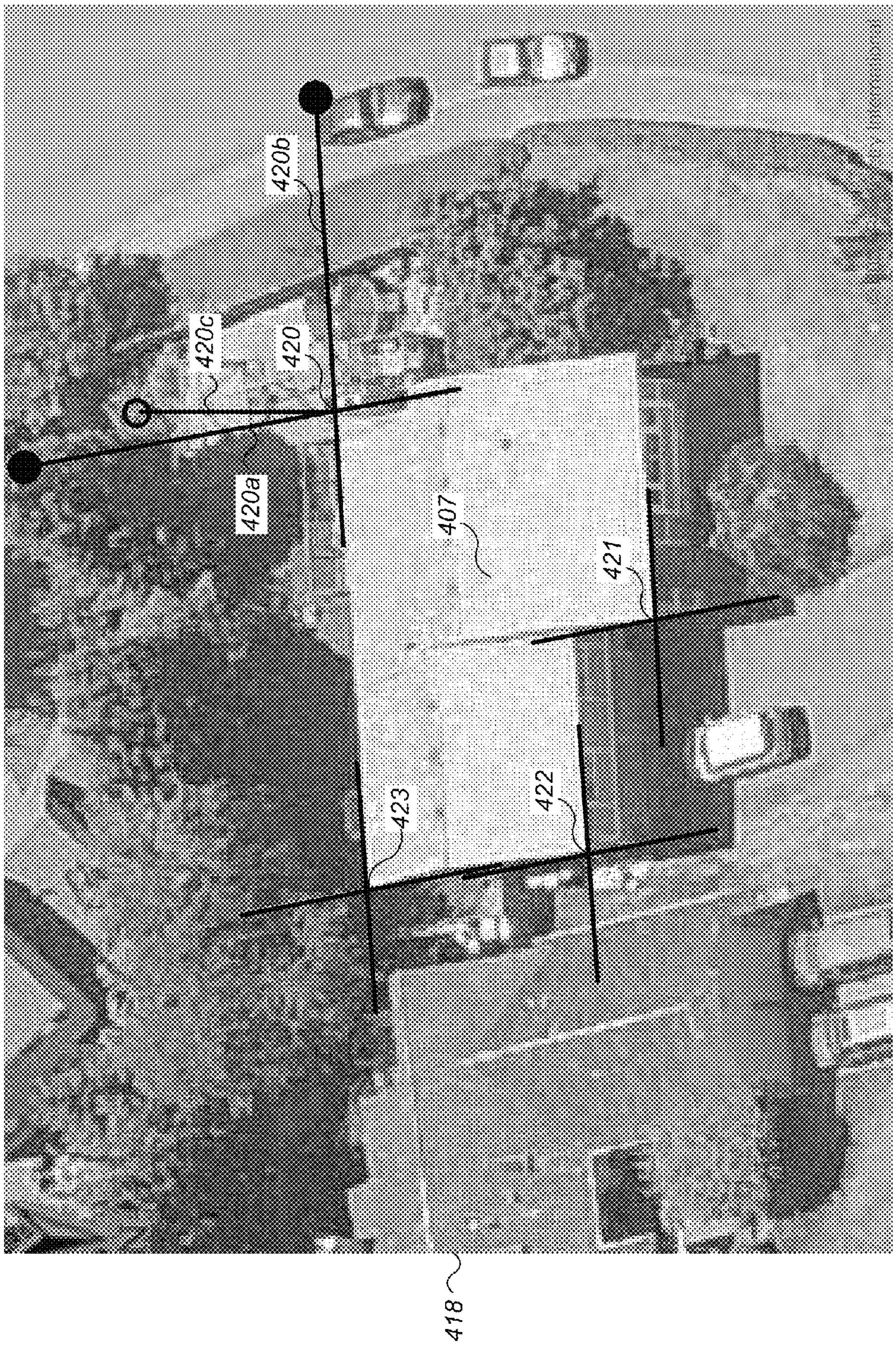


Fig. 4E

Fig. 4F

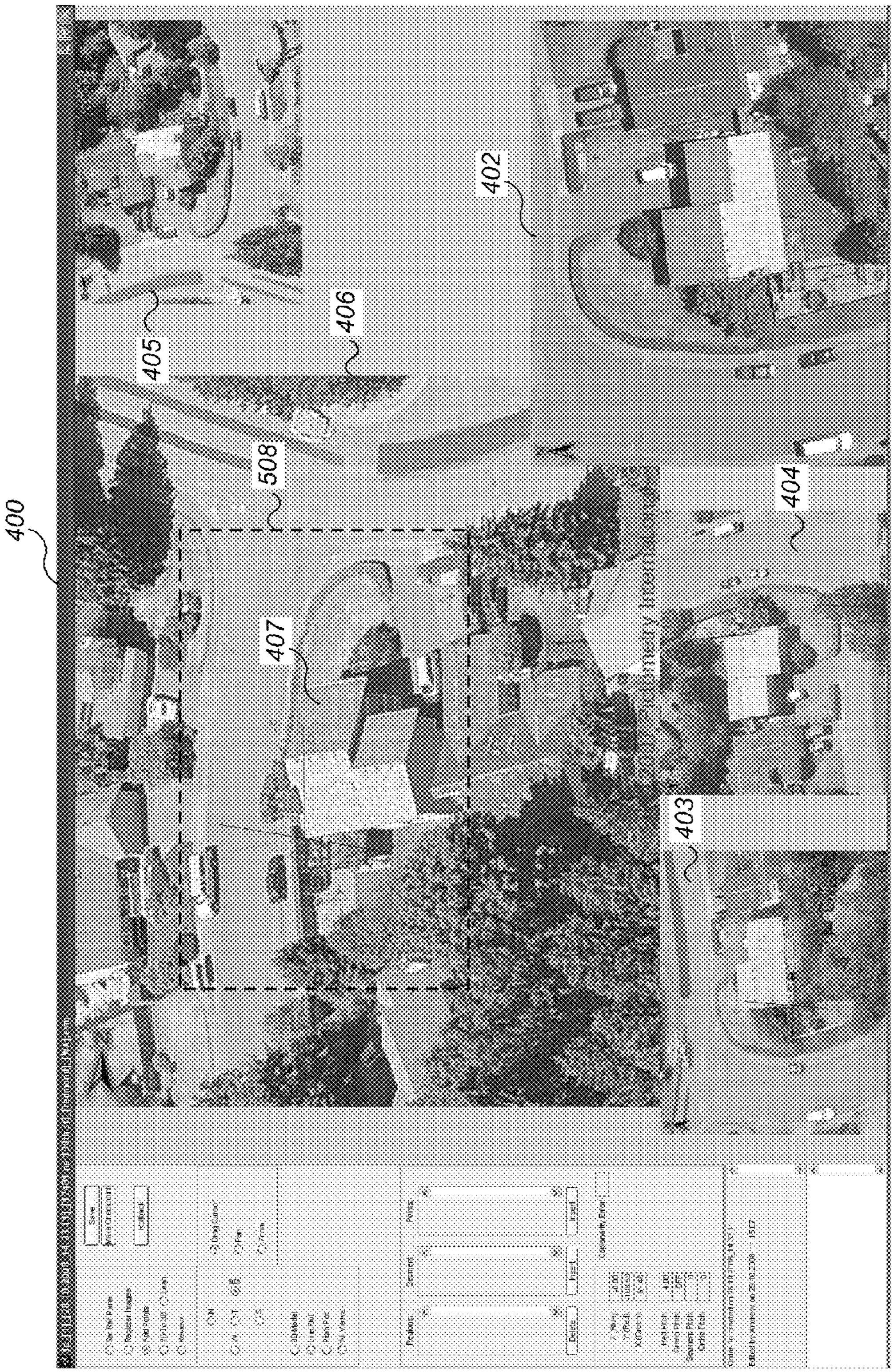


Fig. 5A

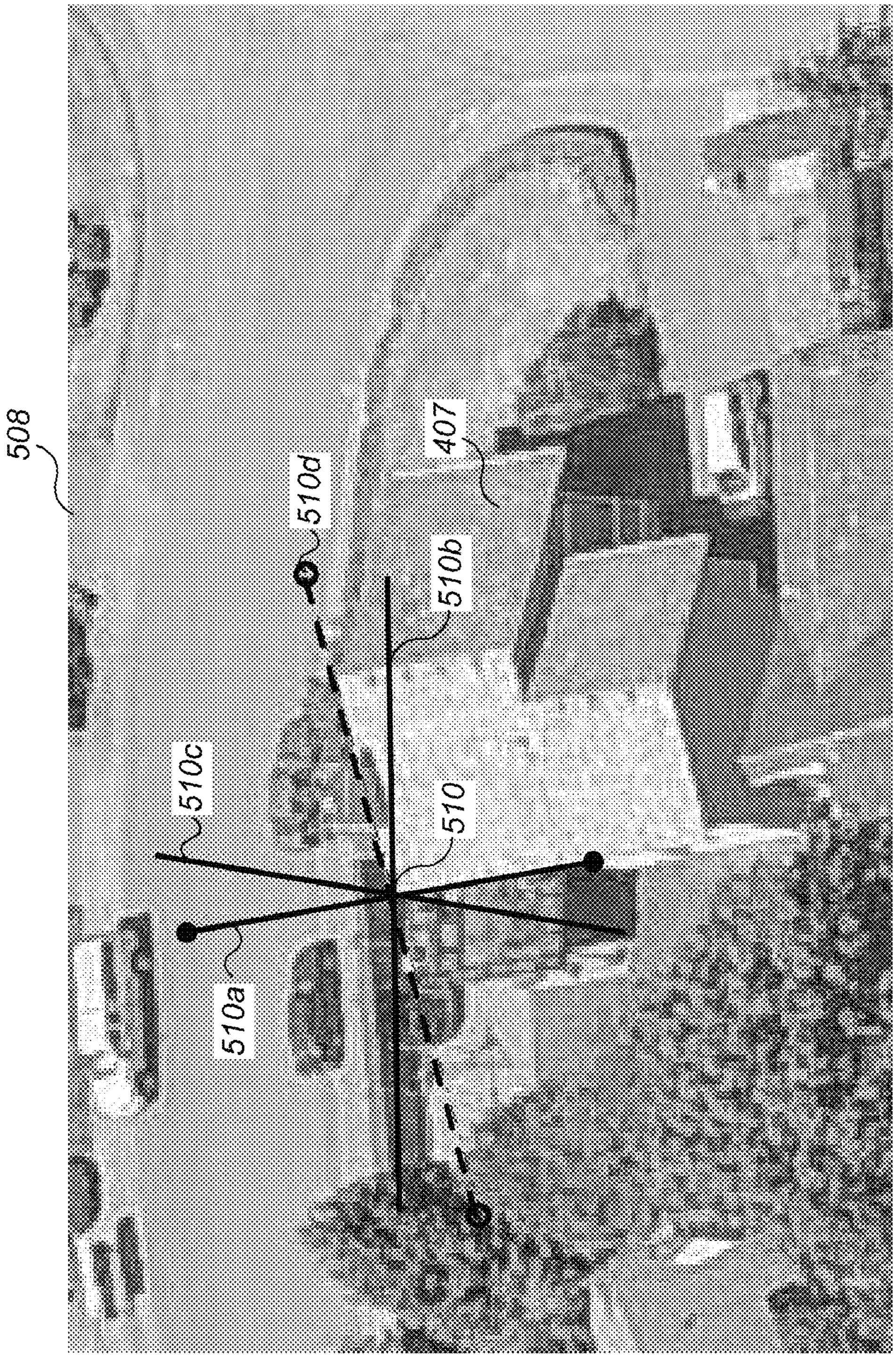


Fig. 5B

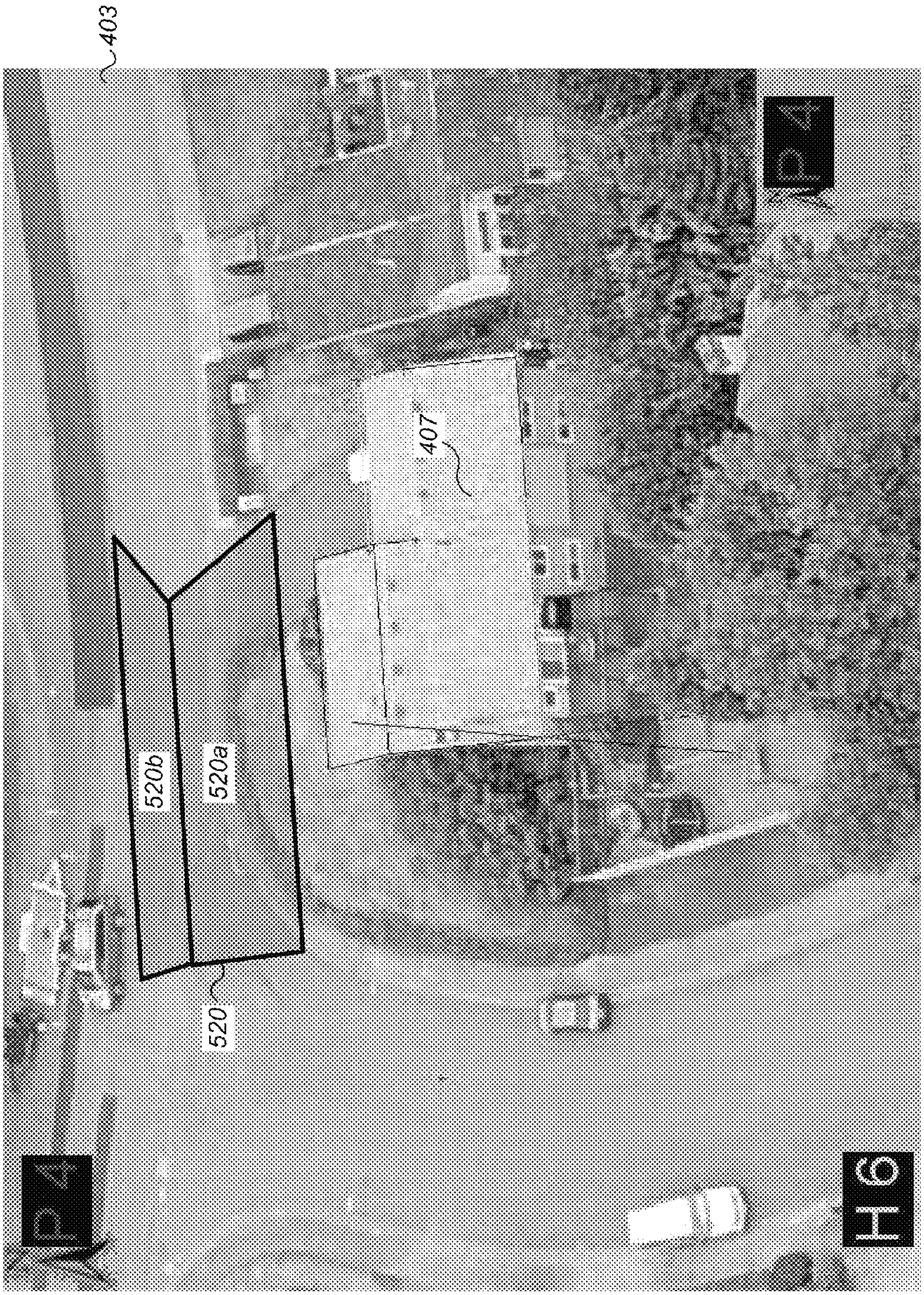


Fig. 5C

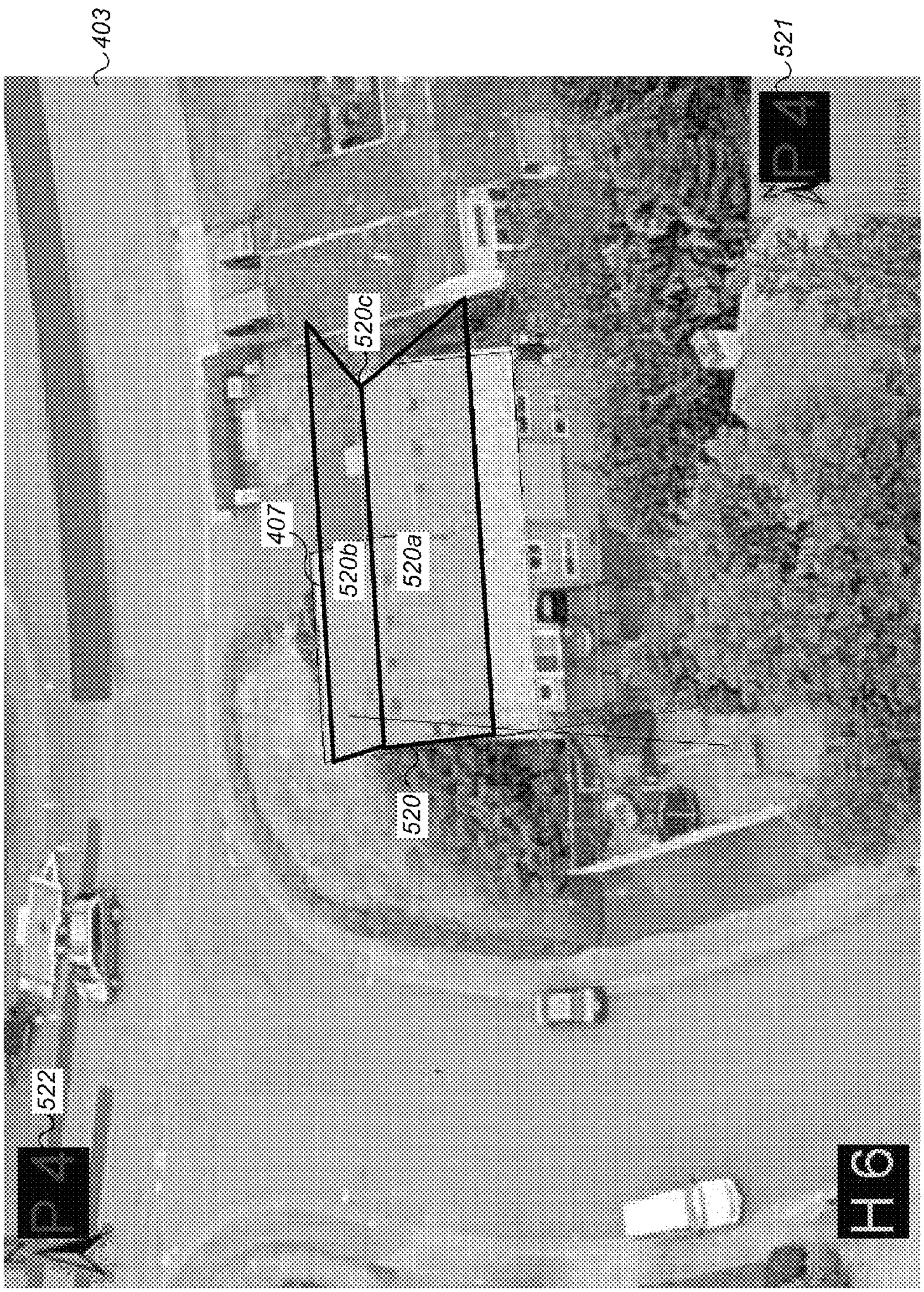


Fig. 5D

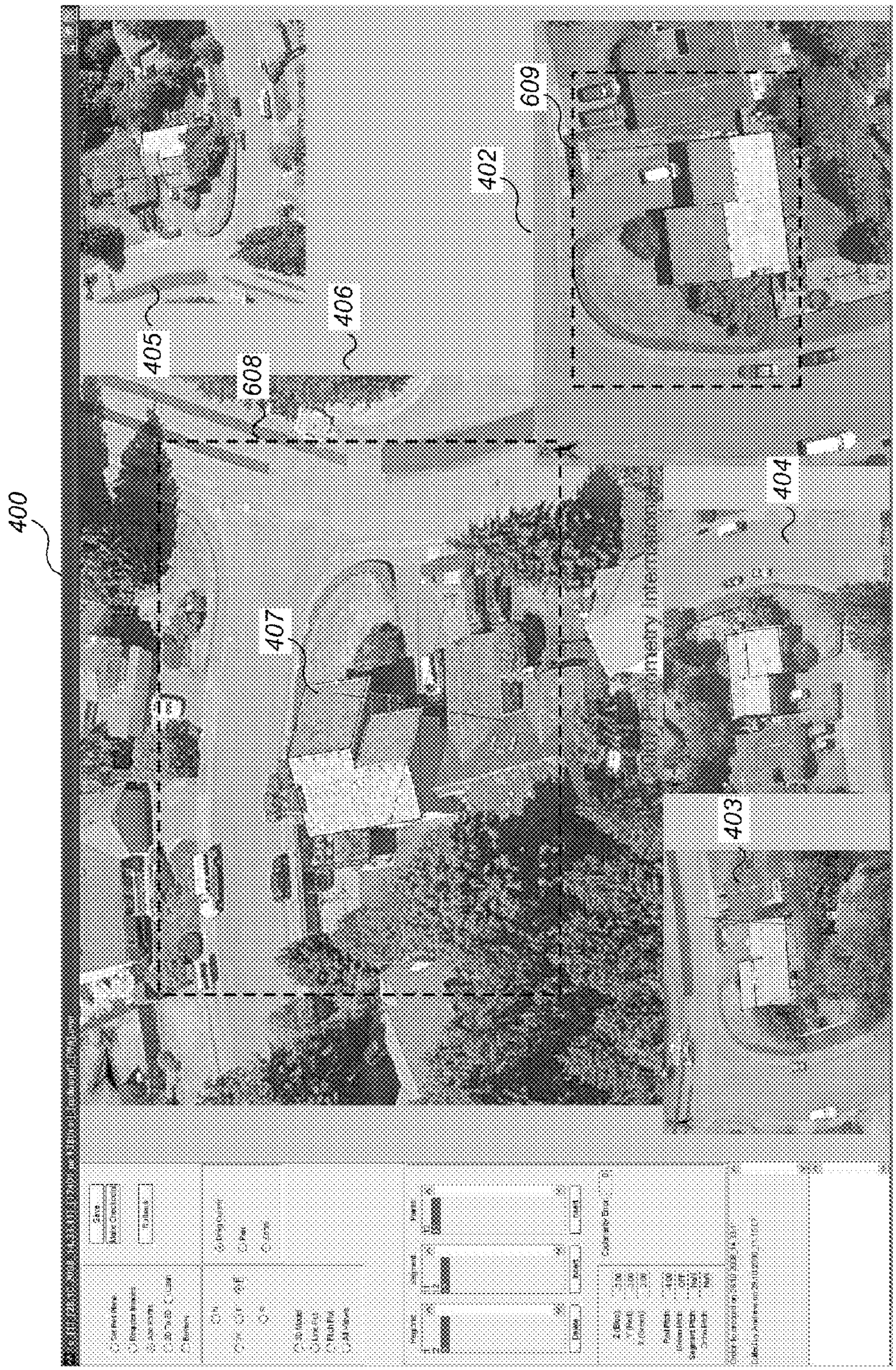


Fig. 6A

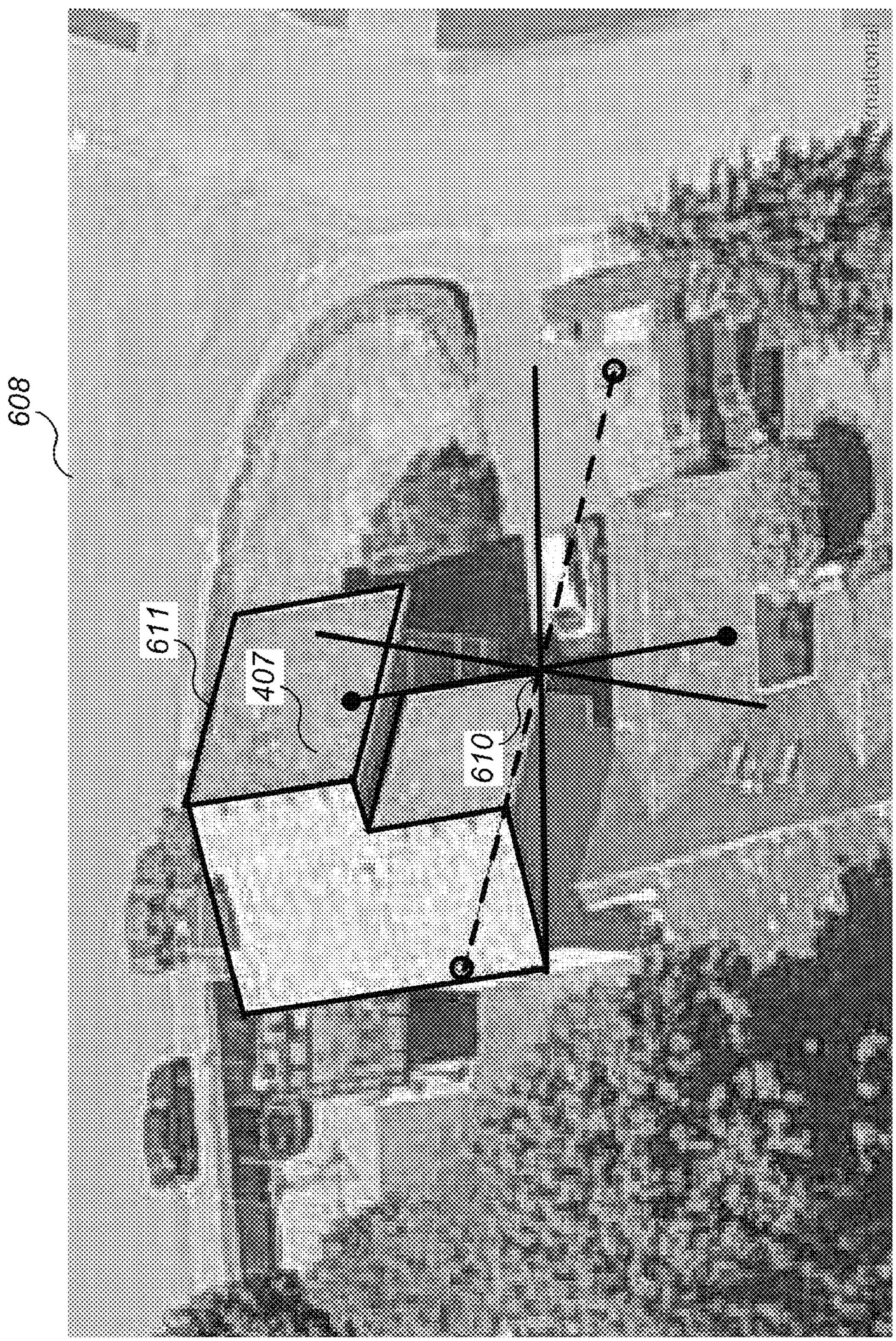


Fig. 6B

Fig. 6C

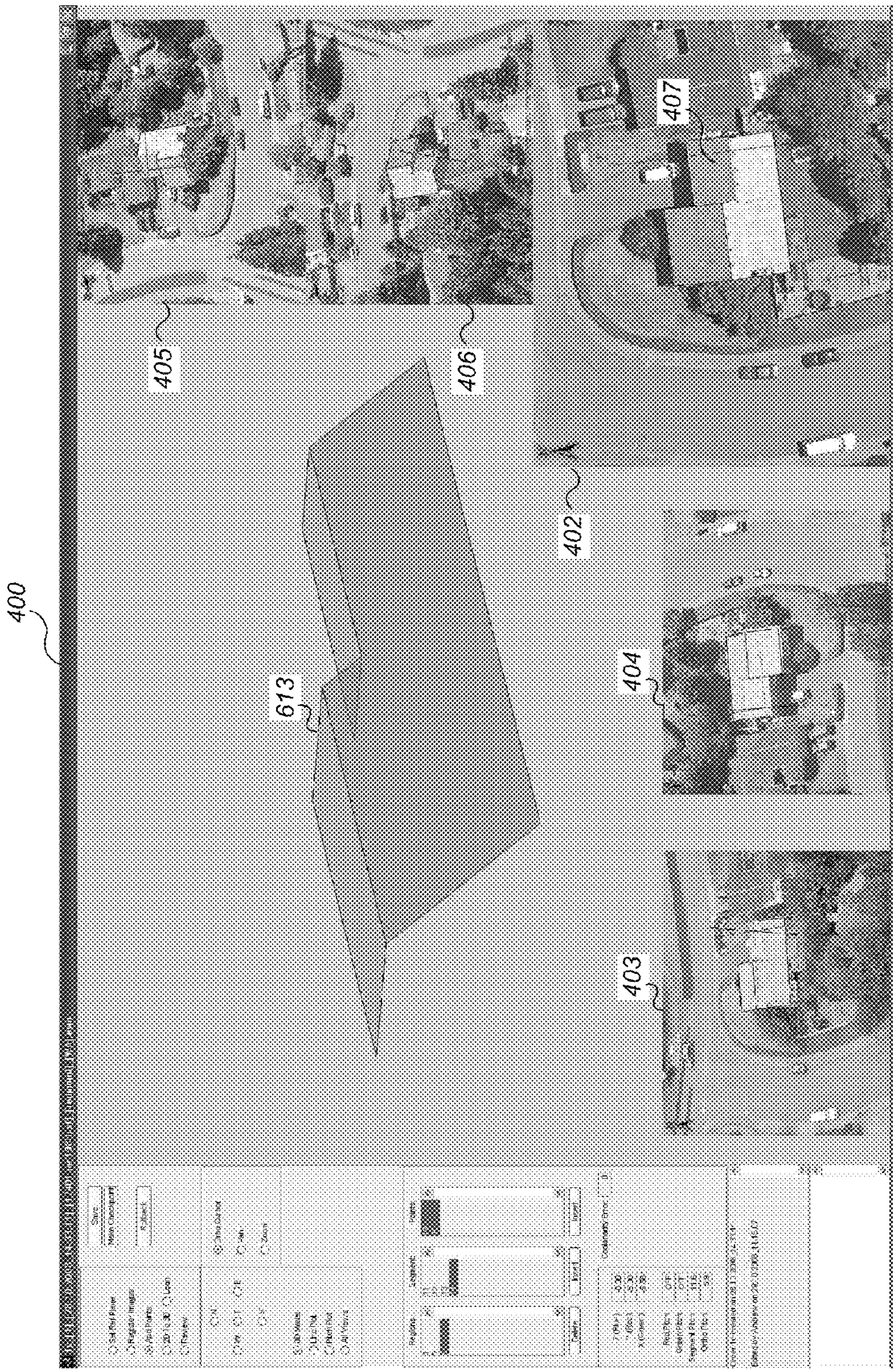


Fig. 6D

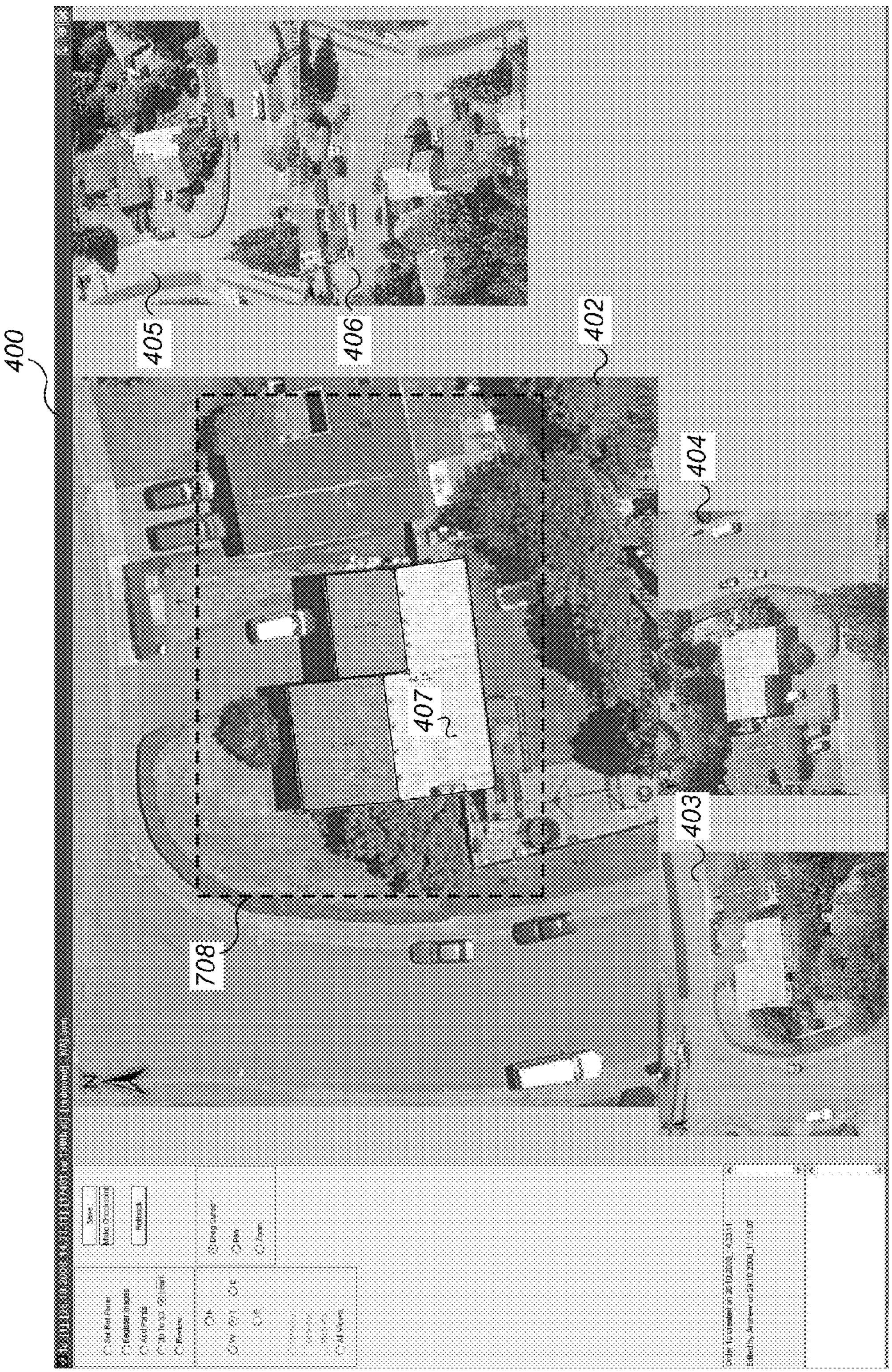


Fig. 7A

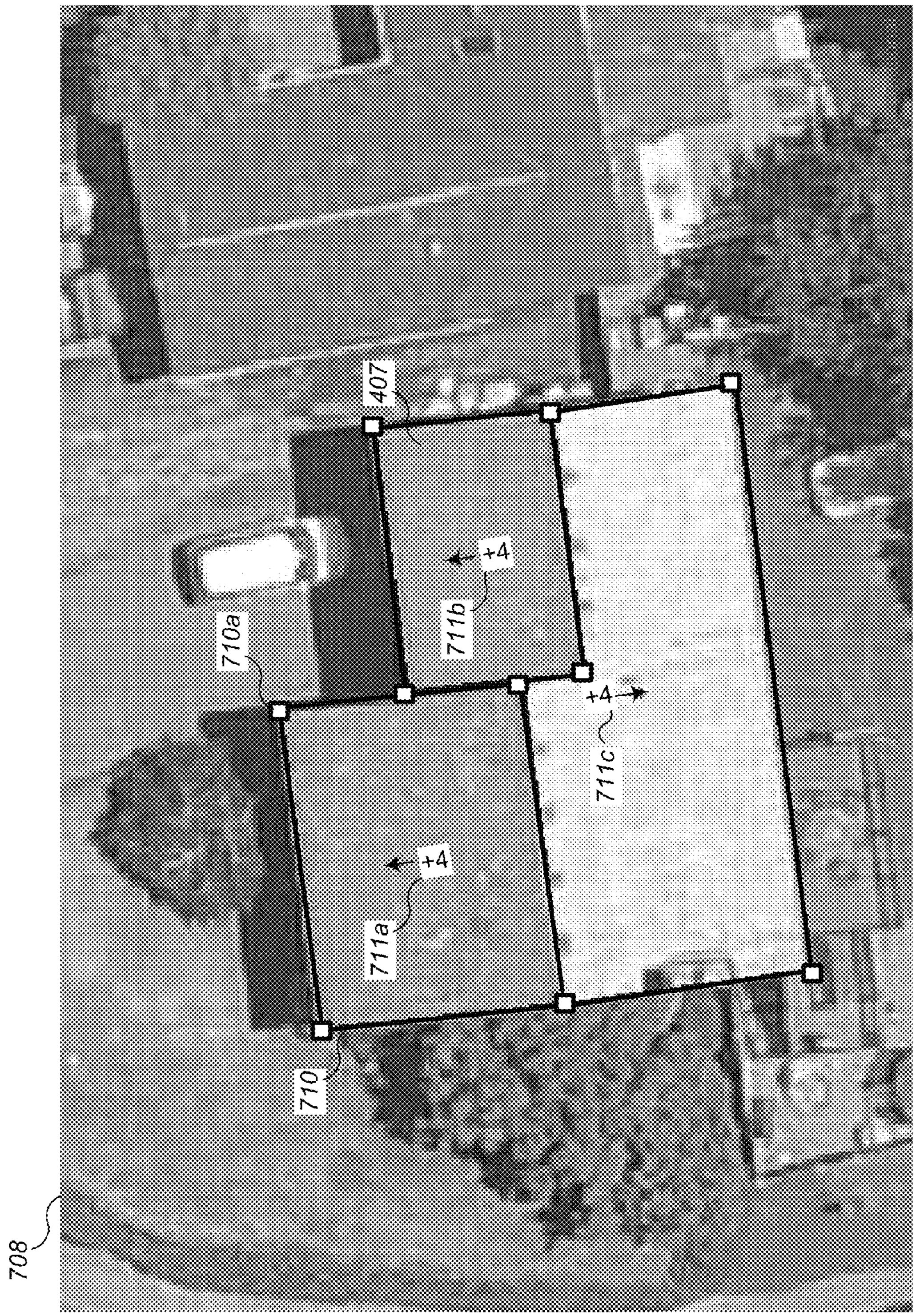


Fig. 7B

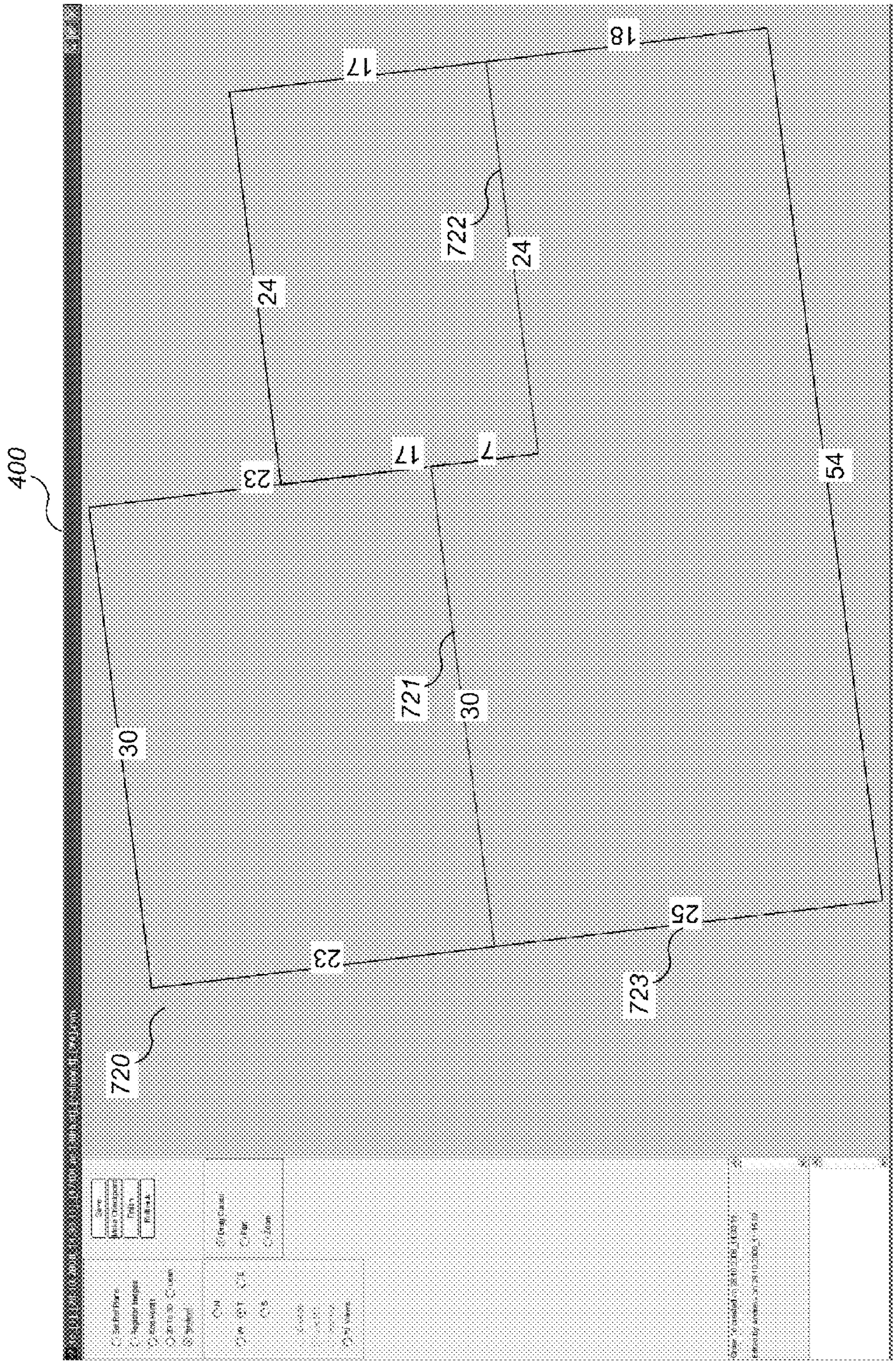


Fig. 7C

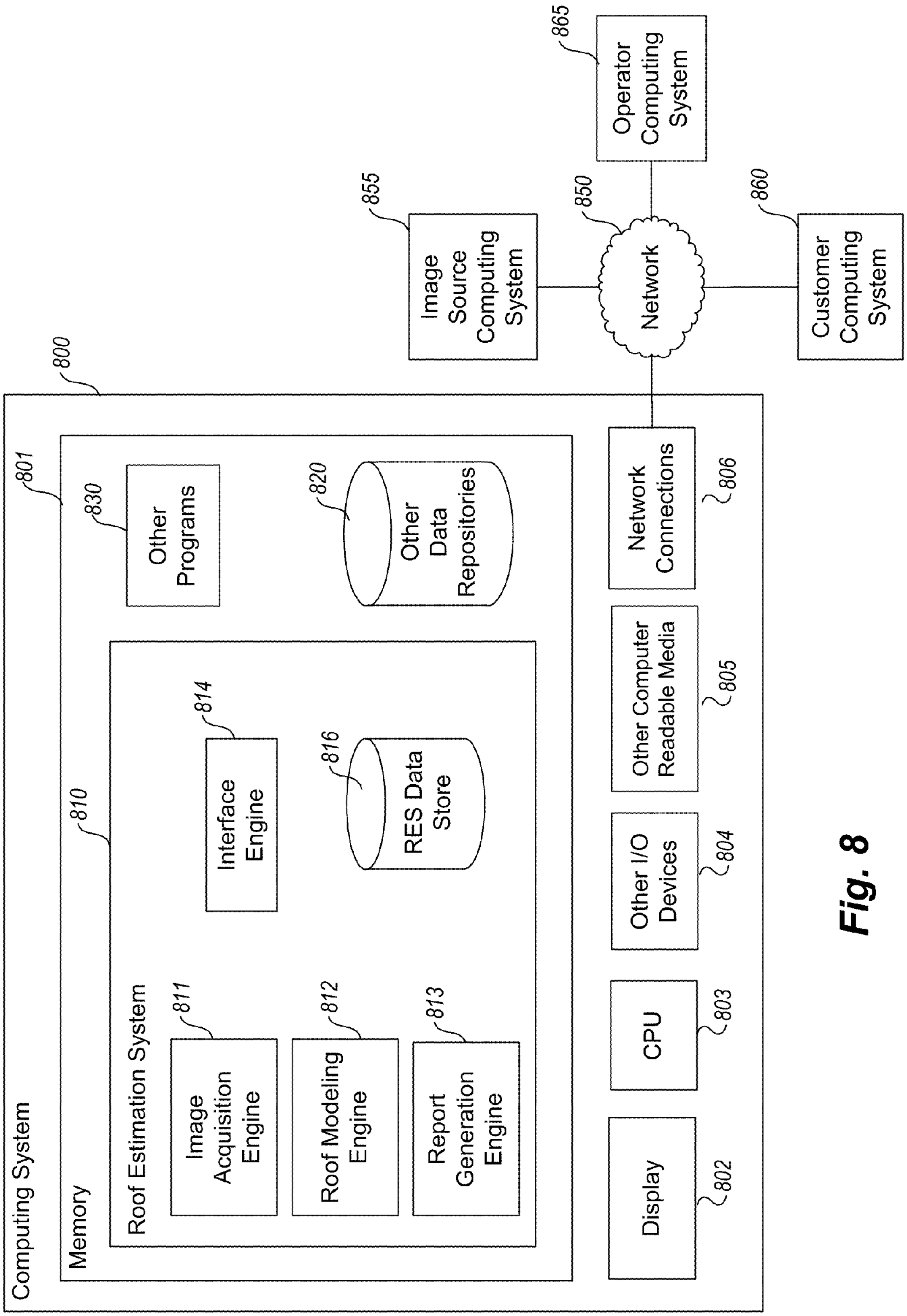

865
Operator Computing System
855
Image Source Computing System
850
Network
860
Customer Computing System
800
Computing System
801
Memory
830
Other Programs
820
Other Data Repositories
810
Roof Estimation System
814
Interface Engine
816
RES Data Store
811
Image Acquisition Engine
812
Roof Modeling Engine
813
Report Generation Engine
Display
802
CPU
803
Other I/O Devices
804
Other Computer Readable Media
805
Network Connections
806

Fig. 8

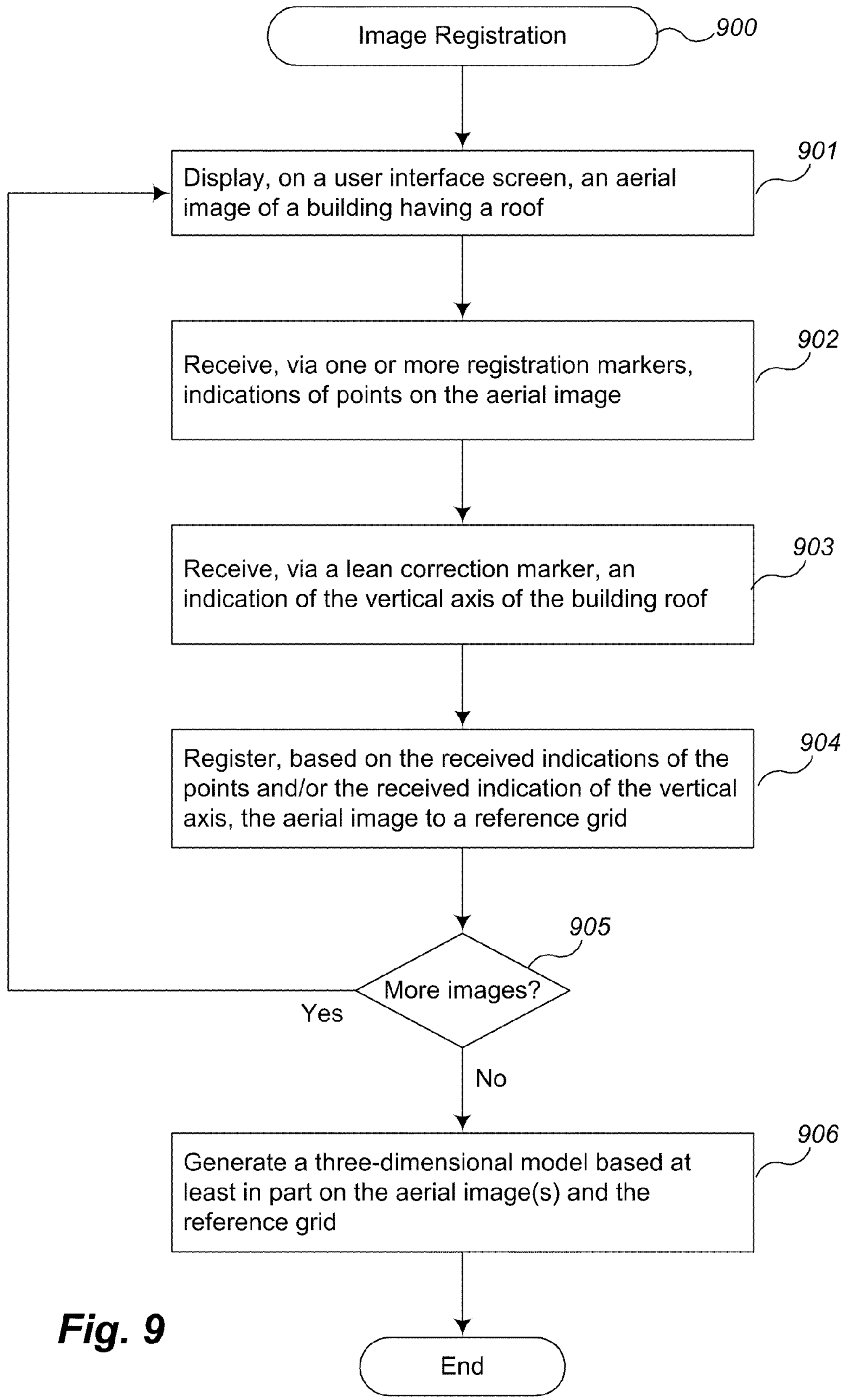


Image Registration
900
Display, on a user interface screen, an aerial image of a building having a roof
901
Receive, via one or more registration markers, indications of points on the aerial image
902
Receive, via a lean correction marker, an indication of the vertical axis of the building roof
903
Register, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid
904
More images?
905
Yes
No
Generate a three-dimensional model based at least in part on the aerial image(s) and the reference grid
906
End

Fig. 9

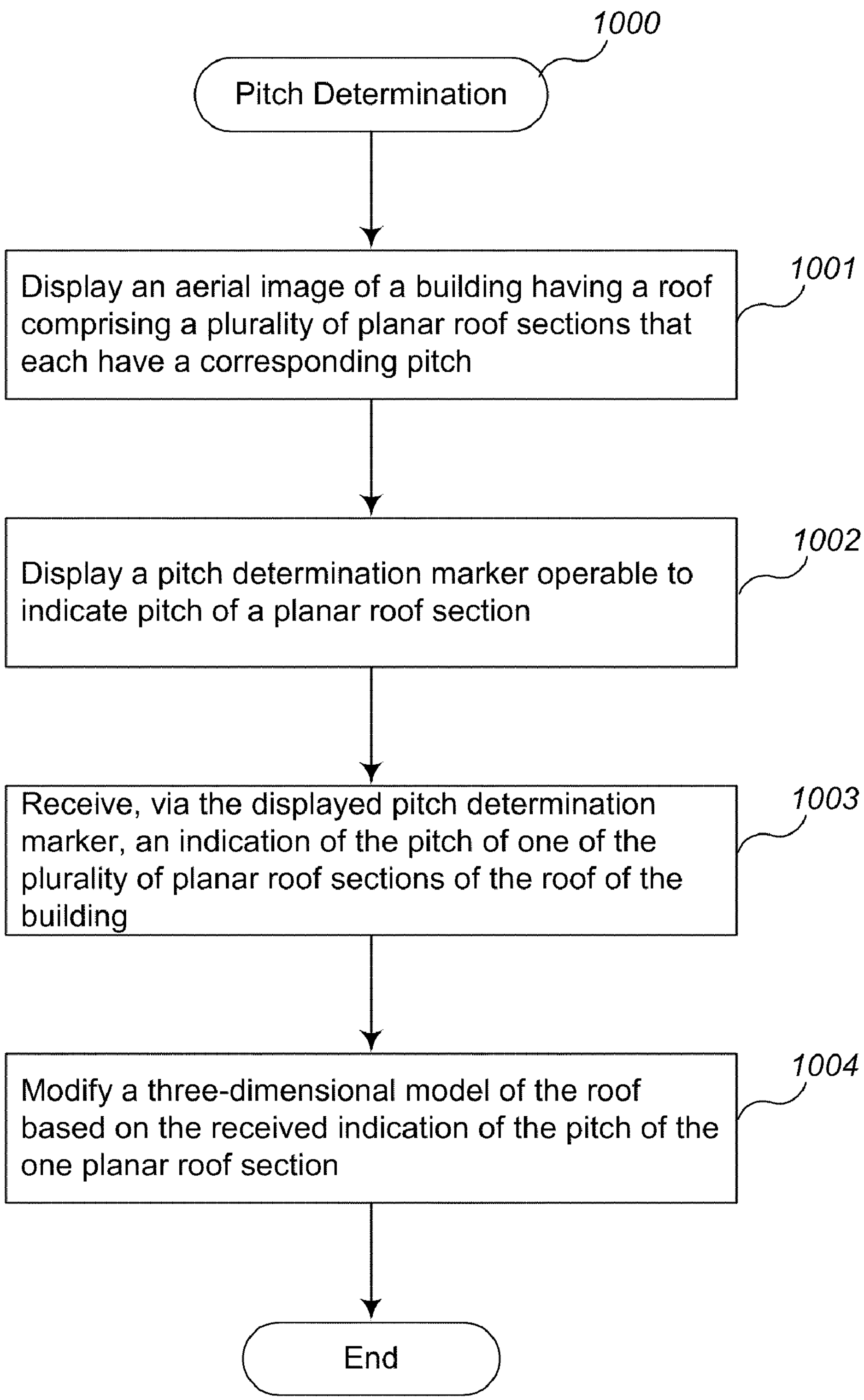

1000
Pitch Determination
Display an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch
1001
Display a pitch determination marker operable to indicate pitch of a planar roof section
1002
Receive, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building
1003
Modify a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section
1004
End

Fig. 10

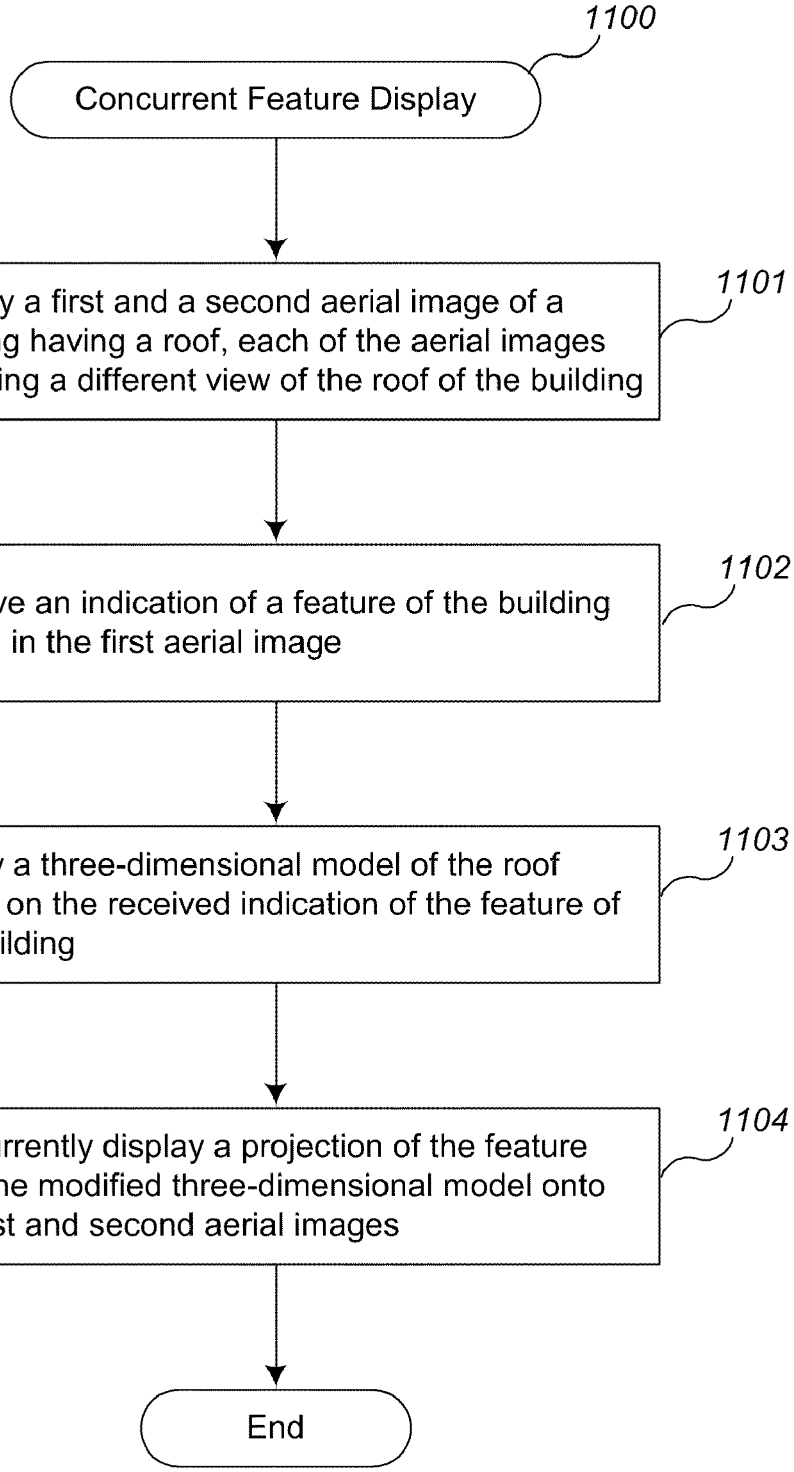

1100
Concurrent Feature Display
1101
Display a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building
1102
Receive an indication of a feature of the building shown in the first aerial image
1103
Modify a three-dimensional model of the roof based on the received indication of the feature of the building
1104
Concurrently display a projection of the feature from the modified three-dimensional model onto the first and second aerial images
End

Fig. 11

CONCURRENT DISPLAY SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 61/197,904, entitled "USER INTERFACE SYSTEMS AND METHODS FOR ROOF ESTIMATION," filed Oct. 31, 2008, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field of the Invention

This invention relates to systems and methods for estimating construction projects, and more particularly, to such systems and methods for determining roof measurement information based on one or more aerial images of a roof of a building.

2. Description of the Related Art

The information provided below is not admitted to be part of the present invention, but is provided solely to assist the understanding of the reader.

Homeowners typically ask several roofing contractors to provide written estimates to repair or replace a roof on a house. Heretofore, the homeowners would make an appointment with each roofing contractor to visit the house to determine the style of roof, take measurements, and to inspect the area around the house for access and cleanup. Using this information, the roofing contractor then prepares a written estimate and then timely delivers it to the homeowner. After receiving several estimates from different rooting contractors, the homeowner then selects one.

There are factors that impact a roofing contractor's ability to provide a timely written estimate. One factor is the size of the roof contractor's company and the location of the roofing jobs currently underway. Most roof contractors provide roofing services and estimates to building owners over a large geographical area. Larger roof contractor companies hire one or more trained individuals who travel throughout the entire area providing written estimates. With smaller roofing contractors, the owner or a key trained person is appointed to provide estimates. With both types of companies, roofing estimates are normally scheduled for buildings located in the same area on a particular day. If an estimate is needed suddenly at a distant location, the time for travel and the cost of commuting can be prohibitive. If the roofing contractor is a small company, the removal of the owner or key person on a current job site can be time prohibitive.

Another factor that may impact the roofing contractor's ability to provide a written estimate is weather and traffic.

Recently, solar panels have become popular. In order to install solar panels, the roof's slope, geometrical shape, and size as well as its orientation with respect to the sun all must be determined in order to provide an estimate of the number and type of solar panels required. Unfortunately, not all roofs on a building are proper size, geometrical shape, or orientation for use with solar panels.

SUMMARY

These and other objects are met by the systems and methods disclosed herein that determine and provide roof measurement information about the sizes, dimensions, slopes and orientations of the roof sections of a building roof. Roof measurement information may be used to generate a roof estimate report that provides and graphically shows this information. A roof estimation system that practices at least some of the techniques described herein may include an image acquisition engine, a roof modeling engine, and a report generation engine. The roof estimation system is configured to generate a model of a roof of a building, based on one or more aerial images. In addition, the roof estimation system is configured to determine roof measurement information and generate a roof estimate report based on the generated model and/or the determined roof measurement information.

In some embodiments, the roof estimation system includes a user interface engine which provides access to at least some of the functions of the roof estimation system. In one embodiment, the user interface engine provides interactive user interface components operable by an operator to perform various functions related to generating a model of a roof of a building, including image registration, lean correction, pitch determination, feature identification, and model review and/or correction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system.

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. (Also shows lean correction.)

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment.

FIGS. **7**A-**7**C are screen displays illustrating roof model review in an example embodiment.

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment.

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment.

DETAILED DESCRIPTION

Embodiments described herein provide enhanced computer- and network-based methods, techniques, and systems for estimating construction projects based on one or more images of a structure. Example embodiments provide a Roof Estimation System ("RES") that is operable to provide a roof estimate report for a specified building, based on one or more aerial images of the building. In one embodiment, a customer of the RES specifies the building by providing an address of the building. The RES then obtains one or more aerial images showing at least portions of the roof of the building. Next, the RES generates a model of the roof of the building, which is then utilized to determine roof measurement information. The roof measurement information may include measurements such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc. The model of the roof and/or the roof measurement information is then used to generate a roof estimate report. The

roof estimate report includes one or more line drawings of the roof of the building, which are annotated with information about the roof, such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc.

Some embodiments of the roof estimation system include an interactive user interface configured to provide access to one or more of the functions of the roof estimation system. In one embodiment, the roof estimation system includes user interface controls that facilitate image registration, image lean correction, roof model generation, pitch determination, and roof model review. Image registration includes aligning, based at least in part on operator inputs, one or more images of a building roof to a set of reference points within a single three-dimensional ("3D") grid that is shared between the one or more images. Roof model generation includes generating a 3D model of a roof, based at least in part on operator inputs specifying various features and/or dimensional attributes of the roof. Roof model generation may further include the determination of the pitches of various planar sections of a roof. Roof model review includes display of a model of a roof, possibly in conjunction with one or more images of the roof, so that an operator may review the model for accuracy and possibly make adjustments and/or corrections to the roof model. In other embodiments, all or some of the functions of the roof estimation system may be performed automatically. For example, image registration may include automatically identifying building features for the placement of reference markers. Further, roof model generation may include automatically recognizing features, dimensional attributes, and/or pitches of various planar roof sections of the roof.

The described user interface is also configured to concurrently display roof features onto multiple images of a roof. For example, in the context of roof model generation, an operator may indicate a roof feature, such as an edge or a corner of a section of the roof, in a first image of the roof. As the roof estimation system receives the indication of the roof feature, the user interface concurrently displays that feature in one or more other images of the roof, so that the operator may obtain feedback regarding the accuracy of the roof model, the image registration, etc.

In the following, FIGS. **1-3** provide an overview of the operation of an example roof estimation system. FIGS. **4-7** provide additional details related an example interactive user interface provided by one embodiment of the roof estimation system. FIGS. **8-11** provide details related to roof estimation system implementation techniques.

1. Roof Estimation System Overview

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system. In particular, FIG. **1** shows an example Roof Estimation System ("RES") **100** comprising an image acquisition engine **101**, a roof modeling engine **102**, a report generation engine **103**, image data **105**, model data **106**, and report data **107**. The RES **100** is communicatively coupled to an image source **110**, a customer **115**, and optionally an operator **120**. The RES **100** and its components may be implemented as part of a computing system, as will be further described with reference to FIG. **8**.

More specifically, in the illustrated embodiment of FIG. **1**, the RES **100** is configured to generate a roof estimate report **132** for a specified building, based on aerial images **131** of the building received from the image source **110**. The image source **110** may be any provider of images of the building for which a roof estimate is being generated. In one embodiment, the image source **110** includes a computing system that provides access to a repository of aerial images of one or more buildings. In addition, the aerial images **131** may include images obtained via manned or unmanned aircraft (e.g., airplane, helicopter, blimp, drone, etc.), satellite, etc. Furthermore, the aerial images **131** may include images obtain via one or more ground-based platforms, such as a vehicle-mounted camera that obtains street-level images of buildings, a nearby building, a hilltop, etc. In some cases, a vehicle-mounted camera may be mounted in an elevated position, such as a boom. Example aerial images are described further with reference to FIGS. **2A-2B**.

The image acquisition engine **101** obtains one or more aerial images of the specified building by, for example, providing an indicator of the location of the specified building (e.g., street address, GPS coordinates, lot number, etc.) to the image source **110**. In response, the image source **110** provides to the image acquisition engine **101** the one or more aerial images of the building. The image acquisition engine **101** then stores the received aerial images as image data **105**, for further processing by other components of the RES **100**. Obtaining aerial images of a specified building may include various forms of geo-coding, performed by the image acquisition engine **101** and/or the image source **110**. In one embodiment, the image source geo-codes a provided street address into latitude and longitude coordinates, which are then used to look up (e.g., query a database) aerial images of the provided street address.

Next, the roof modeling engine **102** generates a model of the roof of the specified building. In the illustrated embodiment, the roof modeling engine **102** generates a three-dimensional ("3D") model, although in other embodiments, a two-dimensional (e.g., top-down roof plan) may be generated instead or in addition. Generating a model of the roof may generally include image calibration, in which the distance between two pixels on a given image is converted into a physical length. Image calibration may be performed automatically, such as based on meta-information provided along with the aerial images **131**.

A variety of automatic and semi-automatic techniques may be employed to generate a model of the roof of the building. In one embodiment, generating such a model is based at least in part on a correlation between at least two of the aerial images of the building. For example, the roof modeling engine **102** receives an indication of a corresponding feature that is shown in each of the two aerial images. In one embodiment, an operator **120**, viewing two or more images of the building, inputs an indication in at least some of the images, the indications identifying which points of the images correspond to each other for model generation purposes.

The corresponding feature may be, for example, a vertex of the roof of the building, the corner of one of the roof planes of the roof, a point of a gable or hip of the roof, etc. The corresponding feature may also be a linear feature, such as a ridge or valley line between two roof planes of the roof. In one embodiment, the indication of a corresponding feature on the building includes "registration" of a first point in a first aerial image, and a second point in a second aerial image, the first and second points corresponding the substantially the same point on the roof of the building. Generally, point registration may include the identification of any feature shown in both aerial images. Thus, the feature need not be a point on the roof of the building. Instead, it may be, for example, any point that is visible on both aerial images, such as on a nearby building (e.g., a garage, neighbor's building, etc.), on a nearby structure (e.g., swimming pool, tennis court, etc.), on a nearby natural feature (e.g., a tree, boulder, etc.), etc.

In some embodiments, the roof modeling engine **102** determines the corresponding feature automatically, such as by

employing on one or more image processing techniques used to identify vertexes, edges, or other features of the roof. In other embodiments, the roof modeling engine **102** determines the corresponding feature by receiving, from the human operator **120** as operator input **133**, indications of the feature shown in multiple images of the building.

In one example embodiment, the RES **100** generates a model of the roof of the building in the following manner. First, a set of reference points are be identified in each of the images. These reference points are identified by the operator **120** utilizing a suitable input device, such as a mouse or joystick. The roof modeling engine **102** then uses these reference points and any acceptable algorithm to co-register the images and reconstruct the three-dimensional geometry of the object identified by the reference points. There are a variety of photogrammetric algorithms that can be utilized to perform this reconstruction. One such algorithm used by the RES **100** uses photographs taken from two or more view points to "triangulate" points of interest on the object in three-dimensional ("3D") space. This triangulation can be visualized as a process of projecting a line originating from the location of the photograph's observation point that passes through a particular reference point in the image. The intersection of these projected lines from the set of observation points to a particular reference point identifies the location of that point in 3D space. Repeating the process for all such reference points allows the software to determine a 3D volume suitable for building a 3D model of the structure. The choice of reconstruction algorithm depends on a number of factors such as the spatial relationships between the photographs, the number and locations of the reference points, and any assumptions that are made about the geometry and symmetry of the object being reconstructed. Several such algorithms are described in detail in textbooks, trade journals, and academic publications.

In addition, generating a model of the roof of a building may include correcting one or more of the aerial images for various imperfections. For example, the vertical axis of a particular aerial image sometimes will not substantially match the actual vertical axis of its scene. This will happen, for example, if the aerial images were taken at different distances from the building, or at a different pitch, roll, or yaw angles of the aircraft from which the images were produced. In such cases, an aerial image may be corrected by providing the operator **120** with a user interface control operable to adjust the scale and/or relative angle of the aerial image to correct for such errors. The correction may be either applied directly to the aerial image, or instead be stored (e.g., as an offset) for use in model generation or other functions of the RES **100**.

Generating a model of the roof of a building further includes the automatic or semi-automatic identification of features of the roof of the building. In one embodiment, one or more user interface controls may be provided, such that the operator **120** may indicate (e.g., draw, paint, etc.) various features of the roof, such as valleys, ridges, hips, vertexes, planes, edges, etc. As these features are indicated by the operator **120**, a corresponding three-dimensional ("3D") model may be updated accordingly to include those features. These features are identified by the operator based on a visual inspection of the images and by providing inputs that identify various features as valleys, ridges, hips, etc. In some cases, a first and a second image view of the roof (e.g., a north and east view) are simultaneously presented to the operator **120**, such that when the operator **120** indicates a feature in the first image view, a projection of that feature is automatically presented in the second image view. By presenting a view of the 3D model, simultaneously projected into multiple image views, the operator **120** is provided with useful visual cues as to the correctness of the 3D model and/or the correspondence between the aerial images.

In addition, generating a model of the roof of a building may include determining the pitch of one or more of the sections of the roof. In some embodiments, one or more user interface controls are provided, such that the operator **120** may accurately determine the pitch of each of the one or more roof sections. An accurate determination of the roof pitch may be employed (by a human or the RES **100**) to better determine an accurate cost estimate, as roof sections having a low pitch are typically less costly surfaces to repair and/or replace.

The generated model typically includes a plurality of planar roof sections that each correspond to one of the planar sections of the roof of the building. Each of the planar roof sections in the model has a number of associated dimensions and/or attributes, among them slope, area, and length of each edge of the roof section. Other information may include any information relevant to a roof builder or other entity having an interest in construction of, or installation upon, the roof. For example, the other information may include identification of valleys, ridges, rakes, eaves, or hip ridges of the roof and/or its sections; roof and/or roof section perimeter dimensions and/or outlines; measurements of step heights between different roof levels (e.g., terraces); bearing and/or orientation of each roof section; light exposure and/or shadowing patterns due to chimneys, other structures, trees, latitude, etc.; roofing material; etc? Once a 3D model has been generated to the satisfaction of the roof modeling engine **102** and/or the operator **120**, the generated 3D model is stored as model data **106** for further processing by the RES **100**. In one embodiment, the generated 3D model is then stored in a quality assurance queue, from which it is reviewed and possibly corrected by a quality control operator.

The report generation engine **103** generates a final roof estimate report based on a model stored as model data **106**, and then stores the generated report as report data **107**. Such a report typically includes one or more plan (top-down) views of the model, annotated with numerical values for the slope, area, and/or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof. The report may also include information about total area of the roof, identification and measurement of ridges and/or valleys of the roof, and/or different elevation views rendered from the 3D model (top, side, front, etc). An example report is illustrated and discussed with respect to FIGS. **3**A-**3**E, below.

In some embodiments, generating a report includes labeling one or more views of the model with annotations that are readable to a human user. Some models include a large number of small roof details, such as dormers or other sections, such that applying uniformly sized, oriented, and positioned labels to roof section views results in a visually cluttered diagram. Accordingly, various techniques may be employed to generate a readable report, including automatically determining an optimal or near-optimal label font size, label position, and/or label orientation, such that the resulting report may be easily read and understood by the customer **115**.

In addition, in some embodiments, generating a report includes automatically determining a cost estimate, based on specified costs, such as those of materials, labor, transportation, etc. For example, the customer **115** provides indications of material and labor costs to the RES **100**. In response, the report generation engine **103** generates a roof estimate report that includes a cost estimate, based on the costs provided by the customer **115** and the attributes of the particular roof, such as area, pitch, etc.

In one embodiment, the generated report is then provided to a customer. The generated report can be represented, for example, as an electronic file (e.g., a PDF file) or a paper document. In the illustrated example, roof estimate report **132** is transmitted to the customer **115**. The customer **115** may be or include any human, organization, or computing system that is the recipient of the roof estimate report **132**. For example, the customer **115** may be a property owner, a property manager, a roof construction/repair company, a general contractor, an insurance company, a solar power panel installer, a climate control (e.g., heating, ventilation, and/or air conditioning) system installer, a roof gutter installer, an awning installer, etc. Reports may be transmitted electronically, such as via a network (e.g., as an email, Web page, etc.) or by some shipping mechanism, such as the postal service, a courier service, etc.

In some embodiments, one or more of the models stored as model data **106** are provided directly to the customer or other computing system, without first being transformed into a report. For example, a model and/or roof measurement information based thereon may be exported and/or transmitted as a data file, in any suitable format, that may be consumed or otherwise utilized by some other computing system, such as a computer-aided design ("CAD") tool, a drawing program, a labor and material estimation software, a project management/estimation software, etc.

The RES **100** may be operated by various types of entities. In one embodiment, the RES **100** is operated by a roof estimation service that provides roof estimate reports to customers, such as roofing contractors, in exchange for payment. In another embodiment, the RES **100** is operated by a roof construction/repair company, to generate roof estimate reports that are used internally and/or provided to customers, such as property owners.

In addition, the RES **100** may be operated in various ways. In one embodiment, the RES **100** executes as a desktop computer application that is operated by the operator **120**. In another embodiment, the RES **100** executes as a network-accessible service, such as by a Web server, that may be operated remotely by the operator **120** and/or the customer **115**. Additional details regarding the implementation of an example roof estimation system are provided with respect to FIG. **8**, below.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address. In the illustrated example, the aerial images are represented as stylized line drawings for clarity of explanation. As noted above, such aerial images may be acquired in various ways. In one embodiment, an aircraft, such as an airplane or helicopter is utilized to take photographs while flying over one or more properties. Such aircraft may be manned or unmanned. In another embodiment, a ground-based vehicle, such as a car or truck, is utilized to take photographs (e.g., "street view" photographs) while driving past one or more properties. In such an embodiment, a camera may be mounted on a boom or other elevating member, such that images of building roofs may be obtained. In another embodiment, photographs may be taken from a fixed position, such as a tall building, hilltop, tower, etc.

In particular, FIG. **2**A shows a top plan (top-down) aerial image **210** of a building **200**. The roof of the building **200** includes multiple planar roof sections **200***a*-**200***d*. FIG. **2**A also shows a second aerial image **211** providing a perspective (oblique) view of the building **200**. The roof sections **200***a* and **200***c* are also visible in image **211**.

FIG. **2**B shows a top-down, wide angle image **212** of the building **200**. The image **212** includes details of the surrounding areas **220** of the building **220**. Information about the surrounding areas **220** of the building **220** are in some embodiments used to determine additional cost factors related to a roof estimate. For example, the cleanup of, or access to, a worksite at building **220** may be complicated by various factors, including a substantial amount of landscaping; steeply sloped building sites; proximity to environmentally sensitive areas; etc. In such cases, the roof estimation system may automatically increase a cost factor in a corresponding roof estimate report.

In some embodiments, an aerial image has corresponding meta-information. Such meta-information may include details about the type of camera used (e.g., focal length, exposure, etc.), the position of the camera (e.g., GPS coordinates of the aircraft at the time the image was captured), the orientation of the camera (e.g., the angle of the camera), the time and/or date the image was captured, etc.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system. As discussed with respect to FIG. **1**, a roof estimate report is generated by the roof estimation system based on one or more aerial images of a building. The roof estimate report may be based on a computer model (e.g., a 3D model) of the roof, and includes one or more views of the model. In this example, the various views of the model are presented as annotated line drawings, which provide information about the roof, such as the roof section areas, roof section edge lengths, roof section pitches, etc. The roof estimate report may be in an electronic format (e.g., a PDF file) and/or paper format (e.g., a printed report). In some embodiments, the roof estimate report may be in a format that may be consumed by a computer-aided design program.

FIG. **3**A shows a cover page **301** of the report and includes the address **301***a* of a building **301***c* and an overhead aerial image **301***b* of the building **301***c*.

FIG. **3**B shows a second page **302** of the report and includes two wide perspective (oblique) views **302***a* and **302***b* of the building **301***c* at the address with the surrounding areas more clearly shown.

FIG. **3**C shows a third page **303** of the report and includes a line drawing **303***a* of the building roof showing ridge lines **303***b* and **303***c*, and a compass indicator **303***d*. In addition, a building roof having valleys would result in a line drawing including one or more valley lines. The ridge and/or valley lines may be called out in particular colors. For example, ridge lines **303***b* and **303***c* may be illustrated in red, while valley lines may be illustrated in blue. The line drawing **303***a* is also annotated with the dimensions of the planar sections of the building roof. In this case, the dimensions are the lengths of the edges of the planar roof sections.

FIG. **3**D shows a fourth page **304** of the report and includes a line drawing **304***a* of the building roof showing the pitch of each roof section along with a compass indicator. The pitch in this example is given in inches, and it represents the number of vertical inches that the labeled planar roof section drops over 12 inches of horizontal run. The slope can be easily calculated from such a representation using basic trigonometry. The use of a numerical value of inches of rise per foot of run is a well known measure of slope in the roofing industry. A roof builder typically uses this information to assist in the repair and/or construction of a roof. Of course, other measures and/or units of slope may be utilized as well, including percent grade, angle in degrees, etc.

FIG. **3**E shows a fifth page **305** of the report and includes a line drawing **305***a* of the building roof showing the square footage of each roof section along with the total square foot area value. Of course, other units of area may be used as well,

such as square meters or the number of "squares" of roofing material required for covering each roof section.

FIG. **3**F shows a fifth page **306** of the report and includes a line drawing **306***a* of the building roof where notes or comments may be written. The line drawing **306***a* includes a label for each roof section (shown here as "A", "B", "C"), such that comments may be conveniently related to specific roof sections.

In other embodiments, more or less information may be provided, or the illustrated information may be arranged in different ways. For example, the report may be provided in electronic form, such as a PDF file or a computer aided design software format. In some embodiments, the report may be "active" or editable, such that the user of the report may make changes to the report, based on on-site observations.

2. Roof Estimation System User Interface

FIGS. **4**A-**4**F, **5**A-**5**D, **6**A-**6**D, and **7**A-**7**C describe an example interactive user interface provided by one embodiment of the roof estimation system. As noted, the RES **100** described with reference to FIG. **1** includes a user interface engine **104** that is configured to provide access to one or more functions of the RES **100**, including image registration (described with respect to FIGS. **4**A-**4**F), roof pitch determination (described with respect to FIGS. **5**A-**5**D), roof model construction (described with reference to FIGS. **6**A-**6**D), and roof model review (described with respect to FIGS. **7**A-**7**C).

A. Image Registration

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. In particular, FIG. **4**A shows a user interface screen **400** that is utilized by an operator to generate a three dimensional model of a roof of a building. The user interface screen **400** shows a roof modeling project in an initial state, after the operator has specified an address of a building and after images of the building have been obtained and loaded into the roof estimation system.

The user interface screen **400** includes a control panel **401** and five images **402**-**406** of a building roof **407**. The control panel **401** includes user selectable controls (e.g., buttons, check boxes, menus, etc.) for various roof modeling tasks, such as setting reference points for the images, setting the vertical (Z) axis for the images, switching between different images, saving the model, and the like. Each of the images **402**-**406** provides a different view of the building roof **407**. In particular, images **402**-**406** respectively provide substantially top-down, south, north, west, and east views of the building roof **407**. Each image **402**-**406** includes four marker controls (also called "reference points" or "registration markers") that are used by the operator to set reference points in the image for purposes of image registration. The registration markers will be described further with respect to an enlargement of image portion **408** described with respect to FIGS. **4**B-**4**C, below.

FIGS. **4**B-**4**C show an enlarged view of image portion **408** during the process of image registration for image **402**, which provides a top-down view of the building roof **407**. As shown in FIG. **4**B, image portion **408** includes the building roof **407** and registration markers **410**-**413**. The markers **410**-**413** are interactive user interface controls that can be directly manipulated (e.g., moved, rotated, etc.) by the operator in order to specify points to use for purposes of image registration. In particular, image registration includes determining a transformation between each of one or more images and a uniform 3D reference grid. The uniform 3D reference grid is used as a coordinate system for a 3D model of the roof. By registering multiple images to the reference grid, an operator may indicate a roof feature on an image (such as a roof edge), which may then be translated from the coordinate system of the image to the coordinate system of the reference grid, for purposes of including of the indicated feature in the 3D model.

Marker **410** is an origin marker control, and includes arms **410***a*-**410***c*. Arms **410***a* and **410***b* are horizontal arms that are utilized to specify the X and Y axes (e.g., the horizontal plane) of the reference grid. Arm **410***c* is a vertical arm that may be utilized to specify the Z axis (e.g., the vertical axis) of the reference grid. The use of the vertical arm to specify the Z axis will be further described with respect to FIG. **4**E, below.

Typically, markers **410**-**413** are color coded, such that they may be distinguished from one another. For example, marker **411**-**413** may be respectively colored red, blue, and green. Origin marker **410** has a different appearance than markers **411**-**413**, so may be of any color. In other embodiments, markers **411**-**413** may be distinguished in other ways, such as by utilizing different sized dashed lines, different line thicknesses, etc. In still other embodiments, markers are not distinguished any way from each other, such as by being of uniform shape, color, etc.

FIG. **4**C shows image portion **408** with markers **410**-**413** after they have been placed by an operator. Typically, registration markers are placed at four spatially distributed corners of the roof. As shown in FIG. **4**C, the operator has placed markers **410**-**413** at four different corners of the building roof **407**. In particular, the operator first placed the origin marker **410** at the lower left corner of the building roof **407**, and has adjusted (e.g., rotated) the arms **410***a* and **410***b* to align with the major horizontal axes of the roof. By adjusting the arms **410***a* and **410***b* of the origin marker **410**, the rotational orientation of markers **411**-**413** is automatically adjusted by the roof estimation system. Next, the operator places markers **411**-**413** on some other corners of the roof. In general, the operator can place registration marker over any roof feature, but roof corners are typically utilized because they are more easily identified by the operator. After the operator is satisfied with the placement of markers **410**-**413**, the operator typically registers a next image of the building roof **407**, as will be described next.

FIGS. **4**D-**4**F illustrate image registration for image **404**, which provides a north view of the building roof **407**. In particular, FIG. **4**D shows the user interface screen **400** described with reference to FIG. **4**A. Here, image **402** has been minimized, while image **404** has been enlarged so that the operator may register that image by placing markers on image **404**, as will be described below with respect to an enlarged view of image portion **418**.

FIG. **4**E shows an enlarged view of image portion **418** during the process of image registration for image **404**. Image portion **418** includes the building roof **407** and registration markers **420**-**423**. Markers **420**-**423** respectively correspond to markers **410**-**413** described above. In particular, marker **420** is an origin marker control that includes arms **420***a*-**420***c*. Arms **420***a* and **420***b* are horizontal arms that are utilized to specify the X and Y axes of the reference grid. Arm **420***c* is a vertical arm that may be utilized to specify the Z axis of the reference grid.

In the example of FIG. **4**E, the operator has moved each of markers **420**-**423** to a corner of the roof **407**. Note that the markers **420**-**423** are moved to roof corners that correspond to those selected by the operator with markers **410**-**413**, as described with reference to FIG. **4**C. In particular, origin marker **420** has been moved to the corner of the roof **407** selected with origin marker **410** in image **408**; marker **421** has been moved to the corner selected with marker **411** in image **408**; marker **422** has been moved to the corner selected with

marker **412** in image **408**; and marker **423** has been moved to the corner selected with marker **413** in image **408**. In addition, markers **420**-**423** have been rotated, by operator rotation of the origin marker **420**, to align with the major axes of the roof **407**.

As noted, the operator can utilize the origin marker **420** to specify the vertical axis of the reference grid. In particular, the operator can adjust (e.g., by dragging with a mouse or other pointing device) arm **420***c* of marker **420** to specify the vertical (Z) axis of the image. In some cases, aerial images may include some amount of lean, due to the orientation of the aircraft during image capture. For example, pitch, yaw, or roll of an aircraft during the course of image capture may result in images that are misaligned with respect to the vertical axis of the building and its roof. Typically, an operator may adjust arm **420***c* to line up with a feature of a building or roof that is known to be substantially vertical, such as a wall of a house or a chimney. Then, based on the angle of arm **420***c* with respect to the vertical axis of the image, the roof estimation system can determine a correction between the reference grid and the image.

FIG. **4**F shows an enlarged view of image portion **418** after registration of image **404**. Once the operator has placed and adjusted markers **420**-**423**, the operator may direct (e.g., by clicking a button) the roof estimation system to register the image to the reference grid, based on the positions and orientations of markers **420**-**423**. Once the roof estimation system registers the image, it provides the operator with feedback so that the operator may determine the correctness or accuracy of the registration.

In the example of FIG. **4**F, the operator has directed the roof estimation system to register image **404**, and the roof estimation system has updated image portion **418** with registration indicators **430**-**433**. Registration indicators **430**-**433** provide the operator with feedback so that the operator may judge the accuracy of the registration of image **404**.

Registration indicator **430** is an origin registration indicator that includes two arms **430***a*-**430***b* and three reference grid indicators **430***c*-**430***e*, shown as dashed lines. The reference grid indicators **430***c*-**430***e* show the vertical axis (**430***c*) and the two horizontal axes (**430***d* and **430***e*) of the reference grid determined based on the placement and orientation of the markers **420**-**423**. Arms **430***a* and **430***b* correspond to the placement of arms **420***a*-**420***c* of origin marker **420**. If the arms **430***a* and **430***b* do not substantially align with the corresponding reference grid indicators **430***e* and **430***d*, then the determined reference grid is out of alignment with the specified axes of the house. Typically, an operator will return to the view of FIG. **4**E to make adjustments to origin marker, such as adjusting one or more of the vertical or horizontal axes, in order to refine the registration of the image. Although the arms **430***a*-**430***b* and the reference grid indicators **430***c*-**430***e* are here illustrated as solid and dashed lines, in other embodiments they may be color coded. For example, arms **430***a*-**430***b* may be red, while reference grid indicators **430***c*-**430***e* may be blue.

Registration indicators **431**-**433** provide the operator with information regarding the accuracy of the placement of markers **421**-**423**. In particular, each registration indicator **431**-**433** includes a solid crosshairs and a reference indicator, shown for example as a dashed line **432***a*. The crosshair of a registration indicator corresponds to the placement of a marker. For example, the crosshairs of registration indicator **431** corresponds to the placement of marker **421** in FIG. **4**E. If the reference indicator intersects the center (or substantially near the center) of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is accurate. On the other hand, if the reference indicator does not intersect the center of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is inaccurate. Typically, such an inaccuracy arises when the placement of markers in the top view of the roof does not agree with (correspond to) the placement of corresponding markers in another view of the roof. In such cases, the operator can return to the view of FIG. **4**C or **4**E to adjust the position of one or more markers.

After registering image **404**, the operator will proceed to register additional images of the building roof **407** utilizing a process similar to that described above. In this example, the operator will register images **403**, **405**, and **406**. Although the operator is here described as registering a total of five images, in other cases more or fewer images may be registered.

B. Roof Model Construction

FIGS. **5**A-**5**D and **6**A-**6**C generally illustrate aspects of the process of roof model generation based on multiple registered images. In particular, these figures illustrate the construction of a roof model by an operator. Model generation/construction may include identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. Each identified roof feature is incorporated by the roof estimation system into a 3D model of the roof, based on a translation between an image in which the feature is identified and the reference grid, as determined by the process described with reference to FIGS. **4**A-**4**F, above.

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment. In particular, FIG. **5**A shows the user interface screen **400** after images **402**-**406** have been registered. In this example, the operator is using a pitch determination control (also called a "pitch determination marker" or "pitch determination tool") to specify the pitch of a planar roof section of the building roof **407** visible in image **406**. The pitch determination control will be further described in FIG. **5**B, below, with respect to an enlargement of image portion **508**.

FIG. **5**B shows an enlarged view of image portion **508** during the process of pitch determination for image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **5**B, the image portion **508** includes the building roof **407** and a pitch determination marker **510** (also called a "protractor tool"). The pitch determination marker **510** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**.

The pitch determination marker **510** includes arms **510***a*-**510***d*. Arms **510***a*-**510***c* are axes, which are automatically aligned, based on the registration of image **406**, with the major (X, Y, and Z) axes of the building roof. Arm **510***d* is a "protractor" arm that is adjustable by the operator to specify roof pitch.

The marker **510** is typically first moved by the operator to a convenient location on the building roof **407**, usually corner of a planar section of the roof **407**. Next, the operator adjusts arm **510***d* so that is substantially aligns with the sloped edge of the planar roof section. Then, the roof estimation system determines the pitch of the roof section, based on the configuration of the marker **510** with respect to the image and the reference grid.

After specifying the pitch of a planar roof section, the operator will typically specify other information about the planar roof section, such as its outline, as will be described with reference to FIGS. **6**A-**6**D. Note that as the operator provides additional information about the geometry of the

roof **407**, the roof estimation system may automatically determine the pitch and/or other features of at least some of the other planar roof sections, based on the provided geometric information and/or assumptions about roof symmetry or other standard architectural practices.

FIG. **5**C shows a second type of pitch determination marker being used in the context of image **403** which provides a south perspective view of the building roof **407**. The illustrated pitch determination marker may be used in addition to, or instead of, the pitch determination marker **510** described with respect to FIGS. **5**A-**5**B, above. In particular, FIG. **5**C shows a pitch determination marker **520** (also called an "envelope tool") that includes surfaces **520***a* and **520***b*. The pitch determination marker **520** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**. In particular, the pitch determination marker **520** may be moved and/or adjusted so that it appears to lie substantially atop two adjacent planar sections of roof **407**.

FIG. **5**D shows the pitch determination marker **520** after the operator has used it to specify the pitch of two sections of roof **407**. Here, the operator has moved the marker **520** to a position in which the spine of the marker **520** is substantially aligned with the ridge line of roof **407**. Then, the operator has adjusted the angle of the surfaces **520***a* and **520***b* so that they appear to lie substantially atop corresponding sections of roof **407**. Then, the roof estimation system determines the pitch of the roof sections, based on the configuration of the marker **520** with respect to the image and the reference grid. Also illustrated are pitch indicators **521** and **522**. Pitch indicator **521** corresponds to the measured pitch of surface **520***a*, and pitch indicator **522** corresponds to the measured pitch of surface **520***b*. As the operator adjusts the angle of surfaces **520***a* and/or **520***b*, the corresponding pitch indicators **521**-**522** are automatically updated to reflect the determined pitch. In this example, the pitch of both surfaces is given as 4 inches of rise per foot of run.

The envelope pitch determination marker **520** may be adjusted in other ways, to specify pitches for types of roofs other than the gabled roof shown in image **403**. For example, when measuring pitch of roof sections that form a roof hip, point **520***c* may be manipulated by the operator, such as by dragging it to the left or right, to adjust the shape of the surfaces **520***a* and **520***b*, so that the surfaces align with the edges formed by the intersection of the sections that form the roof hip.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment. In particular, FIGS. **6**A-**6**D illustrate the construction of a three dimensional wire frame model of a building roof, based on the specification of roof features by an operator. In addition, FIGS. **6**A-**6**D illustrate the concurrent display of operator specified roof features in multiple views of a building roof.

FIG. **6**A shows the user interface screen **400** after images **402**-**406** have been registered, and after roof pitches have been determined. In this example, the operator is specifying sections of roof **407**, visible in image **406**, that are to be added to a 3D wire frame model of the roof **407** maintained by the roof estimation system. The specification of roof sections will be further described with reference to enlarged portion **608** of image **406** in FIG. **6**B, below. In addition, as the operator specifies roof sections in image **406**, the roof estimation system concurrently displays the specified roof sections in each of the other images **402**-**405**. The concurrent display of operator specified roof features will be further described with reference to enlarged portion **609** of image **402** in FIG. **6**C, below.

FIG. **6**B is an enlarged view of image portion **608** during the process of wire frame model construction in the context of image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **6**B, the image portion **608** includes the building roof **407**, drawing tool **610**, and wire frame **611**. The drawing tool **610** (also called a "drawing marker" or a "drawing control") is an interactive user interface control that can be directly manipulated by the operator in order to specify roof features, such as edges, ridges, valleys, corners, etc. In the illustrated embodiment, the operator uses the drawing tool **610** to trace or outline planar sections of the roof **407**, leading to the generation of wire frame **611**. The drawing tool **610** may be used to establish a series of connected line segments that result in a closed polygon representing a planar roof section. As the operator specifies a planar roof section in this manner, the roof estimation system determines, based on the image and the reference grid, the geometry of the planar roof section, and includes (adds) the specified planar roof section in a 3D model that corresponds to roof **407**.

FIG. **6**C is an enlarged view of image portion **609** illustrating the concurrent display of operator specified roof features, in the context of image **402**, which provides a top plan view of the building roof **407**. As the operator specifies roof sections as described with respect to FIG. **6**B, the roof estimation system concurrently displays the specified roof features in one or more of the other images displayed by the user interface screen **400**. More specifically, image portion **609** includes building roof **407** and wire frame **612**. Wire frame **612** corresponds to wire frame **611** constructed by the operator with reference to FIG. **6**B, except that wire frame **612** is automatically displayed as a projection from the 3D model into the top-down view of image **402**. Changes that the operator makes to wire frame **611** are concurrently displayed by the roof estimation system as wire frame **612** in image portion **609**. For example, if a new planar roof section is added by the operator to wire frame **611**, the new planar roof section is automatically displayed in wire frame **612**. By concurrently displaying operator identified features in multiple views of building roof **407**, the operator obtains feedback regarding the correctness and/or accuracy of the 3D model or other aspects of the model generation process, such as image registration and pitch determination.

Generally, the roof estimation system can be configured to concurrently display any operator-identified features, such as corners, ridges, valleys, planar sections, and the like, in multiple views of a building.

Furthermore, the concurrently displayed wire frame **612** is an interactive user interface element, in that the operator can make changes to the wire frame **612**, which are then concurrently displayed in wire frame **611**. Wire frames similar to those described above are also projected by the roof estimation system into images **403**, **404**, and **405** displayed by the user interface screen **400**. In this manner, the operator can switch between various images of the building roof **407**, making refinements to the 3D model by adjusting the wire frame in whichever image is more convenient and/or provides a more suitable perspective/view of the model.

FIG. **6**D shows the user interface screen **400** during construction of a 3D model of the building roof **407**. In particular, the user interface **400** includes a shaded wire frame **613** representation of the 3D model constructed as described above. In this view, the operator can review the wire frame **613** in isolation from any images to determine whether the

wire frame **613** accurately represents the building roof **407**. The wire frame **613** is an interactive user interface component, in that it can be directly manipulated (e.g., moved, rotated, resized, etc.). In some embodiments, manipulating the wire frame **613**, such as by changing its shape, results in corresponding changes in the underlying 3D model.

C. Roof Model Review

FIGS. **7**A-**7**C are screen displays illustrating roof model review in an example embodiment. In particular, FIGS. **7**A-**7**C illustrate various techniques to facilitate the review of a roof model by an operator. Reviewing the roof model may include reviewing roof section pitches (e.g., to determine whether they conform to the building roof and/or standard construction practices), reviewing the shape and/or location of the roof model (e.g., to determine whether it substantially conforms to the building roof), etc.

FIG. **7**A shows the user interface screen **400** after the operator has constructed a model of the roof **407** using one or more of the images **402**-**406**. In this example, a wire frame has been projected onto (superimposed upon) image **402** and annotated with roof section pitches, as will be described further with respect to enlarged portion **708** of image **402** in FIG. **7**B, below.

FIG. **7**B is an enlarged view of image portion **708** during the process of roof model review in the context of image **402**, which provides a substantially top plan view of the building roof **407**. As shown in FIG. **7**B, the image portion **708** includes a wire frame **710** and labels **711***a*-**711***c* that indicate pitches of corresponding sections of roof **407**. The wire frame **710** and the illustrated pitches are determined by the roof estimation system based on the pitch determination described with respect to FIGS. **5**A-**5**D, above, and the operator's specification of the wire frame model described with respect to FIGS. **6**A-**6**D, above.

The wire frame **710** includes multiple vertexes connected by line segments. Each vertex includes a handle, such as handle **710***a*. The handles may be directly manipulated (individually or in groups) by the operator to make adjustments/modifications to the wire frame **710**. For example, when an operator drags handle **710***a* to a new location, the ends of the two line segments connected to handle **710***a* will also move to the new location.

FIG. **7**C is an alternative view of the 3D model of roof **407** during the process of roof model review. In FIG. **7**C, the user interface screen **400** includes a wire frame **720** representation of the 3D model of the roof **407**. The wire frame **720** consists of multiple line segments corresponding to edges of planar roof sections. Each line segment is annotated with a label, such as label **723**, indicating the determined length of the corresponding roof section edge. Furthermore, some of the line segments indicate that they correspond to a particular roof feature. For example, line segments **721** and **722** may be colored (e.g., red) so as to indicate that they correspond to roof ridges. Other line segments may be differently colored (e.g., blue) so as to indicate a correspondence to roof valleys or other features. In addition, the wire frame **720** may be directly manipulated by the operator in order to make adjustments to the underlying model of the roof **407**. For example, the operator could increase or decrease the length of line segment **721**, resulting in a change in the corresponding feature of the 3D model of roof **407**.

Note that although the operator is shown, in FIGS. **5**-**7** above, operating upon a total of five images, in other cases, fewer images may be used. For example, in some cases fewer images may be available, or some images may provide obstructed views of the building roof, such as due to tree cover, neighboring buildings, etc.

3. Implementation Techniques

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system. FIG. **8** shows a computing system **800** that may be utilized to implement a Roof Estimation System ("RES") **810**. One or more general purpose or special purpose computing systems may be used to implement the RES **810**. More specifically, the computing system **800** may comprise one or more distinct computing systems present at distributed locations. In addition, each block shown may represent one or more such blocks as appropriate to a specific embodiment or may be combined with other blocks. Moreover, the various blocks of the RES **810** may physically reside on one or more machines, which use standard inter-process communication mechanisms (e.g., TCP/IP) to communicate with each other. Further, the RES **810** may be implemented in software, hardware, firmware, or in some combination to achieve the capabilities described herein.

In the embodiment shown, computing system **800** comprises a computer memory ("memory") **801**, a display **802**, one or more Central Processing Units ("CPU") **803**, Input/Output devices **804** (e.g., keyboard, mouse, joystick, track pad, CRT or LCD display, and the like), other computer-readable media **805**, and network connections **806**. The RES **810** is shown residing in memory **801**. In other embodiments, some portion of the contents, some of, or all of the components of the RES **810** may be stored on and/or transmitted over the other computer-readable media **805**. The components of the RES **810** preferably execute on one or more CPUs **803** and generate roof estimate reports, as described herein. Other code or programs **830** (e.g., a Web server, a database management system, and the like) and potentially other data repositories, such as data repository **820**, also reside in the memory **801**, and preferably execute on one or more CPUs **803**. Not all of the components in FIG. **8** are required for each implementation. For example, some embodiments embedded in other software do not provide means for user input, for display, for a customer computing system, or other components.

In a typical embodiment, the RES **810** includes an image acquisition engine **811**, a roof modeling engine **812**, a report generation engine **813**, an interface engine **814**, and a roof estimation system data repository **816**. Other and/or different modules may be implemented. In addition, the RES **810** interacts via a network **850** with an image source computing system **855**, an operator computing system **865**, and/or a customer computing system **860**.

The image acquisition engine **811** performs at least some of the functions of the image acquisition engine **101** described with reference to FIG. **1**. In particular, the image acquisition engine **811** interacts with the image source computing system **855** to obtain one or more images of a building, and stores those images in the RES data repository **816** for processing by other components of the RES **810**. In some embodiments, the image acquisition engine **811** may act as an image cache manager, such that it preferentially provides images to other components of the RES **810** from the RES data repository **816**, while obtaining images from the image source computing system **855** when they are not already present in the RES data repository **816**. In other embodiments, images may be obtained in an "on demand" manner, such that they are provided, either by the image acquisition engine **811** or the image source computing system **855**, directly to modules of the RES **810** and/or the operator computing system **865**, without intervening storage in the RES data repository **816**.

The roof modeling engine **812** performs at least some of the functions of the roof modeling engine **102** described with reference to FIG. **1**. In particular, the roof modeling engine **812** generates a model based on one or more images of a building that are obtained from the RES data repository **816** or directly from the image source computing system **855**. As noted, model generation may be performed semi-automatically, based on at least some inputs received from the computing system **865**. In addition, at least some aspects of the model generation may be performed automatically, based on image processing and/or image understanding techniques. After the roof modeling engine **812** generates a model, it stores the generated model in the RES data repository **816** for further processing by other components of the RES **810**.

The report generation engine **813** performs at least some of the functions of the report generation engine **103** described with reference to FIG. **1**. In particular, the report generation engine **813** generates roof reports based on models stored in the RES data repository **816**. Generating a roof report may include preparing one or more views of a given 3D model of a roof, annotating those views with indications of various characteristics of the model, such as dimensions of sections or other features (e.g., ridges, valleys, etc.) of the roof, slopes of sections of the roof, areas of sections of the roof, etc. In some embodiments, the report generation engine **813** facilitates transmission of roof measurement information that may or may not be incorporated into a roof estimate report. For example, the roof generation engine **813** may transmit roof measurement information based on, or derived from, models stored in the RES data repository **816**. Such roof measurement information may be provided to, for example, third-party systems that generate roof estimate reports based on the provided information.

The interface engine **814** provides a view and a controller that facilitate user interaction with the RES **810** and its various components. For example, the interface engine **814** implements a user interface engine **104** described with reference to FIG. **1**. Thus, the interface engine **814** provides an interactive graphical user interface that can be used by a human user operating the operator computing system **865** to interact with, for example, the roof modeling engine **812**, to perform functions related to the generation of models, such as point registration, feature indication, pitch estimation, etc. In other embodiments, the interface engine **814** provides access directly to a customer operating the customer computing system **860**, such that the customer may place an order for a roof estimate report for an indicated building location. In at least some embodiments, access to the functionality of the interface engine **814** is provided via a Web server, possibly executing as one of the other programs **830**.

In some embodiments, the interface engine **814** provides programmatic access to one or more functions of the RES **810**. For example, the interface engine **814** provides a programmatic interface (e.g., as a Web service, static or dynamic library, etc.) to one or more roof estimation functions of the RES **810** that may be invoked by one of the other programs **830** or some other module. In this manner, the interface engine **814** facilitates the development of third-party software, such as user interfaces, plug-ins, adapters (e.g., for integrating functions of the RES **810** into desktop applications, Web-based applications, embedded applications, etc.), and the like. In addition, the interface engine **814** may be in at least some embodiments invoked or otherwise accessed via remote entities, such as the operator computing system **865**, the image source computing system **855**, and/or the customer computing system **860**, to access various roof estimation functionality of the RES **810**.

The RES data repository **816** stores information related the roof estimation functions performed by the RES **810**. Such information may include image data **105**, model data **106**, and/or report data **107** described with reference to FIG. **1**. In addition, the RES data repository **816** may include information about customers, operators, or other individuals or entities associated with the RES **810**.

In an example embodiment, components/modules of the RES **810** are implemented using standard programming techniques. For example, the RES **810** may be implemented as a "native" executable running on the CPU **803**, along with one or more static or dynamic libraries. In other embodiments, the RES **810** is implemented as instructions processed by virtual machine that executes as one of the other programs **830**. In general, a range of programming languages known in the art may be employed for implementing such example embodiments, including representative implementations of various programming language paradigms, including but not limited to, object-oriented (e.g., Java, C++, C#, Matlab, Visual Basic.NET, Smalltalk, and the like), functional (e.g., ML, Lisp, Scheme, and the like), procedural (e.g., C, Pascal, Ada, Modula, and the like), scripting (e.g., Perl, Ruby, Python, JavaScript, VBScript, and the like), declarative (e.g., SQL, Prolog, and the like).

The embodiments described above may also use well-known synchronous or asynchronous client-server computing techniques. However, the various components may be implemented using more monolithic programming techniques as well, for example, as an executable running on a single CPU computer system, or alternatively decomposed using a variety of structuring techniques known in the art, including but not limited to, multiprogramming, multithreading, client-server, or peer-to-peer, running on one or more computer systems each having one or more CPUs. Some embodiments execute concurrently and asynchronously, and communicate using message passing techniques. Equivalent synchronous embodiments are also supported by an RES implementation. Also, other functions could be implemented and/or performed by each component/module, and in different orders, and by different components/modules, yet still achieve the functions of the RES.

In addition, programming interfaces to the data stored as part of the RES **810**, such as in the RES data repository **816**, can be available by standard mechanisms such as through C, C++, C#, and Java APIs; libraries for accessing files, databases, or other data repositories; through scripting languages such as XML; or through Web servers, FTP servers, or other types of servers providing access to stored data. For example, the RES data repository **816** may be implemented as one or more database systems, file systems, memory buffers, or any other technique for storing such information, or any combination of the above, including implementations using distributed computing techniques.

Also, the example RES **810** can be implemented in a distributed environment comprising multiple, even heterogeneous, computer systems and networks. For example, in one embodiment, the image acquisition engine **811**, the roof modeling engine **812**, the report generation engine **813**, the interface engine **814**, and the data repository **816** are all located in physically different computer systems. In another embodiment, various modules of the RES **810** are hosted each on a separate server machine and are remotely located from the tables which are stored in the data repository **816**. Also, one or more of the modules may themselves be distributed, pooled or otherwise grouped, such as for load balancing, reliability or security reasons. Different configurations and locations of programs and data are contemplated for use with techniques

of described herein. A variety of distributed computing techniques are appropriate for implementing the components of the illustrated embodiments in a distributed manner including but not limited to TCP/IP sockets, RPC, RMI, HTTP, Web Services (XML-RPC, JAX-RPC, SOAP, and the like).

Furthermore, in some embodiments, some or all of the components of the RES are implemented or provided in other manners, such as at least partially in firmware and/or hardware, including, but not limited to one or more application-specific integrated circuits (ASICs), standard integrated circuits, controllers (e.g., by executing appropriate instructions, and including microcontrollers and/or embedded controllers), field-programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs), and the like Some or all of the system components and/or data structures may also be stored (e.g., as software instructions or structured data) on a computer-readable medium, such as a hard disk, a memory, a network, or a portable media article to be read by an appropriate drive or via an appropriate connection. The system components and data structures may also be stored as data signals (e.g., by being encoded as part of a carrier wave or included as part of an analog or digital propagated signal) on a variety of computer-readable transmission mediums, which are then transmitted, including across wireless-based and wired/cable-based mediums, and may take a variety of forms (e.g., as part of a single or multiplexed analog signal, or as multiple discrete digital packets or frames). Such computer program products may also take other forms in other embodiments. Accordingly, embodiments of this disclosure may be practiced with other computer system configurations.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment. The illustrated routine **900** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **900** facilitates image registration based upon operator indicated registration points and/or image lean corrections.

More specifically, the routine begins in step **901**, where it displays, on a user interface screen, an aerial image of a building having a roof. As part of the user interface screen, the routine also displays user interface controls such as markers that may be used by an operator for purposes of image registration and/or lean correction, as described with reference to FIG. **4**A, above.

In step **902**, the routine receives, via one or more registration markers, indications of one or more points on the aerial image. The registration markers are manipulated by the operator to specify points on the aerial image, as described with reference to FIGS. **4**A-**4**E. Typically, the points are visually identifiable features, such as corners of the roof of the building. For example, if the roof has four corners (e.g., a northwest, southwest, northeast, and southwest corner) the operator may place one registration marker on each of the four corners as shown in the aerial image. Then, the positions (e.g., coordinates on the aerial image) of the markers are transmitted to the routine for use in registering the aerial image, as described below.

In step **903**, the routine receives, via a lean correction marker, an indication of the vertical axis of the building roof. In at least some cases, the aerial image of the building is out of alignment with respect to the vertical axis of the building. This may be caused, for example, by pitch, roll, and/or yaw experienced by the aircraft during the process of photographing the building. To correct for such misalignment, the lean correction marker is manipulated by the operator to indicate a vertical axis of the building. Typically, the operator aligns the lean correction marker with known, substantially vertical feature of the building, such as a chimney, wall corner, etc., as described with reference to FIG. **4**E, above. After the operator has aligned the lean correction marker, the position (e.g., angle of the marker, coordinates of the endpoints of the marker, etc.) of the lean correction marker is transmitted to the routine for use in registering the aerial image, as described below.

Particular benefits may be obtained from lean correction performed in the context of an overhead, or "top down," view. An "overhead lean" occurs when the camera is not directly overhead with respect to the building when the photo is taken. In some cases, leans in excess of 5 degrees have been observed in "top down" photos. Furthermore, unlike oblique, perspective views, a top-down lean is typically less likely to include a convenient visual marker that provides sufficient angle to assess the lean direction and magnitude, such as the edge of the building or a tall chimney. An overhead lean affects the perceived location of the roof lines in a top down view. This effect is amplified as the pitch of the roof increases and/or as the vertical separation between disconnected roof sections increases. Without lean correction, superimposing a wire frame over the visible ridgelines (and other features of a building that reside at different elevations) may produce asymmetries in otherwise symmetric structures. Further, an absence of lean correction may introduce errors in pitch estimation, as the wire frame may not appear consistent between top and oblique view points. More specifically, without top view lean correction, the positions for the roof lines in an otherwise correct (i.e., accurate with respect to the actual geometry of the roof) wire frame will typically not line up on the visible roof lines in the overhead reference photo. This often leads the user (or software) to either introduce errors by incorrectly drawing the wire frame to the image lines or perform a subjective determination of where and how to shift the wire frame lines off the image lines to produce a correct model. Top view lean correction allows the roof estimation system to trace to, or substantially to, the actual roof lines seen in the top image while still producing an accurate wire frame model.

Image misalignment may be specified in other ways. For example, in other embodiments, the operator may instead rotate the image to a position in which the building appears to be in a substantially vertical position. Then, the angle of rotation of the image may be transmitted to the routine for use in registering the aerial image.

In step **904**, the routine registers, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid. Registering the image to a reference grid may include determining a transformation between the reference grid and the image, based on the indicated points and/or the indicated vertical axis. Determining such a transformation may be based on other information as well, such as meta-information associated with the aerial image. In some embodiments, the aerial image has corresponding meta-information that includes image capture conditions, such as camera type, focal length, time of day, camera position (e.g., latitude, longitude, and/or elevation), etc.

In step **905**, the routine determines whether there are additional aerial images to be registered, and if so, returns to step **901**, else proceeds to step **906**. During execution of the loop of steps **901-905**, the operator typically indicates, for each registration marker, the same feature (e.g., corner) of the roof as shown in each of multiple images, such that the routine can register the multiple images to a single, uniform reference grid. Upon completion of the registration process, the routine has determined a uniform coordinate system for the multiple

aerial images, for use during other phases of model construction, such as pitch determination or feature identification.

In step **906**, the routine generates a three-dimensional model based at least in part on the aerial image(s) and the reference grid. As discussed above with reference to FIGS. **5**A-**5**D and **6**A-**6**D, model generation includes identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. In other embodiments, the routine performs other functions with the registered images, such as storing them for later use (e.g., by an automated model generation module), transmitting them to another computing (e.g., for use in a third-party design application), etc. After step **906**, the routine ends.

Note that in at least some embodiments, aspects of the routine **900** may be performed in an automated manner. For example, operations discussed above as being performed by an operator, such as the determination of the location of image registration points of step **902** and/or the indication of lean of step **903**, may be performed by automated image processing techniques.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment. The illustrated routine **1000** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1000** facilitates the determination of the pitch of a section of a roof, by displaying a pitch determination marker and modifying a 3D model of a roof based on an indication of roof pitch received via the pitch determination marker.

More specifically, the routine begins at step **1001** where it displays an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch. The aerial image is displayed in the context of a user interface screen, such as is described with reference to FIGS. **4**A-**6**C, above. The aerial images may be received from, for example, the image source computing system **855** and/or from the RES data repository **816** described with reference to FIG. **8**. As discussed above, aerial images may be originally created by cameras mounted on airplanes, balloons, satellites, etc. In some embodiments, images obtained from ground-based platforms (e.g., vehicle-mounted cameras) may be used instead or in addition.

In step **1002**, the routine displays a pitch determination marker operable to indicate pitch of a planar roof section. The pitch determination marker may be, for example, a pitch determination marker **510** ("protractor tool") or **520** ("envelope tool"), such as are respectively described with respect to FIGS. **5**B and **5**C, above. The routine displays the pitch determination marker by, for example, presenting it on a user interface screen displayed on a computer monitor or other display device. The pitch determination marker is a direct manipulation user interface control, in that an operator may manipulate it (e.g., adjust an angle, change its shape, alter its position, etc.) in order to indicate pitch of a planar roof section. Additional details regarding pitch determination controls are provided with respect to FIGS. **5**A-**5**D, above.

In step **1003**, the routine receives, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building. Receiving an indication of the pitch includes receiving an indication (e.g., via an event, callback, etc.) that the marker has been manipulated by the operator, and then determining an angle based on the shape and/or position of the marker. In some embodiments, such an indication may be received on an event driven basis, such as every time the marker is manipulated in some manner. In other embodiments, the routine may poll the marker from time to time to determine its current state. In addition, the operator may explicitly indicate that the current state of the marker is to be transmitted to the routine, such as by pressing a button or other indication.

In step **1004**, the routine modifies a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section. Modifying the 3D model of the roof includes associating the indicated pitch with a portion of the model corresponding to the one planar roof section. For example, the 3D model may include one or more data structures representing planar roof sections, and the indicated pitch may be included as part of the data structure representing the one planar roof section. In some embodiments, the 3D model may not at this point include representations of the planar roof sections, such as because the operator has not yet specified them. In such a case, the routine may store the indicated pitch in association with the location and orientation at which the pitch was specified by the operator, as determined from the aerial image. Then, at a later time, when the operator specifies a roof section that has the same orientation as the stored pitch and that includes or is near the stored location, the roof estimation system can store the indicated pitch in association with the specified roof section.

After step **1004**, the routine ends. In other embodiments, the routine may instead return to step **1001**, to determine the pitch for another planar roof section (of the same or different roof).

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment. The illustrated routine **1100** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1100** concurrently displays operator indicated features in multiple aerial images of a building roof.

More specifically, the routine begins in step **1101**, where it displays a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building. The aerial images are displayed in the context of a user interface screen, such as is described with reference to FIGS. **6**A-**6**C, above.

In step **1102**, the routine receives an indication of a feature of the building shown in the first aerial image. The indication is typically received via a user interface control, such as a drawing tool or marker, upon its manipulation by an operator. For example, the operator may manipulate a drawing tool in order to specify one or more features of the building roof, such as a corner on the roof, an edge of the roof, an outline of a section of the roof, etc. In one embodiment, the operator utilizes a drawing tool to indicate roof section corner points and roof section edges connecting those corner points. Additional details regarding feature indication are provided with respect to FIGS. **6**A-**6**C, above.

In step **1103**, the routine modifies a three-dimensional model of the roof based on the received indication of the feature of the building. Modifying the 3D model may include adding or updating the indicated feature to a wire frame model of the roof. For example, if the indicated feature is a roof section corner point, the corner point will be added to the 3D model, along with the location (e.g., the X, Y, and Z position of the point) of the point. The location of the point is automatically determined based on a translation of the position of the point in the image to a point in the uniform reference grid associated with the image. If the indicated feature is a roof section edge, the edge will be added to the 3D model, such as by associating the edge with two points corresponding to the end points of the edge. Higher-level features can also be indicated. For example, a planar roof section may be indicated by "closing" a sequence of two or more connected line segments, to create a closed polygon that represents the outline or perimeter of the planar roof section.

In step **1104**, the routine concurrently displays a projection of the feature from the modified three-dimensional model onto the first and second aerial images. In one embodiment, displaying the feature from the modified three-dimensional model includes projecting the three-dimensional model onto both the first and second aerial images. For example, if the first image (for which the indicated feature was received) provides a west view of the building, and the second image provides an east view of the building, the routine will concurrently display a projection of the indicated feature from the 3D model onto both the first and second images. The projection of the indicated feature into the second image is based at least in part on a translation from the position of the feature in the reference grid to a position in the second image. In addition, the concurrent display onto two or more images occurs at substantially the same time (within a short time interval, at times that are substantially coincident) as the indication of the feature of the building in step **1102**, giving the operator the illusion that as they are indicating a feature in the first image, the feature is being simultaneously projected into the second image.

After step **1104**, the routine ends. In other embodiments, the routine may instead return to step **1101**, to perform an interactive loop of steps **1101-1104** with the operator, so that the routine can concurrently display multiple features as they are indicated by the operator. Note that in such an embodiment, each iteration of the loop of steps **1101-1104** may be performed at near real-time speeds, so as to provide a fluid, interactive model generation experience for the operator enabling the operator to drag, draw, or otherwise indicate/manipulate features in a first image and view the results of their work concurrently projected into a second image.

All of the above U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, including but not limited to U.S. Provisional Patent Application No. 61/197,904, entitled "USER INTERFACE SYSTEMS AND METHODS FOR ROOF ESTIMATION," filed Oct. 31, 2008, are incorporated herein by reference, in their entireties.

From the foregoing it will be appreciated that, although specific embodiments have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the present disclosure. For example, the methods, systems, and techniques for generating and providing roof estimate reports discussed herein are applicable to other architectures other than the illustrated architecture or a particular roof estimation system implementation. Also, the methods and systems discussed herein are applicable to differing network protocols, communication media (optical, wireless, cable, etc.) and devices (such as wireless handsets, electronic organizers, personal digital assistants, portable email machines, game machines, pagers, navigation devices such as GPS receivers, etc.). Further, the methods and systems discussed herein may be utilized by and/or applied to other contexts or purposes, such as by or for solar panel installers, roof gutter installers, awning companies, HVAC contractors, general contractors, and/or insurance companies.

The invention claimed is:

1. A computer-implemented method for generating a roof estimate report, the method comprising:

displaying a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building;

receiving an indication of a feature of the building shown in the first aerial image;

modifying a three-dimensional model of the roof based on the received indication of the feature of the building; and

displaying a projection of the feature from the modified three-dimensional model onto the first and second aerial images as a line drawing of the feature, each overlaid on corresponding locations of the feature on the first and second aerial images.

2. The method of claim **1** wherein modifying the three-dimensional model of the roof includes adding a planar roof section to the three-dimensional model.

3. The method of claim **1** wherein the indicated feature is at least one of: a point on the roof, a section of the roof, a ridgeline of the roof, a valley of the roof, a rake edge of the roof, an eave of the roof, a hip ridge of the roof, an edge of a section of the roof, and a corner of a section of the roof.

4. The method of claim **1** wherein displaying the projection of the feature comprises:

displaying the feature in the first aerial image at a first time; and

displaying the feature in the second aerial image at a second time that is substantially coincident to the first time.

5. The method of claim **1** wherein receiving the indication of the feature of the building occurs at a first time, and wherein displaying the projection of the feature occurs at a second time that is substantially coincident to the first time.

6. The method of claim **1** wherein displaying the projection of the feature includes initiating display of a line on the first and second image.

7. The method of claim **1** wherein the first image provides a substantially top plan view of the roof of the building, and wherein the second image provides a perspective view of the roof of the building.

8. The method of claim **1** wherein the first image provides a first perspective view of the roof of the building and the second image provides a second perspective view of the roof of the building.

9. The method of claim **1** further comprising:

transmitting roof measurement information based at least in part on the modified three-dimensional model.

10. The method of claim **1** further comprising:

displaying a marker operable to specify a point on an image;

receiving, via the marker, an indication of a point on the first aerial image; and

registering, based on the received indication of the point, the aerial image to a reference grid corresponding to the three-dimensional model.

11. The method of claim **1** further comprising:

displaying a lean correction marker operable to indicate a vertical axis of an aerial image;

receiving, via the lean correction marker, an indication of a vertical axis of the first aerial image; and

registering, based on the received indication of the vertical axis, the first aerial image to a reference grid corresponding to the three-dimensional model.

12. A computing system for generating a roof estimate report, the computing system comprising:

a memory;

a roof estimation module that is stored on the memory and that is configured, when executed, to:

display a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building;

receive an indication of a feature of the building shown in the first aerial image;

modify a three-dimensional model of the roof based on the received indication of the feature of the building;

display a projection of the feature from the modified three-dimensional model onto the first and second aerial images as a line drawing of the feature, each overlaid on corresponding locations of the feature on the first and second aerial images;

transmit roof measurement information based at least in part on the modified three-dimensional model.

13. The computing system of claim **12** wherein the roof estimation module includes an interactive roof modeling user interface.

14. The computing system of claim **12** wherein the computing system is a desktop computer and the roof estimation module is part of an interactive roof modeling program executing on the computing system.

15. The computing system of claim **12** wherein the roof estimation module is part of a network accessible roof modeling program executing on the computing system.

16. A non-transitory computer-readable storage medium whose contents enable a computing system to generate a roof estimate report for a building having a roof, by performing a method comprising:

receiving an indication of a feature of the building shown in a first aerial image that provides a first view of the roof of the building;

modifying a three-dimensional model of the roof based on the received indication of the feature of the building; and

in response to the receiving of the indication of the feature of the building, displaying a projection of the feature from the modified three-dimensional model onto a second aerial image that provides a second view of the roof of the building as a line drawing of the feature, each overlaid on corresponding locations of the feature on the first and second aerial images.

17. The non-transitory computer-readable storage medium of claim **16** wherein modifying the three-dimensional model of the roof includes adding a planar roof section to the three-dimensional model.

18. The non-transitory computer-readable storage medium of claim **16** wherein receiving an indication of the feature of the building includes receiving position information of the feature in the first aerial image, and wherein concurrently displaying the projection of the feature includes:

translating the received position information into position information of the feature in the three-dimensional model; and

translating the position information of the feature in the three-dimensional model into position information of the feature in the second aerial image.

19. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature comprises:

displaying the feature in the first aerial image at a first time; and

displaying the feature in the second aerial image at a second time that is within two seconds of the first time.

20. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature includes displaying the projection of the feature concurrently with receiving of the indication of the feature of the building.

21. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature includes displaying the projection of the feature at substantially the same time as receiving the indication of the feature of the building.

22. The non-transitory computer-readable storage medium of claim **16** wherein the method is performed iteratively, and the method further comprising:

providing an operator with an interactive model generation experience.

23. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature includes initiating display of a line on the first and second image.

24. The non-transitory computer-readable storage medium of claim **16** wherein the first image provides a perspective view of the roof of the building, and wherein the second image provides a substantially top plan view of the roof of the building.

25. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises:

generating a roof estimate report based at least in part on the modified three-dimensional model.

* * * * *

EXHIBIT 7

US008542880B2

(12) **United States Patent**
Thornberry et al.

(10) **Patent No.: US 8,542,880 B2**
(45) **Date of Patent: *Sep. 24, 2013**

(54) **SYSTEM AND PROCESS FOR ROOF MEASUREMENT USING AERIAL IMAGERY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

(63) Continuation of application No. 12/470,984, filed on May 22, 2009, now Pat. No. 8,401,222.

(51) **Int. Cl.**
G06K 9/00 (2006.01)

(52) **U.S. Cl.**
USPC **382/103**

(58) **Field of Classification Search**
USPC 345/423–426; 703/1–9; 382/100–107; 715/835–838; 340/990–995.27
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2009/0141020 A1 * 6/2009 Freund et al. 345/419

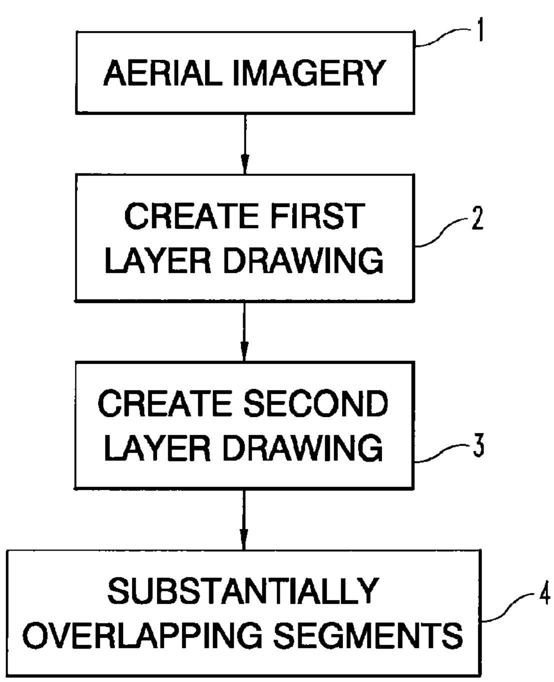
* cited by examiner

Primary Examiner — Atiba O Fitzpatrick
(74) *Attorney, Agent, or Firm* — Dunlap Codding, P.C.

(57) **ABSTRACT**

Processes and systems are disclosed for determining attributes of a roof structure of real-world three-dimensional building(s), including providing computer input field(s) for a user to input location data generally corresponding to the location of the building, providing visual access to a nadir image of a region including the roof structure of the building; on the nadir image of the region, providing a visual marker that is moveable on the computer monitor around the region, the visual marker initially corresponding to the location data but which may be moved to a final location, having location coordinates, on top of the building to more precisely identify the location of the building roof structure; providing a computer input capable of signaling user-acceptance of the final location of the marker; and, providing visual access to one or more oblique images of an aerial imagery database corresponding to location coordinates of the final location.

20 Claims, 21 Drawing Sheets



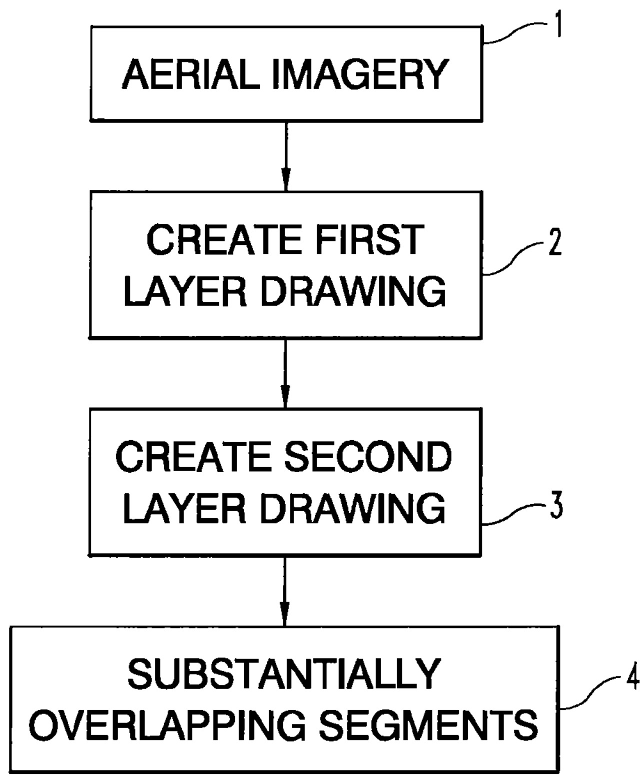
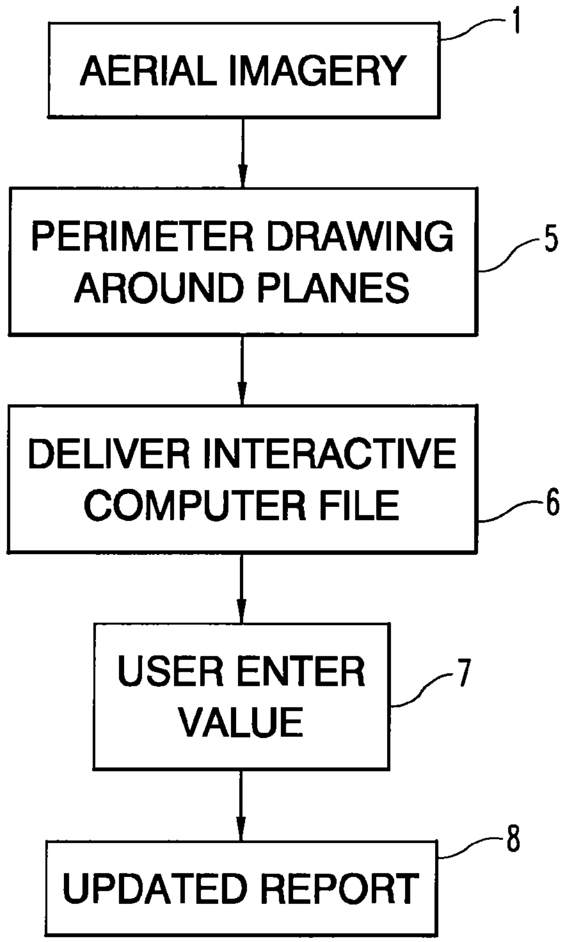

AERIAL IMAGERY
1
CREATE FIRST LAYER DRAWING
2
CREATE SECOND LAYER DRAWING
3
SUBSTANTIALLY OVERLAPPING SEGMENTS
4

Fig. 1



AERIAL IMAGERY
1
PERIMETER DRAWING AROUND PLANES
5
DELIVER INTERACTIVE COMPUTER FILE
6
USER ENTER VALUE
7
UPDATED REPORT
8

Fig. 2

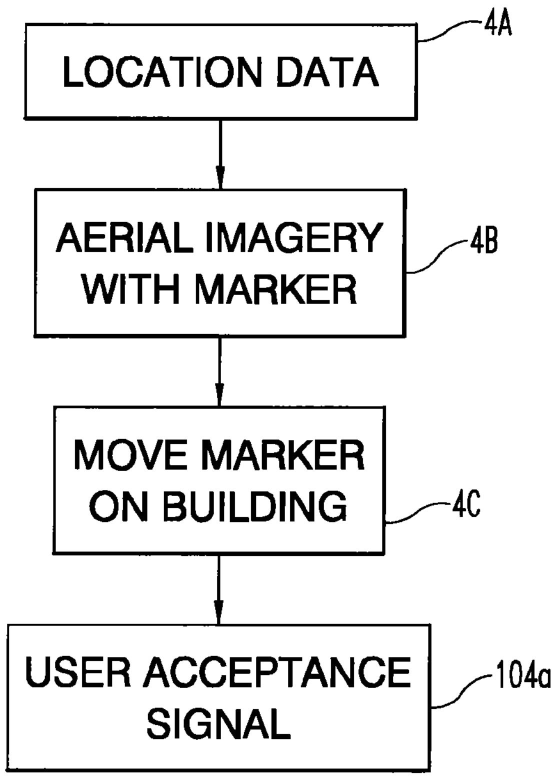
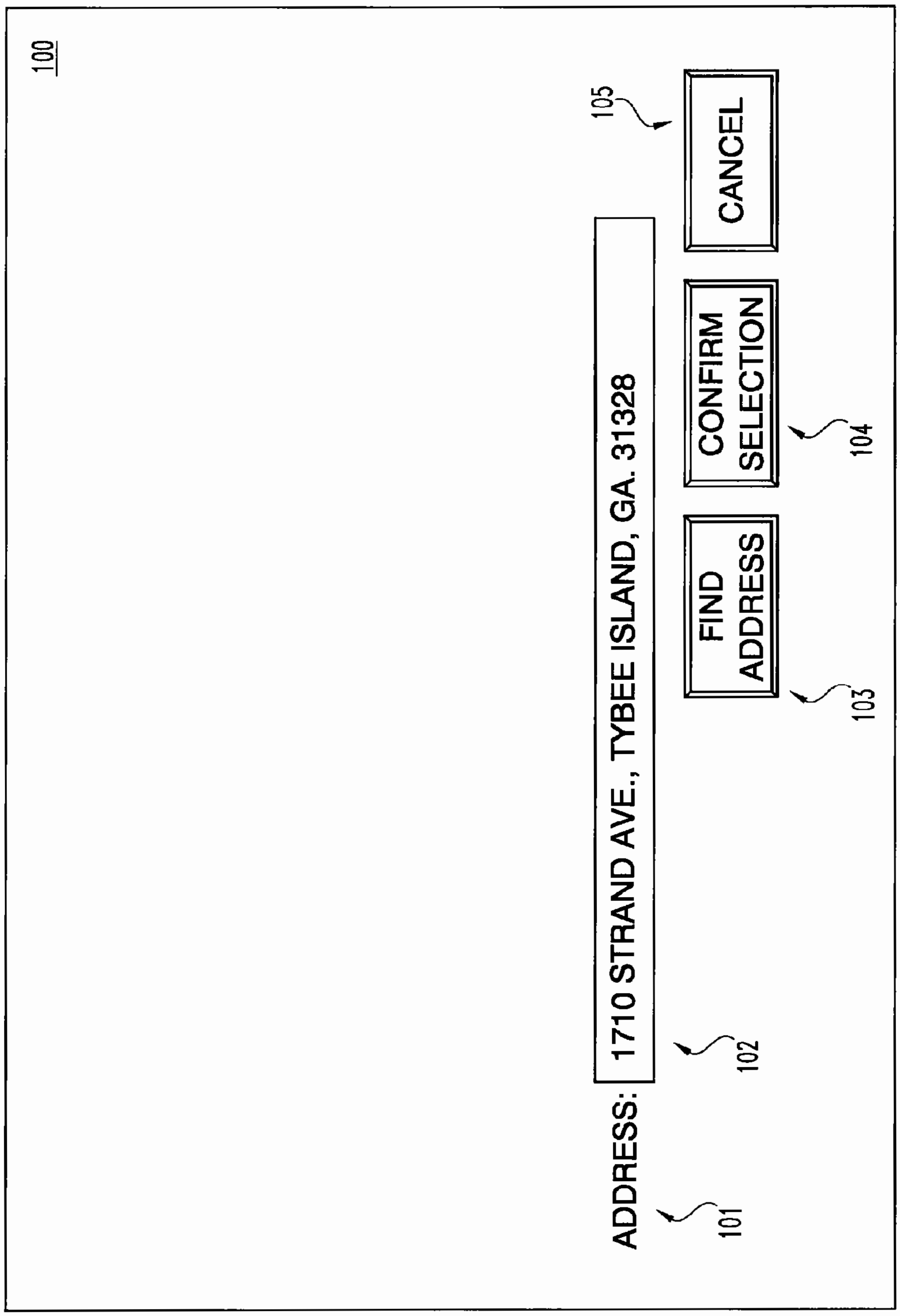

LOCATION DATA
4A
AERIAL IMAGERY WITH MARKER
4B
MOVE MARKER ON BUILDING
4C
USER ACCEPTANCE SIGNAL
104a

Fig. 3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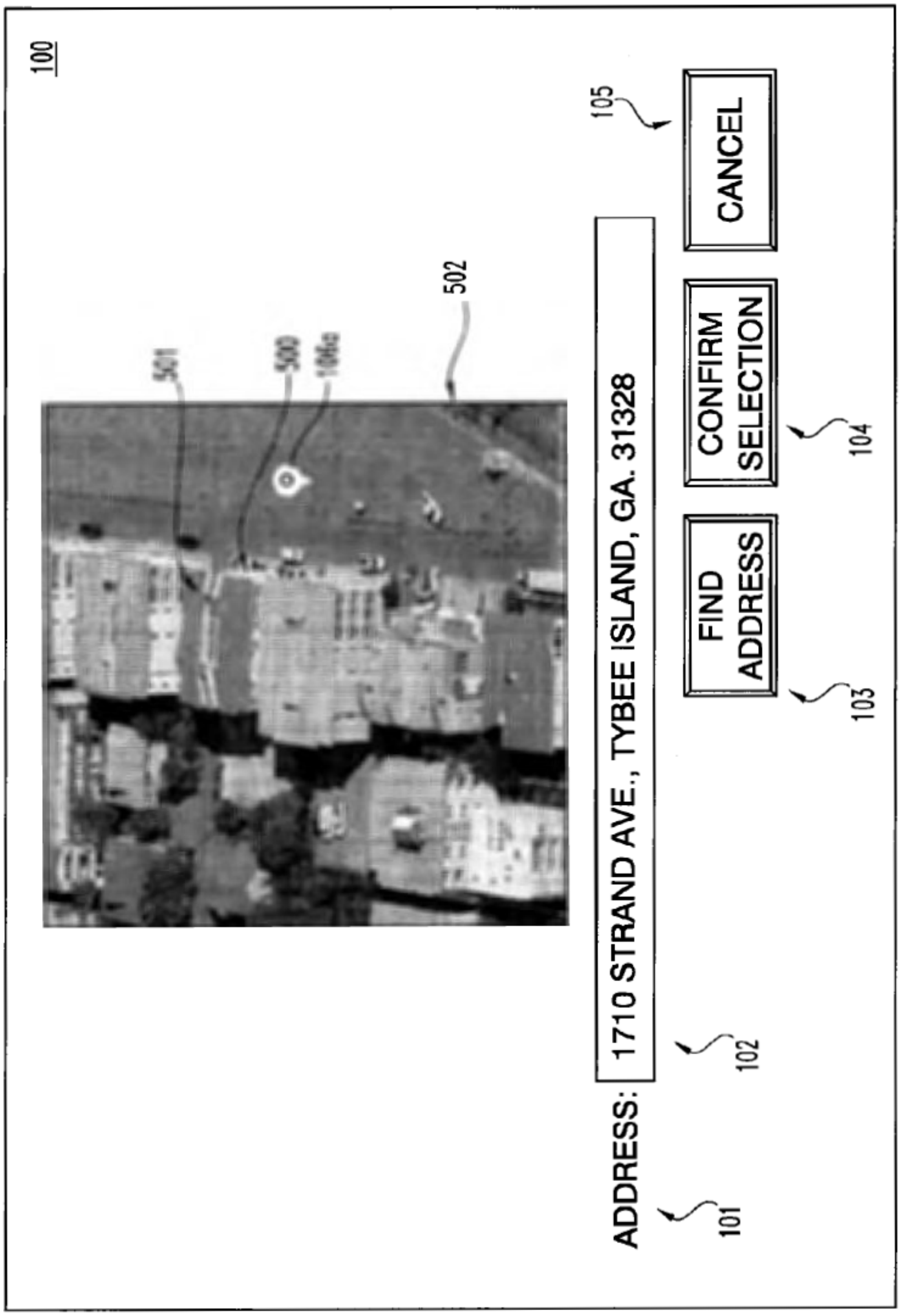
ADDRESS:
1710 STRAND AVE., TYBEE ISLAND, GA. 31328
101
102
FIND ADDRESS
103
CONFIRM SELECTION
104
CANCEL
105

Fig. 4A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500
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102
101

Fig. 4B

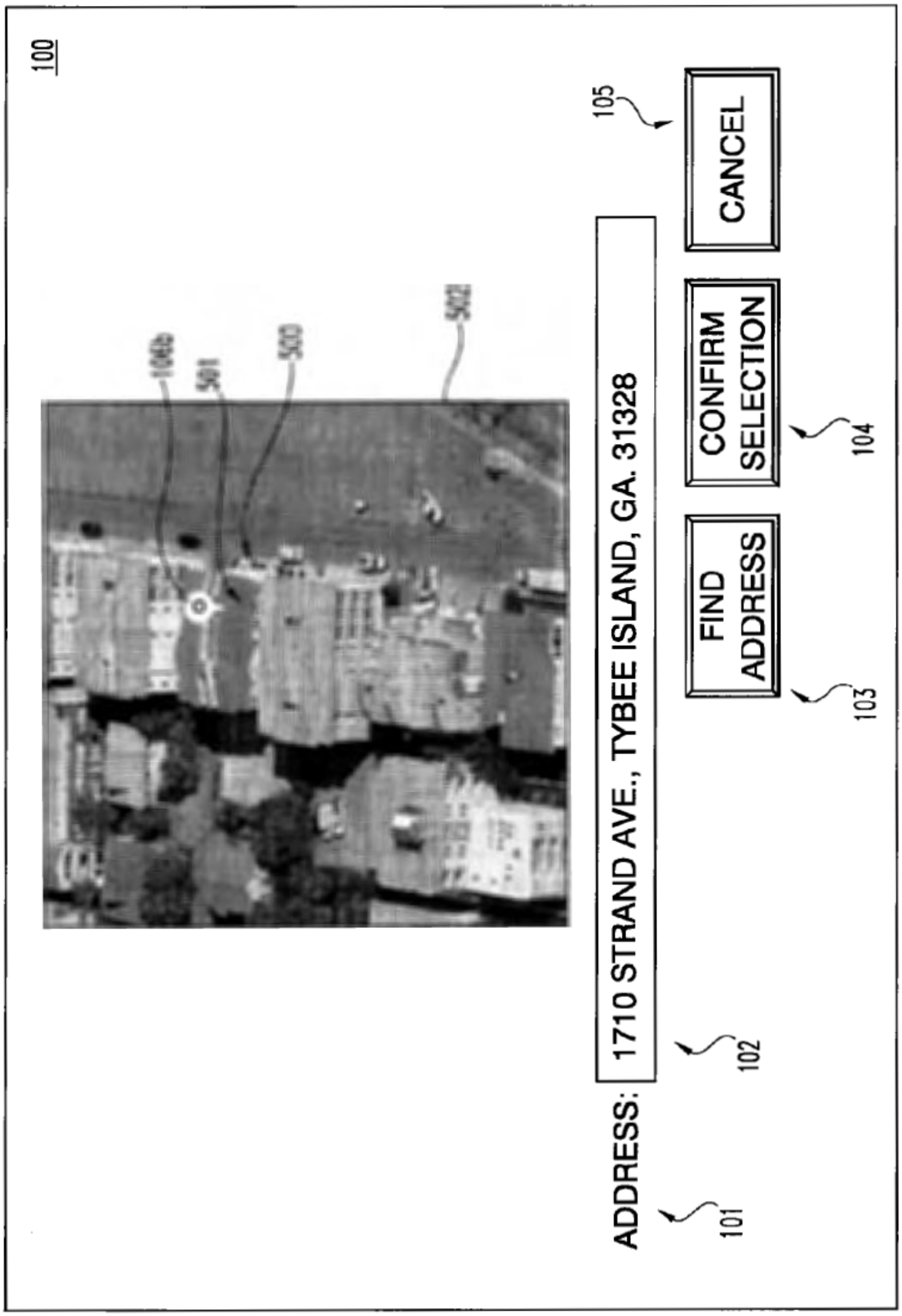
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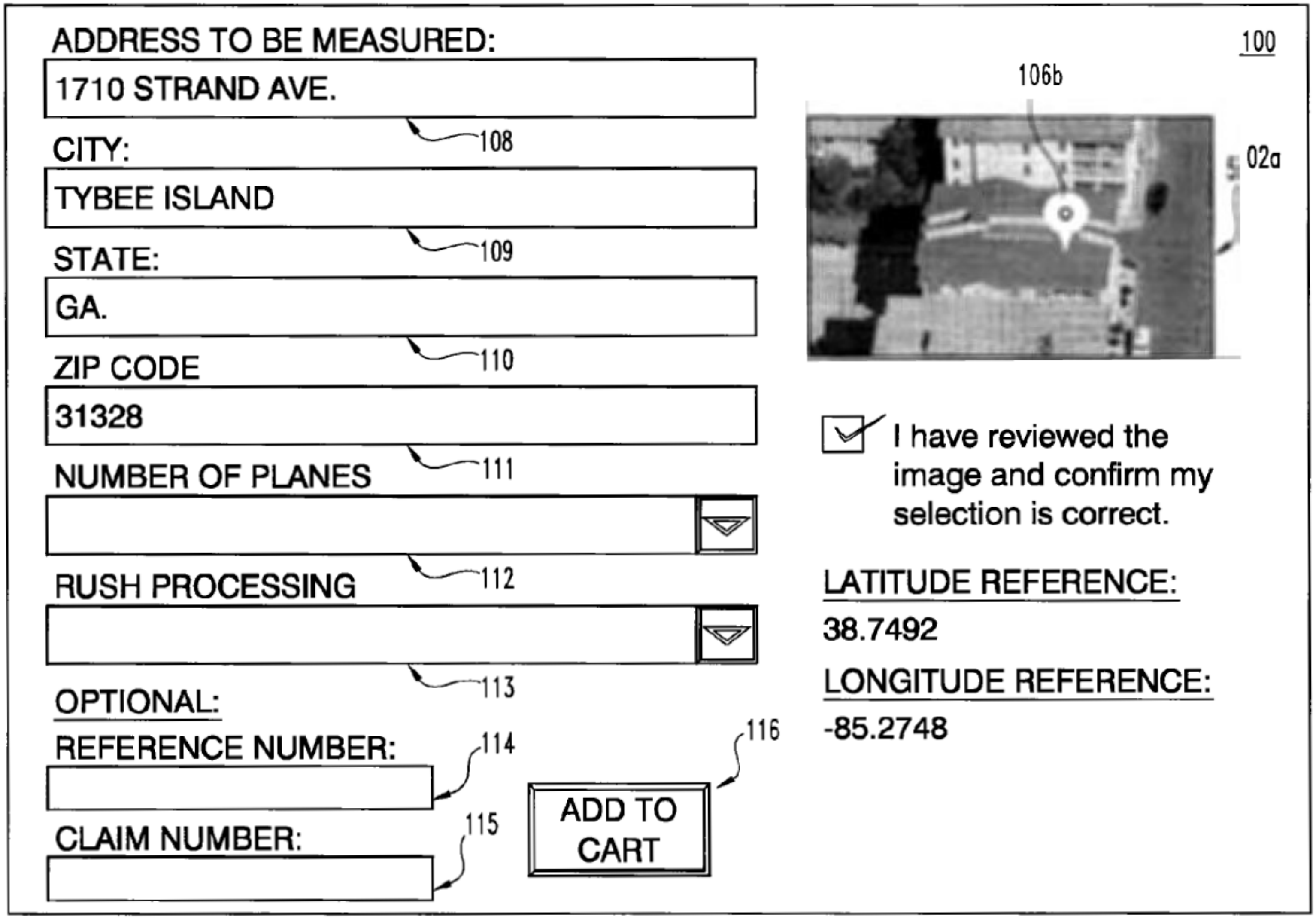
Fig. 4C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108
CITY:
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STATE:
GA.
110
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NUMBER OF PLANES
112
RUSH PROCESSING
113
OPTIONAL:
REFERENCE NUMBER:
114
CLAIM NUMBER:
115
ADD TO CART
116
100
106b
102a
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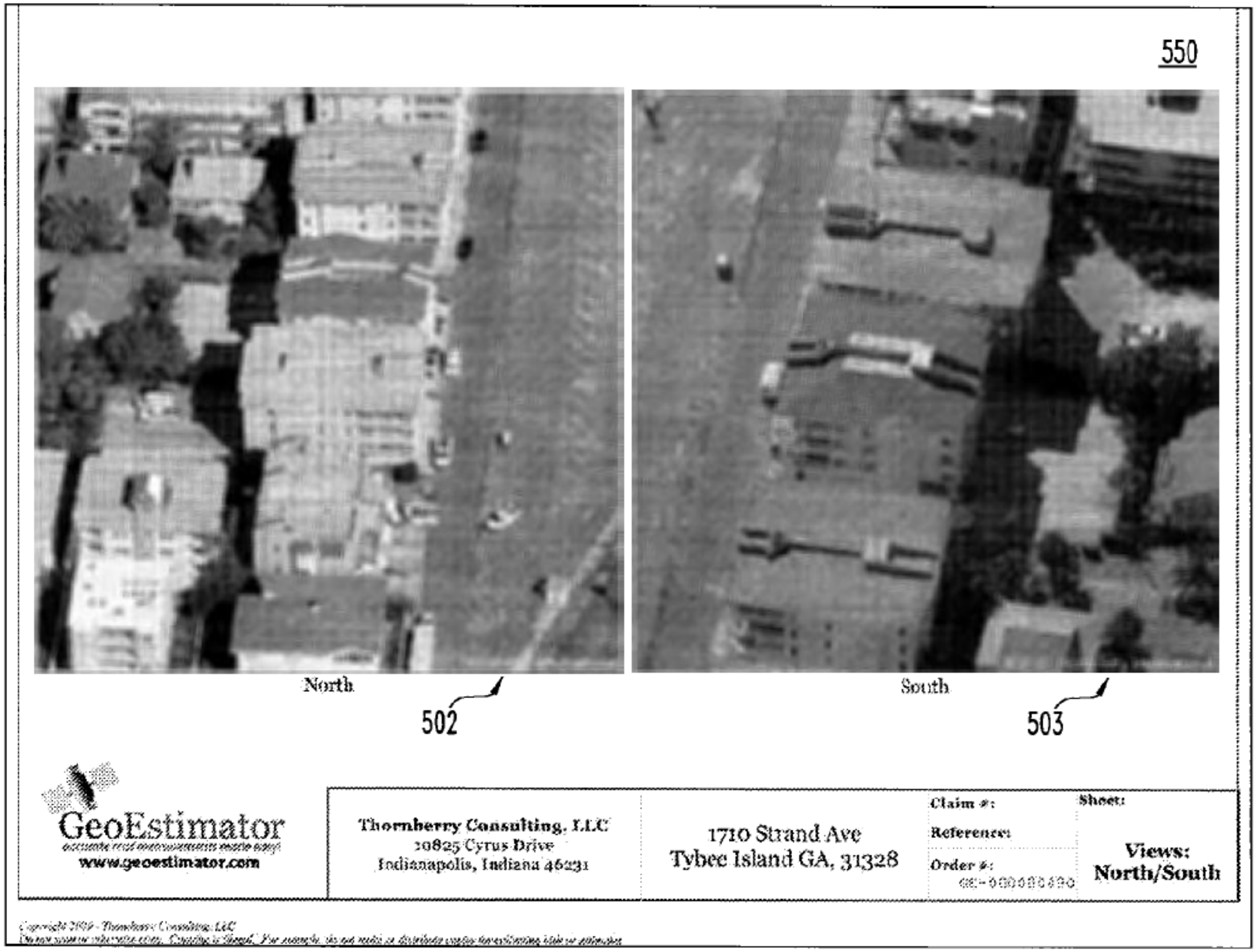
LONGITUDE REFERENCE:
-85.2748

Fig. 4D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North
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South
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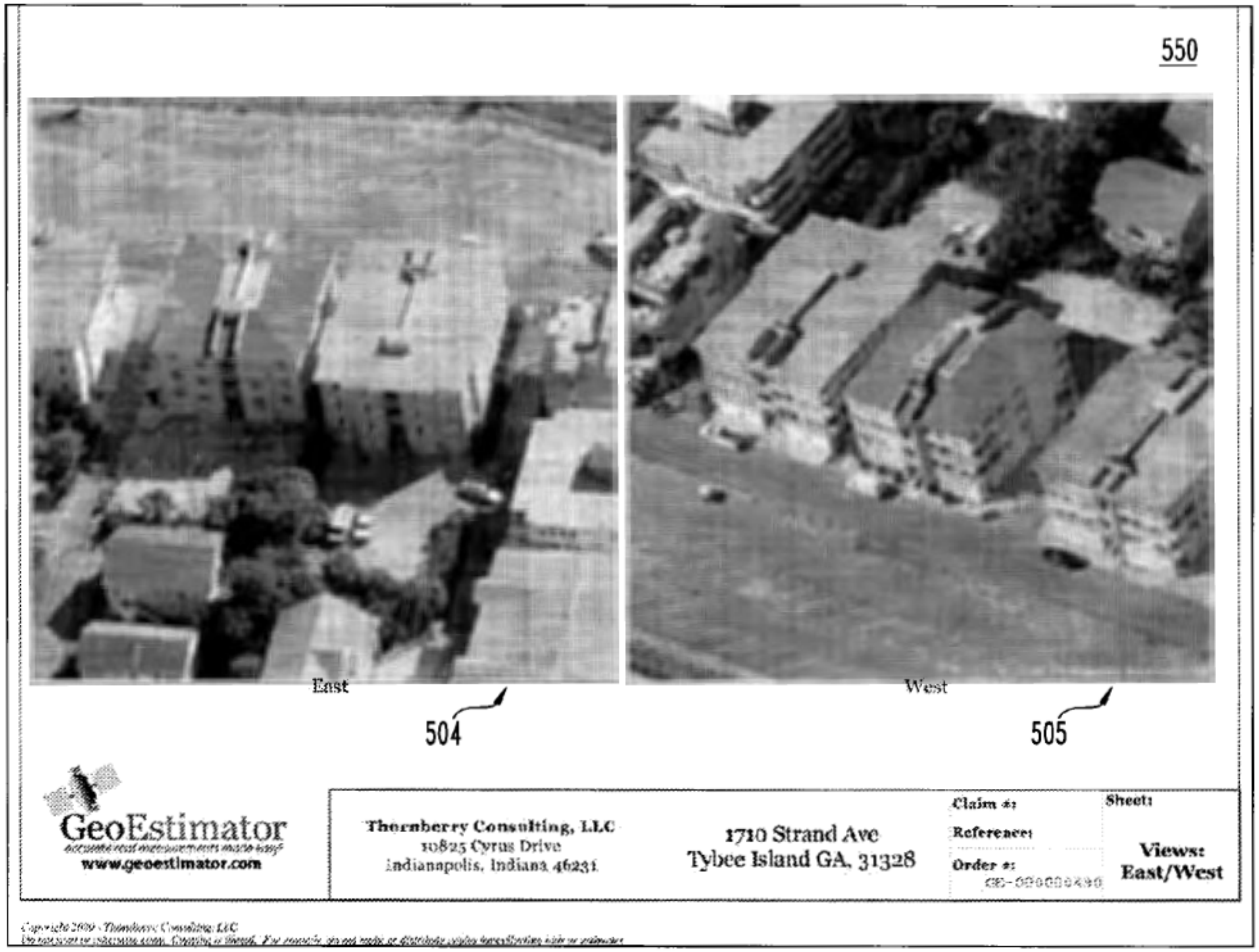
GeoEstimator
www.geoestimator.com
Thornberry Consulting, LLC
10825 Cyrus Drive
Indianapolis, Indiana 46231
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Reference:
Order #:
Sheet:
Views:
North/South

Fig. 5A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West
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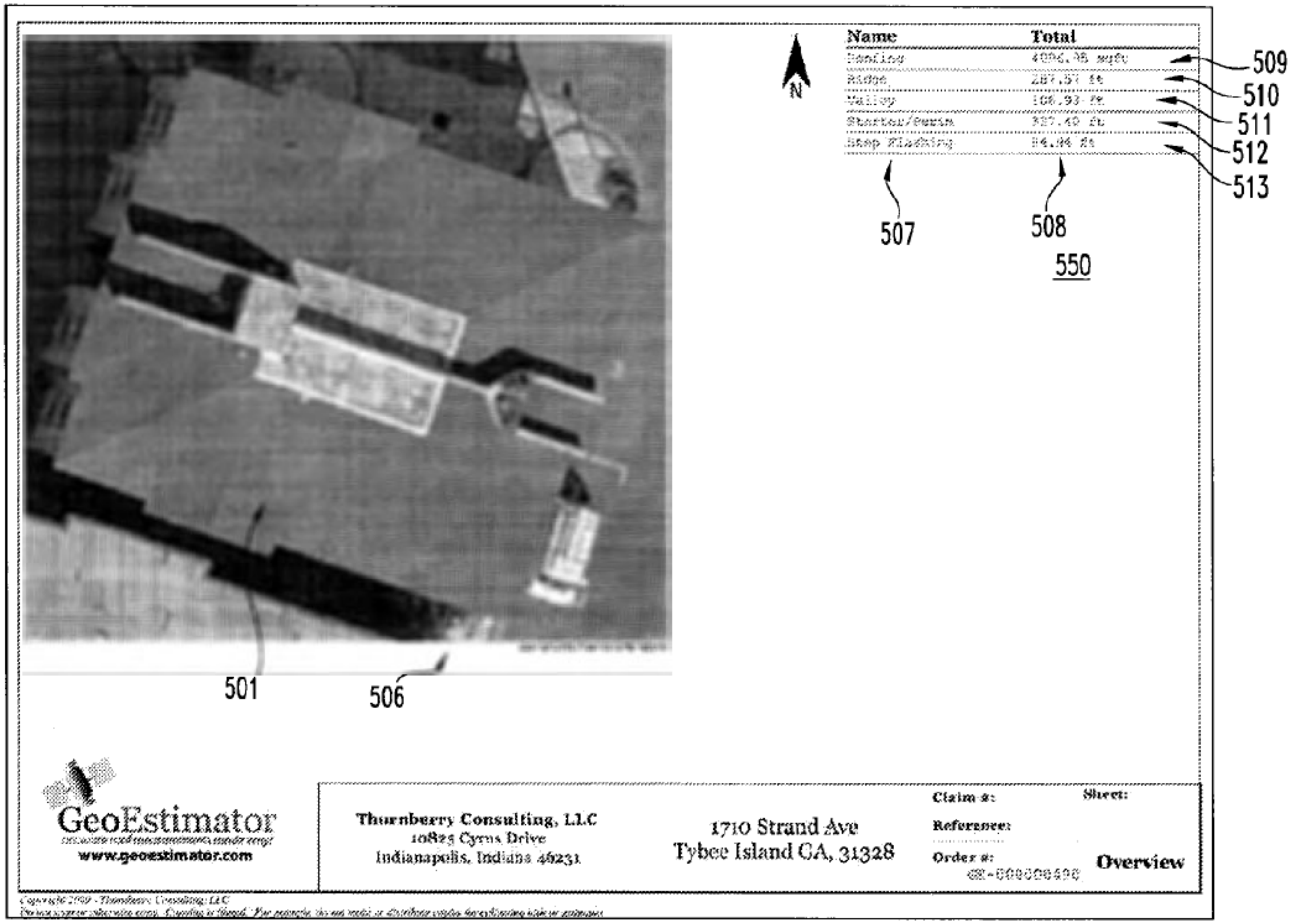
www.geoestimator.com
Thornberry Consulting, LLC
10825 Cyrus Drive
Indianapolis, Indiana 46231
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Reference:
Order #:
Sheet:
Views:
East/West

Fig. 5B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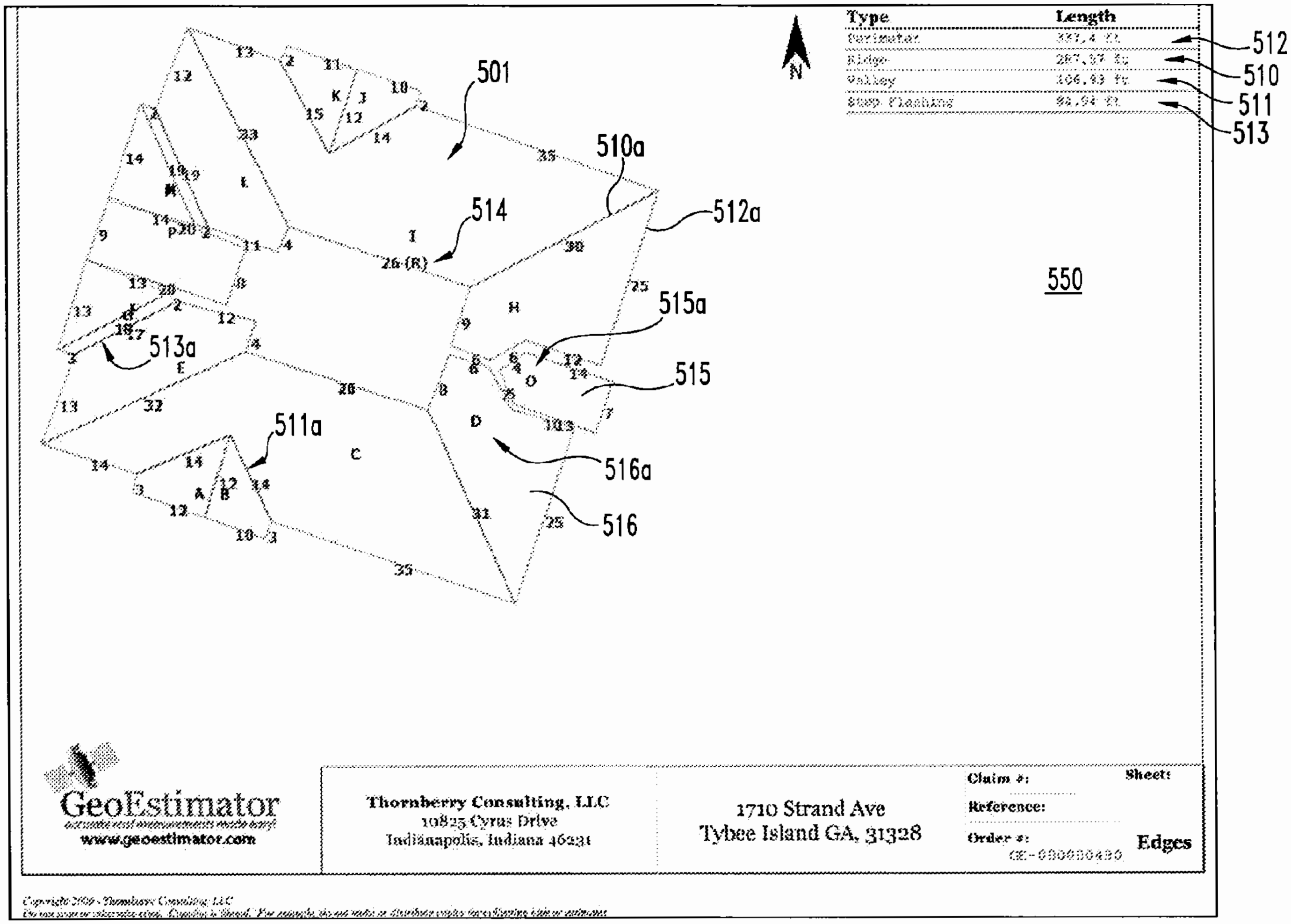
www.geoestimator.com
Thurnberry Consulting, LLC
10825 Cyrus Drive
Indianapolis, Indiana 46231
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Sheet:
Reference:
Order #:
Overview

Fig. 5C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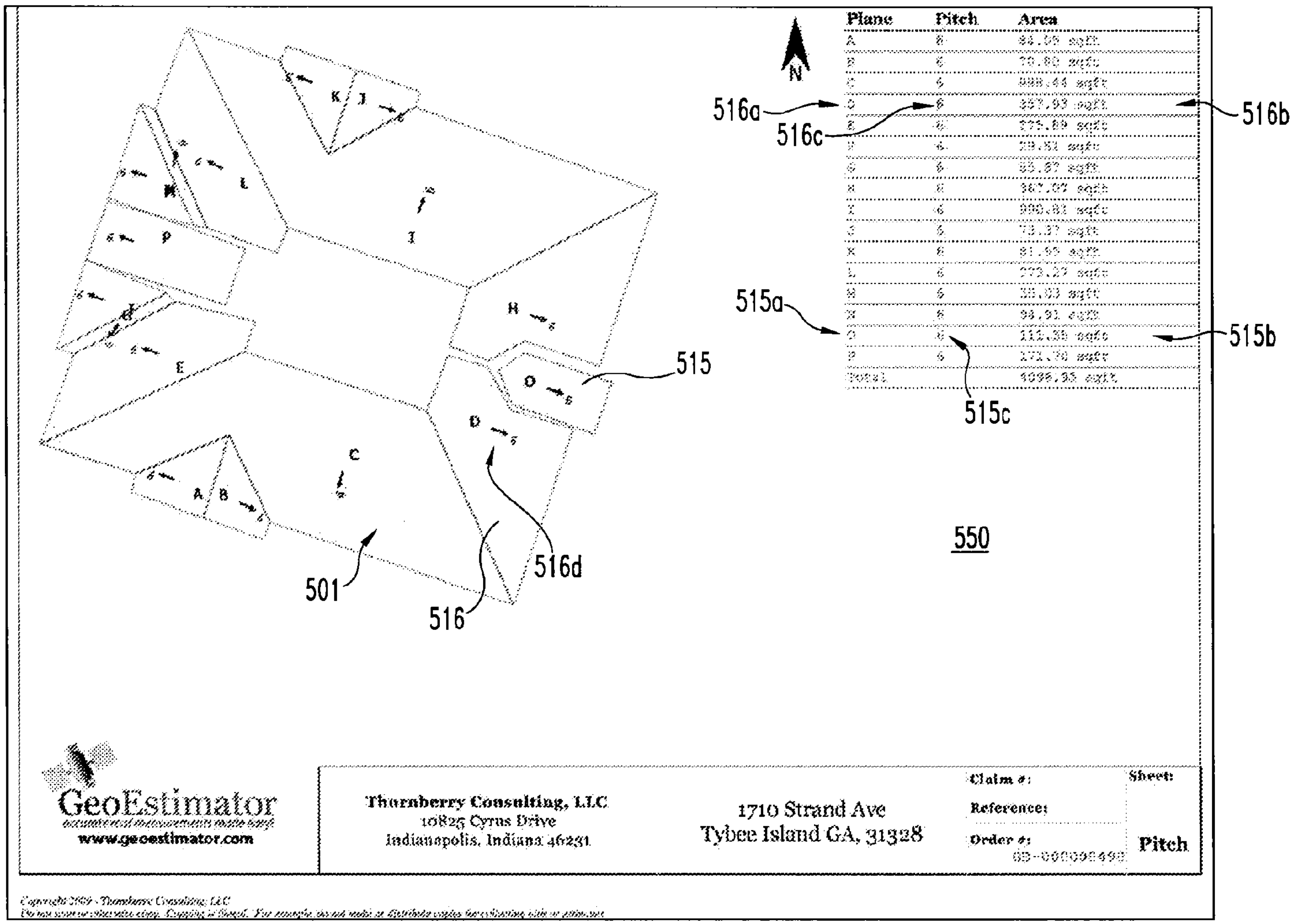
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Sheet:
Reference:
Order #:
Edges

Fig. 5D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Area
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516b
516c
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515c
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516
501
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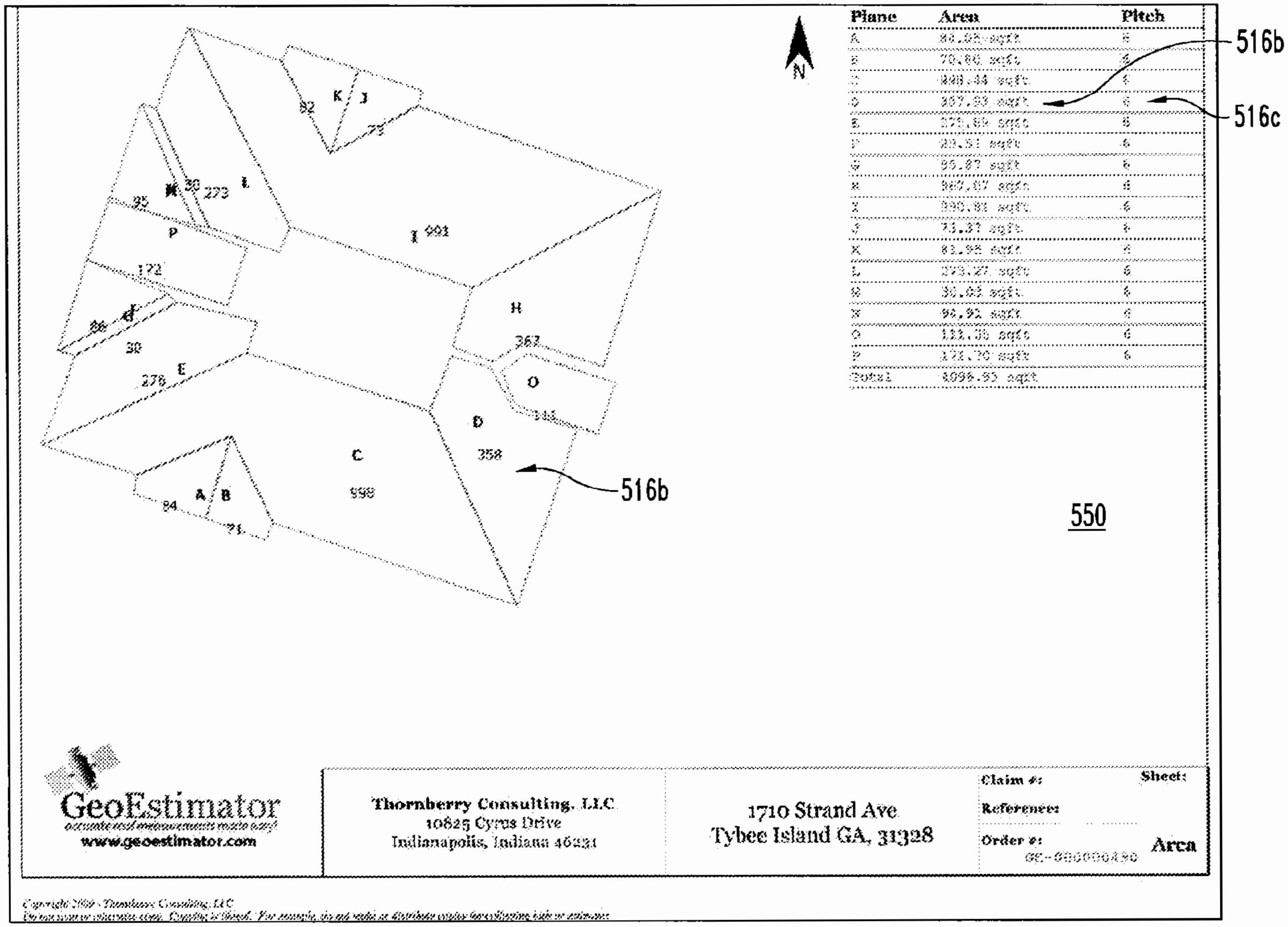
GeoEstimator
www.geoestimator.com
Thornberry Consulting, LLC
10825 Cyrus Drive
Indianapolis, Indiana 46231
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Reference:
Order #:
Sheet:
Pitch

Fig. 5E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Pitch
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516c
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GeoEstimator
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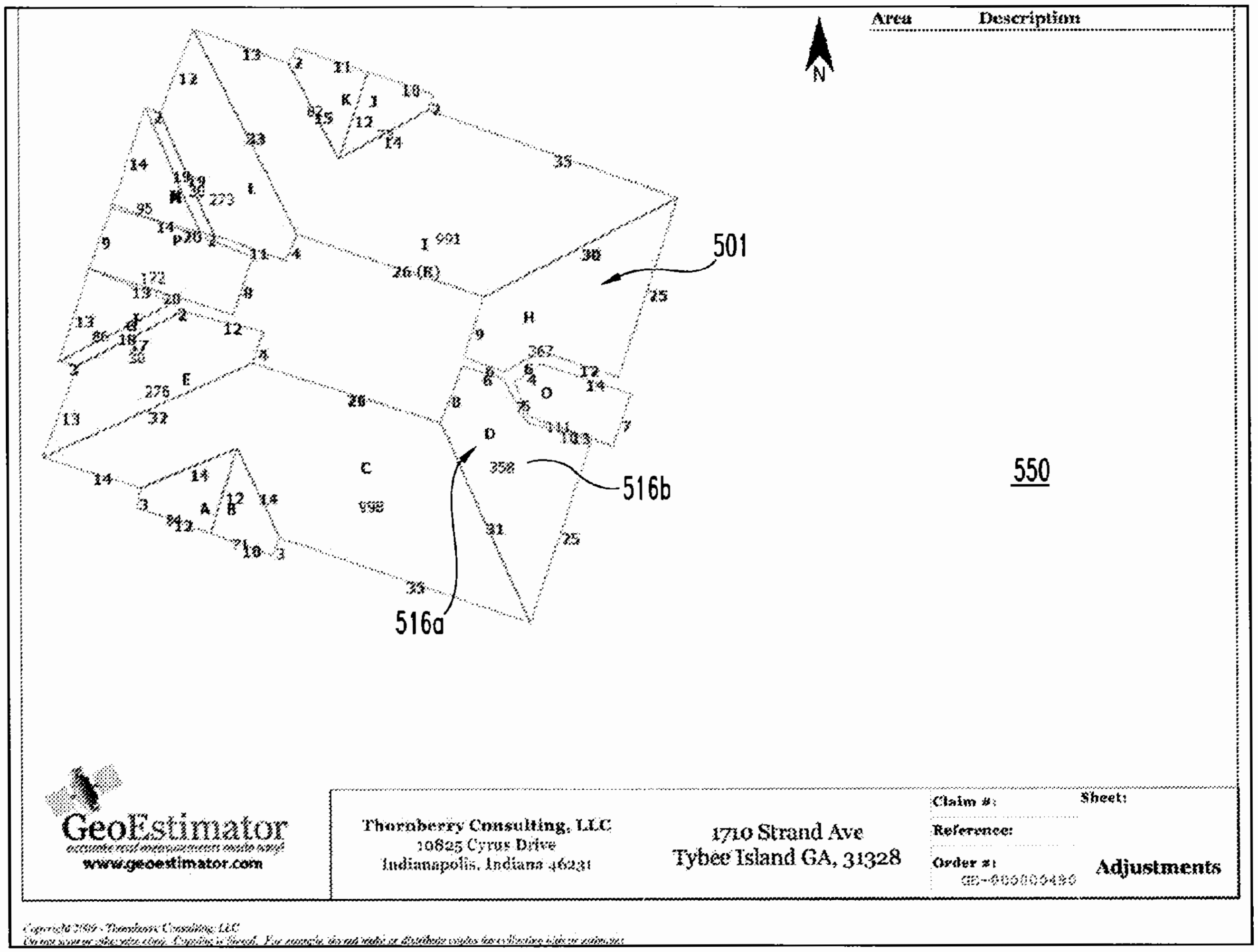
Indianapolis, Indiana 46231
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Reference:
Order #:
Sheet:
Area

Fig. 5F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GeoEstimator
www.geoestimator.com
Thornberry Consulting, LLC
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Indianapolis, Indiana 46231
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Sheet:
Reference:
Order #:
Adjustments

Fig. 5G

Roofing		Ridge		Valley	
Plane	Area	Plane	Length	Plane	Length
A	84.07 sqft	A	11.72 ft	A	14.38 ft
B	70.80 sqft	B	0 ft	B	13.35 ft
C	998.44 sqft	C	44.09 ft	C	0 ft
D	357.88 sqft	D	8.06 ft	D	7.05 ft
E	275.89 sqft	E	16.84 ft	E	17.09 ft
F	29.51 sqft	F	17.86 ft	F	0 ft
G	89.87 sqft	G	0 ft	G	0 ft
H	567.07 sqft	H	38.94 ft	H	5.94 ft
I	290.83 sqft	I	58.65 ft	I	24.48 ft
J	73.37 sqft	J	12.15 ft	J	0 ft
K	61.96 sqft	K	0 ft	K	0 ft
L	273.27 sqft	L	15.10 ft	L	13.06 ft
M	30.03 sqft	M	19.09 ft	M	0 ft
N	94.91 sqft	N	0 ft	N	0 ft
O	111.35 sqft	O	0 ft	O	0 ft
P	171.70 sqft	P	0 ft	P	0 ft
Total	3098.93 sqft	Total	287.97 ft	Total	106.93 ft

517 518 519

550

GeoEstimator
www.geoestimator.com

Thornberry Consulting, LLC
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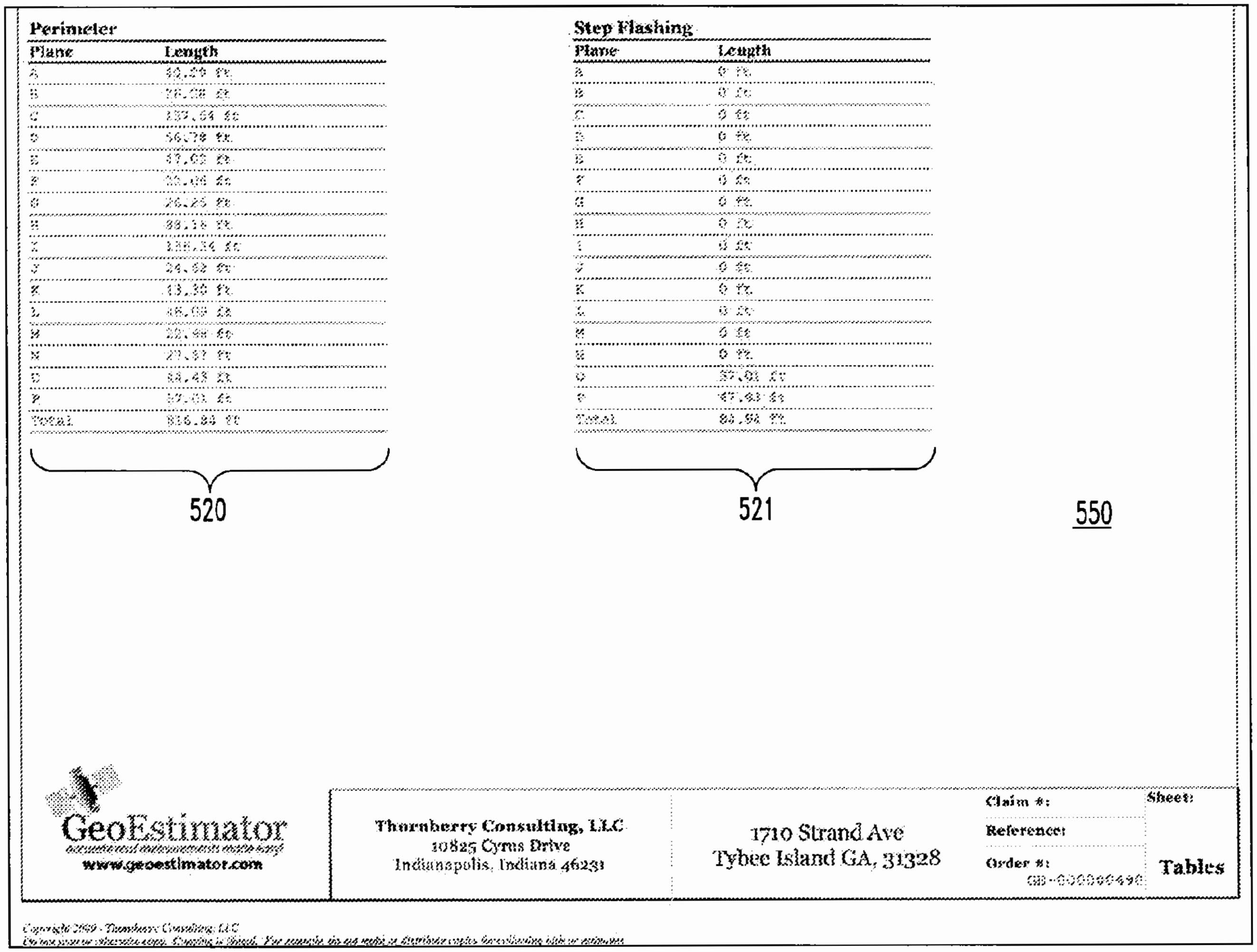
Indianapolis, Indiana 46231

1710 Strand Ave
Tybee Island GA, 31328

Claim #:
Reference:
Order #: GB-000000490

Sheet:
Tables

Fig. 5H



Perimeter

Plane	Length
A	40.29 ft
B	26.08 ft
C	137.64 ft
D	56.78 ft
E	37.02 ft
F	20.06 ft
G	26.25 ft
H	88.16 ft
I	138.34 ft
J	24.82 ft
K	13.30 ft
L	46.09 ft
M	22.48 ft
N	27.37 ft
O	88.43 ft
P	37.01 ft
Total	836.84 ft

520

Step Flashing

Plane	Length
A	0 ft
B	0 ft
C	0 ft
D	0 ft
E	0 ft
F	0 ft
G	0 ft
H	0 ft
I	0 ft
J	0 ft
K	0 ft
L	0 ft
M	0 ft
N	0 ft
O	37.01 ft
P	47.93 ft
Total	84.94 ft

521

550

GeoEstimator
www.geoestimator.com

Thornberry Consulting, LLC
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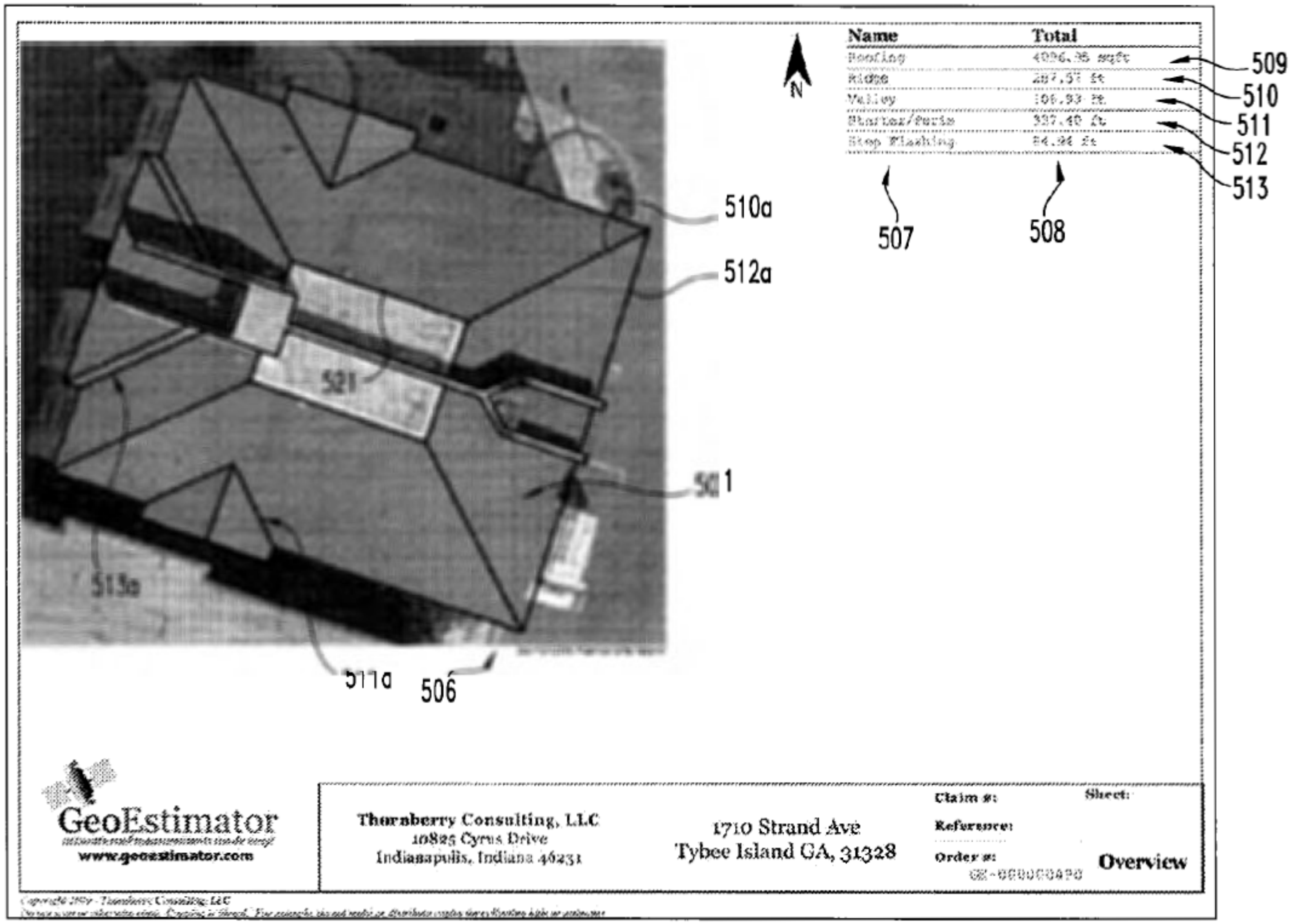
Indianapolis, Indiana 46231

1710 Strand Ave
Tybee Island GA, 31328

Claim #:
Reference:
Order #: GB-000000490

Sheet:
Tables

Fig. 5I



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GeoEstimator
www.geoestimator.com
Thornberry Consulting, LLC
10825 Cyrus Drive
Indianapolis, Indiana 46231
1710 Strand Ave
Tybee Island GA, 31328
Claim #:
Sheet:
Reference:
Order #:
Overview

Fig. 6

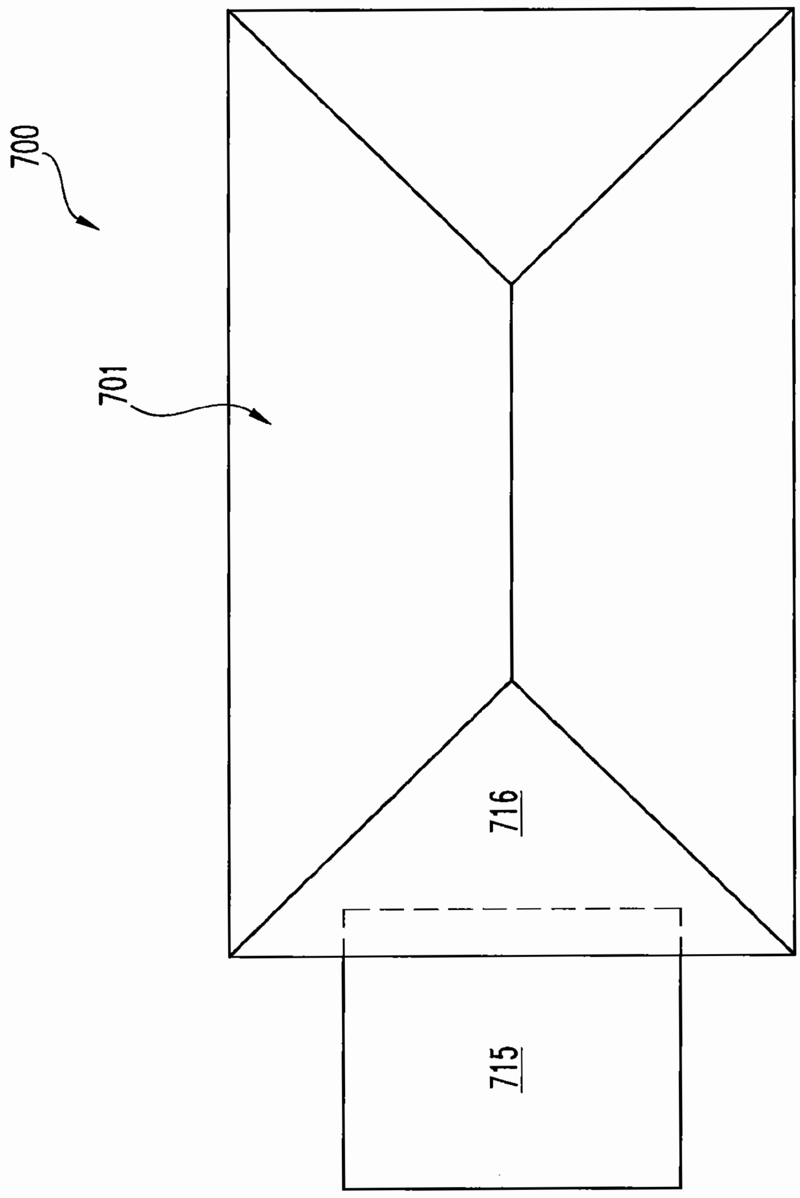
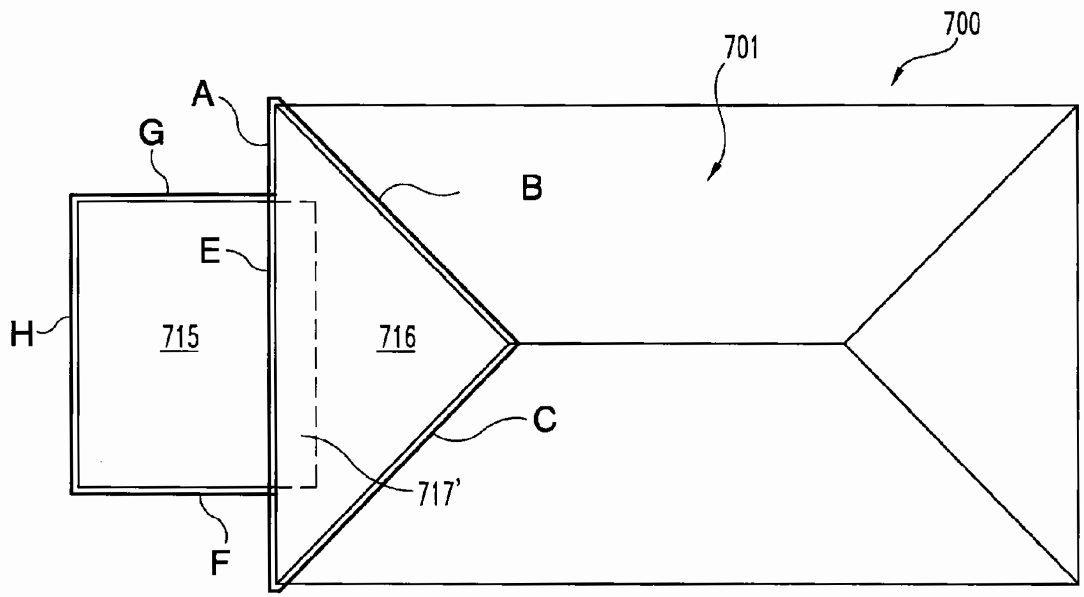
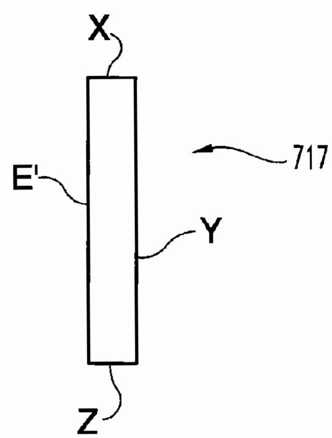


Fig. 7A





721

PLANE	AREA
715	200 SQ. FT.
716	550 SQ. FT.
717	40 SQ. FT.

720

LINE	ATTRIBUTE
A	GUTTER FE
B	RIDGE
C	RIDGE
E	COMMON
F	NO GUTTER
G	NO GUTTER FE
H	NO GUTTER FE
E'	COMMON
X	NO GUTTER FE
Y	FLASHING
Z	NO GUTTER FE

Fig. 7B

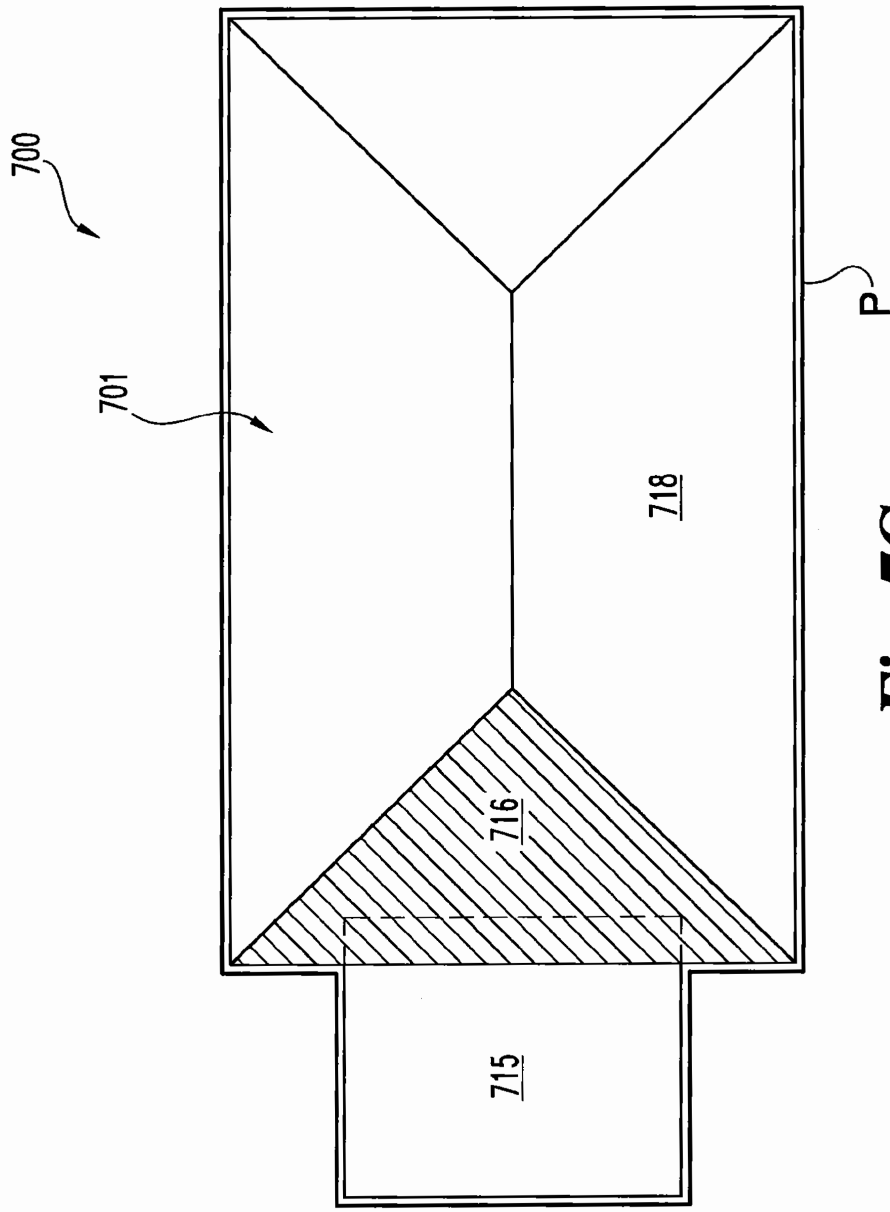


Fig. 7C

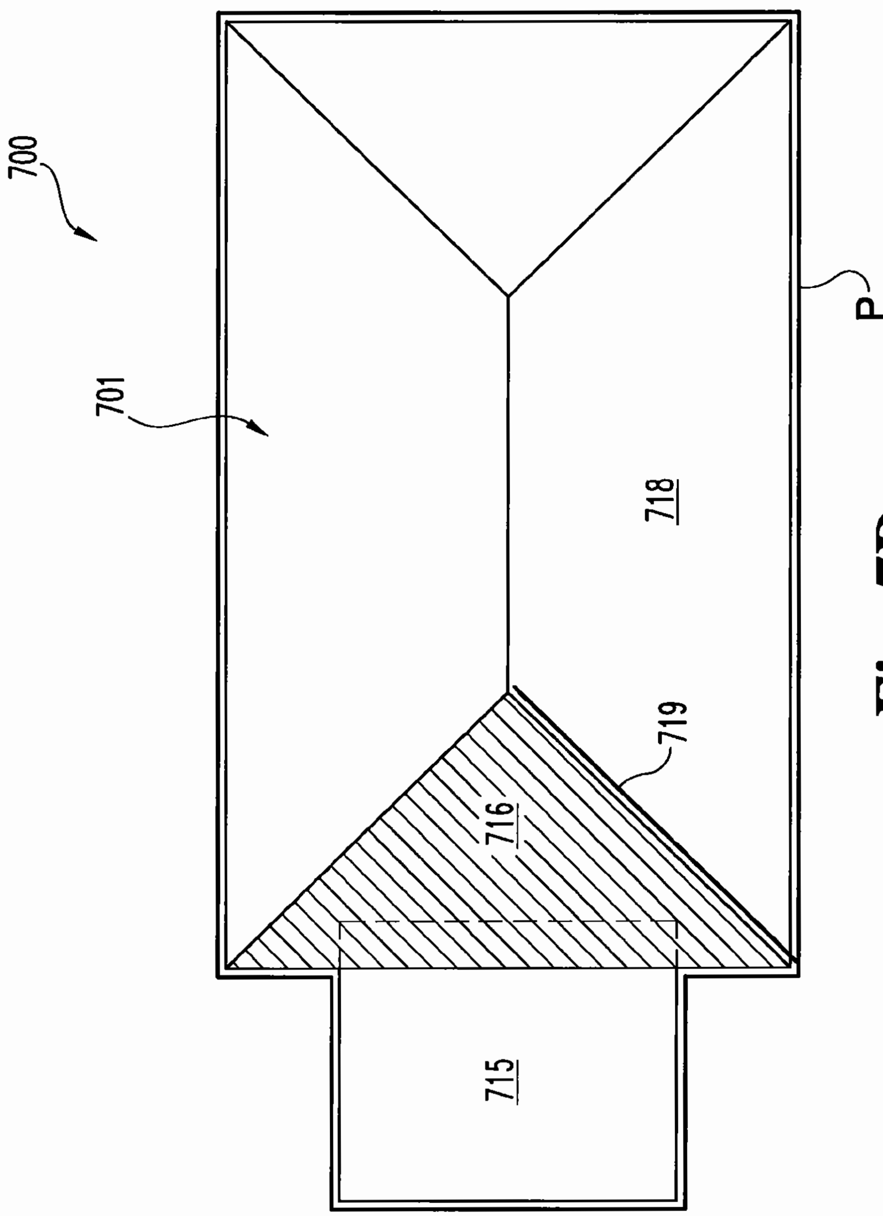


Fig. 7D

SYSTEM AND PROCESS FOR ROOF MEASUREMENT USING AERIAL IMAGERY

INCORPORATION BY REFERENCE

The present patent application is a continuation of the patent application identified by U.S. Ser. No. 12/470,984, filed May 22, 2009, of which the entire content of which is hereby incorporated herein by reference.

FIELD OF INVENTION

The present invention is in the field of measuring roofing dimensions and other attributes, and more particularly pertains to the use of aerial imagery in that field.

BACKGROUND

Roof measuring, for example, dimension, length and areas has been done for many years, such as in connection with for estimating and bidding roofing jobs. Also, for many years, companies and products have offered such estimation services and reporting software reports using aerial imagery on which roof line outlines are traced, dimensions and areas are automatically based on those tracings, and vertical elevations (via pitch or otherwise) are included in mathematical models.

The present invention is an improvement on such aerial imagery, systems and processes, providing non-obvious features that enhance convenience, flexibility, and/or accuracy.

SUMMARY

The claims, and only the claims, define the invention. The present invention includes several, but not necessarily all, of creating a first layer and a second layer, in computer memory and substantially overlapping at least a segment of line from said first layer with at least a segment of another line from said second layer, wherein said first non-dimensional attribute is different from said second non-dimensional attribute; and/or an interactive computer file, said interactive computer file including: length numeric values and at least one user length field enabling a client with said interactive file to override at least one of said length numeric values, where said area operator may automatically recalculate area based on said length field override; and/or, providing at least one computer input field for a user to input first location data generally corresponding to the location of the building; on said imagery of an area providing a visual marker that is moveable on said computer monitor around a region, said marker initially corresponding to said first location data, wherein said marker may be moved to a final location on top of the building to more precisely identify the location of the building roof structure; and providing a computer input capable of signaling user-acceptance of the final location of said marker; and/or other features, optionally combined in various ways as set forth in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is one example of a flow chart of acts according to the present invention.

FIG. **2** is another example of a flow chart of acts according to the present invention.

FIG. **3** is another example of a flow chart of acts according to the present invention.

FIG. **4**A is one example of a computer screen shot to enter an address.

FIG. **4**B is one example of a computer screen shot depicting imagery and a marker based on an address.

FIG. **4**C is a computer screen shot like FIG. **4**B with the marker moved over a selected building.

FIG. **4**D is a computer screen shot and/or reporting confirming selection of a building.

FIG. **5**A is an example of reporting.

FIG. **5**B is another example of a screen shot and/or reporting.

FIG. **5**C is another example of a screen shot and/or reporting.

FIG. **5**D is another example of a screen shot and/or reporting.

FIG. **5**E is another example of a screen shot and/or reporting.

FIG. **5**F is another example of a screen shot and/or reporting.

FIG. **5**G is another example of a screen shot and/or reporting.

FIG. **5**H is another example a screen shot and/or of reporting.

FIG. **5**I is another example of a screen shot and/or reporting.

FIG. **6** is another example of a screen shot and/or reporting.

FIG. **7**A is a top plan view of aerial imagery of a building roof structure.

FIG. **7**B is a display of the imagery of FIG. **7**A with some optional features.

FIG. **7**C depicts the imagery of FIG. **7**A with shadowing.

FIG. **7**D depicts FIG. **7**C with the addition of computer generated line.

BRIEF DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the examples, sometimes referred to as embodiments, illustrated and/or described herein. Those are mere examples. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Such alterations and further modifications in the described processes, systems or devices, any further applications of the principles of the invention as described herein, are contemplated as would normally occur to one skilled in the art to which the invention relates, now and/or in the future in light of this document.

As used in the claims and the specification, the following terms have the following definitions:

The term "adjustment roof plane" means a roof plane, having at least three border lines, that may be hidden (partially or totally) from view from some or all aerial imagery and which may be included to add to (or subtract from) an aggregate roof area or other attributes.

The term "aerial imagery" means pictures, normally including photographs (visual light, infrared, color, black and white, or otherwise) taken from an overhead view (straight down, oblique, or otherwise) with respect to a building roof. This may include imagery taken from airplanes, satellites, balloons, or otherwise.

The term "attributes" means one or more distinguishing or identifying characteristic.

The term "border line" means a line segment, straight, curved, free form or otherwise that generally corresponds with the edge of a roof plane.

The term "building" means a real estate structure, such as for example, a house, condominium, office building, outbuilding, garage, warehouse, factory or otherwise.

The term "client" means a person or entity that orders or obtains an aerial imagery report.

The term "computer input" means data, information and/or signals provided by a computer user. This may include numbers, words, mouse clicks, "enter", check boxes, dialog boxes, and otherwise.

The term "computer monitor" includes any computer screen or other visual output, including projectors, flat panel screens, LCD screens, LED screens and otherwise that provide visual output from a computer.

The term "computer processing means" means computer hardware and software, including computer memory, microprocessors, computer code and computer logic to provide digital computing.

The term "contrast" means discernable relative differences in lightness and darkness.

The term "deliverable" means that which is or may be delivered to a client, including printed and/or electronic reports and information.

The term "digital" means using numeric digits, specifically including binary digits.

The term "direct proportion" means that one or more variables that change as a function as another value in a generally linear function.

The term "dissects" means to sub-divide into two or more parts.

The term "electronic drawing" means to draw lines and/or shapes electronically via computer. This can include pixel-based drawings, vector-based drawings, and/or otherwise.

The term "field" means a location for computer data input and/or output of a value having at least one corresponding associated place in computer memory.

The term "final location" is the relative spot for placing a marker. This normally corresponds to unique latitude and longitude coordinates.

The term "generating" means to make or create.

The term "imagery database" means a computer database containing aerial imagery computer files and the associated location coordinates.

The term "interactive computer file" is a computer file in which a user may input and/or override one or more numeric values stored in memory as part of the file.

The term "internet-based imagery" means imagery, such as aerial imagery, which is accessible through an internet access connection. One popular example is Google® Earth.

The term "latitude and longitude coordinates" mean numeric coordinates for a location on the planet corresponding to latitude (east, west) and longitude (north, south).

The term "layer" means a part of a graphic computer file that visually overlays one or more other parts and which has at least partially transparent portions allowing visualizations of parts/layers below it.

The term "lines" means a straight, curved, and/or free form segment.

The term "location data" means information which uniquely identifies geographic position. This may include latitude and longitude coordinates, street addresses and/or otherwise.

The term "non-dimensional attribute" means an attribute other than a numeric value, such as other than length, width, height, or area.

The term "numeric values" means alphanumeric numbers, and/or their binary equivalent.

The term "operator" means a mathematical function including, but not limited to multiplication, division, addition, subtraction, sum, average, square root and/or the foregoing with or without constant and/or co-efficient.

The term "orientation" means the direction of something with respect to something else.

The term "outline" means the path or collection of lines generally coinciding with the outside of a shape.

The term "outline drawing" means drawing of lines around an outline.

The term "over said imagery" means position on top of and in alignment with underlying Imagery.

The term "override" means to substitute or replace one value for another value. This may be done with numeric values, non-dimensional attributes and otherwise.

The term "perimeter lines" means a line or lines that outline the outer most edge of a roof structure. This can include, but is not limited to, a roof free edge with a gutter and to a roof free edge without a gutter.

The term "pitch numeric value" is a single numeric value corresponding to the pitch or slope of a portion of roofing.

The term "proportioning" means to increase or decrease the size of a line, outline or other object to directly proportional to the change in another object.

The term "region" means a location on earth that is depicted in aerial imagery. Ordinarily, it will include at least one entire building structure, and preferably, will include at least some features, such as streets, trees, or other buildings adjacent the building structure.

The term "report" means one or more pages or screen shots, or both, made available to a user including aerial imagery and/or data from such imagery. This includes, but is not limited to, one or more interactive computer files.

The term "roof flashing edge" means an edge where roofing meets with a generally vertical structure, such as a wall, typically with flashing.

The term "roof free edge with a gutter" means the unbound edge of a roof with a rain drainage gutter.

The term "roof free edge without a gutter" means the unbound edge of a roof without a rain drainage gutter.

The term "roof hip" means an edge where two roof planes meet to form a generally upward sloping ridge.

The term "roof pitch" means the slope of a roof plane. It may be expressed in angles, ratios, or otherwise. This includes stating the rise over run, as well as stating merely the rise in view of an assumed or industry standard run. For example, a slope of 6 inch rise for every 12 inch run (horizontal") may be stated to be a "6" pitch.

The term "roof plane" means a generally planer, segment of a roof.

The term "roof ridge" means an edge where two generally upward sloping roof planes meet.

The term "roof structure" means the top of a building which shelters the building from weather.

The term "roof valley" means an edge where two generally downward sloping roof planes meet.

The term "street address data" means the location typically used by postal identification, typically including at least one numeric value and at least one street name, and further typically including a zip code or other postal code and/or a town and state or province.

The term "street address look up field" means a computer field for entry of street address data.

The term "substantially overlapping" means that where one line, in whole or in substantial part, coincides with another line in terms of direction and overlap. This may include situations where the respective lines are of substantially different length, or not.

The term "substituent triangles" means two or more congruent triangles which collectively form a subset of another geometric shape.

The term "tracing" means drawing around an outline or along a line or feature depicted in Imagery.

The term "user-acceptance" means an affirmative step or series of steps or computer input, undertaken by user to make a selection.

The term "vector direction" means, in relative space, either two dimensionally or three dimensionally where a vector is pointing.

The term "visual marker" is a shape, pointer, label, icon, avatar or other indicator which is movable or displayable on a computer screen and which may be visually differentiated from other objects on the computer screen.

The term "visually depicting" means to show or illustrate something on a computer monitor as a graphical image.

Articles and phases such as, "the", "a", "an", "at least one", and "a first", are not limited to mean only one, but rather are inclusive and open ended to also include, optionally, two or more of such elements.

The language used in the claims is to only have its plain and ordinary meaning, except as explicitly defined above. Such plain and ordinary meaning is inclusive of all consistent dictionary definitions from the most recently published Webster's dictionaries and Random House dictionaries.

Referring to the drawing figures, these are only examples of the invention, and the invention is not limited to what is shown in the drawings.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIG. **1**, a process for determining attributes of a roof structure **501** (see FIGS. **4**B, **4**C) of a real-world three-dimensional building **500** may optionally comprise several acts. This may include viewing on a computer monitor **100** in digital aerial imagery **1** of a region **502** (see FIGS. **4**B, **4**C) including the roof structure **501**. Ordinarily, the roof structure will have one or more roof planes, and unless the roof is a simple single-plane roof, will have at least two or more roof planes. In FIG. **1**, the act of creating of a first layer drawing **2** is undertaken. Such act may be used by the ultimate end-user enabled by the software, but optionally and more preferably is done by a commercial vendor based on an order placed by a user. Such order may be placed by telephone, on-line, such as on computer screen **100** as shown in FIGS. **4**A-**4**D, by mail, email or otherwise.

The creation of the first line drawing **2** may be done a multitude of ways, in one example is illustrated in FIGS. **5**A-**5**I and FIG. **6**, discussed further below. Likewise, in FIG. **1** creating a second layer drawing **3** is another act. For example, in FIG. **5**D, various roof planes are denoted by letters A-P. For example, the roof plane **515** denoted by the letter "0" may be drawn in a second layer, whereas roof plane **516** indicated by the letter "D" may be in a first layer. In such example, roof plane **515** and roof plane **516** have substantially overlapping segments **4** (see FIG. **1**). For example, along the upper edge of plane **515** appears the number "5" denoting a five foot **20** line; whereas, plane **516** has the substantially overlapping line denoted by "7" indicating a seven foot line segment of roof plane **516**. Such seven foot roof segment of plane **516** may comprise a perimeter line (part of the 56.78 feet perimeter length of plane D depicted in table **520** of report **550** of FIG. **5**I); whereas, the substantially overlapping five foot length of plane **515** may comprise a second non-dimensional attribute, namely flashing, such as step flashing line (part of the 37.01 feet of step flashing for plane **0** depicted in table **521** of FIG. **5**I). Accordingly, this is one example of substantially overlapping lines such as segment of line A and segment of line E set forth in the claims, each having respective first and second non-dimensional attributes. This allows for separate reporting of such non-dimensional attributes, such as the length of perimeter, the length of step flashing or otherwise. Such non-dimensional attributes may be of any type. As mere examples that have use in the roofing industry include the non-dimensional attributes of roof ridge, roof hip, roof valley, roof flashing edge, perimeter line, roof free edge with a gutter, and roof free edge without a gutter. For example, line **510***a* in FIG. **6** is an example of a roof ridge, whereas line **511***a* and line **513***a* are each examples of a roof valley. Line **512***a* in FIG. **6** is an example of a perimeter edge, which also happens to comprise a roof free edge without a gutter. Optionally, while not illustrated, if line **512***a* had, or were to have, a gutter along it, then it would be in that case a perimeter line and be a roof free edge with a gutter. FIG. **6**. also depicts an optional table and/or fields showing the non-dimensional attributes at **507** and the total 15 values for them at **508**. This can include the area of roofing **509**, the linear ridge feet **510**, linear valley feet **511**, starter/perimeter linear feet **512**, step flashing **513**, and/or others.

Another optional feature is computer processing means for calculating a vector direction corresponding to roof pitch for a roof plane. Optionally, this may be based on at least one of said non-dimensional attributes of roof plane outline lines and their orientation. Such computer processing means typically includes computer logic and/or code with a set of rules to establish such vector. Examples of such vector are shown in FIG. **5**E. Specifically, they are preferably shown as arrows. In the illustrated example, they are ordinarily indicated as arrows pointing in the downward direction, corresponding to the downward direction of rain flow. Optionally, there may be other illustrations, including an upwardly directed arrow, although this is not preferred. For example, vector **516***d* is shown in a downwardly directed arrow with a number 6 next to it. This depicts the vector corresponding roof plane **516**, namely plane D previously discussed. As seen, the value "6" for the pitch is entered at field **516***c* in the table also showing the area (for that particular roof plane D at field **516***a*) 357.93 sq. ft. as shown at field **516***b*. Note further with respect to roof plane **515** (plane "0") as illustrated in the table at field **515***a*, it likewise has a roof pitch of "6" shown at **515***c*. The total area of roof plane "0" is 111.35 sq. ft. in this particular example, as shown at **515***b*.

An example of computer programming to determine pitch direction is as follows.

1.) Pitch will run towards a perimeter line. If only one perimeter line pitch goes towards the perimeter (most standard roofs, all but the ends of hips);

2.) If there are multiple perimeters that are not parallel, look for ridge. If there is only a single ridge line and it is parallel to one of the perimeter lines, pitch runs from the ridge towards the perimeter. (Perimeters that are not straight and have small outcroppings where the roof extends further down the same slope).

3.) If a shape has no multiple perimeters and multiple ridges where none are parallel, take an average of the ridge angles and see if that direction is perpendicular to a perimeter line. If so, that direction is the direction of the pitch. (The end of hip roofs).

Most planes are resolved by the above acts, 2 and/or 3. Acts 4 and 5, below, are also optional but preferred, and address totally enclosed roof planes which most standard roofs do not have.

4.) If there are no perimeter lines and a single ridge line, the pitch is from the ridge.

5.) If there are no perimeter lines and multiple ridge lines, once finding the pitch for all other shapes look at the ridges and the shared shapes. If the shared shape has a pitch directly away (is perpendicular) from the shared ridge, use that ridge as if it were 2 (from above). If the other pitch goes at an angle to the ridge, look at other ridges.

The case where you can make it past act 5 and not have pitch direction is for completely enclosed shapes where all sides are valleys at the intersection of multiple planes, set forth in this optional act:

6.) take the average slope of all other planes connected via shared lines and average the slope direction of the planes, whose pitch runs into the plane in question; use that direction as the pitch direction for the plane.

Variations on that logic, including changing the order, and/or combining or splitting acts, may optionally be used. For example, rather than beginning with logic looking to run pitch towards a perimeter, the logic could begin to look to first run the pitch vector away from a ridge line, although this is less preferred.

As illustrated in report **550** as seen in FIG. **5**E, the visual depiction of pitch vectors, such as **516***d* may help visualize the shape, orientation, pitches of the roof structure and/or roof planes.

Optionally, one or more deliverables to the client include one or more reports such as report **550**. Report **550** may include one or more of the features as depicted in the various drawings of FIGS. **5**A-**5**I and/or FIG. **6** and/or FIGS. **7**A-**7**D, alone or combination.

Optionally, such report may be printed on a piece of paper, or provided on a non-interactive computer file such as a .pdf (Adobe® Acrobat®) type image or otherwise, illustrated on a computer screen for the user to print out (web based or otherwise) and/or delivered on recordable media such USB drive, floppy disk, CD, DVD, email attachment or otherwise. However, preferably, such file is delivered as an interactive computer file. For example, referring again to FIG. **5**E, the pitch value as shown in the table, such as the 6 pitch for plane D and **516***c* allows the person, the end-user or otherwise, to enter at least one pitch numeric value. This pitch numeric value may correspond to roof pitch of the roof plane. Hence, in FIG. **5**E, one or more of the pitch values in computer fields corresponding to the table, may be empty or null. They may allow a person, such as an end user, to data input via their computer, the pitch value. For example, this may be based on the end user, or one of their agents, taking field measurements of the roof to provide the input. As such, value **516***c* may be entered to be "6" corresponding to a 6 pitch (e.g., 6" vertical rise for every 12" of horizontal run). Such value "6" may be changed, updated, or overridden.

As can be appreciated in three-dimensional geometry, given the shape of plane D (**516**) the value of the pitch ordinarily will affect the overall area of such roofing (see e.g. FIG. **5**F, area value **516***b*).

Mathematical equations demonstrating-area relationship for a sloped, rectangular roof plane are known, an example of which is set forth below:

$$\text{Area}=W\times Z$$

$$Z=\text{square root of: }(X^2+Y^2)$$

Where:

W=width

X=horizontal run

Y=vertical rise

Z=hypotenuse of X-Y-Z right triangle.

Other, geometries may be calculated using known math, coefficients and/or tables. See for example: Miller, Mark; *Miller's Guide to Roofing* (2005) ISBN 0-07-145144-7. Thus, in combination with the perimeter measurements supplied with the report based on the creation of roof plane D from the imagery, the addition of the roof pitch value may lead to the calculation such as in the example 357.93 sq. ft. shown at **516***b*. Likewise, for plane **0**, the value of "6" may be entered in the table at **515***c* to arrive at the area calculation **515***b* as previously described. It should be appreciated, that optionally these pitch values may be provided by the end user or other persons based on field measurement. However, optionally, they also may be based on measurements and/or computer calculations precisely, by estimate or otherwise, such as by viewing oblique imagery such as region image **502** shown in FIG. **4**B. In such case, for example, a vendor may provide default values (and/or absolute values) for the pitch and the table shown at FIG. **5**E. In an interactive computer file with such fields being interactive, and with operators to calculate area taking into account pitch, preferably part of said file, even with such default values based on oblique imagery the end user would be free to override them, such as for example if they determine that field measurements indicate a different pitch.

Another optional feature may include other attributes deliverable to the client including an interactive computer file. For example, the length values of lines forming an outline of a drawing may be overridden. For example, referring again to **5**D, a reference line **514** is depicted. In this one example, it is depicted in the parenthetical quote ("R"), although this is not required. In such case, it is denoted "26" corresponding to 26 ft. in length. Note that all dimensions in this case may be converted to or express in metric, rather than English units, although for purpose of illustration English dimensions are utilized here.

In such case, even thought the referenced dimension 26 is based on scaling that line off of the imagery, such as imagery **506** (see FIG. **6**; FIG. **5**C) there is an opportunity for greater precision. Such interactive computer file, for example, in the report page shown at FIG. **5**D, the value 26 depicted there in connection with the reference may actually be the location of a data entry field. In such case, the field operator may determine that the precise measurements are not 26 feet, but rather are 26.15 feet. In such case, the user operator may enter in their computer by typing in the value "26.15" the reference line field, thereby overriding it from 26 to 26.15 in this hypothetical. In such case, the interactive computer file may use co-efficient and other ratios to proportion (by multiplication or otherwise) some, or preferably, each of the other lines of an outline in direct proportion to the plane field override. While the foregoing is mentioned in terms of the referenced mentioned **514**, optionally the interactive computer file may provide multiple reference directions and/or all line values in their report may, optionally, be interactive and override fields. As mere examples, in FIG. **5**D this could include fields for **510***a*, **511***a*, **512***a* and/or otherwise, including without limitation most or all numeric values.

Moreover, while not illustrated, optional report **550** may include a separate table and/or field entry point apart from the drawing of the building roof structure **501** in which the reference line may be overridden instead or, or in addition to, fields directly overlying the aerial imagery and/or the drawn lines.

Optionally, but preferably, in addition to the length of the other lines being proportionally recalculated, likewise the area values, such as depicted in the area column of the table at FIG. **5**E as well as the area values on FIG. **5**F and/or FIG. **6** (see the total roofing area value **509** of 4096.95 sq. ft. may be automatically recalculated. This may be done in a separate application, in the interactive computer file (including with embedded operators), both or otherwise.

Various area calculations used in connection with computer data processing means are available based on known geometry. These could include things as simple as multiplying length times width of a single rectangle. They also may include modifying such area to take into account the additional area generated by pitch, as previously discussed. However, while not limited to this, preferably, taking advantage of the pixilated imagery that may be used, one optional feature in determining one or more areas of the respective roof planes is as follows. If you know the points (corners) of the shape and can order them in a clockwise (or optionally, counter-clockwise) fashion following the perimeter or outline of the shape, then the following algorithm can apply. Starting at the first endpoint, 0 (zero), while N+1 is less than the total ordered end points take the triangle made by the 3 points 0, N, and N+I and compute the area of the triangle created, which is done by the dot product method using vectors created by going from 0 to N and 0 to N+I. Add this area to a running sum.

Note that when the three ordered endpoints are not in the proper order (they create a convex perimeter or outline of the shape that reduces the overall area as opposed to adding to), the dot product method of finding the area will return a (–) negative area which subtracts from the overall area in the running sum.

Dot product (2-Dimensional Vectors) can be expressed in the equation:

$$uv=u_1v_1+u_2v_2$$

This can be used to find the area of the square that the two vectors produce. Dividing the result by two (2) gives the area of the triangle the two vectors produce.

Thus, in this way an example is provided of computer data processing means that dissects the outlines of the roof planes into substituent triangles and calculates the area of such triangles. The areas are aggregated to provide the area of respective roof planes, and the areas of such respective roof planes may in turn be aggregated (summed) to arrive at the total area of the roof structure. Examples of this are shown in the table in FIG. **5**F and/or table **517** in FIG. **5**H. Note also in FIG. **5**H the report **550** may also include other tables and information, such as ridge length table **518** and/or valley length table **519**.

Hence, in FIG. **2**, aerial imagery **1** is used and perimeter drawings around roof planes are acts. Thereafter, one or more interactive computer files are delivered **6**. The user may enter values in the interactive computer file **7**, such as pitch, length, or otherwise as discussed. This may result in the act of updating the report **8**.

Another optional feature is to provide for user acceptance of the final location of a roof structure. One optional way to do this is to provide an internet based interface for the customer/user. One example of such is shown in FIGS. **4**A-**4**D. For example, in FIG. **4**A, computer screen **100** provides a place to enter an address, such as field **102** for address entry (denoted by label **101**). In the illustrated example, the street address "1710 Strand Ave, Tybee Island, Ga. 31328" may be entered in field **102** of the computer. The user may enter by clicking or otherwise button **103** to find that address. In response, computer screen **100** may appear like FIG. **4**B. As such, it may depict imagery **502** of a region, the region including building **500** with its roof structure **501**. Ordinarily, this includes not only the building structure **500**, but also depicts adjacent buildings, trees, streets, and/or other features. Such imagery may come from a variety of places. One example could be Google® Earth imagery database which is web based and provides address location information. Such imagery covers much of the world, although it may or may not be comparatively low resolution imagery. In FIG. **5**B, marker **106*a*** is shown in the region **502**, corresponding to the street address in field **102**. Note further that while marker **106*a*** is close to roof structure **501**, it does not directly or perfectly correspond to roof structure **501**. As such, the customer or other user may be allowed to move the marker (by click and dragging via computer mouse, arrows, or otherwise) to a final location **106*b*** as depicted in FIG. **4**C. Such final location is on top of the building **500** and such movement more precisely identifies the location of the building roof structure **501** to be measured. Optionally, in FIG. **4**C when said marker has been moved to final location **106*b***, the user may activate a selection confirmation, such as confirm selection button **104**, enter, checkbox or otherwise. Optionally, to potentially start over the user may be afforded the option of hitting the cancel button **105** or merely logging off. However, if confirmed selection button **104** or other such user acceptance is activated, another screen (and/or report) optionally may be provided, such as screen **100** as depicted in FIG. **4**D. While this may be a wide variety in the formats, in the one example provided, some or all of the regional image **502*a*** may be depicted showing the marker in its final location **106*b***. Also, a checkbox may be providing a further reconfirmation that the users reviewed the image is correct. In this way, the end user/customer will be sure that when placing an order, the vendor is measuring the correct roof structure as opposed to, for example, measuring the nearby roof structure due to mistake/miscommunication. Optionally, as shown in FIG. **4**D, fields may depict the address to be measured **108**, the city **109**, the state **110**, the postal code **111**, and otherwise. Optionally, a drop down box **112** may be provided corresponding to the number of planes ordered. Additionally, other options, such as rush processing **113** or other special features may be provided. Also optionally, a reference number or other such job number field **114** or claim number field **115** and/or other fields may be available. Thus, for example, a roofer having a job number and/or bidding pursuant to an insurance claim number and/or an insurance company doing the same may optionally enter data therein. When they do so, optionally, such reference numbers and/or claim numbers may be reprinted or otherwise depicted on the deliverables to the client, such as report **550**. This provides convenience to the end user/customer in that they may cross reference their deliverable report to their internal calendaring, docketing, invoicing, and/or job number system.

Also with reference to FIG. **4**D, computer screen **100** and/or the reports may also depict latitude references and/or longitude references corresponding to the street address and/or more precisely to the final location **106*b*** of the marker confirmed by the end user. Again, optionally, such latitude and longitude coordinates may be reflected in one or more of the reports.

Such translation to latitude and longitude coordinates also provides another optional feature. The present system and method may optionally include two or more separate imagery databases. For example, a lower resolution and/or less expensive image database such Google® Earth may be used as a first database, whereas a higher quality, higher resolution and/or more robust image database, such as by Pictometry International (as depicted here) may be used. Other vendors of imagery databases may be used and/or one may use their own image database(s). Thus, by translating the street address stated in longitude and latitude, it is easier to correlate to the second database. In this way, first imagery database from which the final location is selected may be internet based imagery having to corresponding street address look up field.

Only further using the latitude and longitude coordinates to access imagery from a second imagery database, such as for example Pictometry's database. Thereafter, using the imagery from the second database can generate in computer memory outline drawings around outlines corresponding to roof planes based on tracing from imagery from said second imagery database. Such outline drawings may include drawings such as depicted in FIGS. **5**D, **5**E, **5**F, **5**G and/or FIGS. **6** and/or **7**B-D for example. Additionally, since the first imagery database may merely be straight down, or plan views, whereas the second imagery may include a variety of oblique images, such as image **502** and **503** in FIG. **5**A and/or oblique imagery **504** and **505** in FIG. **5**B, as well as diagonal, top down imagery such as image **506** in FIG. **5**C. This allows the optional, more complete image reporting to the client in report **505**.

Such oblique imagery also permits the optional feature, as previously discussed, determining vertical measurements and/or roof pitches based on the imagery, as opposed to based on field measurements. Conversely, one can undertake this without any oblique imagery and/or any determination of vertical measurements or pitch, and instead rely on field measurements or other means for pitch.

In FIG. **3**, the location data **4**A is entered. Aerial imagery with a marker is provided **4**B. A person moves the marker on the image of the building **4**C. User acceptance of that marker position is then signaled **104***b*.

Mere examples of other optional features are depicted in FIGS. **7**A and **7**B. A simplified diagrammatic image of building **700** includes roof structure **701**. While several roof planes are illustrated, the particular focus is directed to roof planes **715** and **716**. As illustrated in FIG. **7**B, a first electronic drawing (preferably in a first layer of the drawing) is made over the imagery comprising lines A, Band C. Moreover, a second electronic drawing (preferably, but not necessarily, in a second layer of the drawing) is made over to imagery comprising lines E, F, G and H. Note that in this illustrated example, at least a segment of line A is substantially overlapping with at least a segment of line E. Thus, for example, roof plane **715** outlined by E, F, G and H may comprise a flat roof (0 pitch) porch whereas the remainder of the roof structure **701** may comprise a hip roof over a rectangular house, the hip roof being depicted in a plan view with two triangles and two isosceles rhombuses, as shown.

Note further that FIG. **7**B preferably is depiction of a deliverable, such as a report (and/or a screen shot), and optionally and more preferably is part of an interactive computer file. In this regard, it may include, optionally, table **720** and/or **721**, as well as any of the other tables and/or fields and/or features previously depicted in the previous drawings. For example, table **721** includes at least columns with a line and a column for the attribute, which preferably in this context is the non-dimensional attribute. Note in the example of these substantially overlapping lines A and E, A has the attribute of being a gutter free edge, whereas E has the attribute label "common".

In this regard, the label "common" also corresponds to Line E' in connection with roof plane **717'** illustrated in isolation as roof plane **717**. Other terms may be used instead of "common", but this indication denotes two lines that are substantially overlapping and in which the main purpose of the line is merely for dissecting a common roof plane, normally for determining square feet area, as opposed to a non-dimensional attribute. This is because such "common" lines, in a sense, are imaginary between roof plane **715** and roof plane **717'** and/or **717**. Alternatively, in the context of this building the attribute of line E could be "flashing" (instead of line Y being flashing) based on the reasonable assumption that this flat planed porch roof abuts the side of the building and has roof flashing along line Y. However, in such situation by denoting line E as flashing, in lieu of line Y, since they are of common length, this is merely a substitute for the total linear estimate of flashing of the type illustrated, for example at **513** (FIG. **20 6**) and/or table **521** (FIG. **5**I).

Plane **716** illustrates a minimum number of three lines, A, B and C, to denote the area of plane **716**. Conversely, note that plane **715** includes not only three lines, lines E, F and G, but also a fourth line, line H since it is rectilinear. This is consistent with the claiming of the present invention being open-ended in that at least three lines are required to define a roof plane, but it may be more. Likewise, a plane may be defined by 5, 6, 7 or more lines depending on its particular geometry.

As mentioned, it is not required, but is preferable that the lines defining the respective plane **715** and **716** are separate from each other, and even more preferable that they be in separate computer file layers overlaying one another. This helps facilitate having differing attributes along a common line as previously described in connection with the substantial overlap of lines A and E. Optionally, in the report the lines may be shown in different colors (and/or patterns) designated for each non-dimensional attribute.

Moreover, one or more additional adjustment planes, such as adjustment plane **717** prime, also depicted as free standing adjustment plane **717** may optionally be provided. This allows generating computer memory at least one adjustment roofing plane, such as by drawing lines E', X, Y and Z (as well as others). This is useful for a variety of situations, such as, for example, to adjust for portions of the roof structure which are not fully visible from the aerial imagery. This is shown in FIGS. **7**A and **7**B in that due to the overhanging eve of the hip roof of the house in plane **716**, part of the porch's roof structure is hidden by the overhanging roof hang. This hidden portion is depicted by roof plane **717'** and/or **717**.

It should also be noted that optionally, this adjustment plane does not necessarily have to be graphically depicted, as shown in FIG. **7**B. Rather, or in addition, an additional numeric field **20** may be provided. For example, in FIG. **5**F, the planes A-P are shown with their respective areas, and in some total of such areas. In this context, with or without a graphical depiction, an additional "plane" row may be provided denoted "adjustment" or otherwise with a numeric field allowing user entry of an area (square foot or otherwise) number be typed in or otherwise imported. Thus, the adjustment plane **717** (FIG. **7**B) even if not graphically depicted, might have known dimensions of, for example, 20 feet wide, with a two foot pitch overhand, resulting in an additional 40 feet of area. In this situation, in the adjustment field the user might simply enter the value "40" in square footage terms for the adjustment field. This adjustment field will be added to the sum total, such as shown in the table of FIG. **5**E. Note also that the adjustment value may be negative for a variety of reasons, given the user the ability to override and reduce the total estimation of square footage for reasons of discounting, or other circumstances.

Thus, for example, in FIG. **7**B at table **21**, it is denoted in that table as plane **717** with corresponding area of 40 square feet may correspond to a report that it is 20 feet wide (line E prime times 2 feet deep under the eaves, lines X and/or Z, thereby resulting in the calculation of 40 square feet. Or, as described above, alternatively with or without graphic depiction of plane **717**, the user might simply enter the value "40" square feet in the area field of table **721**.

FIGS. **7**C and **7**D, using the same structure of **7**A and **7**B, illustrates another feature which is optional, and may be used alone, or in connection with one or more of the features previously described. In particular, it provides for a computer data processing means that identifies light and dark contrast between adjacent roof planes, such as roof planes **716** and **718**, and based on that automatically generates at least one border line, such as for example line **719** shown in FIG. **7**D between such roof plane **716** and **718**. In this regard, note that as illustrated in FIGS. **7**C and D, roof plane **716** is shown as shaded. This represented in imagery of shadowing, typically caused by sun or other lighting casting different degrees of shadow in brightness and darkness depending on the orientation of the roof plane with the source of the light. The generation of various lines, such as line **719**, is automatically computer generated. This may be done by a variety of techniques borrowed from the separate field of computer face recognition used in connection with digital images such as for security purposes. This may be done to create some or all of the line values, or more preferably at least starting point default lines drawing by the computer. However, optionally the default generation of the lines can be done after perimeter lines P, around the entire outer perimeter of the roof structure **701**, having drawn ordinarily by a human user. This has the advantage of establishing a closed, finite area within the region for which the computer software automatically generates one or more of the lines separating the geometries of the separate roof planes. Preferably, this is done by generating and labeling discreet lines which may be overridden by the user, such as deleting extraneous or erroneous or duplicative lines and/or moving them. Moreover, optionally such lines may be generated as the subparts of geometric shapes set as presumptive default shapes common in roof planes. This normally would include rectangles, triangles and rhombuses.

Additionally, such automatic and/or default generation of lines may optionally be coupled with the previously described pitch generation algorithms. In this way, default pitches may be generated by the computer and depicted in the report output. Again, this can be overridden by the user, including the vendor of such report information.

Note also that in FIG. **7**A-**7**D, the various lettered lines (A, B, C, E, F, G, H), are illustrated here slightly offset from the actual underlying line in the building imagery. In practice, preferably so as to maximize accuracy, there is not such offset. Rather, the offset is depicted here in FIG. **7**A-D merely for drawing clarity to separately depict the line in the aerial image from the computer drawn line overlaying the image.

Another optional feature is that the information, including reporting, may be made to interface electronically (and/or manually) with other products. For example, the information provided here may be uploaded or transferred to Xactimate™ Insurance estimating software known in the prior art. Naturally, this feature, while helpful, is not required.

What is claimed:

1. A process for determining attributes of a roof structure of a real-world three-dimensional building, comprising the acts of:

providing at least one computer input field for a user to input first location data generally corresponding to the location of the building;

providing visual access to an aerial image of a region including the roof structure of the building corresponding to said first location data, the aerial image taken from a straight down overhead view with respect to the roof structure;

on the aerial image of the region, providing a visual marker that is moveable on a computer monitor around said region, said visual marker initially corresponding to said first location data, wherein said visual marker may be moved to a final location on top of the building to more precisely identify the location of the building roof structure, the final location having location coordinates;

providing a computer input capable of signaling user-acceptance of the final location of said marker; and,

providing visual access to one or more oblique images of an aerial imagery database corresponding to location coordinates of the final location.

2. The process of claim **1** and wherein said first location data comprised street address data, and wherein said location coordinates of said final location are translated to latitude and longitude coordinates.

3. The process of claim **2** and wherein said image corresponding to the first location data is from a first imagery database from which said final location is selected and is internet-based imagery having a corresponding street address look up field, and wherein the aerial imagery database is a second imagery database, and further comprising the act of:

using said latitude and longitude coordinates to access imagery from the second imagery database.

4. The process of claim **3** and further comprising the act of:

generating, in computer memory, outline drawings around outlines corresponding to roof planes based on tracing from said imagery from said second imagery database.

5. The process of claim **4** and wherein said providing acts are provided over an internet interface.

6. The process of claim **5** and further comprising the act of:

providing a printed report that includes an aerial image of the building roof structure.

7. The process of claim **1** and further comprising the act of:

generating, in computer memory, outline drawings around outlines corresponding to roof planes based on tracing from said imagery.

8. The process of claim **1** and wherein said providing acts are provided over an internet interface.

9. The process of claim **1** and further comprising the act of:

providing a printed report that includes an aerial image of the building roof structure.

10. The process of claim **9** and wherein the printed report includes a latitude reference and/or a longitude reference corresponding to the location of the building roof structure.

11. The process of claim **1**, wherein the user is a customer.

12. The process of claim **1**, wherein the user is a commercial vendor.

13. The process of claim **1**, further comprising providing visual access to the one or more images of the aerial imagery database corresponding to the final location data.

14. A non-transient computer memory storing computer logic, that when executed by computer hardware causes the computer hardware to determine attributes of a roof structure of a real-world three-dimensional building by:

providing at least one computer input field for a user to input first location data generally corresponding to the location of the building;

providing visual access to an aerial image of a region including the roof structure of the building corresponding to said first location data, the aerial image taken from a straight down overhead view with respect to the roof structure;

on the aerial image of the region, providing a visual marker that is moveable on a computer monitor around said region, said visual marker initially corresponding to said first location data, wherein said visual marker may be moved to a final location on top of the building to more precisely identify the location of the building roof structure, the final location having location coordinates;

providing a computer input capable of signaling user-acceptance of the final location of said marker; and,

providing visual access to one or more oblique images of an aerial imagery database corresponding to location coordinates of the final location.

15. The non-transient computer memory of claim **14**, wherein said first location data comprised street address data, and wherein said location coordinates of said final location are translated to latitude and longitude coordinates.

16. The non-transient computer memory of claim **15**, wherein said aerial image corresponding to the first location data is from a first imagery database from which said final location is selected and is internet-based imagery having a corresponding street address look up field, and wherein the aerial imagery database is a second imagery database, and wherein said computer logic when executed by computer hardware causes the computer hardware to:

use said latitude and longitude coordinates to access imagery from the second imagery database.

17. The non-transient computer memory of claim **16**, wherein said computer logic when executed by computer hardware causes the computer hardware to:

generate, in computer memory, outline drawings around outlines corresponding to roof planes based on tracing from said imagery from said second imagery database.

18. The non-transient computer memory of claim **17**, wherein said computer logic when executed by computer hardware causes the computer hardware to:

provide a printed report that includes an aerial image of the building roof structure.

19. The non-transient computer memory of claim **14**, wherein said computer logic when executed by computer hardware causes the computer hardware to:

generate, in computer memory, outline drawings around outlines corresponding to roof planes based on tracing from said imagery.

20. The non-transient computer memory of claim **14**, wherein said providing acts are provided over an internet interface.

* * * * *

EXHIBIT 8

US008818770B2

(12) **United States Patent**
Pershing

(10) **Patent No.: US 8,818,770 B2**
(45) **Date of Patent: Aug. 26, 2014**

(54) **PITCH DETERMINATION SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION**

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(73) Assignee: **Eagle View Technologies, Inc.**, Bothell, WA (US)

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(51) **Int. Cl.**

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G06F 7/60	(2006.01)
G06F 17/10	(2006.01)
G06K 9/00	(2006.01)
G06T 7/00	(2006.01)
G06T 17/20	(2006.01)

(52) **U.S. Cl.**

CPC ***G06T 7/0083*** (2013.01); ***G06F 17/5004*** (2013.01); ***G06K 9/00637*** (2013.01); *G06T 2207/10032* (2013.01); ***G06T 17/20*** (2013.01); ***G06T 7/0042*** (2013.01); *G06T 2207/30184* (2013.01); *G06T 2200/24* (2013.01)

USPC **703/1**; 703/2

(58) **Field of Classification Search**

CPC ... G06F 17/20; G06F 17/5004; G06T 7/0083; G06T 7/0042; G06T 2200/24; G06T 2200/30184; G06T 2207/10032; G06K 9/00637

USPC 703/1

See application file for complete search history.

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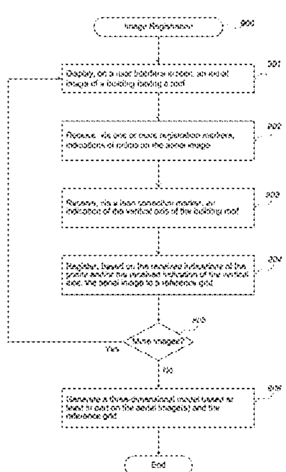
(57) **ABSTRACT**

User interface systems and methods for roof estimation are described. Example embodiments include a roof estimation system that provides a user interface configured to facilitate roof model generation based on one or more aerial images of a building roof. In one embodiment, roof model generation includes image registration, image lean correction, roof section pitch determination, wire frame model construction, and/or roof model review. The described user interface provides user interface controls that may be manipulated by an operator to perform at least some of the functions of roof model generation. In one embodiment, the user interface provides user interface controls that facilitate the determination of pitch of one or more sections of a building roof. This abstract is provided to comply with rules requiring an abstract, and it is submitted with the intention that it will not be used to interpret or limit the scope or meaning of the claims.

26 Claims, 29 Drawing Sheets



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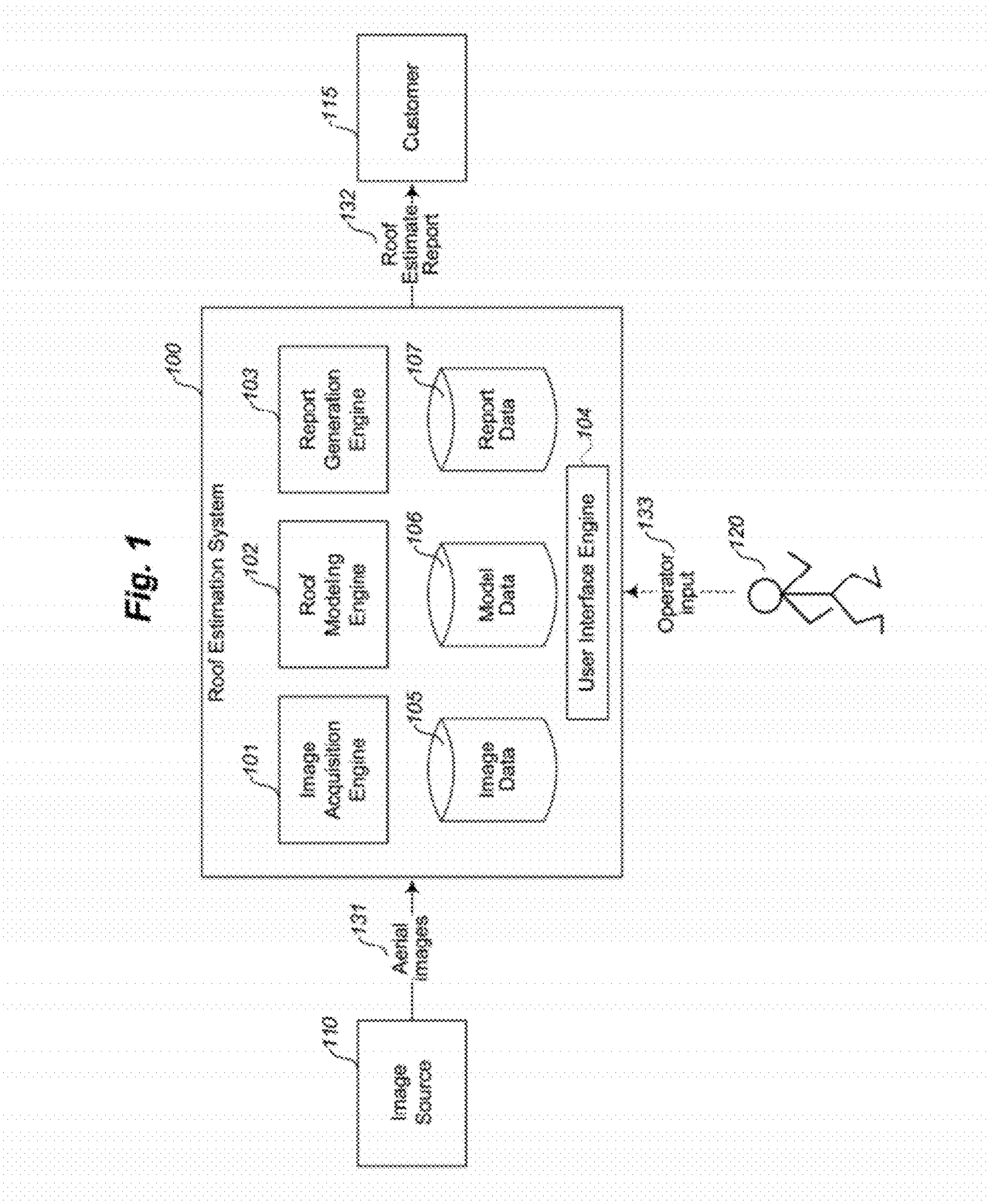
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Operator Input
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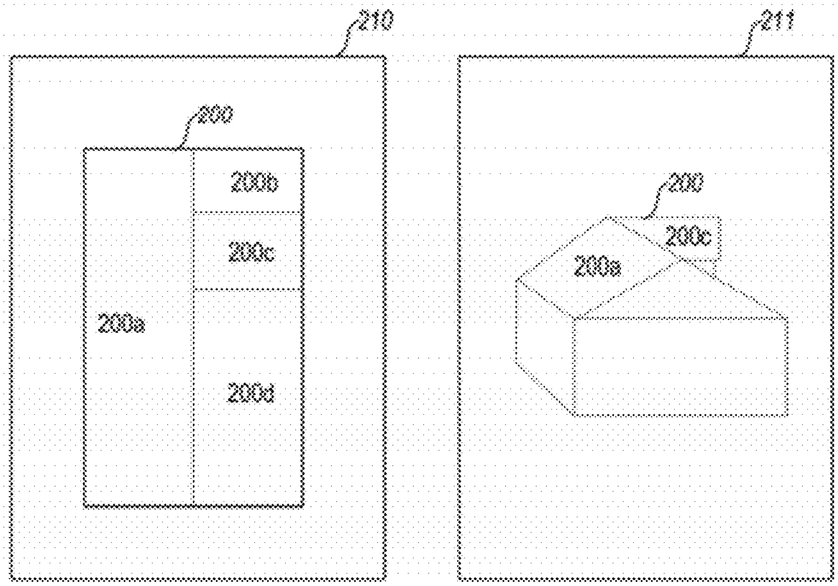
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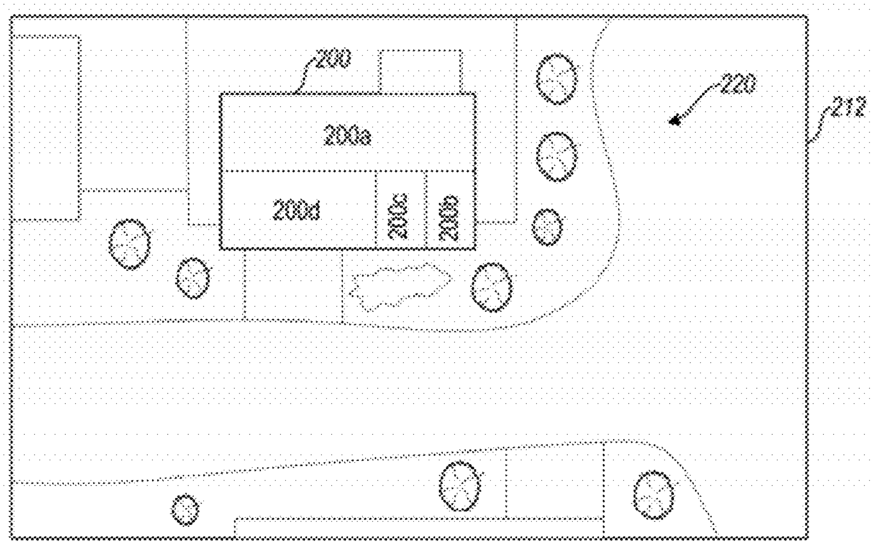
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Fig. 2B

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301a

1234 Main Street, Redmond, WA

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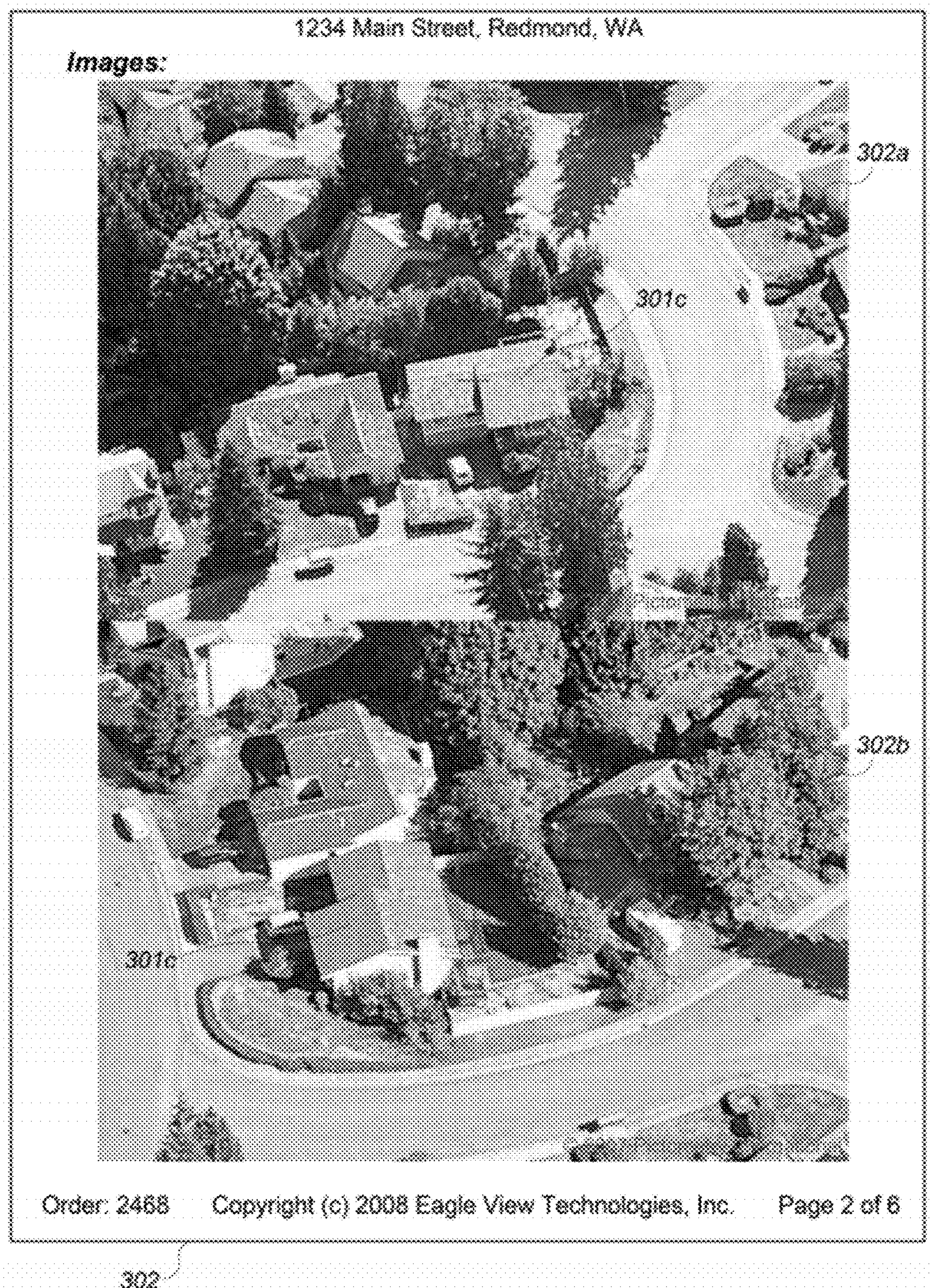
301

Fig. 3A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Page 2 of 6
302

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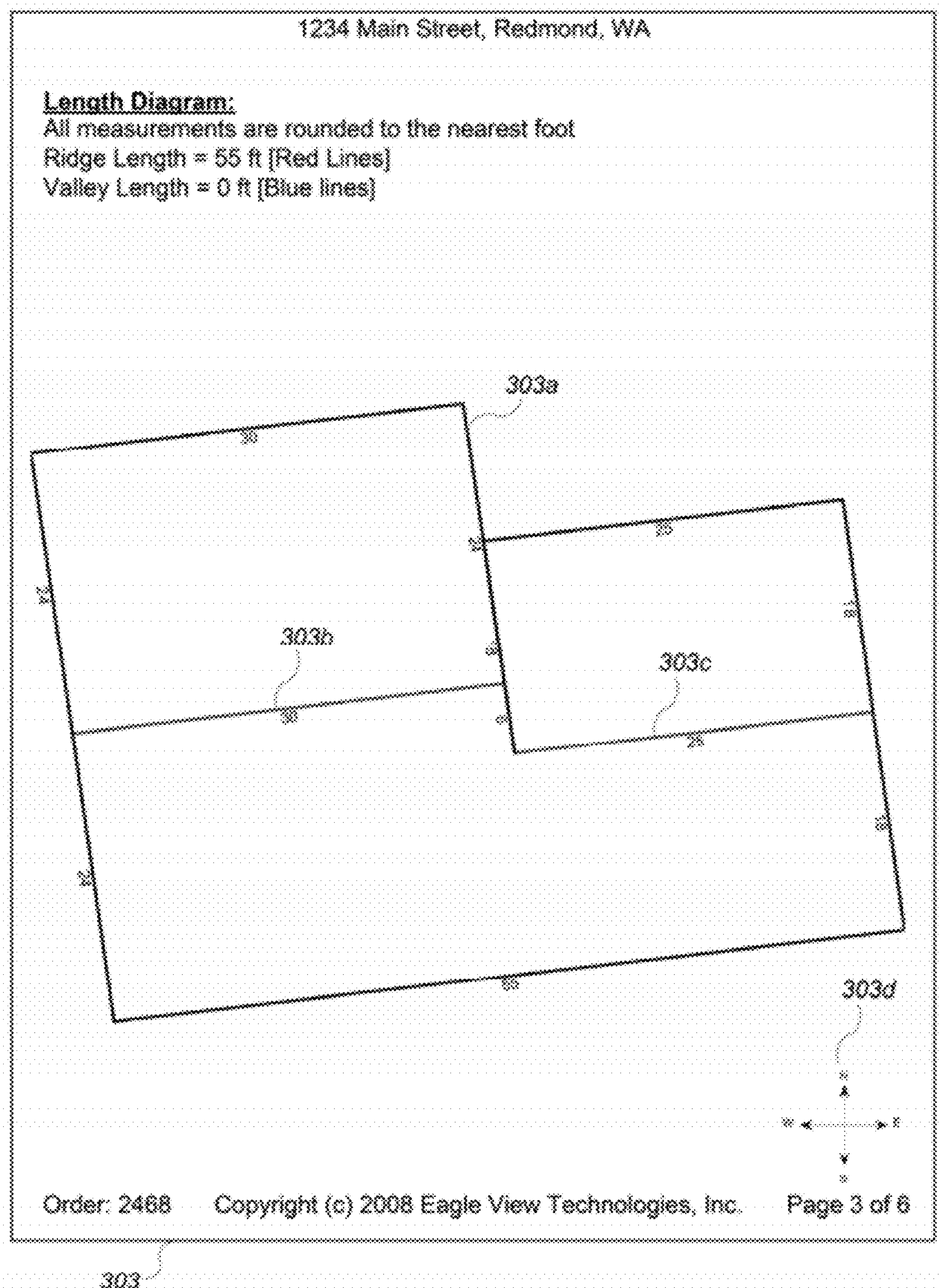
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Ridge Length = 55 ft [Red Lines]
Valley Length = 0 ft [Blue lines]
303a
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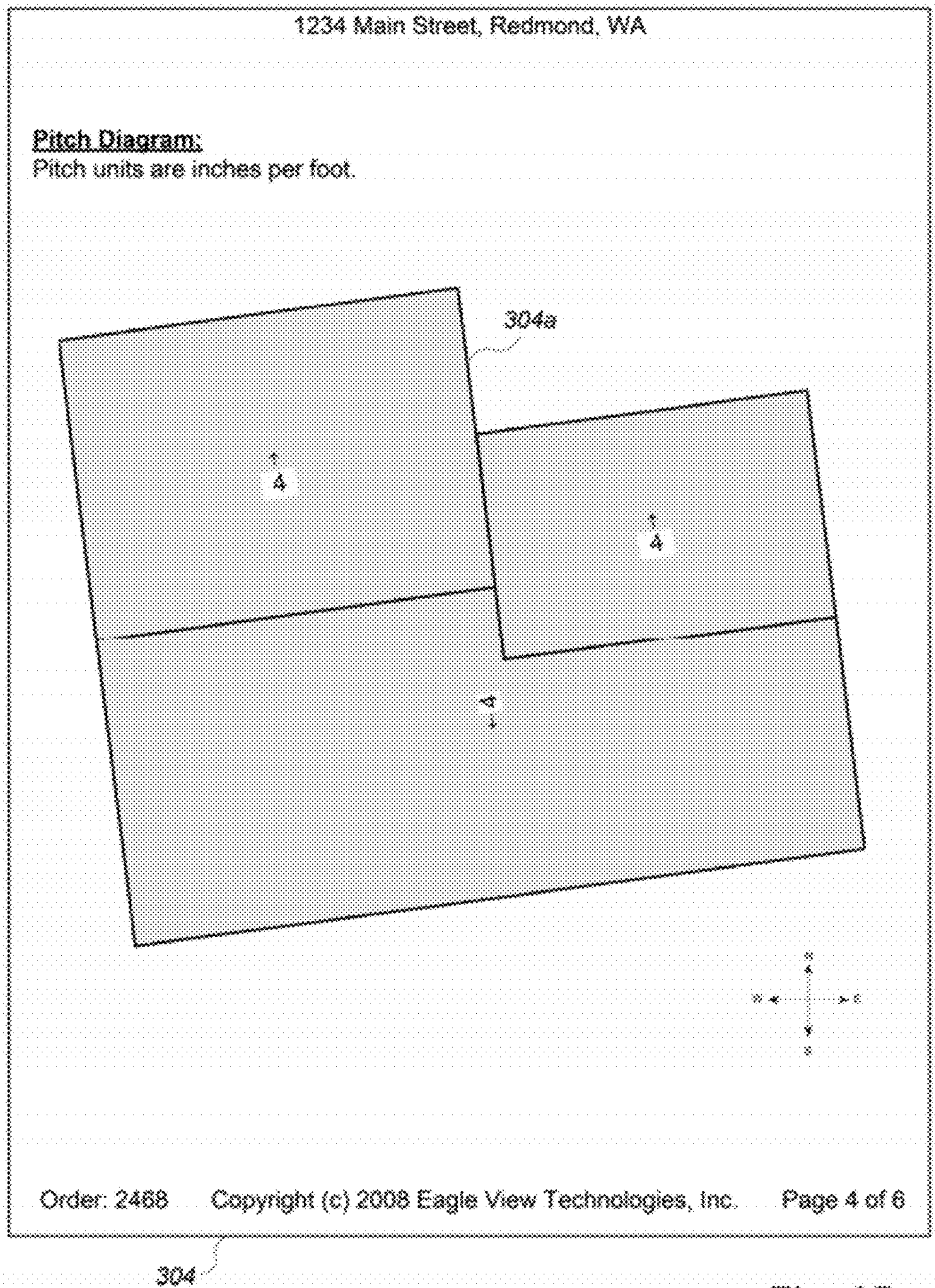
Page 3 of 6
303

Fig. 3C



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Pitch Diagram:
Pitch units are inches per foot.
304a
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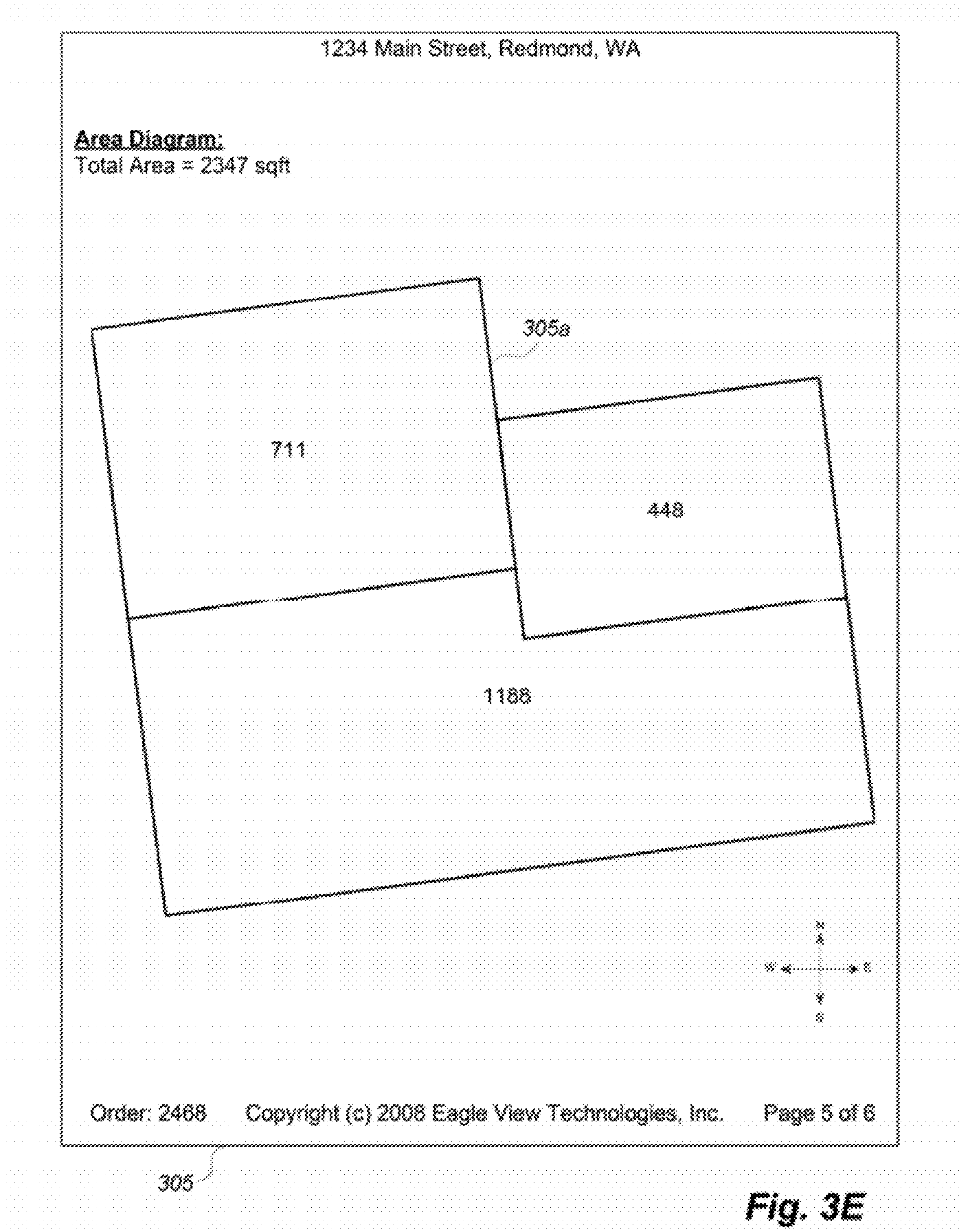
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 4 of 6
304

Fig. 3D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Page 5 of 6
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Fig. 3E

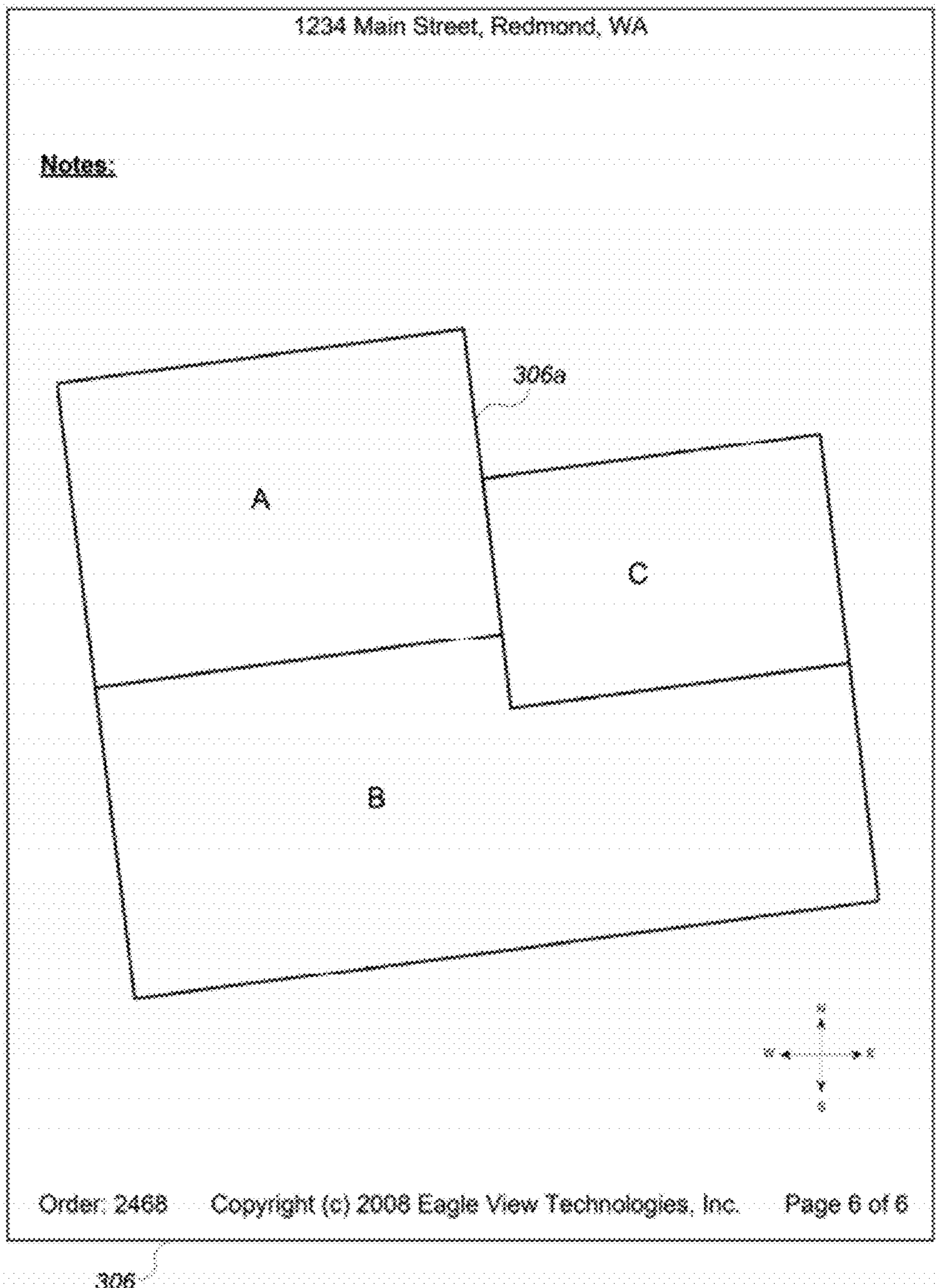
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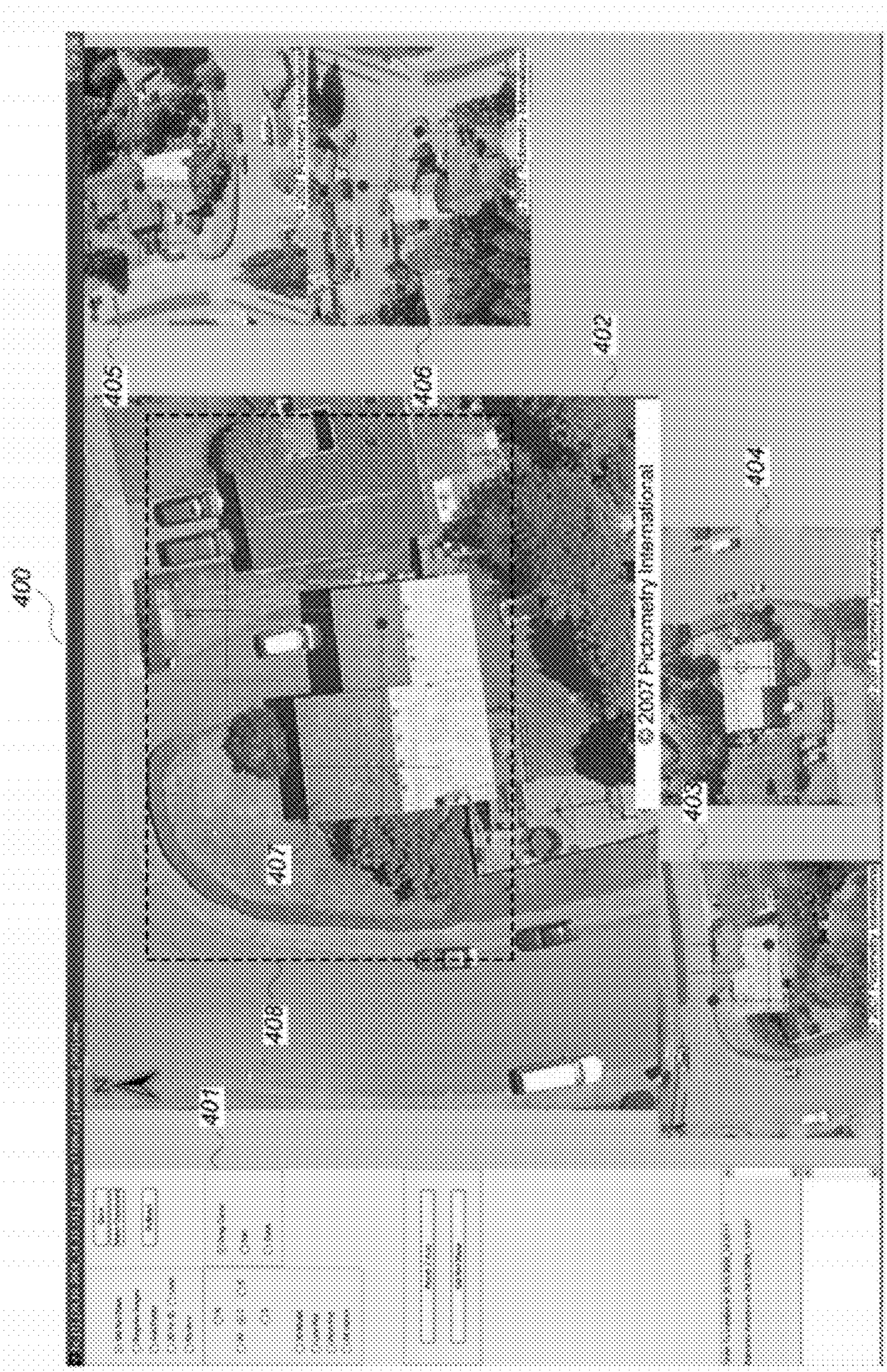
Fig. 3F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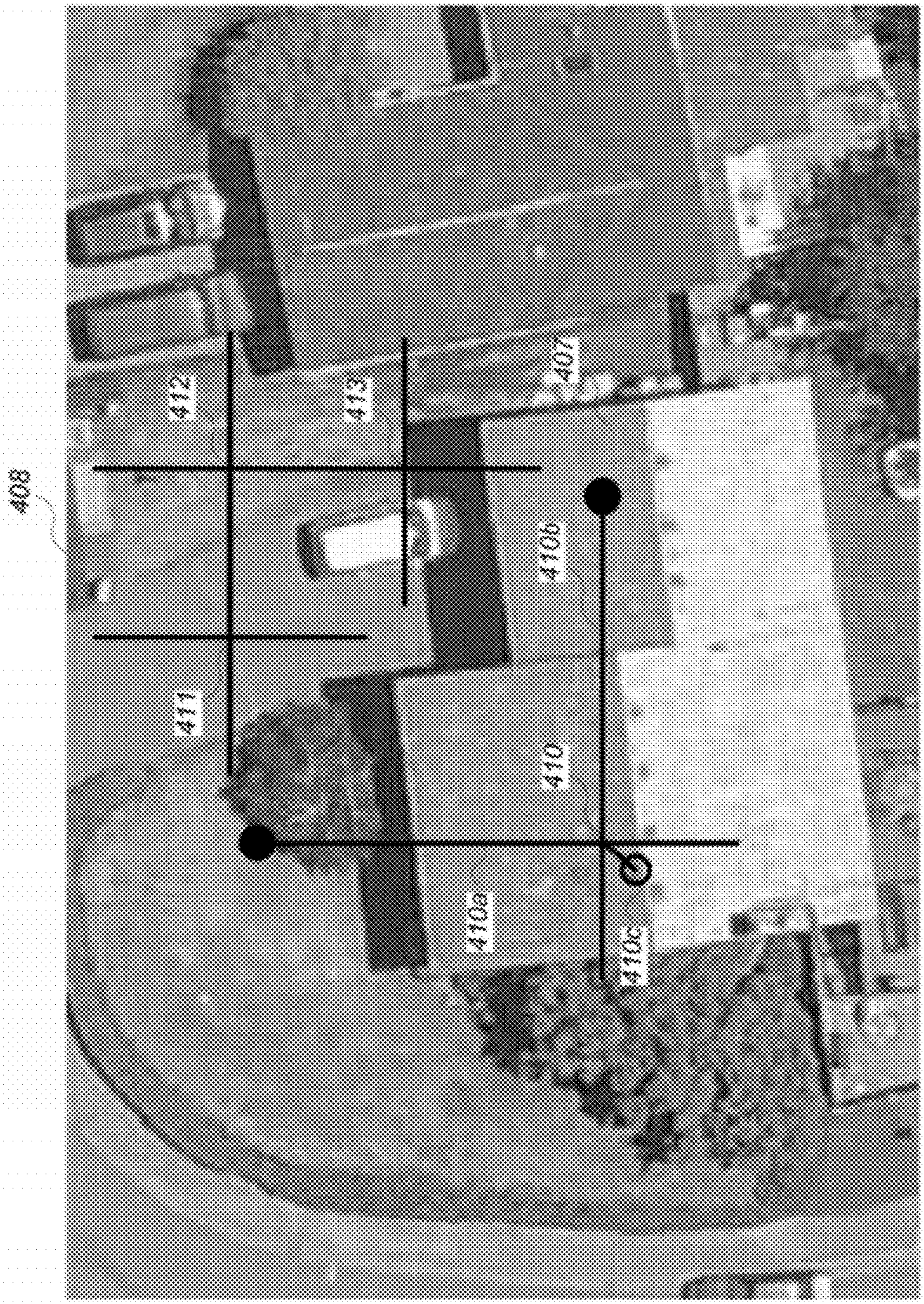

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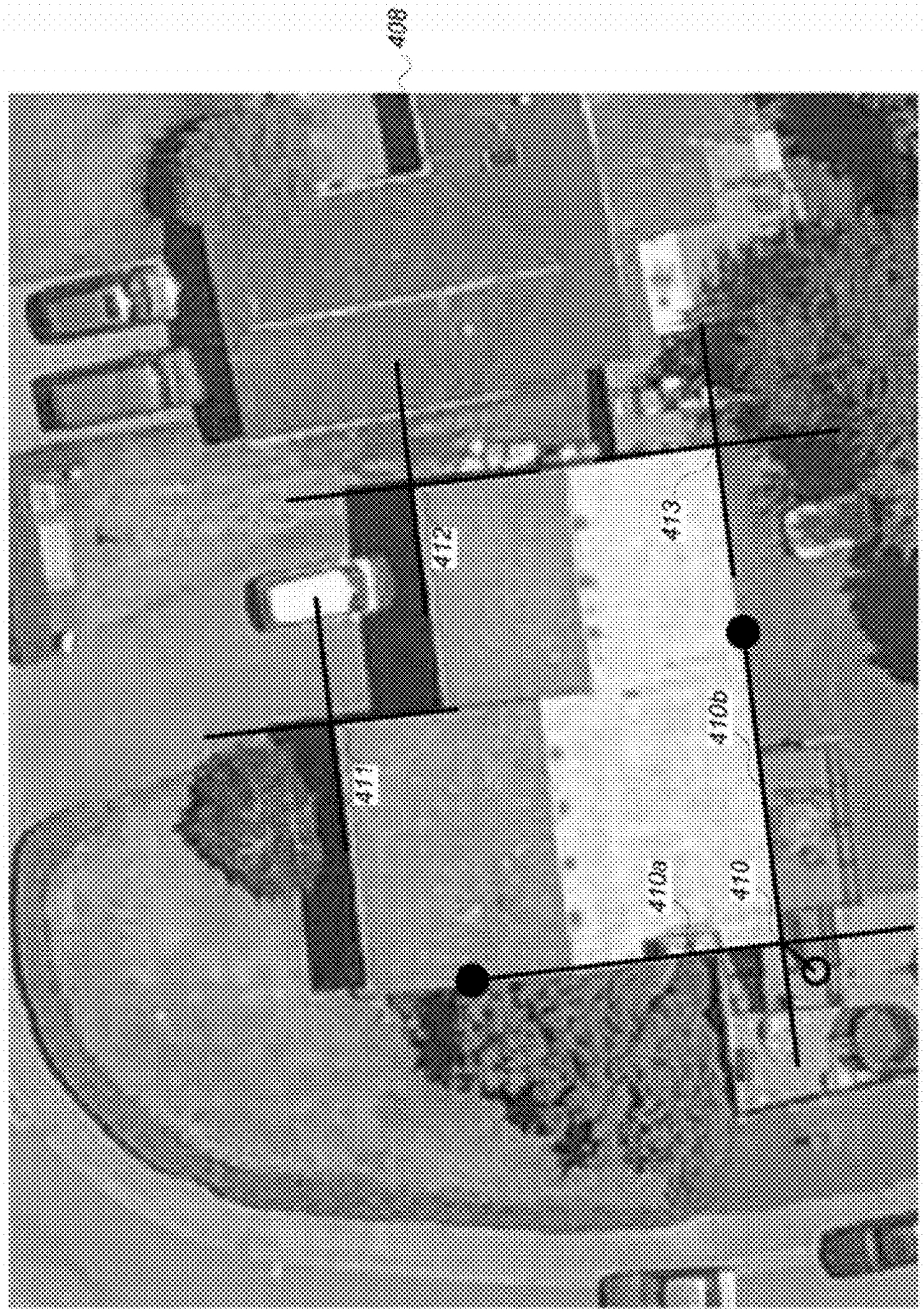

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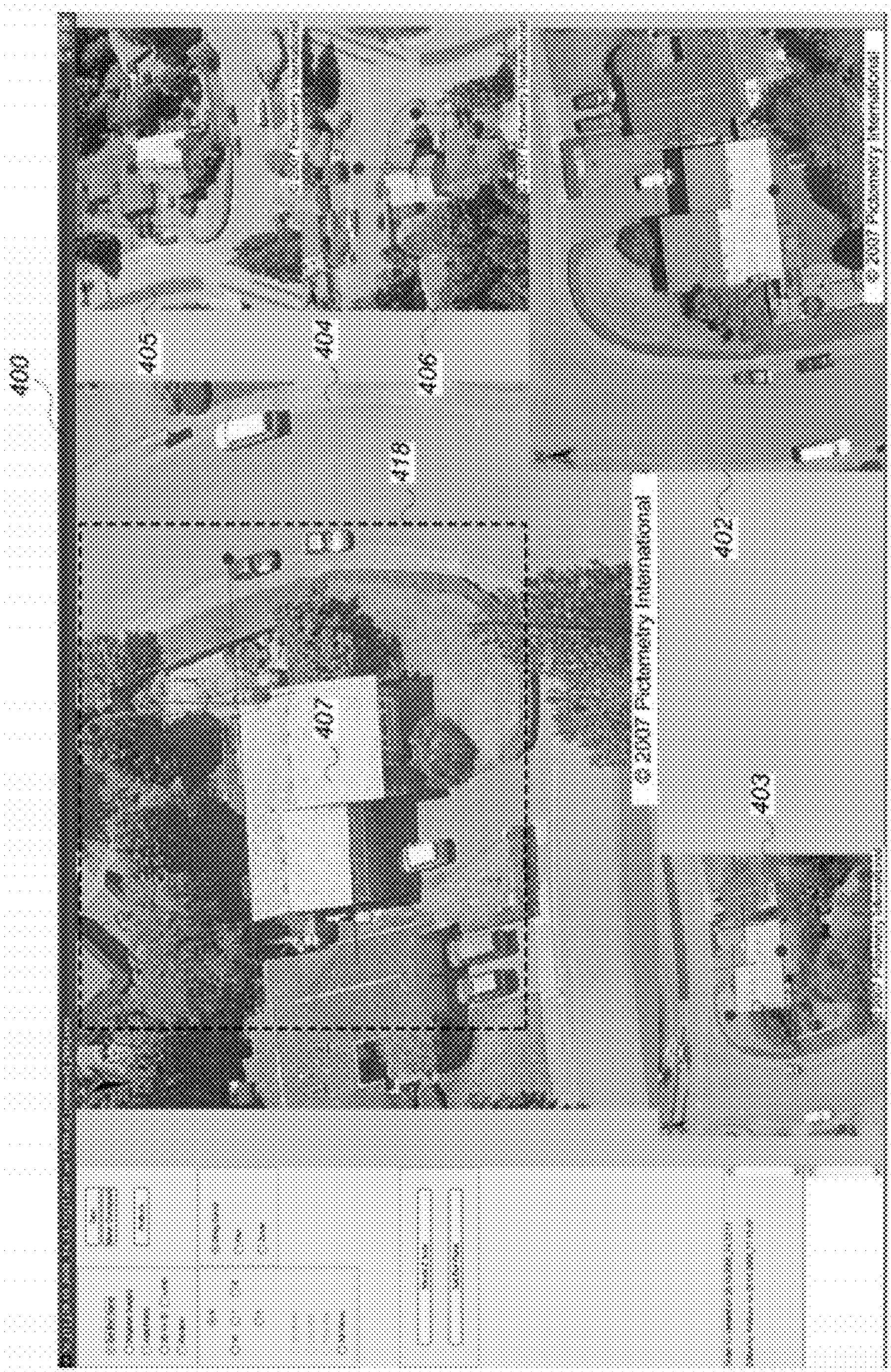
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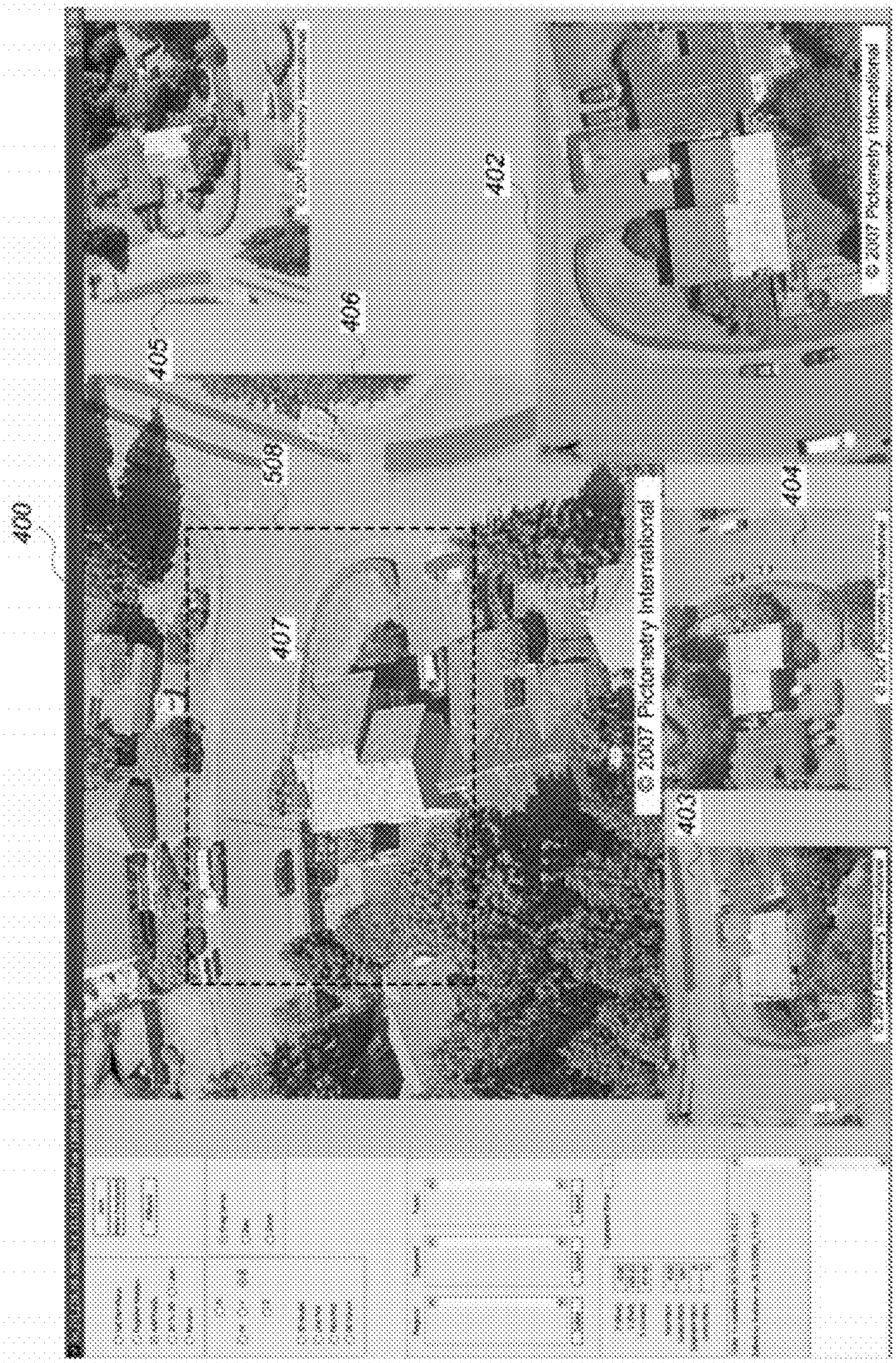
Fig. 4D

Fig. 4E

418

Fig. 4F



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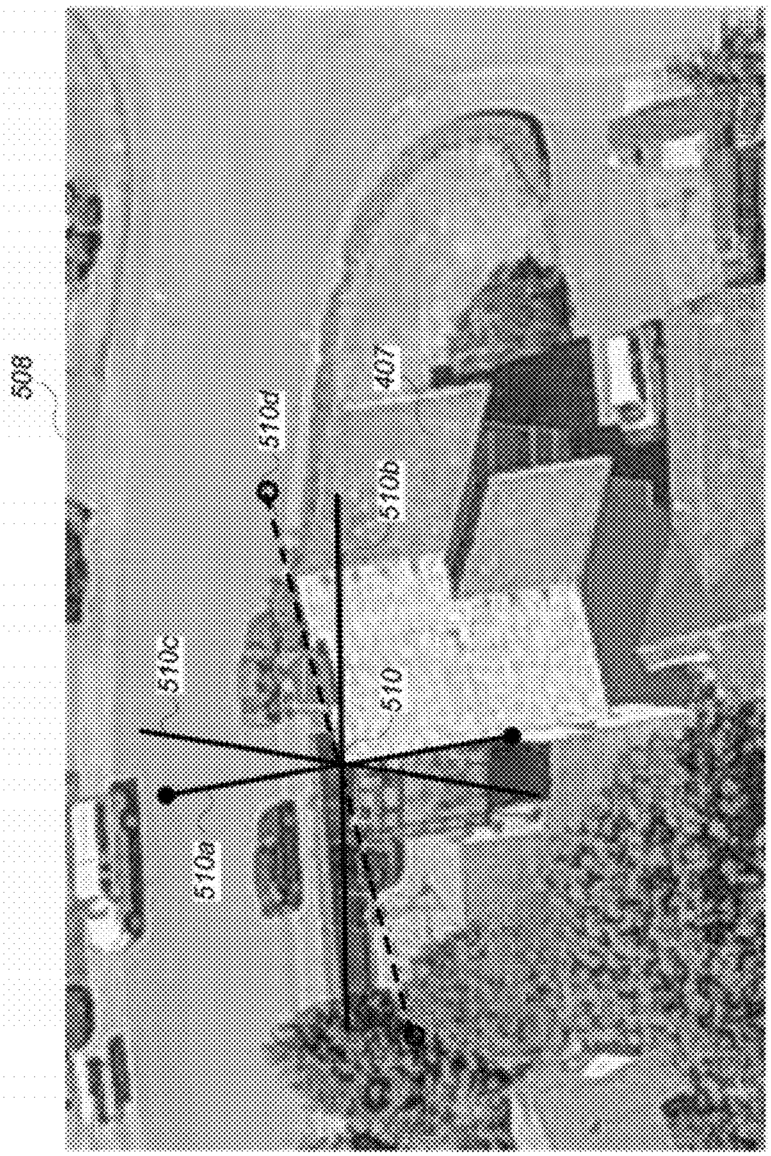

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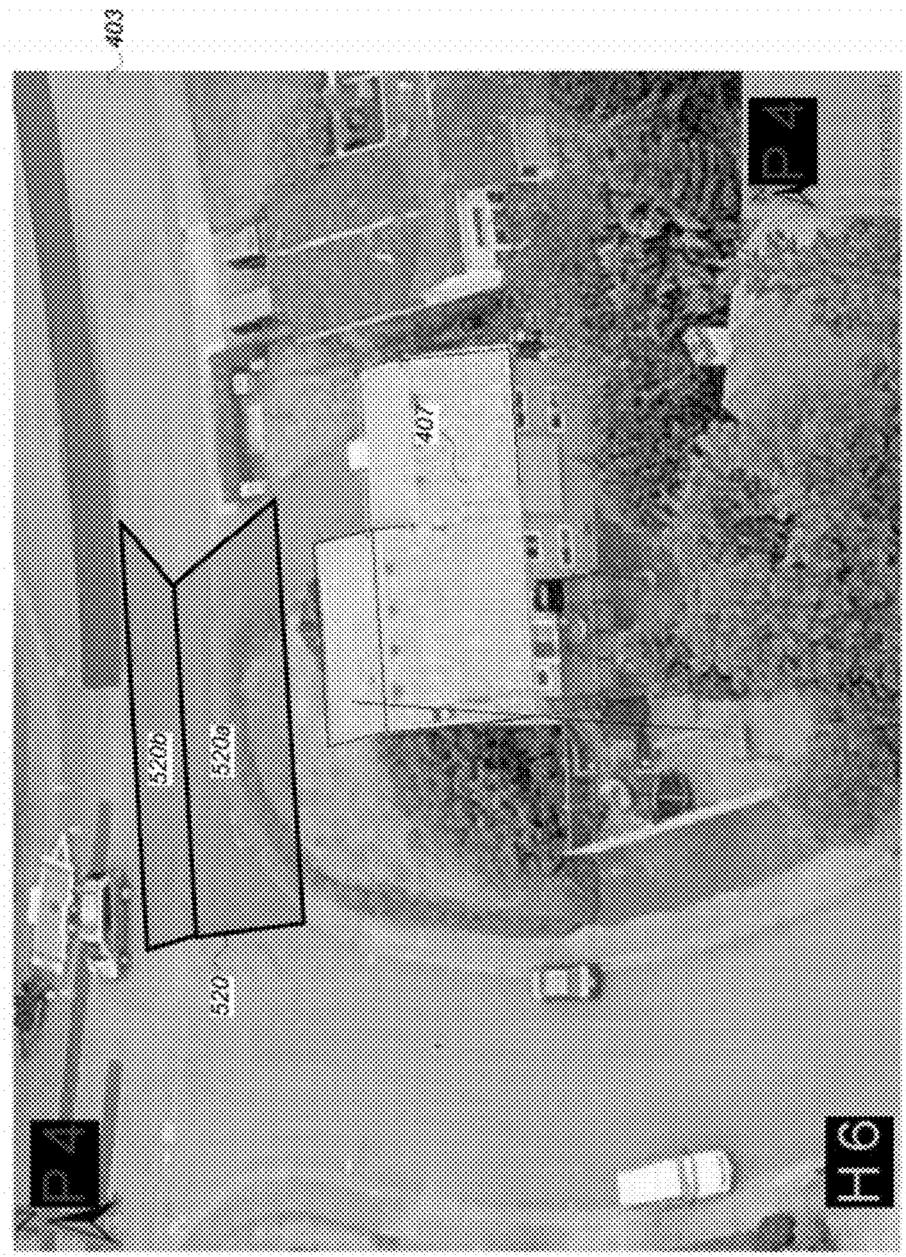

Fig. 5C

Fig. 5D

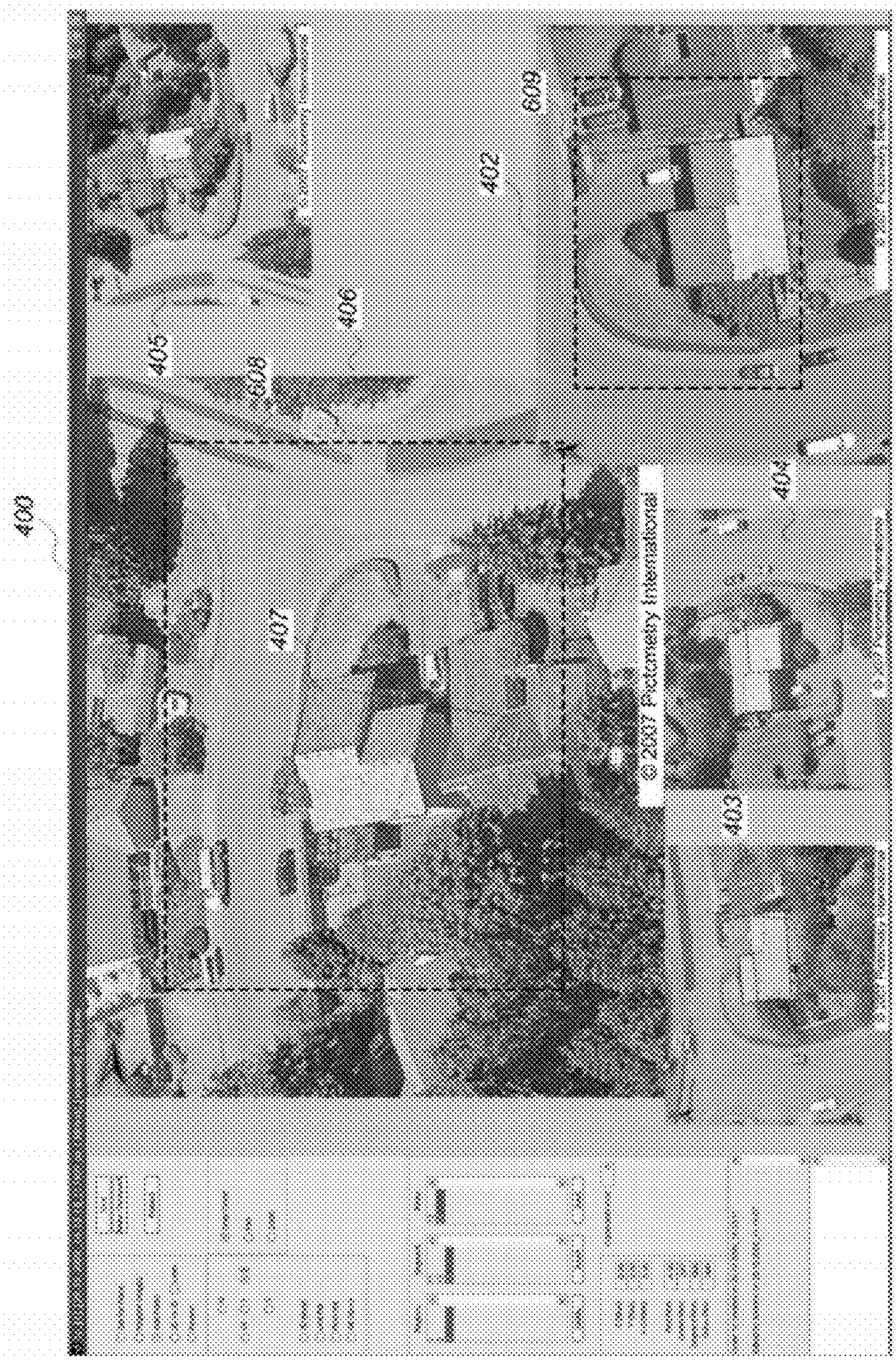
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Fig. 6A

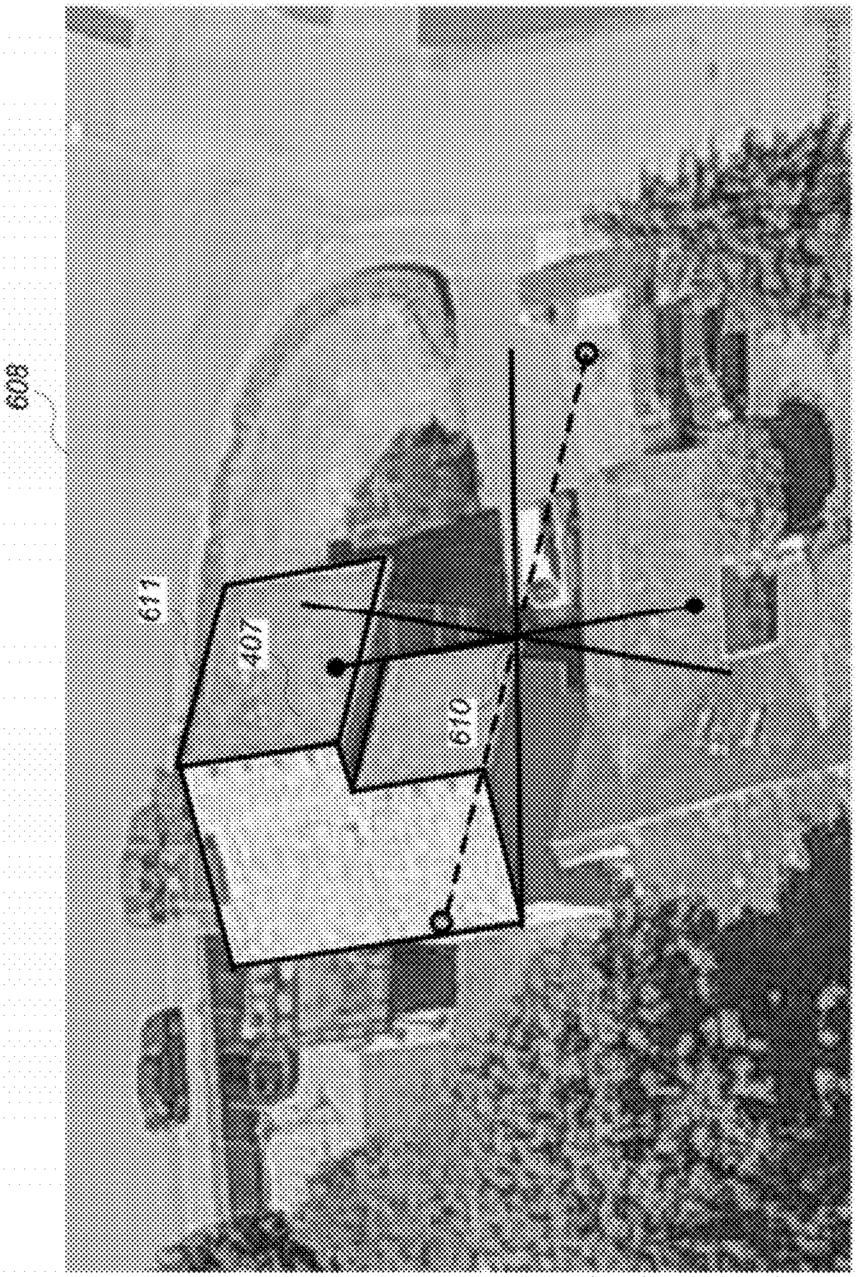
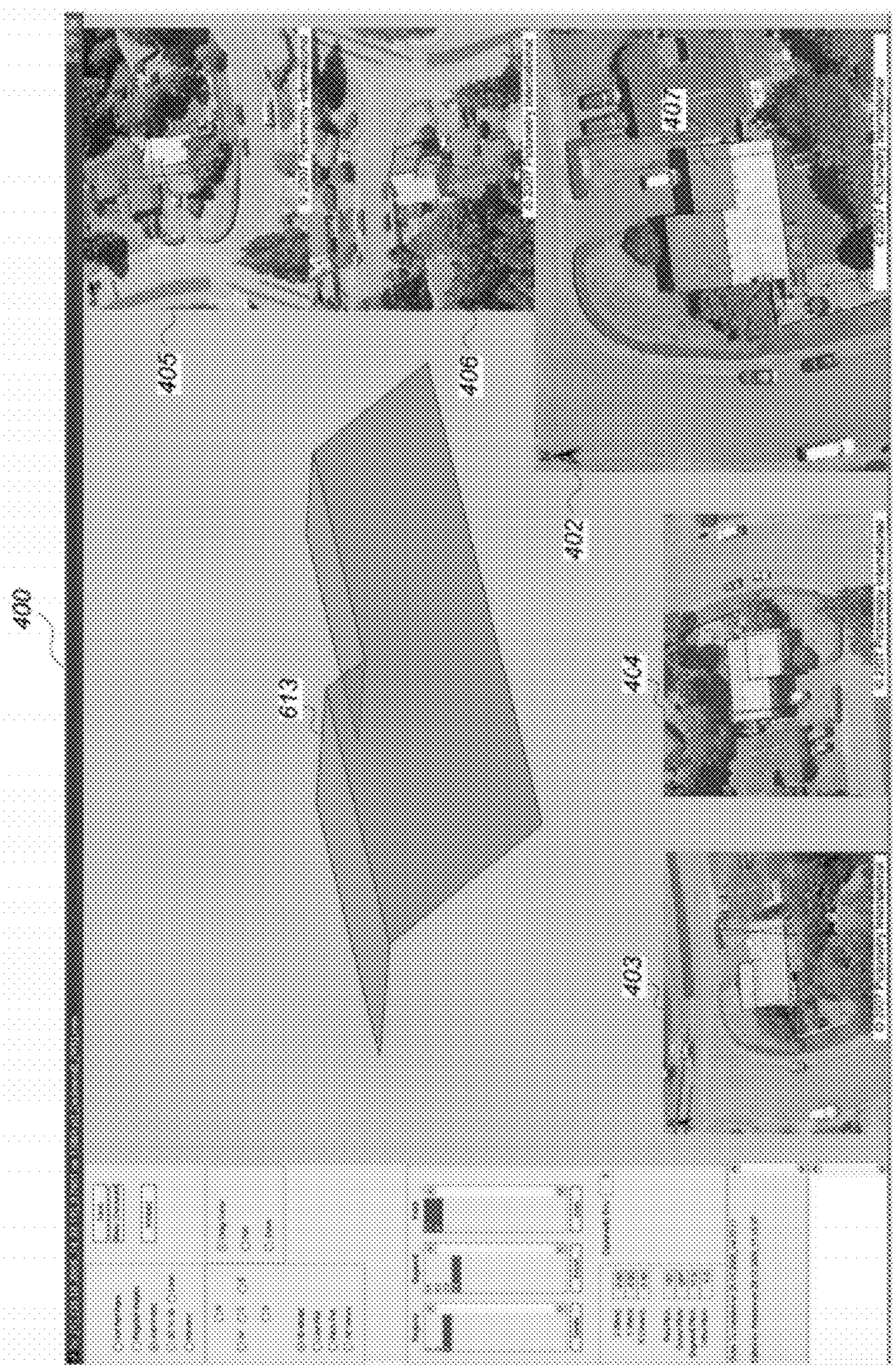


Fig. 6B

Fig. 6C



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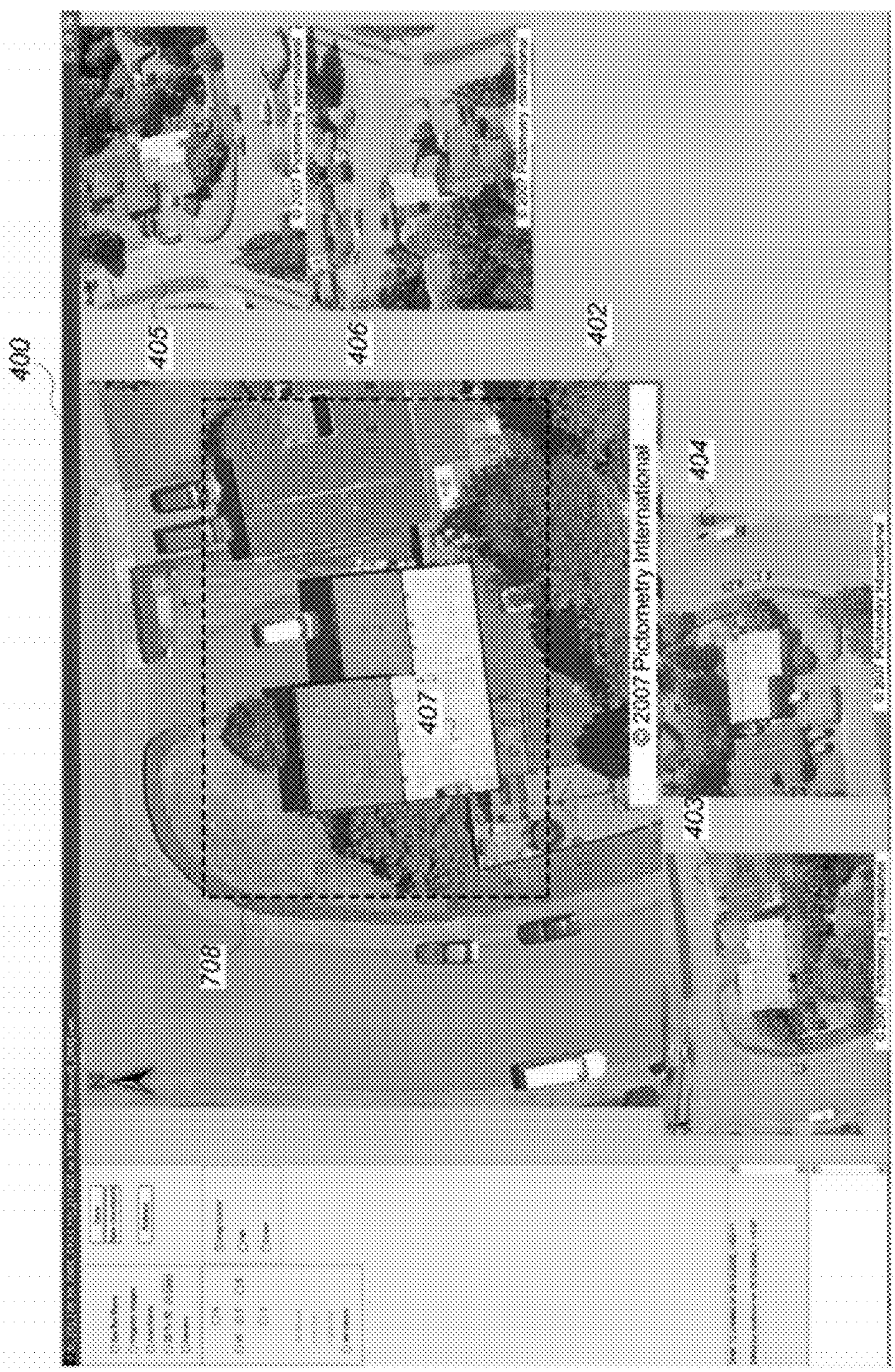
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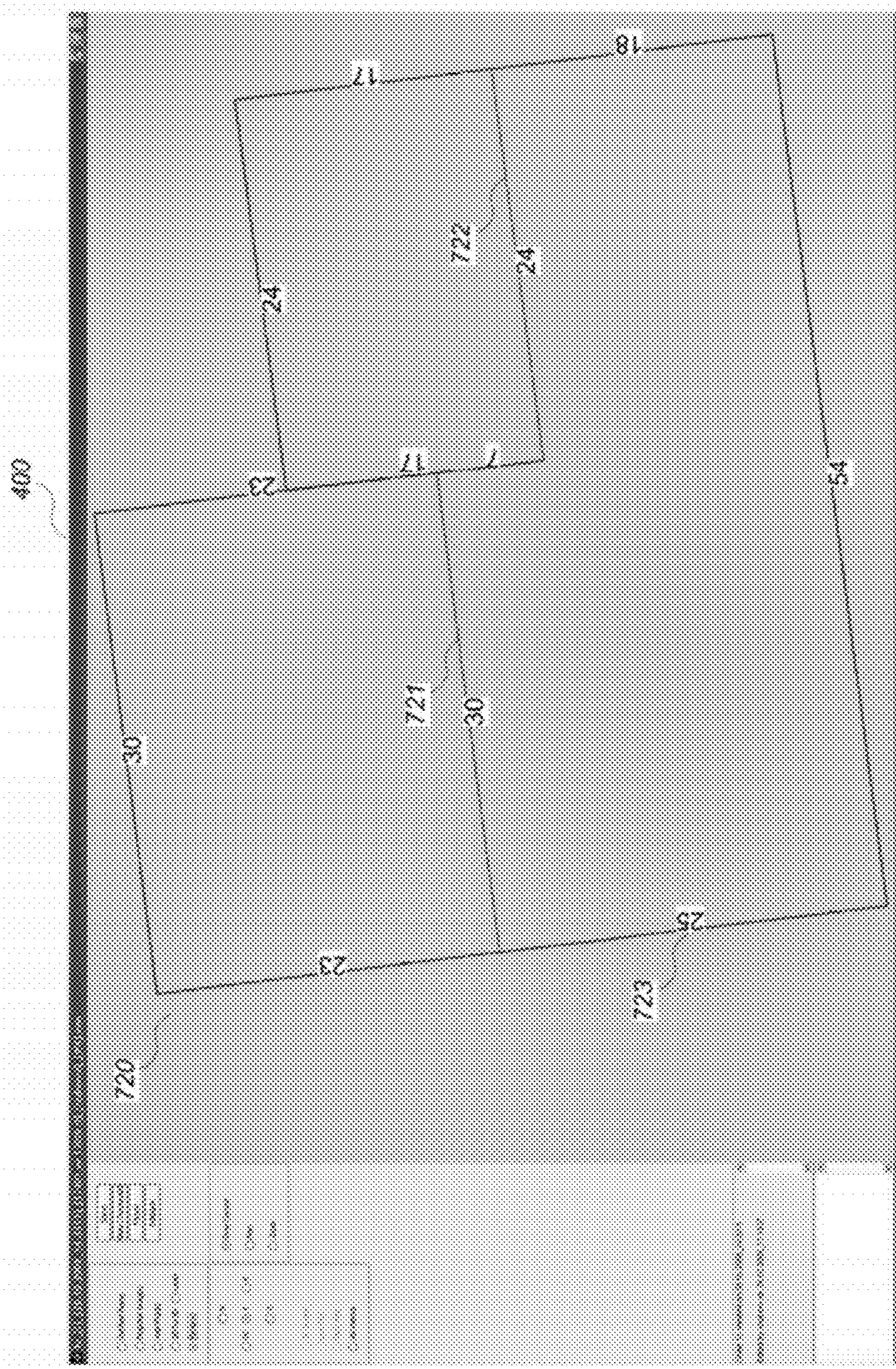
Fig. 7A

Fig. 7B



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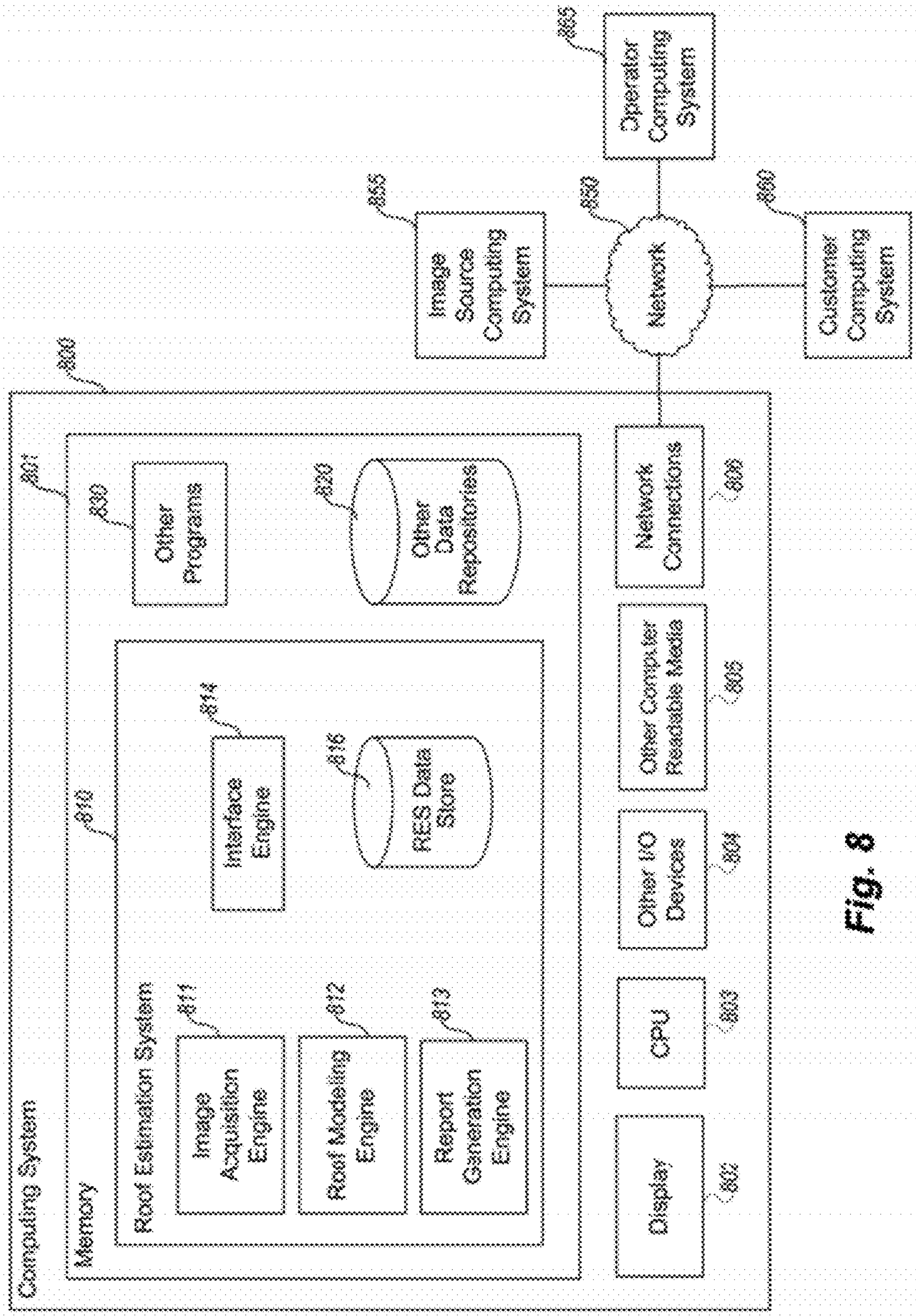
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Report Generation Engine
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Interface Engine
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830
Other Programs
820
Other Data Repositories
Display
802
CPU
803
Other I/O Devices
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Other Computer Readable Media
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Network Connections
806
850
Network
855
Image Source Computing System
860
Customer Computing System
865
Operator Computing System

Fig. 8

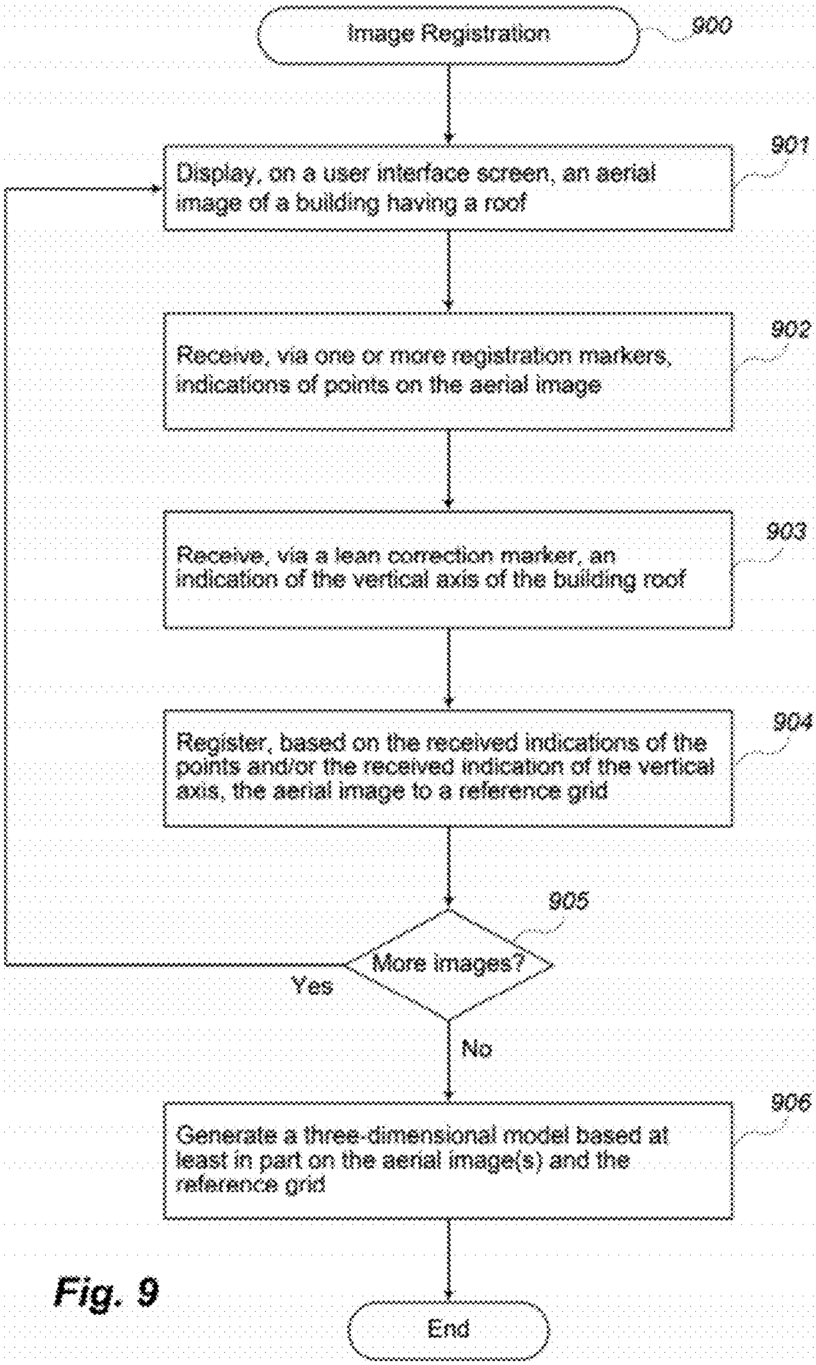
Image Registration
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Display, on a user interface screen, an aerial image of a building having a roof
901
Receive, via one or more registration markers, indications of points on the aerial image
902
Receive, via a lean correction marker, an indication of the vertical axis of the building roof
903
Register, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid
904
More images?
905
Yes
No
Generate a three-dimensional model based at least in part on the aerial image(s) and the reference grid
906
End

Fig. 9

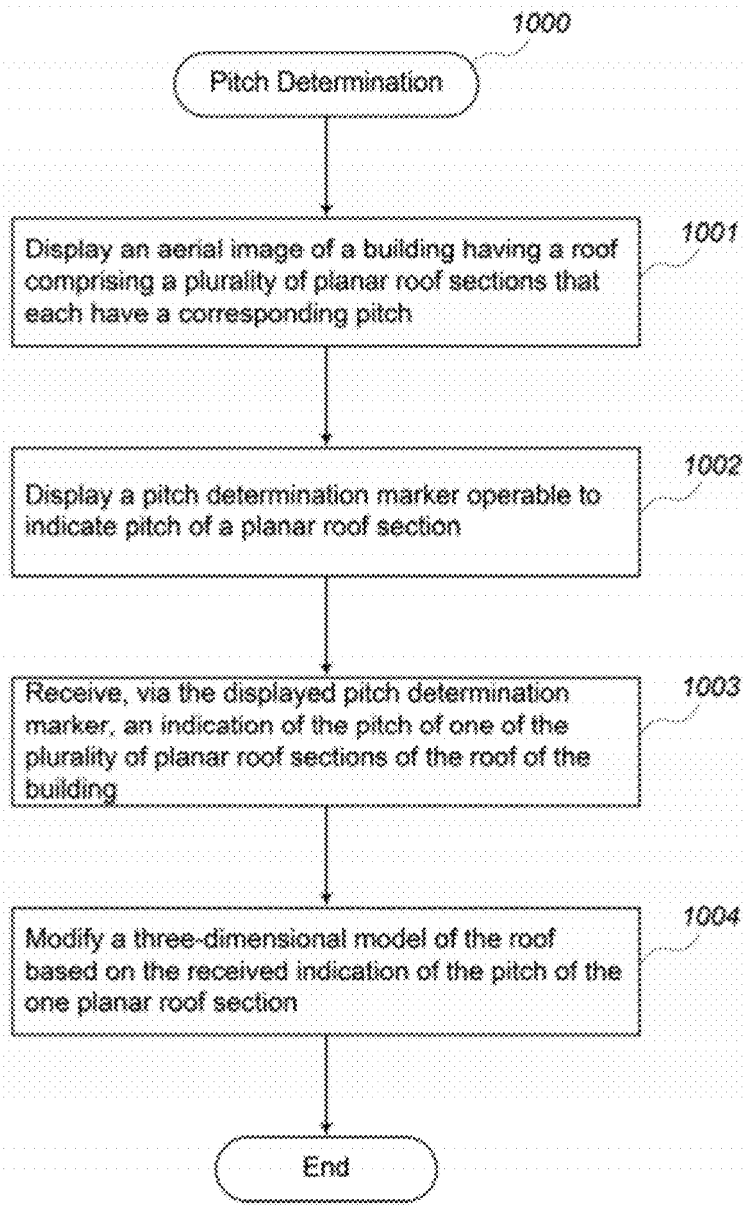
1000
Pitch Determination
1001
Display an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch
1002
Display a pitch determination marker operable to indicate pitch of a planar roof section
1003
Receive, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building
1004
Modify a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section
End

Fig. 10

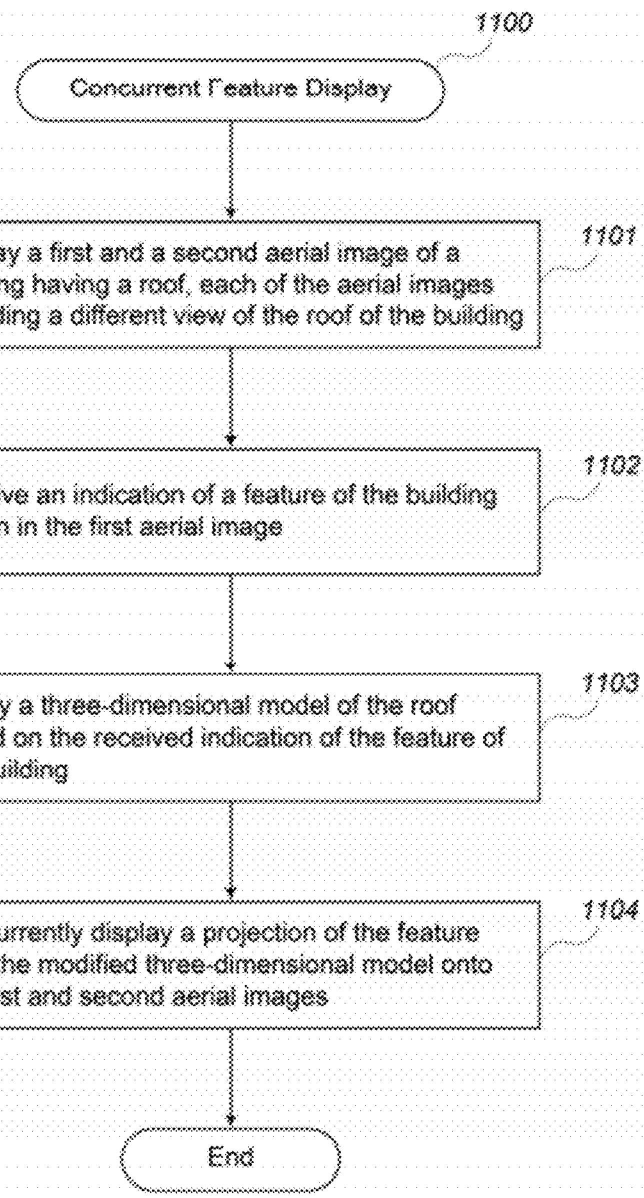
1100
Concurrent Feature Display
1101
Display a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building
1102
Receive an indication of a feature of the building shown in the first aerial image
1103
Modify a three-dimensional model of the roof based on the received indication of the feature of the building
1104
Concurrently display a projection of the feature from the modified three-dimensional model onto the first and second aerial images
End

Fig. 11

PITCH DETERMINATION SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/467,244, filed May 15, 2009, which claims benefit of U.S. Provisional Application No. 61/197,904 filed on Oct. 31, 2008, which applications are incorporated herein by reference in their entirety.

BACKGROUND

1. Field of the Invention

This invention relates to systems and methods for estimating construction projects, and more particularly, to such systems and methods for determining roof measurement information based on one or more aerial images of a roof of a building.

2. Description of the Related Art

The information provided below is not admitted to be part of the present invention, but is provided solely to assist the understanding of the reader.

Homeowners typically ask several roofing contractors to provide written estimates to repair or replace a roof on a house. Heretofore, the homeowners would make an appointment with each roofing contractor to visit the house to determine the style of roof, take measurements, and to inspect the area around the house for access and cleanup. Using this information, the roofing contractor then prepares a written estimate and then timely delivers it to the homeowner. After receiving several estimates from different rooting contractors, the homeowner then selects one.

There are factors that impact a roofing contractor's ability to provide a timely written estimate. One factor is the size of the roof contractor's company and the location of the roofing jobs currently underway. Most roof contractors provide roofing services and estimates to building owners over a large geographical area. Larger roof contractor companies hire one or more trained individuals who travel throughout the entire area providing written estimates. With smaller roofing contractors, the owner or a key trained person is appointed to provide estimates. With both types of companies, roofing estimates are normally scheduled for buildings located in the same area on a particular day. If an estimate is needed suddenly at a distant location, the time for travel and the cost of commuting can be prohibitive. If the roofing contractor is a small company, the removal of the owner or key person on a current job site can be time prohibitive.

Another factor that may impact the roofing contractor's ability to provide a written estimate is weather and traffic.

Recently, solar panels have become popular. In order to install solar panels, the roof's slope, geometrical shape, and size as well as its orientation with respect to the sun all must be determined in order to provide an estimate of the number and type of solar panels required. Unfortunately, not all roofs on a building are proper size, geometrical shape, or orientation for use with solar panels.

SUMMARY

These and other objects are met by the systems and methods disclosed herein that determine and provide roof measurement information about the sizes, dimensions, slopes and orientations of the roof sections of a building roof. Roof measurement information may be used to generate a roof estimate report that provides and graphically shows this information. A roof estimation system that practices at least some of the techniques described herein may include an image acquisition engine, a roof modeling engine, and a report generation engine. The roof estimation system is configured to generate a model of a roof of a building, based on one or more aerial images. In addition, the roof estimation system is configured to determine roof measurement information and generate a roof estimate report based on the generated model and/or the determined roof measurement information.

In some embodiments, the roof estimation system includes a user interface engine which provides access to at least some of the functions of the roof estimation system. In one embodiment, the user interface engine provides interactive user interface components operable by an operator to perform various functions related to generating a model of a roof of a building, including image registration, lean correction, pitch determination, feature identification, and model review and/or correction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system.

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. (Also shows lean correction.)

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment.

FIGS. **7**A-**7**C are screen displays illustrating roof model review in an example embodiment.

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment.

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment.

DETAILED DESCRIPTION

Embodiments described herein provide enhanced computer- and network-based methods, techniques, and systems for estimating construction projects based on one or more images of a structure. Example embodiments provide a Roof Estimation System ("RES") that is operable to provide a roof estimate report for a specified building, based on one or more aerial images of the building. In one embodiment, a customer of the RES specifies the building by providing an address of the building. The RES then obtains one or more aerial images showing at least portions of the roof of the building. Next, the RES generates a model of the roof of the building, which is then utilized to determine roof measurement information. The roof measurement information may include measurements such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc. The model of the roof and/or the roof measurement information is then used to generate a roof estimate report. The

roof estimate report includes one or more line drawings of the roof of the building, which are annotated with information about the roof, such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc.

Some embodiments of the roof estimation system include an interactive user interface configured to provide access to one or more of the functions of the roof estimation system. In one embodiment, the roof estimation system includes user interface controls that facilitate image registration, image lean correction, roof model generation, pitch determination, and roof model review. Image registration includes aligning, based at least in part on operator inputs, one or more images of a building roof to a set of reference points within a single three-dimensional ("3D") grid that is shared between the one or more images. Roof model generation includes generating a 3D model of a roof, based at least in part on operator inputs specifying various features and/or dimensional attributes of the roof. Roof model generation may further include the determination of the pitches of various planar sections of a roof. Roof model review includes display of a model of a roof, possibly in conjunction with one or more images of the roof, so that an operator may review the model for accuracy and possibly make adjustments and/or corrections to the roof model. In other embodiments, all or some of the functions of the roof estimation system may be performed automatically. For example, image registration may include automatically identifying building features for the placement of reference markers. Further, roof model generation may include automatically recognizing features, dimensional attributes, and/or pitches of various planar roof sections of the roof.

The described user interface is also configured to concurrently display roof features onto multiple images of a roof. For example, in the context of roof model generation, an operator may indicate a roof feature, such as an edge or a corner of a section of the roof, in a first image of the roof. As the roof estimation system receives the indication of the roof feature, the user interface concurrently displays that feature in one or more other images of the roof, so that the operator may obtain feedback regarding the accuracy of the roof model, the image registration, etc.

In the following, FIGS. **1-3** provide an overview of the operation of an example roof estimation system. FIGS. **4-7** provide additional details related an example interactive user interface provided by one embodiment of the roof estimation system. FIGS. **8-11** provide details related to roof estimation system implementation techniques.

1. Roof Estimation System Overview

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system. In particular, FIG. **1** shows an example Roof Estimation System ("RES") **100** comprising an image acquisition engine **101**, a roof modeling engine **102**, a report generation engine **103**, image data **105**, model data **106**, and report data **107**. The RES **100** is communicatively coupled to an image source **110**, a customer **115**, and optionally an operator **120**. The RES **100** and its components may be implemented as part of a computing system, as will be further described with reference to FIG. **8**.

More specifically, in the illustrated embodiment of FIG. **1**, the RES **100** is configured to generate a roof estimate report **132** for a specified building, based on aerial images **131** of the building received from the image source **110**. The image source **110** may be any provider of images of the building for which a roof estimate is being generated. In one embodiment, the image source **110** includes a computing system that provides access to a repository of aerial images of one or more buildings. In addition, the aerial images **131** may include images obtained via manned or unmanned aircraft (e.g., airplane, helicopter, blimp, drone, etc.), satellite, etc. Furthermore, the aerial images **131** may include images obtain via one or more ground-based platforms, such as a vehicle-mounted camera that obtains street-level images of buildings, a nearby building, a hilltop, etc. In some cases, a vehicle-mounted camera may be mounted in an elevated position, such as a boom. Example aerial images are described further with reference to FIGS. **2**A-**2**B.

The image acquisition engine **101** obtains one or more aerial images of the specified building by, for example, providing an indicator of the location of the specified building (e.g., street address, GPS coordinates, lot number, etc.) to the image source **110**. In response, the image source **110** provides to the image acquisition engine **101** the one or more aerial images of the building. The image acquisition engine **101** then stores the received aerial images as image data **105**, for further processing by other components of the RES **100**. Obtaining aerial images of a specified building may include various forms of geo-coding, performed by the image acquisition engine **101** and/or the image source **110**. In one embodiment, the image source geo-codes a provided street address into latitude and longitude coordinates, which are then used to look up (e.g., query a database) aerial images of the provided street address.

Next, the roof modeling engine **102** generates a model of the roof of the specified building. In the illustrated embodiment, the roof modeling engine **102** generates a three-dimensional ("3D") model, although in other embodiments, a two-dimensional (e.g., top-down roof plan) may be generated instead or in addition. Generating a model of the roof may generally include image calibration, in which the distance between two pixels on a given image is converted into a physical length. Image calibration may be performed automatically, such as based on meta-information provided along with the aerial images **131**.

A variety of automatic and semi-automatic techniques may be employed to generate a model of the roof of the building. In one embodiment, generating such a model is based at least in part on a correlation between at least two of the aerial images of the building. For example, the roof modeling engine **102** receives an indication of a corresponding feature that is shown in each of the two aerial images. In one embodiment, an operator **120**, viewing two or more images of the building, inputs an indication in at least some of the images, the indications identifying which points of the images correspond to each other for model generation purposes.

The corresponding feature may be, for example, a vertex of the roof of the building, the corner of one of the roof planes of the roof, a point of a gable or hip of the roof, etc. The corresponding feature may also be a linear feature, such as a ridge or valley line between two roof planes of the roof. In one embodiment, the indication of a corresponding feature on the building includes "registration" of a first point in a first aerial image, and a second point in a second aerial image, the first and second points corresponding the substantially the same point on the roof of the building. Generally, point registration may include the identification of any feature shown in both aerial images. Thus, the feature need not be a point on the roof of the building. Instead, it may be, for example, any point that is visible on both aerial images, such as on a nearby building (e.g., a garage, neighbor's building, etc.), on a nearby structure (e.g., swimming pool, tennis court, etc.), on a nearby natural feature (e.g., a tree, boulder, etc.), etc.

In some embodiments, the roof modeling engine **102** determines the corresponding feature automatically, such as by

employing on one or more image processing techniques used to identify vertexes, edges, or other features of the roof. In other embodiments, the roof modeling engine **102** determines the corresponding feature by receiving, from the human operator **120** as operator input **133**, indications of the feature shown in multiple images of the building.

In one example embodiment, the RES **100** generates a model of the roof of the building in the following manner. First, a set of reference points are be identified in each of the images. These reference points are identified by the operator **120** utilizing a suitable input device, such as a mouse or joystick. The roof modeling engine **102** then uses these reference points and any acceptable algorithm to co-register the images and reconstruct the three-dimensional geometry of the object identified by the reference points. There are a variety of photogrammetric algorithms that can be utilized to perform this reconstruction. One such algorithm used by the RES **100** uses photographs taken from two or more view points to "triangulate" points of interest on the object in three-dimensional ("3D") space. This triangulation can be visualized as a process of projecting a line originating from the location of the photograph's observation point that passes through a particular reference point in the image. The intersection of these projected lines from the set of observation points to a particular reference point identifies the location of that point in 3D space. Repeating the process for all such reference points allows the software to determine a 3D volume suitable for building a 3D model of the structure. The choice of reconstruction algorithm depends on a number of factors such as the spatial relationships between the photographs, the number and locations of the reference points, and any assumptions that are made about the geometry and symmetry of the object being reconstructed. Several such algorithms are described in detail in textbooks, trade journals, and academic publications.

In addition, generating a model of the roof of a building may include correcting one or more of the aerial images for various imperfections. For example, the vertical axis of a particular aerial image sometimes will not substantially match the actual vertical axis of its scene. This will happen, for example, if the aerial images were taken at different distances from the building, or at a different pitch, roll, or yaw angles of the aircraft from which the images were produced. In such cases, an aerial image may be corrected by providing the operator **120** with a user interface control operable to adjust the scale and/or relative angle of the aerial image to correct for such errors. The correction may be either applied directly to the aerial image, or instead be stored (e.g., as an offset) for use in model generation or other functions of the RES **100**.

Generating a model of the roof of a building further includes the automatic or semi-automatic identification of features of the roof of the building. In one embodiment, one or more user interface controls may be provided, such that the operator **120** may indicate (e.g., draw, paint, etc.) various features of the roof, such as valleys, ridges, hips, vertexes, planes, edges, etc. As these features are indicated by the operator **120**, a corresponding three-dimensional ("3D") model may be updated accordingly to include those features. These features are identified by the operator based on a visual inspection of the images and by providing inputs that identify various features as valleys, ridges, hips, etc. In some cases, a first and a second image view of the roof (e.g., a north and east view) are simultaneously presented to the operator **120**, such that when the operator **120** indicates a feature in the first image view, a projection of that feature is automatically presented in the second image view. By presenting a view of the 3D model, simultaneously projected into multiple image views, the operator **120** is provided with useful visual cues as to the correctness of the 3D model and/or the correspondence between the aerial images.

In addition, generating a model of the roof of a building may include determining the pitch of one or more of the sections of the roof. In some embodiments, one or more user interface controls are provided, such that the operator **120** may accurately determine the pitch of each of the one or more roof sections. An accurate determination of the roof pitch may be employed (by a human or the RES **100**) to better determine an accurate cost estimate, as roof sections having a low pitch are typically less costly surfaces to repair and/or replace.

The generated model typically includes a plurality of planar roof sections that each correspond to one of the planar sections of the roof of the building. Each of the planar roof sections in the model has a number of associated dimensions and/or attributes, among them slope, area, and length of each edge of the roof section. Other information may include any information relevant to a roof builder or other entity having an interest in construction of, or installation upon, the roof. For example, the other information may include identification of valleys, ridges, rakes, eaves, or hip ridges of the roof and/or its sections; roof and/or roof section perimeter dimensions and/or outlines; measurements of step heights between different roof levels (e.g., terraces); bearing and/or orientation of each roof section; light exposure and/or shadowing patterns due to chimneys, other structures, trees, latitude, etc.; roofing material; etc? Once a 3D model has been generated to the satisfaction of the roof modeling engine **102** and/or the operator **120**, the generated 3D model is stored as model data **106** for further processing by the RES **100**. In one embodiment, the generated 3D model is then stored in a quality assurance queue, from which it is reviewed and possibly corrected by a quality control operator.

The report generation engine **103** generates a final roof estimate report based on a model stored as model data **106**, and then stores the generated report as report data **107**. Such a report typically includes one or more plan (top-down) views of the model, annotated with numerical values for the slope, area, and/or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof. The report may also include information about total area of the roof, identification and measurement of ridges and/or valleys of the roof, and/or different elevation views rendered from the 3D model (top, side, front, etc). An example report is illustrated and discussed with respect to FIGS. **3**A-**3**E, below.

In some embodiments, generating a report includes labeling one or more views of the model with annotations that are readable to a human user. Some models include a large number of small roof details, such as dormers or other sections, such that applying uniformly sized, oriented, and positioned labels to roof section views results in a visually cluttered diagram. Accordingly, various techniques may be employed to generate a readable report, including automatically determining an optimal or near-optimal label font size, label position, and/or label orientation, such that the resulting report may be easily read and understood by the customer **115**.

In addition, in some embodiments, generating a report includes automatically determining a cost estimate, based on specified costs, such as those of materials, labor, transportation, etc. For example, the customer **115** provides indications of material and labor costs to the RES **100**. In response, the report generation engine **103** generates a roof estimate report that includes a cost estimate, based on the costs provided by the customer **115** and the attributes of the particular roof, such as area, pitch, etc.

In one embodiment, the generated report is then provided to a customer. The generated report can be represented, for example, as an electronic file (e.g., a PDF file) or a paper document. In the illustrated example, roof estimate report **132** is transmitted to the customer **115**. The customer **115** may be or include any human, organization, or computing system that is the recipient of the roof estimate report **132**. For example, the customer **115** may be a property owner, a property manager, a roof construction/repair company, a general contractor, an insurance company, a solar power panel installer, a climate control (e.g., heating, ventilation, and/or air conditioning) system installer, a roof gutter installer, an awning installer, etc. Reports may be transmitted electronically, such as via a network (e.g., as an email, Web page, etc.) or by some shipping mechanism, such as the postal service, a courier service, etc.

In some embodiments, one or more of the models stored as model data **106** are provided directly to the customer or other computing system, without first being transformed into a report. For example, a model and/or roof measurement information based thereon may be exported and/or transmitted as a data file, in any suitable format, that may be consumed or otherwise utilized by some other computing system, such as a computer-aided design ("CAD") tool, a drawing program, a labor and material estimation software, a project management/estimation software, etc.

The RES **100** may be operated by various types of entities. In one embodiment, the RES **100** is operated by a roof estimation service that provides roof estimate reports to customers, such as roofing contractors, in exchange for payment. In another embodiment, the RES **100** is operated by a roof construction/repair company, to generate roof estimate reports that are used internally and/or provided to customers, such as property owners.

In addition, the RES **100** may be operated in various ways. In one embodiment, the RES **100** executes as a desktop computer application that is operated by the operator **120**. In another embodiment, the RES **100** executes as a network-accessible service, such as by a Web server, that may be operated remotely by the operator **120** and/or the customer **115**. Additional details regarding the implementation of an example roof estimation system are provided with respect to FIG. **8**, below.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address. In the illustrated example, the aerial images are represented as stylized line drawings for clarity of explanation. As noted above, such aerial images may be acquired in various ways. In one embodiment, an aircraft, such as an airplane or helicopter is utilized to take photographs while flying over one or more properties. Such aircraft may be manned or unmanned. In another embodiment, a ground-based vehicle, such as a car or truck, is utilized to take photographs (e.g., "street view" photographs) while driving past one or more properties. In such an embodiment, a camera may be mounted on a boom or other elevating member, such that images of building roofs may be obtained. In another embodiment, photographs may be taken from a fixed position, such as a tall building, hilltop, tower, etc.

In particular, FIG. **2**A shows a top plan (top-down) aerial image **210** of a building **200**. The roof of the building **200** includes multiple planar roof sections **200***a*-**200***d*. FIG. **2**A also shows a second aerial image **211** providing a perspective (oblique) view of the building **200**. The roof sections **200***a* and **200***c* are also visible in image **211**.

FIG. **2**B shows a top-down, wide angle image **212** of the building **200**. The image **212** includes details of the surrounding areas **220** of the building **220**. Information about the surrounding areas **220** of the building **220** are in some embodiments used to determine additional cost factors related to a roof estimate. For example, the cleanup of, or access to, a worksite at building **220** may be complicated by various factors, including a substantial amount of landscaping; steeply sloped building sites; proximity to environmentally sensitive areas; etc. In such cases, the roof estimation system may automatically increase a cost factor in a corresponding roof estimate report.

In some embodiments, an aerial image has corresponding meta-information. Such meta-information may include details about the type of camera used (e.g., focal length, exposure, etc.), the position of the camera (e.g., GPS coordinates of the aircraft at the time the image was captured), the orientation of the camera (e.g., the angle of the camera), the time and/or date the image was captured, etc.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system. As discussed with respect to FIG. **1**, a roof estimate report is generated by the roof estimation system based on one or more aerial images of a building. The roof estimate report may be based on a computer model (e.g., a 3D model) of the roof, and includes one or more views of the model. In this example, the various views of the model are presented as annotated line drawings, which provide information about the roof, such as the roof section areas, roof section edge lengths, roof section pitches, etc. The roof estimate report may be in an electronic format (e.g., a PDF file) and/or paper format (e.g., a printed report). In some embodiments, the roof estimate report may be in a format that may be consumed by a computer-aided design program.

FIG. **3**A shows a cover page **301** of the report and includes the address **301***a* of a building **301***c* and an overhead aerial image **301***b* of the building **301***c*.

FIG. **3**B shows a second page **302** of the report and includes two wide perspective (oblique) views **302***a* and **302***b* of the building **301***c* at the address with the surrounding areas more clearly shown.

FIG. **3**C shows a third page **303** of the report and includes a line drawing **303***a* of the building roof showing ridge lines **303***b* and **303***c*, and a compass indicator **303***d*. In addition, a building roof having valleys would result in a line drawing including one or more valley lines. The ridge and/or valley lines may be called out in particular colors. For example, ridge lines **303***b* and **303***c* may be illustrated in red, while valley lines may be illustrated in blue. The line drawing **303***a* is also annotated with the dimensions of the planar sections of the building roof. In this case, the dimensions are the lengths of the edges of the planar roof sections.

FIG. **3**D shows a fourth page **304** of the report and includes a line drawing **304***a* of the building roof showing the pitch of each roof section along with a compass indicator. The pitch in this example is given in inches, and it represents the number of vertical inches that the labeled planar roof section drops over 12 inches of horizontal run. The slope can be easily calculated from such a representation using basic trigonometry. The use of a numerical value of inches of rise per foot of run is a well known measure of slope in the roofing industry. A roof builder typically uses this information to assist in the repair and/or construction of a roof. Of course, other measures and/or units of slope may be utilized as well, including percent grade, angle in degrees, etc.

FIG. **3**E shows a fifth page **305** of the report and includes a line drawing **305***a* of the building roof showing the square footage of each roof section along with the total square foot area value. Of course, other units of area may be used as well,

such as square meters or the number of "squares" of roofing material required for covering each roof section.

FIG. **3**F shows a fifth page **306** of the report and includes a line drawing **306***a* of the building roof where notes or comments may be written. The line drawing **306***a* includes a label for each roof section (shown here as "A", "B", "C"), such that comments may be conveniently related to specific roof sections.

In other embodiments, more or less information may be provided, or the illustrated information may be arranged in different ways. For example, the report may be provided in electronic form, such as a PDF file or a computer aided design software format. In some embodiments, the report may be "active" or editable, such that the user of the report may make changes to the report, based on on-site observations.

2. Roof Estimation System User Interface

FIGS. **4**A-**4**F, **5**A-**5**D, **6**A-**6**D, and **7**A-**7**C describe an example interactive user interface provided by one embodiment of the roof estimation system. As noted, the RES **100** described with reference to FIG. **1** includes a user interface engine **104** that is configured to provide access to one or more functions of the RES **100**, including image registration (described with respect to FIGS. **4**A-**4**F), roof pitch determination (described with respect to FIGS. **5**A-**5**D), roof model construction (described with reference to FIGS. **6**A-**6**D), and roof model review (described with respect to FIGS. **7**A-**7**C).

A. Image Registration

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. In particular, FIG. **4**A shows a user interface screen **400** that is utilized by an operator to generate a three dimensional model of a roof of a building. The user interface screen **400** shows a roof modeling project in an initial state, after the operator has specified an address of a building and after images of the building have been obtained and loaded into the roof estimation system.

The user interface screen **400** includes a control panel **401** and five images **402**-**406** of a building roof **407**. The control panel **401** includes user selectable controls (e.g., buttons, check boxes, menus, etc.) for various roof modeling tasks, such as setting reference points for the images, setting the vertical (Z) axis for the images, switching between different images, saving the model, and the like. Each of the images **402**-**406** provides a different view of the building roof **407**. In particular, images **402**-**406** respectively provide substantially top-down, south, north, west, and east views of the building roof **407**. Each image **402**-**406** includes four marker controls (also called "reference points" or "registration markers") that are used by the operator to set reference points in the image for purposes of image registration. The registration markers will be described further with respect to an enlargement of image portion **408** described with respect to FIGS. **4**B-**4**C, below.

FIGS. **4**B-**4**C show an enlarged view of image portion **408** during the process of image registration for image **402**, which provides a top-down view of the building roof **407**. As shown in FIG. **4**B, image portion **408** includes the building roof **407** and registration markers **410**-**413**. The markers **410**-**413** are interactive user interface controls that can be directly manipulated (e.g., moved, rotated, etc.) by the operator in order to specify points to use for purposes of image registration. In particular, image registration includes determining a transformation between each of one or more images and a uniform 3D reference grid. The uniform 3D reference grid is used as a coordinate system for a 3D model of the roof. By registering multiple images to the reference grid, an operator may indicate a roof feature on an image (such as a roof edge), which may then be translated from the coordinate system of the image to the coordinate system of the reference grid, for purposes of including of the indicated feature in the 3D model.

Marker **410** is an origin marker control, and includes arms **410***a*-**410***c*. Arms **410***a* and **410***b* are horizontal arms that are utilized to specify the X and Y axes (e.g., the horizontal plane) of the reference grid. Arm **410***c* is a vertical arm that may be utilized to specify the Z axis (e.g., the vertical axis) of the reference grid. The use of the vertical arm to specify the Z axis will be further described with respect to FIG. **4**E, below.

Typically, markers **410**-**413** are color coded, such that they may be distinguished from one another. For example, marker **411**-**413** may be respectively colored red, blue, and green. Origin marker **410** has a different appearance than markers **411**-**413**, so may be of any color. In other embodiments, markers **411**-**413** may be distinguished in other ways, such as by utilizing different sized dashed lines, different line thicknesses, etc. In still other embodiments, markers are not distinguished any way from each other, such as by being of uniform shape, color, etc.

FIG. **4**C shows image portion **408** with markers **410**-**413** after they have been placed by an operator. Typically, registration markers are placed at four spatially distributed corners of the roof. As shown in FIG. **4**C, the operator has placed markers **410**-**413** at four different corners of the building roof **407**. In particular, the operator first placed the origin marker **410** at the lower left corner of the building roof **407**, and has adjusted (e.g., rotated) the arms **410***a* and **410***b* to align with the major horizontal axes of the roof. By adjusting the arms **410***a* and **410***b* of the origin marker **410**, the rotational orientation of markers **411**-**413** is automatically adjusted by the roof estimation system. Next, the operator places markers **411**-**413** on some other corners of the roof. In general, the operator can place registration marker over any roof feature, but roof corners are typically utilized because they are more easily identified by the operator. After the operator is satisfied with the placement of markers **410**-**413**, the operator typically registers a next image of the building roof **407**, as will be described next.

FIGS. **4**D-**4**F illustrate image registration for image **404**, which provides a north view of the building roof **407**. In particular, FIG. **4**D shows the user interface screen **400** described with reference to FIG. **4**A. Here, image **402** has been minimized, while image **404** has been enlarged so that the operator may register that image by placing markers on image **404**, as will be described below with respect to an enlarged view of image portion **418**.

FIG. **4**E shows an enlarged view of image portion **418** during the process of image registration for image **404**. Image portion **418** includes the building roof **407** and registration markers **420**-**423**. Markers **420**-**423** respectively correspond to markers **410**-**413** described above. In particular, marker **420** is an origin marker control that includes arms **420***a*-**420***c*. Arms **420***a* and **420***b* are horizontal arms that are utilized to specify the X and Y axes of the reference grid. Arm **420***c* is a vertical arm that may be utilized to specify the Z axis of the reference grid.

In the example of FIG. **4**E, the operator has moved each of markers **420**-**423** to a corner of the roof **407**. Note that the markers **420**-**423** are moved to roof corners that correspond to those selected by the operator with markers **410**-**413**, as described with reference to FIG. **4**C. In particular, origin marker **420** has been moved to the corner of the roof **407** selected with origin marker **410** in image **408**; marker **421** has been moved to the corner selected with marker **411** in image **408**; marker **422** has been moved to the corner selected with

marker **412** in image **408**; and marker **423** has been moved to the corner selected with marker **413** in image **408**. In addition, markers **420**-**423** have been rotated, by operator rotation of the origin marker **420**, to align with the major axes of the roof **407**.

As noted, the operator can utilize the origin marker **420** to specify the vertical axis of the reference grid. In particular, the operator can adjust (e.g., by dragging with a mouse or other pointing device) arm **420***c* of marker **420** to specify the vertical (Z) axis of the image. In some cases, aerial images may include some amount of lean, due to the orientation of the aircraft during image capture. For example, pitch, yaw, or roll of an aircraft during the course of image capture may result in images that are misaligned with respect to the vertical axis of the building and its roof. Typically, an operator may adjust arm **420***c* to line up with a feature of a building or roof that is known to be substantially vertical, such as a wall of a house or a chimney. Then, based on the angle of arm **420***c* with respect to the vertical axis of the image, the roof estimation system can determine a correction between the reference grid and the image.

FIG. **4**F shows an enlarged view of image portion **418** after registration of image **404**. Once the operator has placed and adjusted markers **420**-**423**, the operator may direct (e.g., by clicking a button) the roof estimation system to register the image to the reference grid, based on the positions and orientations of markers **420**-**423**. Once the roof estimation system registers the image, it provides the operator with feedback so that the operator may determine the correctness or accuracy of the registration.

In the example of FIG. **4**F, the operator has directed the roof estimation system to register image **404**, and the roof estimation system has updated image portion **418** with registration indicators **430**-**433**. Registration indicators **430**-**433** provide the operator with feedback so that the operator may judge the accuracy of the registration of image **404**.

Registration indicator **430** is an origin registration indicator that includes two arms **430***a*-**430***b* and three reference grid indicators **430***c*-**430***e*, shown as dashed lines. The reference grid indicators **430***c*-**430***e* show the vertical axis (**430***c*) and the two horizontal axes (**430***d* and **430***e*) of the reference grid determined based on the placement and orientation of the markers **420**-**423**. Arms **430***a* and **430***b* correspond to the placement of arms **420***a*-**420***c* of origin marker **420**. If the arms **430***a* and **430***b* do not substantially align with the corresponding reference grid indicators **430***e* and **430***d*, then the determined reference grid is out of alignment with the specified axes of the house. Typically, an operator will return to the view of FIG. **4**E to make adjustments to origin marker, such as adjusting one or more of the vertical or horizontal axes, in order to refine the registration of the image. Although the arms **430***a*-**430***b* and the reference grid indicators **430***c*-**430***e* are here illustrated as solid and dashed lines, in other embodiments they may be color coded. For example, arms **430***a*-**430***b* may be red, while reference grid indicators **430***c*-**430***e* may be blue.

Registration indicators **431**-**433** provide the operator with information regarding the accuracy of the placement of markers **421**-**423**. In particular, each registration indicator **431**-**433** includes a solid crosshairs and a reference indicator, shown for example as a dashed line **432***a*. The crosshair of a registration indicator corresponds to the placement of a marker. For example, the crosshairs of registration indicator **431** corresponds to the placement of marker **421** in FIG. **4**E. If the reference indicator intersects the center (or substantially near the center) of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is accurate. On the other hand, if the reference indicator does not intersect the center of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is inaccurate. Typically, such an inaccuracy arises when the placement of markers in the top view of the roof does not agree with (correspond to) the placement of corresponding markers in another view of the roof. In such cases, the operator can return to the view of FIG. **4**C or **4**E to adjust the position of one or more markers.

After registering image **404**, the operator will proceed to register additional images of the building roof **407** utilizing a process similar to that described above. In this example, the operator will register images **403**, **405**, and **406**. Although the operator is here described as registering a total of five images, in other cases more or fewer images may be registered.

B. Roof Model Construction

FIGS. **5**A-**5**D and **6**A-**6**C generally illustrate aspects of the process of roof model generation based on multiple registered images. In particular, these figures illustrate the construction of a roof model by an operator. Model generation/construction may include identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. Each identified roof feature is incorporated by the roof estimation system into a 3D model of the roof, based on a translation between an image in which the feature is identified and the reference grid, as determined by the process described with reference to FIGS. **4**A-**4**F, above.

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment. In particular, FIG. **5**A shows the user interface screen **400** after images **402**-**406** have been registered. In this example, the operator is using a pitch determination control (also called a "pitch determination marker" or "pitch determination tool") to specify the pitch of a planar roof section of the building roof **407** visible in image **406**. The pitch determination control will be further described in FIG. **5**B, below, with respect to an enlargement of image portion **508**.

FIG. **5**B shows an enlarged view of image portion **508** during the process of pitch determination for image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **5**B, the image portion **508** includes the building roof **407** and a pitch determination marker **510** (also called a "protractor tool"). The pitch determination marker **510** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**.

The pitch determination marker **510** includes arms **510***a*-**510***d*. Arms **510***a*-**510***c* are axes, which are automatically aligned, based on the registration of image **406**, with the major (X, Y, and Z) axes of the building roof. Arm **510***d* is a "protractor" arm that is adjustable by the operator to specify roof pitch.

The marker **510** is typically first moved by the operator to a convenient location on the building roof **407**, usually corner of a planar section of the roof **407**. Next, the operator adjusts arm **510***d* so that is substantially aligns with the sloped edge of the planar roof section. Then, the roof estimation system determines the pitch of the roof section, based on the configuration of the marker **510** with respect to the image and the reference grid.

After specifying the pitch of a planar roof section, the operator will typically specify other information about the planar roof section, such as its outline, as will be described with reference to FIGS. **6**A-**6**D. Note that as the operator provides additional information about the geometry of the

roof **407**, the roof estimation system may automatically determine the pitch and/or other features of at least some of the other planar roof sections, based on the provided geometric information and/or assumptions about roof symmetry or other standard architectural practices.

FIG. **5**C shows a second type of pitch determination marker being used in the context of image **403** which provides a south perspective view of the building roof **407**. The illustrated pitch determination marker may be used in addition to, or instead of, the pitch determination marker **510** described with respect to FIGS. **5**A-**5**B, above. In particular, FIG. **5**C shows a pitch determination marker **520** (also called an "envelope tool") that includes surfaces **520***a* and **520***b*. The pitch determination marker **520** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**. In particular, the pitch determination marker **520** may be moved and/or adjusted so that it appears to lie substantially atop two adjacent planar sections of roof **407**.

FIG. **5**D shows the pitch determination marker **520** after the operator has used it to specify the pitch of two sections of roof **407**. Here, the operator has moved the marker **520** to a position in which the spine of the marker **520** is substantially aligned with the ridge line of roof **407**. Then, the operator has adjusted the angle of the surfaces **520***a* and **520***b* so that they appear to lie substantially atop corresponding sections of roof **407**. Then, the roof estimation system determines the pitch of the roof sections, based on the configuration of the marker **520** with respect to the image and the reference grid. Also illustrated are pitch indicators **521** and **522**. Pitch indicator **521** corresponds to the measured pitch of surface **520***a*, and pitch indicator **522** corresponds to the measured pitch of surface **520***b*. As the operator adjusts the angle of surfaces **520***a* and/or **520***b*, the corresponding pitch indicators **521**-**522** are automatically updated to reflect the determined pitch. In this example, the pitch of both surfaces is given as 4 inches of rise per foot of run.

The envelope pitch determination marker **520** may be adjusted in other ways, to specify pitches for types of roofs other than the gabled roof shown in image **403**. For example, when measuring pitch of roof sections that form a roof hip, point **520***c* may be manipulated by the operator, such as by dragging it to the left or right, to adjust the shape of the surfaces **520***a* and **520***b*, so that the surfaces align with the edges formed by the intersection of the sections that form the roof hip.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment. In particular, FIGS. **6**A-**6**D illustrate the construction of a three dimensional wire frame model of a building roof, based on the specification of roof features by an operator. In addition, FIGS. **6**A-**6**D illustrate the concurrent display of operator specified roof features in multiple views of a building roof.

FIG. **6**A shows the user interface screen **400** after images **402**-**406** have been registered, and after roof pitches have been determined. In this example, the operator is specifying sections of roof **407**, visible in image **406**, that are to be added to a 3D wire frame model of the roof **407** maintained by the roof estimation system. The specification of roof sections will be further described with reference to enlarged portion **608** of image **406** in FIG. **6**B, below. In addition, as the operator specifies roof sections in image **406**, the roof estimation system concurrently displays the specified roof sections in each of the other images **402**-**405**. The concurrent display of operator specified roof features will be further described with reference to enlarged portion **609** of image **402** in FIG. **6**C, below.

FIG. **6**B is an enlarged view of image portion **608** during the process of wire frame model construction in the context of image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **6**B, the image portion **608** includes the building roof **407**, drawing tool **610**, and wire frame **611**. The drawing tool **610** (also called a "drawing marker" or a "drawing control") is an interactive user interface control that can be directly manipulated by the operator in order to specify roof features, such as edges, ridges, valleys, corners, etc. In the illustrated embodiment, the operator uses the drawing tool **610** to trace or outline planar sections of the roof **407**, leading to the generation of wire frame **611**. The drawing tool **610** may be used to establish a series of connected line segments that result in a closed polygon representing a planar roof section. As the operator specifies a planar roof section in this manner, the roof estimation system determines, based on the image and the reference grid, the geometry of the planar roof section, and includes (adds) the specified planar roof section in a 3D model that corresponds to roof **407**.

FIG. **6**C is an enlarged view of image portion **609** illustrating the concurrent display of operator specified roof features, in the context of image **402**, which provides a top plan view of the building roof **407**. As the operator specifies roof sections as described with respect to FIG. **6**B, the roof estimation system concurrently displays the specified roof features in one or more of the other images displayed by the user interface screen **400**. More specifically, image portion **609** includes building roof **407** and wire frame **612**. Wire frame **612** corresponds to wire frame **611** constructed by the operator with reference to FIG. **6**B, except that wire frame **612** is automatically displayed as a projection from the 3D model into the top-down view of image **402**. Changes that the operator makes to wire frame **611** are concurrently displayed by the roof estimation system as wire frame **612** in image portion **609**. For example, if a new planar roof section is added by the operator to wire frame **611**, the new planar roof section is automatically displayed in wire frame **612**. By concurrently displaying operator identified features in multiple views of building roof **407**, the operator obtains feedback regarding the correctness and/or accuracy of the 3D model or other aspects of the model generation process, such as image registration and pitch determination.

Generally, the roof estimation system can be configured to concurrently display any operator-identified features, such as corners, ridges, valleys, planar sections, and the like, in multiple views of a building.

Furthermore, the concurrently displayed wire frame **612** is an interactive user interface element, in that the operator can make changes to the wire frame **612**, which are then concurrently displayed in wire frame **611**. Wire frames similar to those described above are also projected by the roof estimation system into images **403**, **404**, and **405** displayed by the user interface screen **400**. In this manner, the operator can switch between various images of the building roof **407**, making refinements to the 3D model by adjusting the wire frame in whichever image is more convenient and/or provides a more suitable perspective/view of the model.

FIG. **6**D shows the user interface screen **400** during construction of a 3D model of the building roof **407**. In particular, the user interface **400** includes a shaded wire frame **613** representation of the 3D model constructed as described above. In this view, the operator can review the wire frame **613** in isolation from any images to determine whether the

wire frame **613** accurately represents the building roof **407**. The wire frame **613** is an interactive user interface component, in that it can be directly manipulated (e.g., moved, rotated, resized, etc.). In some embodiments, manipulating the wire frame **613**, such as by changing its shape, results in corresponding changes in the underlying 3D model.

C. Roof Model Review

FIGS. **7**A-**7**C are screen displays illustrating roof model review in an example embodiment. In particular, FIGS. **7**A-**7**C illustrate various techniques to facilitate the review of a roof model by an operator. Reviewing the roof model may include reviewing roof section pitches (e.g., to determine whether they conform to the building roof and/or standard construction practices), reviewing the shape and/or location of the roof model (e.g., to determine whether it substantially conforms to the building roof), etc.

FIG. **7**A shows the user interface screen **400** after the operator has constructed a model of the roof **407** using one or more of the images **402**-**406**. In this example, a wire frame has been projected onto (superimposed upon) image **402** and annotated with roof section pitches, as will be described further with respect to enlarged portion **708** of image **402** in FIG. **7**B, below.

FIG. **7**B is an enlarged view of image portion **708** during the process of roof model review in the context of image **402**, which provides a substantially top plan view of the building roof **407**. As shown in FIG. **7**B, the image portion **708** includes a wire frame **710** and labels **711***a*-**711***c* that indicate pitches of corresponding sections of roof **407**. The wire frame **710** and the illustrated pitches are determined by the roof estimation system based on the pitch determination described with respect to FIGS. **5**A-**5**D, above, and the operator's specification of the wire frame model described with respect to FIGS. **6**A-**6**D, above.

The wire frame **710** includes multiple vertexes connected by line segments. Each vertex includes a handle, such as handle **710***a*. The handles may be directly manipulated (individually or in groups) by the operator to make adjustments/modifications to the wire frame **710**. For example, when an operator drags handle **710***a* to a new location, the ends of the two line segments connected to handle **710***a* will also move to the new location.

FIG. **7**C is an alternative view of the 3D model of roof **407** during the process of roof model review. In FIG. **7**C, the user interface screen **400** includes a wire frame **720** representation of the 3D model of the roof **407**. The wire frame **720** consists of multiple line segments corresponding to edges of planar roof sections. Each line segment is annotated with a label, such as label **723**, indicating the determined length of the corresponding roof section edge. Furthermore, some of the line segments indicate that they correspond to a particular roof feature. For example, line segments **721** and **722** may be colored (e.g., red) so as to indicate that they correspond to roof ridges. Other line segments may be differently colored (e.g., blue) so as to indicate a correspondence to roof valleys or other features. In addition, the wire frame **720** may be directly manipulated by the operator in order to make adjustments to the underlying model of the roof **407**. For example, the operator could increase or decrease the length of line segment **721**, resulting in a change in the corresponding feature of the 3D model of roof **407**.

Note that although the operator is shown, in FIGS. **5**-**7** above, operating upon a total of five images, in other cases, fewer images may be used. For example, in some cases fewer images may be available, or some images may provide obstructed views of the building roof, such as due to tree cover, neighboring buildings, etc.

3. Implementation Techniques

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system. FIG. **8** shows a computing system **800** that may be utilized to implement a Roof Estimation System ("RES") **810**. One or more general purpose or special purpose computing systems may be used to implement the RES **810**. More specifically, the computing system **800** may comprise one or more distinct computing systems present at distributed locations. In addition, each block shown may represent one or more such blocks as appropriate to a specific embodiment or may be combined with other blocks. Moreover, the various blocks of the RES **810** may physically reside on one or more machines, which use standard inter-process communication mechanisms (e.g., TCP/IP) to communicate with each other. Further, the RES **810** may be implemented in software, hardware, firmware, or in some combination to achieve the capabilities described herein.

In the embodiment shown, computing system **800** comprises a computer memory ("memory") **801**, a display **802**, one or more Central Processing Units ("CPU") **803**, Input/Output devices **804** (e.g., keyboard, mouse, joystick, track pad, CRT or LCD display, and the like), other computer-readable media **805**, and network connections **806**. The RES **810** is shown residing in memory **801**. In other embodiments, some portion of the contents, some of, or all of the components of the RES **810** may be stored on and/or transmitted over the other computer-readable media **805**. The components of the RES **810** preferably execute on one or more CPUs **803** and generate roof estimate reports, as described herein. Other code or programs **830** (e.g., a Web server, a database management system, and the like) and potentially other data repositories, such as data repository **820**, also reside in the memory **801**, and preferably execute on one or more CPUs **803**. Not all of the components in FIG. **8** are required for each implementation. For example, some embodiments embedded in other software do not provide means for user input, for display, for a customer computing system, or other components.

In a typical embodiment, the RES **810** includes an image acquisition engine **811**, a roof modeling engine **812**, a report generation engine **813**, an interface engine **814**, and a roof estimation system data repository **816**. Other and/or different modules may be implemented. In addition, the RES **810** interacts via a network **850** with an image source computing system **855**, an operator computing system **865**, and/or a customer computing system **860**.

The image acquisition engine **811** performs at least some of the functions of the image acquisition engine **101** described with reference to FIG. **1**. In particular, the image acquisition engine **811** interacts with the image source computing system **855** to obtain one or more images of a building, and stores those images in the RES data repository **816** for processing by other components of the RES **810**. In some embodiments, the image acquisition engine **811** may act as an image cache manager, such that it preferentially provides images to other components of the RES **810** from the RES data repository **816**, while obtaining images from the image source computing system **855** when they are not already present in the RES data repository **816**. In other embodiments, images may be obtained in an "on demand" manner, such that they are provided, either by the image acquisition engine **811** or the image source computing system **855**, directly to modules of the RES **810** and/or the operator computing system **865**, without intervening storage in the RES data repository **816**.

The roof modeling engine **812** performs at least some of the functions of the roof modeling engine **102** described with reference to FIG. **1**. In particular, the roof modeling engine **812** generates a model based on one or more images of a building that are obtained from the RES data repository **816** or directly from the image source computing system **855**. As noted, model generation may be performed semi-automatically, based on at least some inputs received from the computing system **865**. In addition, at least some aspects of the model generation may be performed automatically, based on image processing and/or image understanding techniques. After the roof modeling engine **812** generates a model, it stores the generated model in the RES data repository **816** for further processing by other components of the RES **810**.

The report generation engine **813** performs at least some of the functions of the report generation engine **103** described with reference to FIG. **1**. In particular, the report generation engine **813** generates roof reports based on models stored in the RES data repository **816**. Generating a roof report may include preparing one or more views of a given 3D model of a roof, annotating those views with indications of various characteristics of the model, such as dimensions of sections or other features (e.g., ridges, valleys, etc.) of the roof, slopes of sections of the roof, areas of sections of the roof, etc. In some embodiments, the report generation engine **813** facilitates transmission of roof measurement information that may or may not be incorporated into a roof estimate report. For example, the roof generation engine **813** may transmit roof measurement information based on, or derived from, models stored in the RES data repository **816**. Such roof measurement information may be provided to, for example, third-party systems that generate roof estimate reports based on the provided information.

The interface engine **814** provides a view and a controller that facilitate user interaction with the RES **810** and its various components. For example, the interface engine **814** implements a user interface engine **104** described with reference to FIG. **1**. Thus, the interface engine **814** provides an interactive graphical user interface that can be used by a human user operating the operator computing system **865** to interact with, for example, the roof modeling engine **812**, to perform functions related to the generation of models, such as point registration, feature indication, pitch estimation, etc. In other embodiments, the interface engine **814** provides access directly to a customer operating the customer computing system **860**, such that the customer may place an order for a roof estimate report for an indicated building location. In at least some embodiments, access to the functionality of the interface engine **814** is provided via a Web server, possibly executing as one of the other programs **830**.

In some embodiments, the interface engine **814** provides programmatic access to one or more functions of the RES **810**. For example, the interface engine **814** provides a programmatic interface (e.g., as a Web service, static or dynamic library, etc.) to one or more roof estimation functions of the RES **810** that may be invoked by one of the other programs **830** or some other module. In this manner, the interface engine **814** facilitates the development of third-party software, such as user interfaces, plug-ins, adapters (e.g., for integrating functions of the RES **810** into desktop applications, Web-based applications, embedded applications, etc.), and the like. In addition, the interface engine **814** may be in at least some embodiments invoked or otherwise accessed via remote entities, such as the operator computing system **865**, the image source computing system **855**, and/or the customer computing system **860**, to access various roof estimation functionality of the RES **810**.

The RES data repository **816** stores information related the roof estimation functions performed by the RES **810**. Such information may include image data **105**, model data **106**, and/or report data **107** described with reference to FIG. **1**. In addition, the RES data repository **816** may include information about customers, operators, or other individuals or entities associated with the RES **810**.

In an example embodiment, components/modules of the RES **810** are implemented using standard programming techniques. For example, the RES **810** may be implemented as a "native" executable running on the CPU **803**, along with one or more static or dynamic libraries. In other embodiments, the RES **810** is implemented as instructions processed by virtual machine that executes as one of the other programs **830**. In general, a range of programming languages known in the art may be employed for implementing such example embodiments, including representative implementations of various programming language paradigms, including but not limited to, object-oriented (e.g., Java, C++, C#, Matlab, Visual Basic-.NET, Smalltalk, and the like), functional (e.g., ML, Lisp, Scheme, and the like), procedural (e.g., C, Pascal, Ada, Modula, and the like), scripting (e.g., Perl, Ruby, Python, JavaScript, VBScript, and the like), declarative (e.g., SQL, Prolog, and the like).

The embodiments described above may also use well-known synchronous or asynchronous client-server computing techniques. However, the various components may be implemented using more monolithic programming techniques as well, for example, as an executable running on a single CPU computer system, or alternatively decomposed using a variety of structuring techniques known in the art, including but not limited to, multiprogramming, multithreading, client-server, or peer-to-peer, running on one or more computer systems each having one or more CPUs. Some embodiments execute concurrently and asynchronously, and communicate using message passing techniques. Equivalent synchronous embodiments are also supported by an RES implementation. Also, other functions could be implemented and/or performed by each component/module, and in different orders, and by different components/modules, yet still achieve the functions of the RES.

In addition, programming interfaces to the data stored as part of the RES **810**, such as in the RES data repository **816**, can be available by standard mechanisms such as through C, C++, C#, and Java APIs; libraries for accessing files, databases, or other data repositories; through scripting languages such as XML; or through Web servers, FTP servers, or other types of servers providing access to stored data. For example, the RES data repository **816** may be implemented as one or more database systems, file systems, memory buffers, or any other technique for storing such information, or any combination of the above, including implementations using distributed computing techniques.

Also, the example RES **810** can be implemented in a distributed environment comprising multiple, even heterogeneous, computer systems and networks. For example, in one embodiment, the image acquisition engine **811**, the roof modeling engine **812**, the report generation engine **813**, the interface engine **814**, and the data repository **816** are all located in physically different computer systems. In another embodiment, various modules of the RES **810** are hosted each on a separate server machine and are remotely located from the tables which are stored in the data repository **816**. Also, one or more of the modules may themselves be distributed, pooled or otherwise grouped, such as for load balancing, reliability or security reasons. Different configurations and locations of programs and data are contemplated for use with techniques

of described herein. A variety of distributed computing techniques are appropriate for implementing the components of the illustrated embodiments in a distributed manner including but not limited to TCP/IP sockets, RPC, RMI, HTTP, Web Services (XML-RPC, JAX-RPC, SOAP, and the like).

Furthermore, in some embodiments, some or all of the components of the RES are implemented or provided in other manners, such as at least partially in firmware and/or hardware, including, but not limited to one or more application-specific integrated circuits (ASICs), standard integrated circuits, controllers (e.g., by executing appropriate instructions, and including microcontrollers and/or embedded controllers), field-programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs), and the like Some or all of the system components and/or data structures may also be stored (e.g., as software instructions or structured data) on a computer-readable medium, such as a hard disk, a memory, a network, or a portable media article to be read by an appropriate drive or via an appropriate connection. The system components and data structures may also be stored as data signals (e.g., by being encoded as part of a carrier wave or included as part of an analog or digital propagated signal) on a variety of computer-readable transmission mediums, which are then transmitted, including across wireless-based and wired/cable-based mediums, and may take a variety of forms (e.g., as part of a single or multiplexed analog signal, or as multiple discrete digital packets or frames). Such computer program products may also take other forms in other embodiments. Accordingly, embodiments of this disclosure may be practiced with other computer system configurations.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment. The illustrated routine **900** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **900** facilitates image registration based upon operator indicated registration points and/or image lean corrections.

More specifically, the routine begins in step **901**, where it displays, on a user interface screen, an aerial image of a building having a roof. As part of the user interface screen, the routine also displays user interface controls such as markers that may be used by an operator for purposes of image registration and/or lean correction, as described with reference to FIG. **4**A, above.

In step **902**, the routine receives, via one or more registration markers, indications of one or more points on the aerial image. The registration markers are manipulated by the operator to specify points on the aerial image, as described with reference to FIGS. **4**A-**4**E. Typically, the points are visually identifiable features, such as corners of the roof of the building. For example, if the roof has four corners (e.g., a northwest, southwest, northeast, and southwest corner) the operator may place one registration marker on each of the four corners as shown in the aerial image. Then, the positions (e.g., coordinates on the aerial image) of the markers are transmitted to the routine for use in registering the aerial image, as described below.

In step **903**, the routine receives, via a lean correction marker, an indication of the vertical axis of the building roof. In at least some cases, the aerial image of the building is out of alignment with respect to the vertical axis of the building. This may be caused, for example, by pitch, roll, and/or yaw experienced by the aircraft during the process of photographing the building. To correct for such misalignment, the lean correction marker is manipulated by the operator to indicate a vertical axis of the building. Typically, the operator aligns the lean correction marker with known, substantially vertical feature of the building, such as a chimney, wall corner, etc., as described with reference to FIG. **4**E, above. After the operator has aligned the lean correction marker, the position (e.g., angle of the marker, coordinates of the endpoints of the marker, etc.) of the lean correction marker is transmitted to the routine for use in registering the aerial image, as described below.

Particular benefits may be obtained from lean correction performed in the context of an overhead, or "top down," view. An "overhead lean" occurs when the camera is not directly overhead with respect to the building when the photo is taken. In some cases, leans in excess of 5 degrees have been observed in "top down" photos. Furthermore, unlike oblique, perspective views, a top-down lean is typically less likely to include a convenient visual marker that provides sufficient angle to assess the lean direction and magnitude, such as the edge of the building or a tall chimney. An overhead lean affects the perceived location of the roof lines in a top down view. This effect is amplified as the pitch of the roof increases and/or as the vertical separation between disconnected roof sections increases. Without lean correction, superimposing a wire frame over the visible ridgelines (and other features of a building that reside at different elevations) may produce asymmetries in otherwise symmetric structures. Further, an absence of lean correction may introduce errors in pitch estimation, as the wire frame may not appear consistent between top and oblique view points. More specifically, without top view lean correction, the positions for the roof lines in an otherwise correct (i.e., accurate with respect to the actual geometry of the roof) wire frame will typically not line up on the visible roof lines in the overhead reference photo. This often leads the user (or software) to either introduce errors by incorrectly drawing the wire frame to the image lines or perform a subjective determination of where and how to shift the wire frame lines off the image lines to produce a correct model. Top view lean correction allows the roof estimation system to trace to, or substantially to, the actual roof lines seen in the top image while still producing an accurate wire frame model.

Image misalignment may be specified in other ways. For example, in other embodiments, the operator may instead rotate the image to a position in which the building appears to be in a substantially vertical position. Then, the angle of rotation of the image may be transmitted to the routine for use in registering the aerial image.

In step **904**, the routine registers, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid. Registering the image to a reference grid may include determining a transformation between the reference grid and the image, based on the indicated points and/or the indicated vertical axis. Determining such a transformation may be based on other information as well, such as meta-information associated with the aerial image. In some embodiments, the aerial image has corresponding meta-information that includes image capture conditions, such as camera type, focal length, time of day, camera position (e.g., latitude, longitude, and/or elevation), etc.

In step **905**, the routine determines whether there are additional aerial images to be registered, and if so, returns to step **901**, else proceeds to step **906**. During execution of the loop of steps **901-905**, the operator typically indicates, for each registration marker, the same feature (e.g., corner) of the roof as shown in each of multiple images, such that the routine can register the multiple images to a single, uniform reference grid. Upon completion of the registration process, the routine has determined a uniform coordinate system for the multiple

aerial images, for use during other phases of model construction, such as pitch determination or feature identification.

In step **906**, the routine generates a three-dimensional model based at least in part on the aerial image(s) and the reference grid. As discussed above with reference to FIGS. **5**A-**5**D and **6**A-**6**D, model generation includes identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. In other embodiments, the routine performs other functions with the registered images, such as storing them for later use (e.g., by an automated model generation module), transmitting them to another computing (e.g., for use in a third-party design application), etc. After step **906**, the routine ends.

Note that in at least some embodiments, aspects of the routine **900** may be performed in an automated manner. For example, operations discussed above as being performed by an operator, such as the determination of the location of image registration points of step **902** and/or the indication of lean of step **903**, may be performed by automated image processing techniques.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment. The illustrated routine **1000** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1000** facilitates the determination of the pitch of a section of a roof, by displaying a pitch determination marker and modifying a 3D model of a roof based on an indication of roof pitch received via the pitch determination marker.

More specifically, the routine begins at step **1001** where it displays an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch. The aerial image is displayed in the context of a user interface screen, such as is described with reference to FIGS. **4**A-**6**C, above. The aerial images may be received from, for example, the image source computing system **855** and/or from the RES data repository **816** described with reference to FIG. **8**. As discussed above, aerial images may be originally created by cameras mounted on airplanes, balloons, satellites, etc. In some embodiments, images obtained from ground-based platforms (e.g., vehicle-mounted cameras) may be used instead or in addition.

In step **1002**, the routine displays a pitch determination marker operable to indicate pitch of a planar roof section. The pitch determination marker may be, for example, a pitch determination marker **510** ("protractor tool") or **520** ("envelope tool"), such as are respectively described with respect to FIGS. **5**B and **5**C, above. The routine displays the pitch determination marker by, for example, presenting it on a user interface screen displayed on a computer monitor or other display device. The pitch determination marker is a direct manipulation user interface control, in that an operator may manipulate it (e.g., adjust an angle, change its shape, alter its position, etc.) in order to indicate pitch of a planar roof section. Additional details regarding pitch determination controls are provided with respect to FIGS. **5**A-**5**D, above.

In step **1003**, the routine receives, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building. Receiving an indication of the pitch includes receiving an indication (e.g., via an event, callback, etc.) that the marker has been manipulated by the operator, and then determining an angle based on the shape and/or position of the marker. In some embodiments, such an indication may be received on an event driven basis, such as every time the marker is manipulated in some manner. In other embodiments, the routine may poll the marker from time to time to determine its current state. In addition, the operator may explicitly indicate that the current state of the marker is to be transmitted to the routine, such as by pressing a button or other indication.

In step **1004**, the routine modifies a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section. Modifying the 3D model of the roof includes associating the indicated pitch with a portion of the model corresponding to the one planar roof section. For example, the 3D model may include one or more data structures representing planar roof sections, and the indicated pitch may be included as part of the data structure representing the one planar roof section. In some embodiments, the 3D model may not at this point include representations of the planar roof sections, such as because the operator has not yet specified them. In such a case, the routine may store the indicated pitch in association with the location and orientation at which the pitch was specified by the operator, as determined from the aerial image. Then, at a later time, when the operator specifies a roof section that has the same orientation as the stored pitch and that includes or is near the stored location, the roof estimation system can store the indicated pitch in association with the specified roof section.

After step **1004**, the routine ends. In other embodiments, the routine may instead return to step **1001**, to determine the pitch for another planar roof section (of the same or different roof).

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment. The illustrated routine **1100** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1100** concurrently displays operator indicated features in multiple aerial images of a building roof.

More specifically, the routine begins in step **1101**, where it displays a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building. The aerial images are displayed in the context of a user interface screen, such as is described with reference to FIGS. **6**A-**6**C, above.

In step **1102**, the routine receives an indication of a feature of the building shown in the first aerial image. The indication is typically received via a user interface control, such as a drawing tool or marker, upon its manipulation by an operator. For example, the operator may manipulate a drawing tool in order to specify one or more features of the building roof, such as a corner on the roof, an edge of the roof, an outline of a section of the roof, etc. In one embodiment, the operator utilizes a drawing tool to indicate roof section corner points and roof section edges connecting those corner points. Additional details regarding feature indication are provided with respect to FIGS. **6**A-**6**C, above.

In step **1103**, the routine modifies a three-dimensional model of the roof based on the received indication of the feature of the building. Modifying the 3D model may include adding or updating the indicated feature to a wire frame model of the roof. For example, if the indicated feature is a roof section corner point, the corner point will be added to the 3D model, along with the location (e.g., the X, Y, and Z position of the point) of the point. The location of the point is automatically determined based on a translation of the position of the point in the image to a point in the uniform reference grid associated with the image. If the indicated feature is a roof section edge, the edge will be added to the 3D model, such as by associating the edge with two points corresponding to the end points of the edge. Higher-level features can also be indicated. For example, a planar roof section may be indicated by "closing" a sequence of two or more connected line segments, to create a closed polygon that represents the outline or perimeter of the planar roof section.

In step **1104**, the routine concurrently displays a projection of the feature from the modified three-dimensional model onto the first and second aerial images. In one embodiment, displaying the feature from the modified three-dimensional model includes projecting the three-dimensional model onto both the first and second aerial images. For example, if the first image (for which the indicated feature was received) provides a west view of the building, and the second image provides an east view of the building, the routine will concurrently display a projection of the indicated feature from the 3D model onto both the first and second images. The projection of the indicated feature into the second image is based at least in part on a translation from the position of the feature in the reference grid to a position in the second image. In addition, the concurrent display onto two or more images occurs at substantially the same time (within a short time interval, at times that are substantially coincident) as the indication of the feature of the building in step **1102**, giving the operator the illusion that as they are indicating a feature in the first image, the feature is being simultaneously projected into the second image.

After step **1104**, the routine ends. In other embodiments, the routine may instead return to step **1101**, to perform an interactive loop of steps **1101-1104** with the operator, so that the routine can concurrently display multiple features as they are indicated by the operator. Note that in such an embodiment, each iteration of the loop of steps **1101-1104** may be performed at near real-time speeds, so as to provide a fluid, interactive model generation experience for the operator enabling the operator to drag, draw, or otherwise indicate/manipulate features in a first image and view the results of their work concurrently projected into a second image.

All of the above U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, including but not limited to U.S. Provisional Patent Application No. 61/197,904, entitled "USER INTERFACE SYSTEMS AND METHODS FOR ROOF ESTIMATION," filed Oct. 31, 2008, are incorporated herein by reference, in their entireties.

From the foregoing it will be appreciated that, although specific embodiments have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the present disclosure. For example, the methods, systems, and techniques for generating and providing roof estimate reports discussed herein are applicable to other architectures other than the illustrated architecture or a particular roof estimation system implementation. Also, the methods and systems discussed herein are applicable to differing network protocols, communication media (optical, wireless, cable, etc.) and devices (such as wireless handsets, electronic organizers, personal digital assistants, portable email machines, game machines, pagers, navigation devices such as GPS receivers, etc.). Further, the methods and systems discussed herein may be utilized by and/or applied to other contexts or purposes, such as by or for solar panel installers, roof gutter installers, awning companies, HVAC contractors, general contractors, and/or insurance companies.

The invention claimed is:

1. A computer-implemented process in a roof estimation system comprising:

displaying, by the roof estimation system, a graphical user interface including a first aerial image of a roof structure of a building and also at least one first visual marker that is moveable by a user in a same display window as the first aerial image while said first aerial image is displayed within the graphical user interface;

moving the first visual marker with respect to the first aerial image of the roof structure to a first location in response to input from the user;

storing data in a memory of the computer of the first location to which the first visual marker was moved;

displaying a second aerial image of the roof structure of the building, the second aerial image providing a different view of the roof than the first aerial image; and

displaying a location of a second visual marker on the roof structure of the building in the second aerial image of the roof structure based on an indication received from the stored data in the memory of the first location on the displayed first aerial image to which the user had moved the first visual marker; and

generating and outputting a roof estimate report using a report generation engine, wherein the roof estimate report includes one or more top plan views of a model of the roof annotated with numerical values for corresponding slope, area, or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof.

2. The process of claim **1** wherein the least one first visual marker includes four visual markers.

3. The process of claim **1** wherein the at least one location over the roof structure includes at least four spatially distributed corners of the roof structure.

4. The process of claim **1** wherein at least one first visual marker is an interactive user interface control that can be directly manipulated by the user in order to specify points on the roof structure in the aerial imagery to be used by the roof estimation system to perform image registration.

5. The process of claim **4**, further comprising receiving, by the roof estimation system, input regarding multiple points on the roof structure in the aerial imagery based on indications received of locations to which the at least one first marker had been moved.

6. The process of claim **5**, further comprising performing, by the roof estimation system, the image registration based on the multiple points on the roof structure in the aerial imagery.

7. The process of claim **6** wherein the image registration includes determining a transformation between each of one or more images of the aerial imagery and a uniform three dimensional reference grid based on the specified multiple points.

8. The process of claim **1**, wherein the at least one first visual marker is a crosshair.

9. The process of claim **1** wherein the location data is an address of the building.

10. The process of claim **1** further comprising:

enabling, by the roof estimation system, a user to input location data corresponding to a location of a building; and

in response to the input, providing, by the roof estimation system, access to aerial imagery of a roof structure of the building corresponding to the location data, wherein the location data is one or more of: a street address, global positioning coordinates and a lot number of the building.

11. The process of claim **1** further comprising:

performing, by the roof estimation system, roof pitch determination of the roof structure based on the at least one location over the roof structure in the displayed aerial imagery to which the user moved the least one first visual marker.

12. The process of claim **1** further comprising:

performing, by the roof estimation system, digital wire frame model construction of the roof structure based on the at least one location over the roof structure in the displayed aerial imagery to which the user moved the least one first visual marker.

13. The process of claim **1** further comprising:

performing, by the roof estimation system, image lean correction of the aerial imagery based on the at least one location over the roof structure in the displayed aerial imagery to which the user moved the least one first visual marker.

14. The process of claim **1** further comprising:

determining, by the roof estimation system, roof measurement information of one or more roof sections of the roof structure based on the at least one location over the roof structure in the displayed aerial imagery to which the user moved the least one first visual marker.

15. The process of claim **14** wherein the roof measurement information includes dimension, slope and orientation of the one or more roof sections of the roof structure.

16. A roof estimation system comprising:

at least on computer processor; and

at least one memory coupled to the at least one computer processor having computer executable instructions thereon that, when executed, cause the at least one processor to:

provide a graphical user interface including at least one first visual marker that is moveable by a user over aerial imagery of a roof structure of a building, the aerial imagery including a first aerial image of the roof structure and a second aerial image of the roof structure that provides a different view than the first aerial image, the first visual marker being provided, while said first aerial image is displayed within the graphical user interface, and moveable by the user to a location over the displayed first aerial image;

receive an indication of a selection of at least one location on the roof structure as a result of detection of movement of the at least one first visual marker to the location on the roof structure in the displayed first aerial image;

use the indication of the selection of at the least one location on the roof structure to identify that location of the roof structure of the building in the aerial imagery; and

display at the same location on the roof structure a second visual on the roof structure of the building in the second aerial image of the roof structure based on the indication received of the location on the displayed first aerial image to which the user had moved the first visual marker; and

generate and output a roof estimate report using a report generation engine, wherein the roof estimate report includes one or more top plan views of a model of the roof annotated with numerical values for corresponding slope, area, or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof.

17. The system of claim **16** wherein the computer executable instructions, when executed, further cause the at least one processor to:

determine roof measurement information of one or more roof sections of the roof structure based on the indication of the selection of at the least one location on the roof structure.

18. The process of claim **17** wherein the roof measurement information includes dimension, slope and orientation of the one or more roof sections of the roof structure.

19. A non-transitory computer readable medium having computer executable instructions thereon that, when executed, cause at least one processor to:

enable a user to input location data corresponding to a location of a building; in response to input of the location data, provide access to aerial imagery of a roof structure of the building, the aerial imagery including a first aerial image of the roof structure and a second aerial image of the roof structure that provides a different view than the first aerial image, corresponding to the location data;

receive an indication of a selection of at least one location on the roof structure indicated as a result of detection of movement of at least one first visual marker in a graphical user interface to the location on the roof structure in the first aerial image while the first aerial image is displayed within the graphical user interface;

use the indication of the selection of at the least one location on the roof structure to identify a location of the roof structure of the building in the first aerial image; and

display the location of a second visual marker corresponding to the first visual marker on the roof structure of the building in the second aerial image of the roof structure based on the indication received of the location on the displayed first aerial image to which the user had moved the first visual marker; and

generate and output a roof estimate report using a report generation engine, wherein the roof estimate report includes one or more top plan views of a model of the roof annotated with numerical values for corresponding slope, area, or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof.

20. The non-transitory computer readable medium of claim **19** wherein the computer executable instructions, when executed, further cause at least one processor to:

provide the at least one first visual marker is as an interactive user interface control of the graphical user interface that can be directly manipulated by the user in order to specify multiple corresponding points on the roof structure in different images that comprise the aerial imagery.

21. A method carried out using a computer system having a memory, the method comprising:

displaying on a visual display a photographic aerial image of a roof of a building, the roof having a pitch;

displaying a pitch determination marker on the visual display overlying the photographic aerial image;

moving at least a portion of the pitch determination marker from a first position to a second position in response to input from a user to align with a pitch of the roof in the aerial image;

calculating, by the computer system, the pitch of the roof based on the pitch determination marker being placed in the second position;

storing that pitch in the computer memory; and

outputting the calculated pitch value of the roof.

22. The method according to claim **21** wherein the pitch determination marker is a protractor tool and the step of moving the pitch determination marker from a first position to a second position comprises:

moving one arm of the protractor tool in response to input from the user.

23. The method according to claim **21** wherein the pitch determination marker is an envelope tool and the step of moving the pitch determination marker from a first position to a second position comprises:

changing angle of the envelope tool to have spine substantially align with a ridge line of the roof and having a first surface lie substantially atop a first section of the roof and a second surface lie substantially atop a second section of the roof in the aerial image of the roof.

24. The method according to claim **21** wherein the step of outputting the calculated value of the pitch includes:

displaying the calculated value of the pitch on the visual display.

25. The method according to claim **24** wherein the step of displaying the calculated value of the pitch on the visual display includes:

displaying the pitch value in a text menu that is adjacent to the aerial image.

26. The method according to claim **24** wherein the step of displaying the calculated value of the pitch on the visual display includes:

displaying the pitch value on the display screen as a numeric value overlaying at least some portion of the aerial image itself.

* * * * *

EXHIBIT 9

US008823732B2

(12) **United States Patent**
Adams et al.

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(45) **Date of Patent:** **Sep. 2, 2014**

(54) **SYSTEMS AND METHODS FOR PROCESSING IMAGES WITH EDGE DETECTION AND SNAP-TO FEATURE**

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G09G 5/00 (2006.01)

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USPC **345/619**; 345/581; 345/629; 345/660; 345/661; 345/662

(58) **Field of Classification Search**
None
See application file for complete search history.

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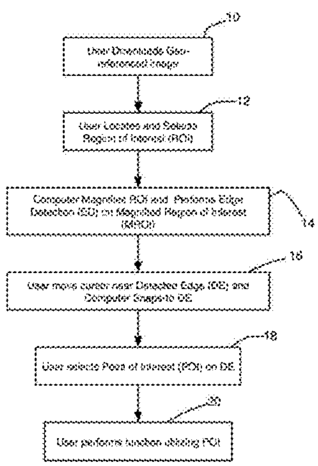
(57) **ABSTRACT**

A method for creating image products includes the following steps. Image data and positional data corresponding to the image data are captured and processed to create geo-referenced images. Edge detection procedures are performed on the geo-referenced images to identify edges and produce geo-referenced, edge-detected images. The geo-referenced, edge-detected images are saved in a database. A user interface to view and interact with the geo-referenced image is also provided such that the user can consistently select the same Points of Interest between multiple interactions and multiple users.

46 Claims, 8 Drawing Sheets



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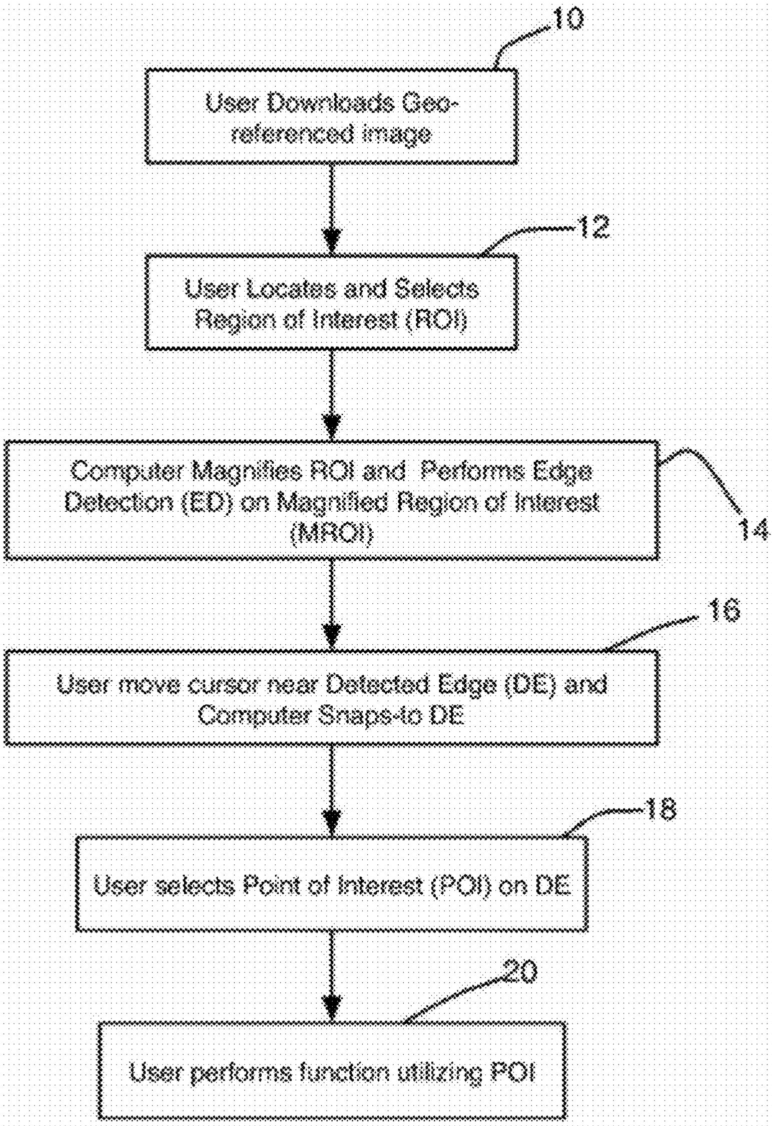
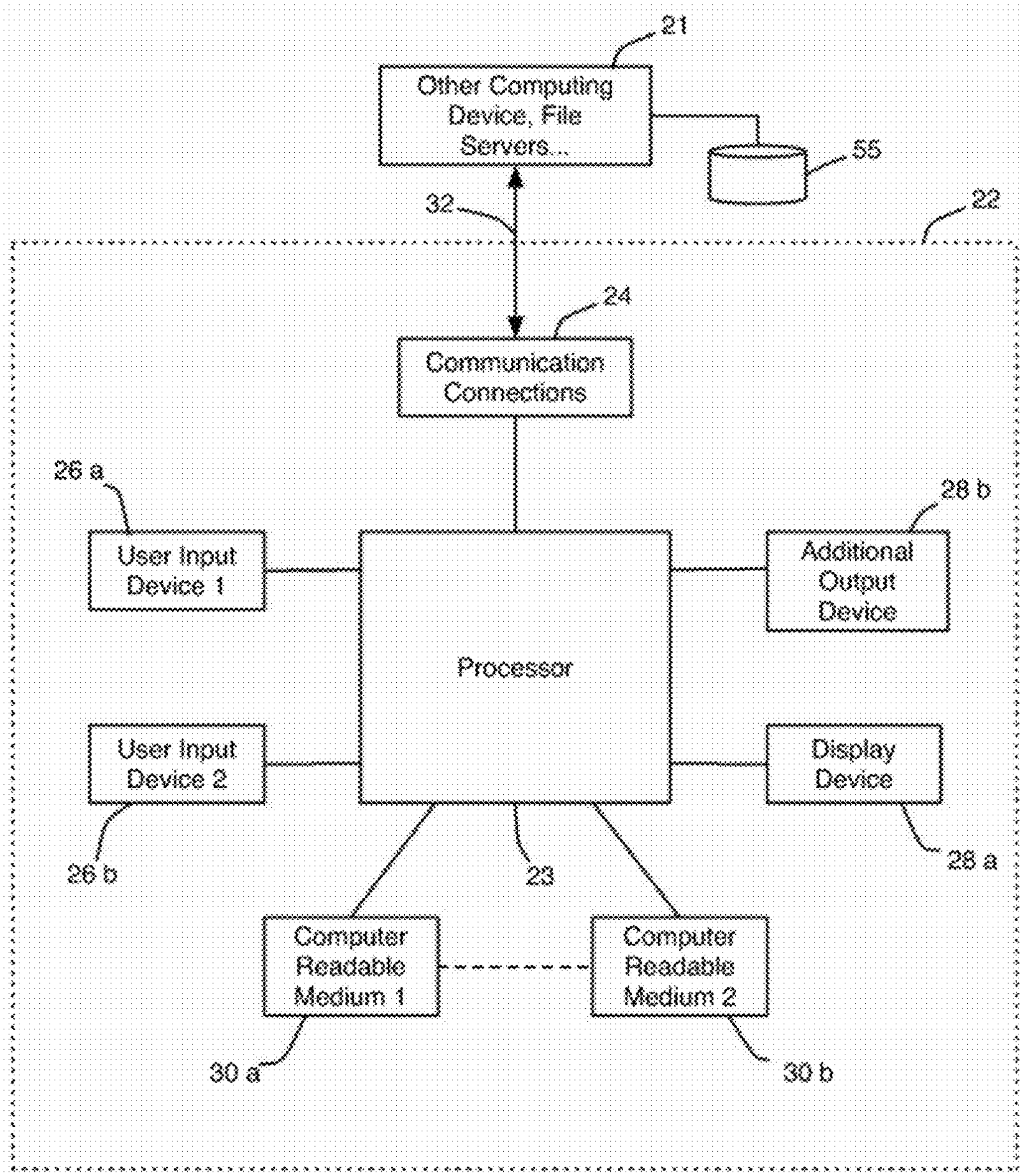

10
User Downloads Geo-referenced image
12
User Locates and Selects Region of Interest (ROI)
Computer Magnifies ROI and Performs Edge Detection (ED) on Magnified Region of Interest (MROI)
14
16
User move cursor near Detected Edge (DE) and Computer Snaps-to DE
18
User selects Point of Interest (POI) on DE
20
User performs function utilizing POI

Fig. 1



21
Other Computing Device, File Servers...
55
32
22
24
Communication Connections
26 a
28 b
User Input Device 1
Additional Output Device
Processor
User Input Device 2
Display Device
26 b
23
28 a
Computer Readable Medium 1
Computer Readable Medium 2
30 a
30 b

Fig. 2

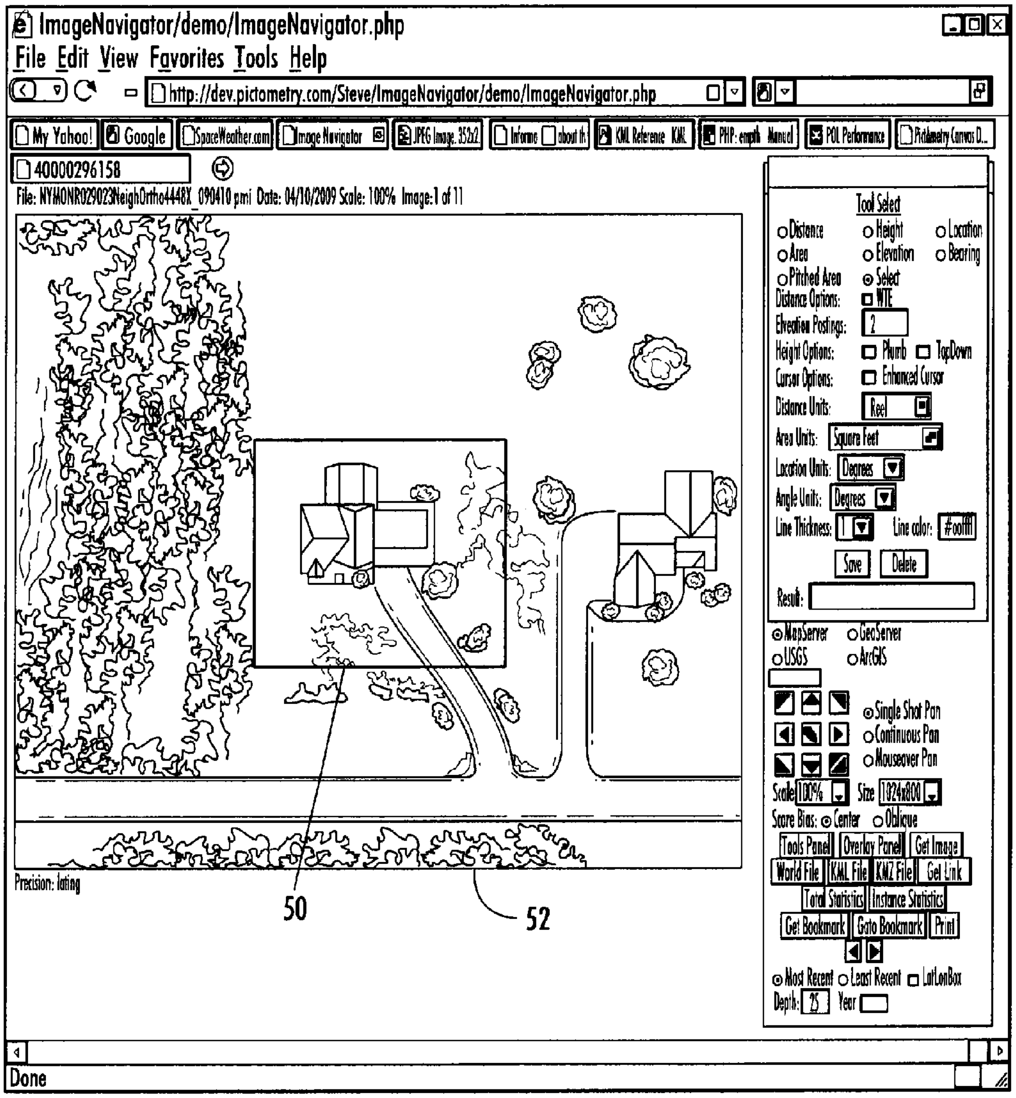

ImageNavigator/demo/ImageNavigator.php
File Edit View Favorites Tools Help
http://dev.pictometry.com/Steve/ImageNavigator/demo/ImageNavigator.php
My Yahoo!
Google
40000296158
Tool Select
Distance
Height
Location
Area
Elevation
Bearing
Pitched Area
Select
Distance Options:
Elevation Postings:
Height Options:
Plumb
TopDown
Cursor Options:
Enhanced Cursor
Distance Units:
Area Units:
Square Feet
Location Units:
Degrees
Angle Units:
Degrees
Line Thickness:
Line color:
Save
Delete
Result:
MapServer
GeoServer
USGS
ArcGIS
Single Shot Pan
Continuous Pan
Mouseover Pan
Scale
Size
Center
Oblique
Tools Panel
Overlay Panel
Get Image
World File
KML File
KMZ File
Get Link
Total Statistics
Instance Statistics
Get Bookmark
Goto Bookmark
Print
Most Recent
Least Recent
LatLonBox
Depth:
Year
Precision:
50
52
Done

FIG. 3

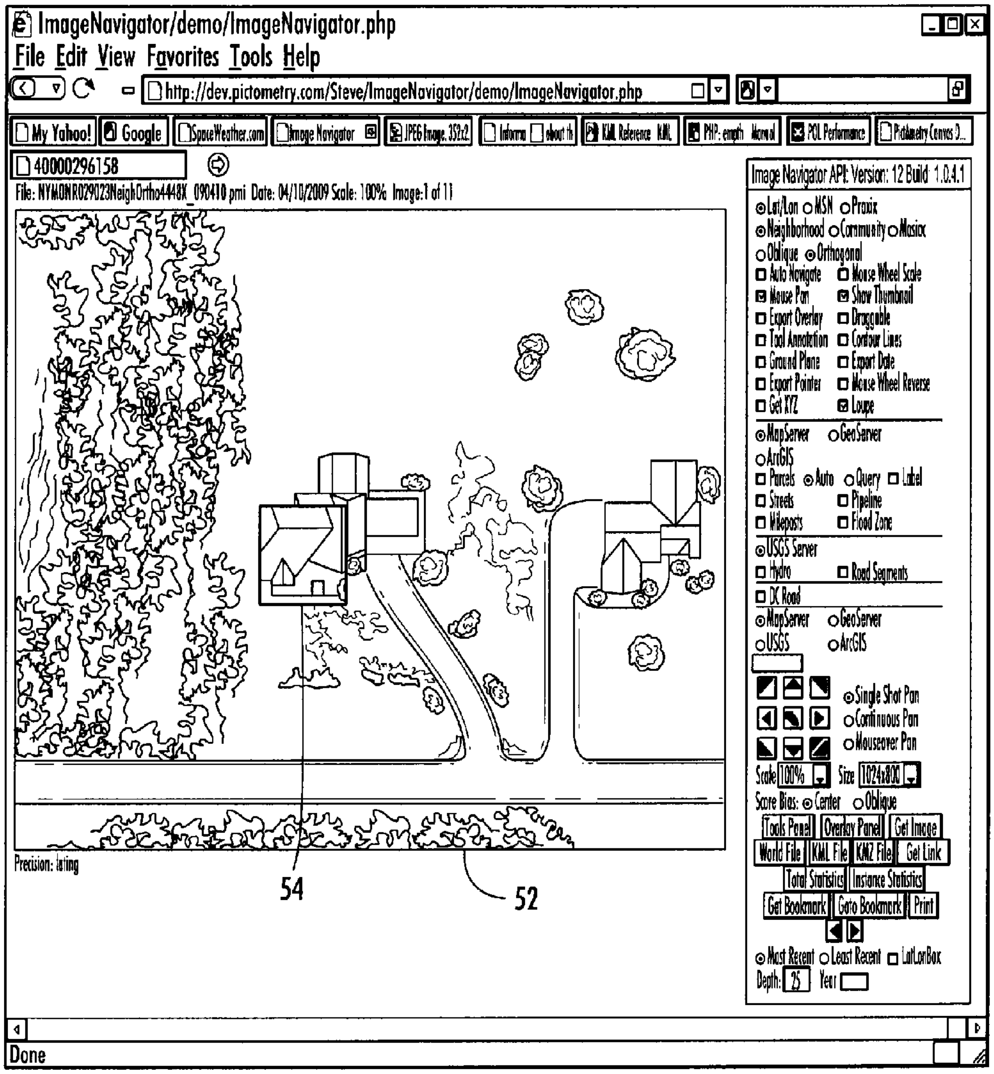

ImageNavigator/demo/ImageNavigator.php
File Edit View Favorites Tools Help
http://dev.pictometry.com/Steve/ImageNavigator/demo/ImageNavigator.php
My Yahoo!
Google
40000296158
Image Navigator API: Version: 12 Build 1.0.4.1
Lat/Lon
MSN
Proxix
Neighborhood
Community
Mosaic
Oblique
Orthogonal
Auto Navigate
Mouse Wheel Scale
Mouse Pan
Show Thumbnail
Export Overlay
Draggable
Tool Annotation
Contour Lines
Ground Plane
Export Date
Export Pointer
Mouse Wheel Reverse
Get XYZ
Loupe
MapServer
GeoServer
ArcGIS
Parcels
Auto
Query
Label
Streets
Pipeline
Mileposts
Flood Zone
USGS Server
Hydro
Road Segments
DC Road
MapServer
GeoServer
USGS
ArcGIS
Single Shot Pan
Continuous Pan
Mouseover Pan
Scale 100%
Size 1024x800
Score Bias: Center
Oblique
Tools Panel
Overlay Panel
Get Image
World File
KML File
KMZ File
Get Link
Total Statistics
Instance Statistics
Get Bookmark
Goto Bookmark
Print
Most Recent
Least Recent
LatLonBox
Depth: 25
Year
Done
54
52

FIG. 4

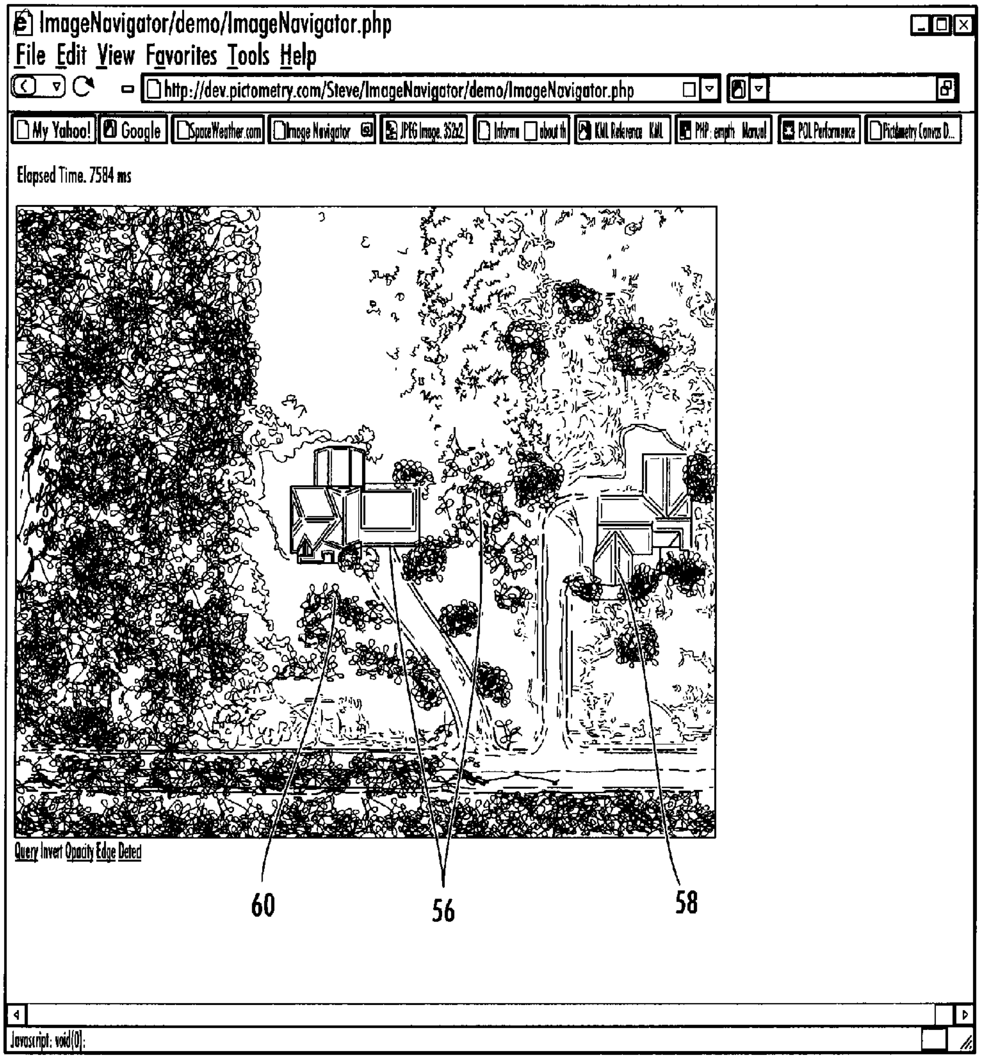
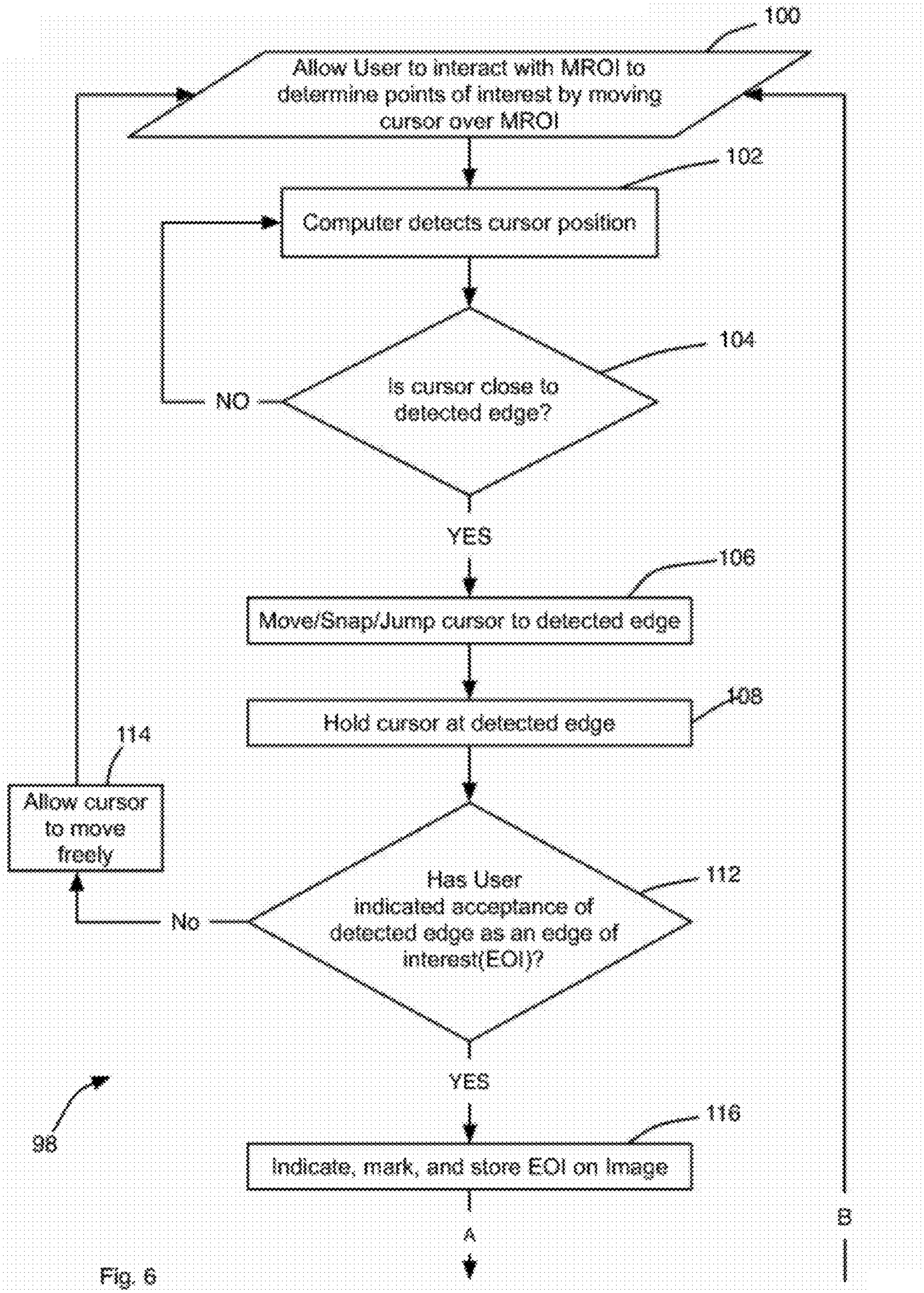

ImageNavigator/demo/ImageNavigator.php
File Edit View Favorites Tools Help
http://dev.pictometry.com/Steve/ImageNavigator/demo/ImageNavigator.php
My Yahoo!
Google
Image Navigator
Elapsed Time. 7584 ms
Query Invert Opacity Edge Detect
60
56
58
Javascript: void(0);

FIG. 5



100
Allow User to interact with MROI to determine points of interest by moving cursor over MROI
102
Computer detects cursor position
104
Is cursor close to detected edge?
NO
YES
106
Move/Snap/Jump cursor to detected edge
108
Hold cursor at detected edge
114
Allow cursor to move freely
112
Has User indicated acceptance of detected edge as an edge of interest(EOI)?
No
YES
116
Indicate, mark, and store EOI on Image
A
B
98

Fig. 6

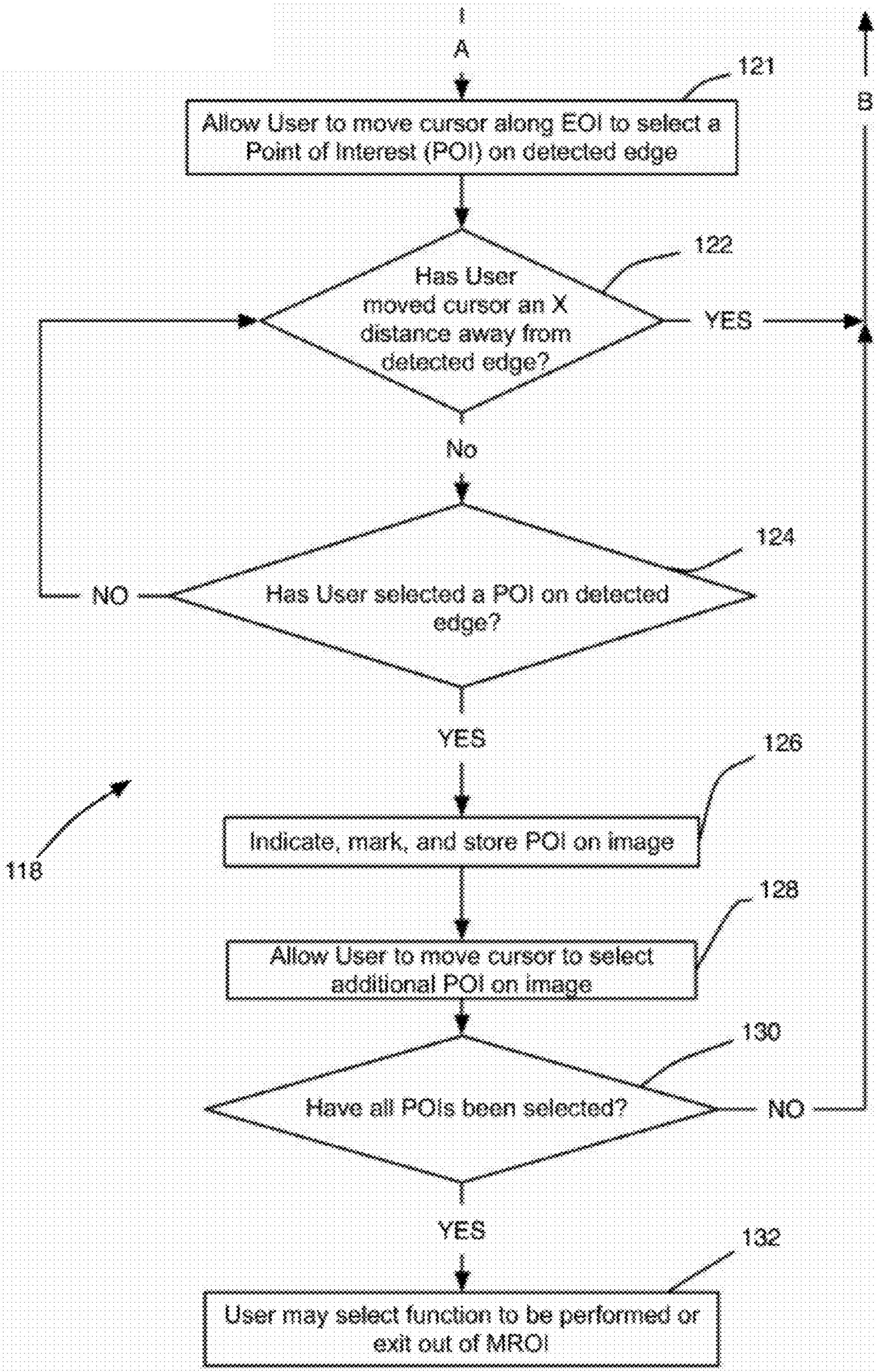

A
121
Allow User to move cursor along EOI to select a Point of Interest (POI) on detected edge
B
122
Has User moved cursor an X distance away from detected edge?
YES
No
124
NO
Has User selected a POI on detected edge?
YES
126
118
Indicate, mark, and store POI on image
128
Allow User to move cursor to select additional POI on image
130
Have all POIs been selected?
NO
YES
132
User may select function to be performed or exit out of MROI

Fig. 7

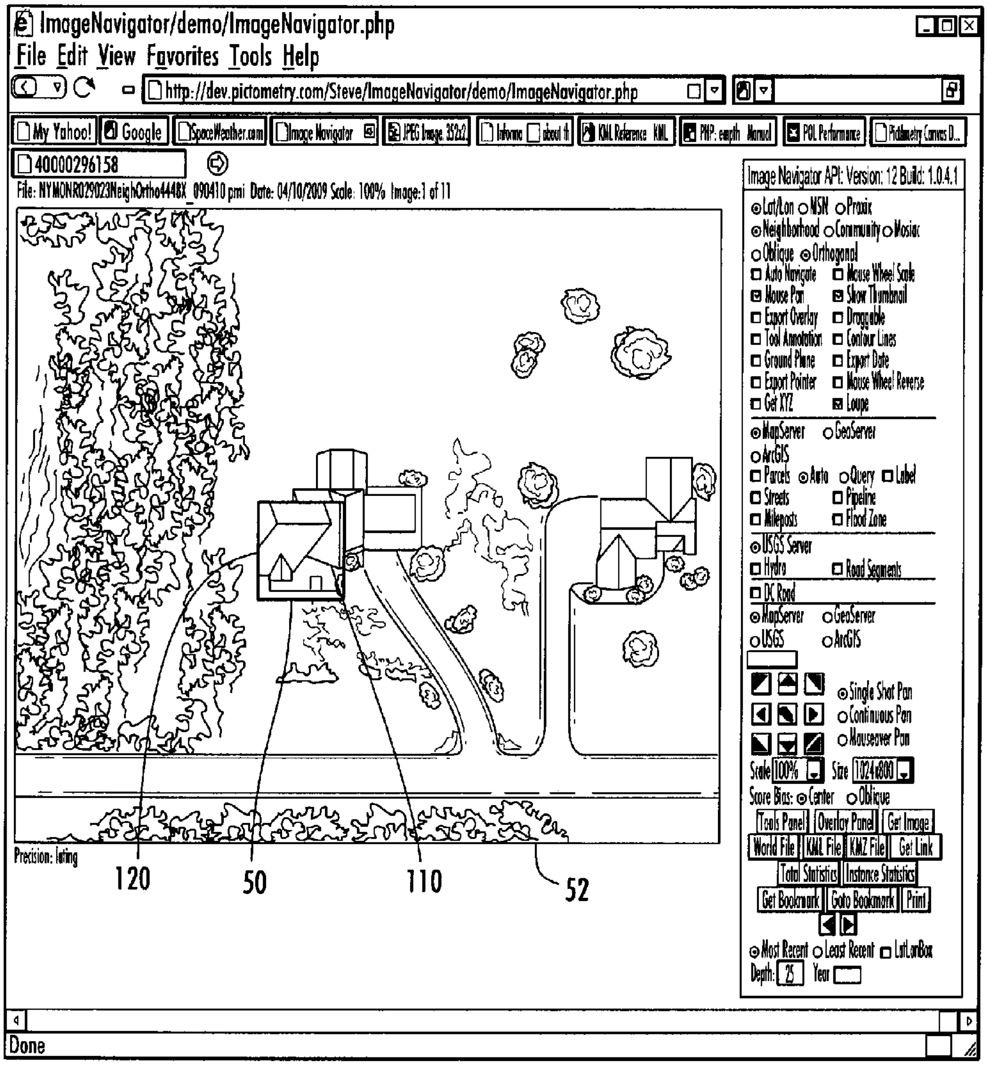

ImageNavigator/demo/ImageNavigator.php
File Edit View Favorites Tools Help
http://dev.pictometry.com/Steve/ImageNavigator/demo/ImageNavigator.php
My Yahoo!
Google
40000296158
Image Navigator API: Version: 12 Build: 1.0.4.1
Lat/Lon
Proxix
Neighborhood
Community
Mosaic
Oblique
Orthogonal
Auto Navigate
Mouse Wheel Scale
Mouse Pan
Show Thumbnail
Export Overlay
Draggable
Tool Annotation
Contour Lines
Ground Plane
Export Date
Export Pointer
Mouse Wheel Reverse
Get XYZ
Loupe
MapServer
GeoServer
ArcGIS
Parcels
Auto
Query
Label
Streets
Pipeline
Mileposts
Flood Zone
USGS Server
Hydro
Road Segments
DC Road
MapServer
GeoServer
USGS
ArcGIS
Single Shot Pan
Continuous Pan
Mouseover Pan
Scale 100%
Size 1024x800
Score Bias: Center
Oblique
Tools Panel
Overlay Panel
Get Image
World File
KML File
KMZ File
Get Link
Total Statistics
Instance Statistics
Get Bookmark
Goto Bookmark
Print
Most Recent
Least Recent
LatLonBox
Depth: 25
Year
Precision: lating
120
50
110
52
Done

FIG. 8

SYSTEMS AND METHODS FOR PROCESSING IMAGES WITH EDGE DETECTION AND SNAP-TO FEATURE

CROSS-REFERENCE TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

THE NAMES OF THE PARTIES TO A JOINT RESEARCH AGREEMENT

Not Applicable.

BACKGROUND OF THE INVENTION

1. Field of Invention

The inventive concepts disclosed and claimed herein relate generally to digital image processing and, more particularly, but not by way of limitation, to finding and selecting points of interest on an edge of interest in a digital image.

2. Brief Description of Related Art

In the remote sensing/aerial imaging industry, imagery is used to capture views of a geographic area to be able to measure objects and structures within the images as well as to be able to determine geographic locations of points within the image. Such imagery is described in, for example, U.S. Patent Application Publication No. 2008/0231700. Photogrammetry is the science of making measurements of and between objects depicted within photographs, especially aerial photographs. A person, or User, may interact with the image to select Points of Interest that may be used to perform other functions such as: determine distance between two points; determine the area outlined by a set of points; determine the volume of a 3-dimensional shape, or other functions. Usually, the greatest error induced into the calculation of the function is the human error introduced by the User selecting the Points of Interest. For example, if a measurement from a building to the edge of a curb is desired and the User selects a point that is close to the edge of the building, but not the actual edge of the building, then the measurement will differ from the actual measurement by the distance the User selected away from the building. In the projected image, several pixels could significantly impair the accuracy of the measurement. Additionally, when multiple Users perform the same measurement, their results can differ significantly.

In light of the foregoing, there is a need for a system and process for allowing a User to select Points of Interest based on the edge elements that exist in a geo-referenced image, wherein the Points of Interest are determined without the error caused by human determination of the position of the edge of an element in an image.

SUMMARY OF THE INVENTION

A method for creating image products includes the following steps. Image data and positional data corresponding to the image data are captured and processed to create geo-referenced images. Edge detection procedures are performed on the geo-referenced images to identify edges and produce geo-referenced, edge-detected images.

In one embodiment, a computerized system includes a computer system for storing a database of captured oblique images with corresponding geo-location data and corresponding detected edge data. The computer system has computer executable logic that, when executed by a processor, causes the computer system to receive a selection of a geographic point from a User, search the database to find images that contain the selected point, and make the images that contain the selected point available to the User.

In another embodiment a method of providing images to a User includes the following steps. A database stores captured oblique images having corresponding geo-location data and corresponding detected edge data. A selection of a geographic point is received from a user and the database is then searched to find images that contain the selected geographic point. The images that contain the selected geographic point are then made available to the User.

In yet another embodiment a sequence of instructions is stored on at least one non-transitory computer readable medium for running on a computer system capable of displaying and navigating imagery. The sequence of instructions includes instructions for causing the computer system to display a pixel representation of a georeferenced, edge-detected image, wherein the pixel representation includes one or more detected edges in the geo-referenced, edge-detected image; instructions for causing the computer system to allow the User to select one of the one or more detected edges by moving a cursor over a region of interest (which may be magnified), wherein the cursor is caused to snap-to a selected detected edge when the cursor is within a predetermined distance from the selected detected edge; instructions for causing the computer system to allow the User to accept the selected detected edge as an edge of interest; and instructions for causing the computer system to allow the User to determine and store one or more points of interest along the edge of interest.

In yet another embodiment, a system for preparing and utilizing geo-referenced images includes one or more image and data files accessible by a computer system capable of displaying and navigating digital imagery, the image and data file including a plurality of image files, detected edge information corresponding to the plurality of image files, and positional data corresponding to the plurality of image files; and image display and analysis software stored on a non-transitory computer readable medium and executable by the computer system. The image display and analysis software causes the computer system to allow a user to download and display, from the image and data file, a pixel representation of an image having a plurality of detected edges within the image, and to select a detected edge within the pixel representation by moving a cursor over the pixel representation, wherein the cursor is caused to snap-to a selected detected edge when the cursor is within a predetermined distance from the selected detected edge. The image display and analysis software also causes the computer system to allow the user to accept the selected detected edge as an edge of interest; and to allow the user to determine and store one or more points of interest along the edge of interest.

Thus, utilizing (1) the technology known in the art; (2) the above-referenced general description of the presently claimed and disclosed inventive concept(s); and (3) the drawings and detailed description of the inventive concepts that follows, the advantages and novelties of the presently claimed and disclosed inventive concept(s) are readily apparent to one of ordinary skill in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

Like reference numerals in the figures represent and refer to the same element or function. Implementations of the disclosure may be better understood when consideration is given to the following detailed description thereof. Such description makes reference to the annexed pictorial illustrations, schematics, graphs, drawings, and appendices. In the drawings:

FIG. **1** is a flow chart showing an exemplary process for selecting a Point of Interest on an edge element in a digital photographic image.

FIG. **2** is a block diagram of an exemplary computer system in accordance with the present disclosure.

FIG. **3** illustrates an exemplary selection of a region of interest on an image.

FIG. **4** illustrates an exemplary magnification of the region of interest on an image such that the magnified region of interest is a subset of the entire image and unmagnified surrounding areas are still visible to the User.

FIG. **5** illustrates an exemplary image showing numerous detected edges.

FIG. **6** is a flow chart describing a User selection of an edge of interest in an embodiment of the invention.

FIG. **7** is a flow chart describing a User selection of a point of interest in an embodiment of the invention.

FIG. **8** illustrates an image showing a selected edge of interest and selected points of interest.

DETAILED DESCRIPTION OF THE INVENTION

Before explaining at least one embodiment of the inventive concepts(s) disclosed herein in detail, it is to be understood that the inventive concept(s) is not limited in its application to the details of construction and the arrangement of the components or steps or methodologies set forth in the following description or illustrated in the drawings. The inventive concept(s) disclosed herein is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

In the following detailed description of embodiments of the disclosure, numerous specific details are set forth in order to provide a more thorough understanding of the disclosure. However, it will be apparent to one of ordinary skill in the art that the concepts within the disclosure can be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the description.

The inventive concept(s) disclosed herein is directed to methods and systems of creating image products, wherein image data is captured, along with positional data corresponding to the image data. The image and positional data are processed to create a plurality of geo-referenced images. In one embodiment disclosed herein, edge detection procedures are performed on the plurality of geo-referenced images to identify edges and produce geo-referenced, edge-detected images, which are saved in a database. A computer system storing such a database of captured oblique images having corresponding geo-location data and corresponding detected edge data, has computer executable logic that when executed by a processor causes the computer system to receive a selection of a geographic point from a user, search the database to find images that contain the selected point, and make the images that contain the selected point available to the user. Alternatively, the database may store captured oblique images without the detected edge data, and the edges within such images can be detected in real-time as the user is viewing the image(s).

In one embodiment, a sequence of instructions is stored on at least one non-transitory computer readable medium for running on a computer system capable of displaying and navigating imagery. Referring now to the drawings, and in particular to FIG. **1**, in general, a User downloads a geo-referenced image as in step **10**. The sequence of instructions optionally includes instructions for locating and selecting a user-requested region of interest (ROI) from a downloaded geo-referenced image as in step **12**. Further instructions can be provided for magnifying the user-requested region of interest (ROI) to provide a magnified region of interest (MROI) and for performing edge detection procedures on the region of interest (ROI) to provide a detected edge DE as in step **14**. However, detected edge data indicative of the detected edge DE can be provided in the downloaded image. The detected edge DE can be either a linear edge or a non-linear edge. In step **16**, instructions cause the cursor to snap-to a detected edge (DE) when the User moves the cursor over the MROI and the cursor nears the DE. Further instructions allow the User to determine points of interest (POI) on a selected DE as in step **18**. It is known that accuracy of selection of a POI of an element in a digital photographic image can be improved by magnifying the ROI so that the User may select a point as close as humanly possible to the actual edge of the element. However, computerized edge detection is more accurate for determination of an edge of an element and it provides consistency between multiple Users and interactions with the image. It has been discovered that by combining magnification of the ROI with edge detection, ED, and a snap-to utility for the cursor to snap to the detected edge, one can obtain synergistic improvements in the accuracy, precision and consistency of measurements of and between objects depicted within the digital photographic image as in step **20**.

Referring now to FIG. **2**, the User preferably interacts with a first computer system **21** to view and download one or more geo-referenced images to a second computer system **22** (although the geo-referenced images can be stored locally). The first and second computer system **21** and **22** can be a stand-alone computer, one or more computing device(s) and/or a distributed computing system. The stand-alone computer can be a personal computer such as a conventional desktop personal computer, laptop computer or tablet, or a mobile computer terminal. The second computer system **22** preferably includes one or more processor **23**, communication connections **24**, input devices **26***a* and **26***b*, output devices **28***a* and **28***b* including a display device **28***a*, and at least one computer readable medium **30***a* and **30***b*. The first computer system **21** can be constructed in a similar manner as the second computer system **22**. While the geo-referenced image is often provided by downloading from an Internet site, the geo-referenced image can be provided by accessing any source of data files having image files and positional data corresponding to the images. Image-capturing and geo-locating systems can include image capturing devices, such as, for example, conventional cameras, digital cameras, digital sensors, charge-coupled devices, or other suitable image-capturing devices capable of capturing images photographically or electronically, and positioning information provided by, for example, a global positioning system and/or an inertial navigation unit. These systems and devices are well known to those skilled in the art.

The image display and analysis software can be stored on a non-transitory computer readable medium and/or executed by the first and/or the second computer systems **21** and **22** Software providing instructions for displaying a pixel representation of image are available commercially and well known to those skilled in the art. Image display and analysis software can include methods for utilizing oblique images such as described in U.S. Pat. No. 7,787,659, the content of which is incorporated herein by reference.

The computer readable mediums **30***a* and/or **30***b* includes, for example, non-volatile read only memory, random access memory, hard disk memory, removable memory cards and/or other suitable memory storage devices and/or media. Input devices **26***a* and **26***b*, such as, for example, a mouse, keyboard, joystick, or other such input device, enable the input of data and interaction of a User with image display and analysis software being executed by the first and/or the second computer systems **21** and **22**. In one embodiment, the first computer system **21** executes the image display and analysis software, and the second computer system **22** executes a communication software package, such as a web browser, to communicate with the first computer system **21** and display the geo-referenced images. An output device such as display device **28***a* can include, for example, a liquid crystal display or cathode ray tube, and displays information to the User of the second computer system **22**. Additional output devices **28***b* can include a second display device, printer, speaker, etc. Communication connections **24** connect the second computer system **22** to a network **32**, such as, for example, a local-area network, a wide-area network, the Internet and/or the World Wide Web for establishing communication with the first computer system **21**.

The second computer system **22** typically uses a computer monitor as a display device **28***a*. These display devices often cannot display an entire image with the detail necessary. This may be due to the resolution of the information in the image and the resolution and size of the display surface. When a full image is not displayable on the monitor in its entirety, the displayable image which is substituted for the full image is often a global image, i.e. the full image with resolution removed to allow the entire image to fit onto the display surface of the display device. Referring now to FIG. **3** and FIG. **4**, to obtain the detail necessary to select a point of interest (POI), algorithms and software have been developed to allow the User to box out a sub-region or region of interest ROI **50** of a photograph or full image **52** and zoom-in or enlarge that sub-region as a magnified region of interest MROI **54**, thus allowing the User to select points and lines from an enlarged detail image with greater ease and accuracy.

The detail image or magnified region of interest MROI **54** shows the details of the region of interest ROI **50**, but when shown alone the global contexts of the details are lost. Thus, in one embodiment, instructions and algorithms known to those skilled in the art are utilized for magnifying a user-requested region of interest (ROI) **50** from the image **52** and displaying the full image or a portion thereof, along with a subsection of the display screen showing a linear magnification of the user-requested ROI **50**. This allows for magnification of a particular ROI in an image while preserving visibility of the larger image as shown in FIG. **4**.

In some applications, a non-linear magnification of the user-selected ROI **50** may be provided so that the connection between the detail image and the immediately surrounding portion of the global image is not obscured. Such methods are also known to those skilled in the art. While non-linear magnification creates a "lens" like distortion to the original image, it still provides increased detail for the ROI **50** while maintaining the connection to the immediately surrounding portion of the global image.

The User typically interprets the image and decides which features are to be measured. By positioning, for example, a mouse cursor, the approximate location of the features can be pointed out to an algorithm. Semi-automatic feature extraction is known to those skilled in the art and is used for measuring height points as well as for measuring specific object corners. A User positions the cursor at some position in the image **52** and the cursor snaps-to the desired surface or object corner. However, the image around this selected point will usually contain gray value gradients caused by the object edges. Thus the snap-to feature may be limited by the size and quality of the pixels.

The extraction of lines from digital images has also been researched for many years. Semi-automatic algorithms have been developed, for example, for the extraction of roads. Most algorithms of this kind are based on so-called "snakes". Extraction of objects like house roofs can be improved by algorithms that extract homogeneous gray value. The algorithms used to find the boundaries of a homogeneous area are usually based on a "region growing algorithm". A common interactive approach is to allow the User to select an appropriate object model, and approximately align the object model with the image. A fitting algorithm can then be used to find the best correspondence between edges of the object model and the location of high gradients in the image.(1)

In an embodiment of the present disclosure, the sequence of instructions stored on at least one computer readable medium **30***a*, **30***b* and/or computer readable medium **55** of the first computer system **21** for running on the first and/or second computer systems **21** and **22** capable of displaying and navigating digital imagery includes instructions for performing edge detection procedures on the user-requested region of interest and/or on the entire pixel representation of the image. Referring now to FIG. **5**, detected edges **56** can include linear edges **58** as well as curved edges **60**. Edge detection is a tool in image processing which identifies discontinuities in a digital image such as points at which the image brightness or color changes sharply. Techniques, procedures and algorithms for edge detection are available commercially and known to those skilled in the art.

Referring now to FIG. **6**, the sequence of instructions stored on the computer readable mediums **30***a*, **30***b* and/or **55** forms a process **98** as discussed below. The process **98** includes instructions for allowing the User to interact with the magnified region of interest MROI **54** as shown in a step **100** to determine points of interest by moving the cursor over the MROI **54**. The User interaction can be accomplished with a mouse, touchpad, stylus or other means. Then the first and/or the second computer systems **21** and **22** detect a cursor position as indicated at a step **102**. Once the first and/or the second computer systems **21** and **22** detects the cursor position, instructions cause the one or more processor **23** to determine the distance between the cursor and a detected edge DE **56** at a step **104**. If the distance is less than a predetermined distance, for example, within 3 pixel lengths, the cursor is caused to snap-to that detected edge DE **56** at a step **106**. Snap-to algorithms are known to those skilled in the art.

In an embodiment, instructions are provided at a step **108** to hold the cursor at the detected edge DE **56** until the User indicates acceptance or rejection of the detected edge DE **56** as an edge of interest EOI **110** at a step **112**. Upon rejection, the cursor is allowed to move freely at a step **114** and the process **98** branches to the step **100** until the cursor position is detected again within a predetermined distance of the same or another detected edge DE **56**, at which point the cursor will again snap-to the detected edge DE **56**. Upon acceptance of the detected edge DE **56** as an edge of interest EOI **110**, the process **98** includes instructions at a step **116** to indicate, mark and store the accepted edge of interest EOI **32** on the image **52** as shown, for example, in FIG. **8**. Acceptance can be indicated by any means of communication with the second computer system **22**, such as, for example, by clicking the mouse or by selecting "Accept" from an opened dialog box. Rejection can be indicated similarly or by lack of acceptance for a specified time.

Referring now to FIG. **7**, the sequence of instructions stored on the computer readable mediums **30***a*, **30***b* and/or **55** forms a process **118** as discussed below for proceeding once the User has accepted an edge of interest EOI **110**. The process **118** includes instructions for allowing the User to move the cursor along the edge of interest EOI **110** as in a step **121** in order to select a point of interest POI **120**. The first and/or the second computer systems **21** and **22** detects the cursor position, and determines whether the cursor is more or less than a predetermined distance from the edge of interest EOI **110** as in a step **122**. If the cursor has moved more than the predetermined distance from the edge of interest EOI **110**, the process **118** branches back to step **100** in process **98**. If the cursor has moved less than the predetermined distance from the edge of interest EOI **110**, the User may select a point of interest POI **120** along the detected edge DE forming the edge of interest **110**. At a step **124** the User may select a point of interest POI **120** and accept or reject the POI by, for example, double clicking a mouse or by any means of communication with the second computer system **22** as described above for accepting or rejecting the edge of interest EOI **110**. If the point of interest POI **120** is rejected, the process **118** branches back to step **122**. Upon acceptance of the point of interest POI **120**, instructions are provided in a step **126** to indicate, mark and store the accepted point of interest POI **120** on the image as shown, for example, in FIG. **8**.

The User is then allowed to move the cursor in a step **128** in order to select additional points of interest POI **120**. The process **118** queries the User at a step **130** regarding whether all of the points of interest POI **120** have been selected. The User can indicate by any means of communication with the second computer system **22**, such as, for example, by selecting "All Done" or "Continue" from an opened dialog box. If additional points of interest POI **120** are desired, process **118** branches back to step **100** of process **98** and additional points of interest POI **120** can be identified using the procedure described above until the User has selected all of the points of interest POI **120** necessary to perform a desired function. If in fact, the User has selected all the necessary points of interest POI **120**, the User may select a function to be performed or exit out of the magnified region of interest MROI **54** as in a step **132**.

Often, the User takes measurements of and between objects depicted in the image **52** by selecting one of several available measuring modes provided within the image display and analysis software. The User selects the desired measurement mode by accessing, for example, a series of pull-down menus or toolbars or via keyboard commands. The measuring modes provided by image display and analysis software may include, for example, a distance mode that enables measurement of the distance between two or more selected points, an area mode that enables measurement of the area encompassed by several selected and interconnected points, a height mode that enables measurement of the height between two or more selected points, and an elevation mode that enables the measurement of the change in elevation of one selected point relative to one or more other selected points.

After selecting the desired measurement mode, the User selects a starting point of interest POI **120** and an ending point of interest POI **120'** on the image **52**, and image display and analysis software automatically calculates and displays the quantity sought. The accuracy, precision and consistency of these measurements depend in great part on the procedure used to select the points of interest POI **120**. By combining edge detection procedures with a snap-to function in a magnified region of interest, edges of interest can be identified and individual points of interest along those edges can be selected in a much more accurate and consistent manner than is currently available.

In one embodiment disclosed herein, edge detection procedures are performed on the plurality of geo-referenced images to identify edges and produce geo-referenced, edge-detected images which are saved in a database on one or more of the computer readable mediums **30***a*, **30***b* and **55**. Either the first and/or the second computer system **21** and **22** storing such a database of captured oblique images having corresponding geo-location data and corresponding detected edge data, has computer executable logic that when executed by a processor causes the computer systems **21** and/or **22** to receive a selection of a geographic point from a user, search the database to find images that contain the selected point, and make the images that contain the selected point available to the user. Alternatively, the database may store captured oblique images without the detected edge data, and the edges within such images can be detected in real-time as the user is viewing the image(s) and/or when the MROI **54** is showing details of a region of interest **50**.

As it will be appreciated by persons of ordinary skill in the art, changes may be made in the construction and the operation of the various components, elements and assemblies described herein or in the steps or the sequence of steps of the methods described herein without departing from the spirit and scope of the inventive concept(s) disclosed herein.

From the above description, it is clear that the inventive concept(s) disclosed herein is well adapted to carry out the objects and to attain the advantages mentioned herein as well as those inherent in the inventive concept(s) disclosed herein. While presently preferred embodiments of the inventive concept(s) disclosed herein have been described for purposes of this disclosure, it will be understood that numerous changes may be made which will readily suggest themselves to those skilled in the art and which are accomplished within the spirit of the inventive concept(s) disclosed and claimed herein.

REFERENCES

(1) George Vosselman, "Cartographic Feature Extraction", Delft University of Technology, Delft, The Netherlands.

What is claimed is:

1. A method of providing images to a user, comprising the steps of:

providing a sequence of instructions for storage on at least one non-transitory computer readable medium and for running on a computer system capable of displaying and navigating digital imagery, the sequence of instructions comprising:

instructions for causing the computer system to download and display a pixel representation of one or more of the geo-referenced, edge-detected images, wherein the pixel representation includes one or more detected edges;

instructions for causing the computer system to allow a user to select one of the one or more detected edges by moving a cursor over the pixel representation, wherein the cursor is caused to snap-to a selected detected edge when the cursor is within a predetermined distance from the selected detected edge;

instructions for causing the computer system to allow the user to accept the selected detected edge as an edge of interest; and

instructions for causing the computer system to allow the user to determine and store a point of interest along the edge of interest;

capturing image data and positional data corresponding to the image data;

storing a database of captured images having corresponding geo-location data and corresponding detected edge data;

receiving a selection of a geographic point from a user;

searching the database to find images that contain the selected geographic point; and

making the images that contain the selected geographic point available to the user.

2. The method of claim **1**, wherein the computer system comprises a personal computer.

3. The method of claim **1**, wherein the sequence of instructions stored on at least one non-transitory computer readable medium further comprises instructions for causing the computer system to magnify a user-requested region of interest from the displayed pixel representation of the geo-referenced image, and to allow the user to select one of the one or more detected edges from within the magnified user-requested region of interest.

4. The method of claim **1**, wherein the sequence of instructions stored on at least one non-transitory computer readable medium further comprises instructions for causing the computer system to display, geolocate and make measurements based on the captured image data and positional data.

5. The method of claim **1**, wherein the captured image data are oblique images.

6. The method of claim **1**, wherein the sequence of instructions stored on at least one non-transitory computer readable medium further comprises instructions for causing the computer system to display a magnification of a user-requested region of interest as a subsection of the pixel representation such that a full image is displayed along with a magnified region of interest.

7. The method of claim **6**, wherein the magnification of the user-requested region of interest is linear.

8. The method of claim **6**, wherein the magnification of the user-requested region of interest is non-linear.

9. The method of claim **1**, wherein the sequence of instructions stored on at least one non-transitory computer readable medium further comprises instructions for causing the computer system to hold the cursor at the selected detected edge until the user has indicated acceptance or rejection of the selected detected edge as an edge of interest.

10. The method of claim **1**, wherein the sequence of instructions stored on at least one non-transitory computer readable medium further comprises instructions for causing the computer system to indicate, mark and store the edge of interest on the image.

11. The method of claim **1**, wherein the sequence of instructions stored on at least one non-transitory computer readable medium further comprises instructions for causing the computer system to indicate, mark and store the point of interest on the image.

12. A sequence of instructions stored on at least one non-transitory computer readable medium for running on a computer system capable of displaying and navigating digital imagery, the sequence of instructions comprising:

instructions for causing the computer system to display a pixel representation of a geo-referenced, edge-detected image, wherein the pixel representation includes one or more detected edges in the geo-referenced, edge-detected image;

instructions for causing the computer system to allow the user to select one of the one or more detected edges by moving a cursor over the pixel representation, wherein the cursor is caused to snap-to a selected detected edge when the cursor is within a predetermined distance from the selected detected edge;

instructions for causing the computer system to allow the user to accept the selected detected edge as an edge of interest; and

instructions for causing the computer system to allow the user to determine and store one or more points of interest along the edge of interest.

13. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, wherein the computer system comprises a personal computer.

14. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, further comprising instructions for causing the computer system to magnify a user-requested region of interest from the displayed pixel representation of the geo-referenced, edge-detected image, and to allow the user to select one of the one or more detected edges from within the magnified user-requested region of interest.

15. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, further comprising instructions for causing the computer system to display, geolocate and make measurements based on geo-referenced, edge-detected images.

16. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, wherein the geo-referenced, edge-detected images comprise oblique images.

17. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, further comprising instructions for causing the computer system to display a magnification of a user-requested region of interest as a subsection of the pixel representation such that a full image is displayed along with a magnified region of interest.

18. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **17**, wherein the magnification of the user-requested region of interest is linear.

19. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **17**, wherein the magnification of the user-requested region of interest is non-linear.

20. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, further comprising instructions for causing the computer system to hold the cursor at the selected detected edge until the user has indicated acceptance or rejection of the selected detected edge as an edge of interest.

21. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, further comprising instructions for causing the computer system to indicate, mark and store the edge of interest on the image.

22. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **12**, further comprising instructions for causing the computer system to indicate, mark and store the one or more points of interest on the image.

23. A system for preparing and utilizing geo-referenced images, the system comprising:

one or more image and data files accessible by a computer system capable of displaying and navigating digital imagery, the image and data file including a plurality of image files, detected edge information corresponding to the plurality of image files, and positional data corresponding to the plurality of image files; and

image display and analysis software stored on a non-transitory computer readable medium and executable by the computer system to cause the computer system to:

allow a user to download and display, from the image and data file, a pixel representation of an image having a plurality of detected edges within the image, and to select a detected edge within the pixel representation by moving a cursor over the pixel representation, wherein the cursor is caused to snap-to a selected detected edge when the cursor is within a predetermined distance from the selected detected edge;

allow the user to accept the selected detected edge as an edge of interest; and

allow the user to determine and store one or more points of interest along the edge of interest.

24. The system of claim **23**, further comprising edge detection software stored on a non-transitory computer readable medium and executable by a computerized system to cause the computerized system to perform edge detection procedures on a plurality of image files to provide a plurality of edge-detected image files for storage on the image and data file.

25. The system of claim **23**, wherein the computer system comprises a personal computer.

26. The system of claim **23**, wherein the image display and analysis software includes instructions for causing the computer system to magnify a user-requested region of interest from the displayed pixel representation of the geo-referenced image, and allow the user to select one of the one or more detected edges from within the magnified user-requested region of interest.

27. The system of claim **23**, wherein the image display and analysis software further includes instructions for causing the computer system to display, geolocate and make measurements based on the image data and positional data.

28. The system of claim **27**, wherein the image data are oblique images.

29. The system of claim **23**, wherein the image display and analysis software further includes instructions for causing the computer system to display a magnification of a user-requested region of interest as a subsection of the pixel representation such that a full image is displayed along with a magnified region of interest.

30. The system of claim **29**, wherein the magnification of the user-requested region of interest is linear.

31. The system of claim **29**, wherein the magnification of the user-requested region of interest is non-linear.

32. The system of claim **23**, wherein the image display and analysis software further includes instructions for causing the computer system to hold the cursor at the selected detected edge until the user has indicated acceptance or rejection of the selected detected edge as an edge of interest.

33. The system of claim **23**, wherein the image display and analysis software further includes instructions for causing the computer system to indicate, mark and store the edge of interest on the image.

34. The system of claim **23**, wherein the image display and analysis software further includes instructions for causing the computer system to indicate, mark and store the one or more points of interest on the image.

35. A sequence of instructions stored on at least one non-transitory computer readable medium for running on a computer system capable of displaying and navigating digital imagery, the sequence of instructions comprising:

instructions for magnifying a user-requested region of interest from a displayed pixel representation of an image;

instructions for performing linear edge detection procedures on the user-requested region of interest to identify one or more detected linear edges within the user-requested region of interest; and

instructions for allowing the user to select one of the one or more detected linear edges within the user-requested region of interest by moving a cursor over the magnified region of interest, wherein the cursor is caused to snap-to a selected detected linear edge when the cursor is within a predetermined distance from the selected detected linear edge;

instructions for allowing the user to accept the selected detected linear edge as an edge of interest; and

instructions for allowing the user to determine and store a point of interest along the edge of interest.

36. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **35**, wherein the computer system is a personal computer.

37. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **35**, further comprising instructions for downloading and viewing one or more geo-referenced images.

38. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **35**, further comprising instructions for displaying, geolocating and making measurements based on images.

39. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **38**, wherein the imaged are oblique images.

40. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **35**, further comprising instructions for displaying a magnification of the user-requested region of interest as a subsection of the image such that a full image is displayed along with a magnified region of interest.

41. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **40**, wherein the magnification of the user-requested region of interest is linear.

42. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **40**, wherein the magnification of the user-requested region of interest is non-linear.

43. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **35**, further comprising instructions to hold the cursor at the selected detected linear edge until the user has indicated acceptance or rejection of the selected detected linear edge as an edge of interest.

44. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **35**, further comprising instructions for indicating, marking and storing the edge of interest on the image.

45. The sequence of instructions stored on at least one non-transitory computer readable medium as in claim **35**, further comprising instructions for indicating, marking and storing the point of interest on the image.

46. A sequence of instructions stored on at least one non-transitory computer readable medium for running on a computer system capable of displaying and navigating oblique imagery, the sequence of instructions comprising:

instructions for displaying a pixel representation of a full image;

instructions for magnifying a user-requested region of interest from the full image, wherein the region of interest is a subset of the full image, wherein unmagnified surrounding areas of the full image are still visible to the user, and wherein the user can interact with the magnified region of interest;

instructions for performing linear edge detection procedures on the magnified region of interest to identify one or more detected linear edges within the region of interest;

instructions for allowing the user to select one of the one or more detected linear edges within the user-requested region of interest by moving a cursor over the magnified region of interest, wherein the cursor is caused to snap-to a selected detected linear edge when the cursor is within a predetermined distance from the selected detected linear edge;

instructions for allowing the user to accept the selected detected linear edge as an edge of interest;

instructions for allowing the user to determine, indicate, mark and store at least one point of interest along the edge of interest; and

instructions for allowing the user to make measurements based upon the at least one point of interest.

* * * * *

EXHIBIT 10

US008825454B2

(12) **United States Patent**
Pershing

(10) **Patent No.: US 8,825,454 B2**
(45) **Date of Patent: *Sep. 2, 2014**

(54) **CONCURRENT DISPLAY SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION**

(75) Inventor: **Chris Pershing**, Redmond, WA (US)

(73) Assignee: **Eagle View Technologies, Inc.**, Bothell, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/474,504**

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(51) **Int. Cl.**

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G06F 17/10	(2006.01)
G06F 7/60	(2006.01)
G06T 17/20	(2006.01)
G06K 9/00	(2006.01)
G06T 7/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G06T 17/20*** (2013.01); ***G06K 9/00637*** (2013.01); *G06T 2207/10012* (2013.01); *G06T 2207/30184* (2013.01); ***G06T 7/0075*** (2013.01); ***G06F 17/5004*** (2013.01)

USPC **703/1**; 703/2

(58) **Field of Classification Search**

CPC ... G06F 17/20; G06F 17/5004; G06T 7/0075; G06T 7/0083; G06T 7/0042; G06T 2200/24; G06T 2207/10012; G06T 2207/30184; G06T 2207/10032; G06K 9/00637

USPC 703/1

See application file for complete search history.

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(57) **ABSTRACT**

User interface systems and methods for roof estimation are described. Example embodiments include a roof estimation system that provides a user interface configured to facilitate roof model generation based on one or more aerial images of a building roof. In one embodiment, roof model generation includes image registration, image lean correction, roof section pitch determination, wire frame model construction, and/or roof model review. The described user interface provides user interface controls that may be manipulated by an operator to perform at least some of the functions of roof model generation. The user interface is further configured to concurrently display roof features onto multiple images of a roof. This abstract is provided to comply with rules requiring an abstract, and it is submitted with the intention that it will not be used to interpret or limit the scope or meaning of the claims.

37 Claims, 29 Drawing Sheets

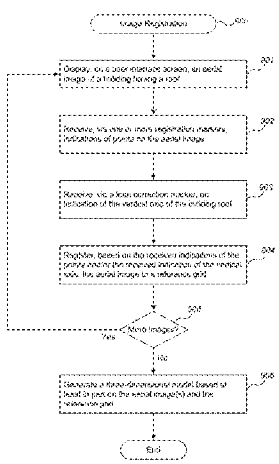

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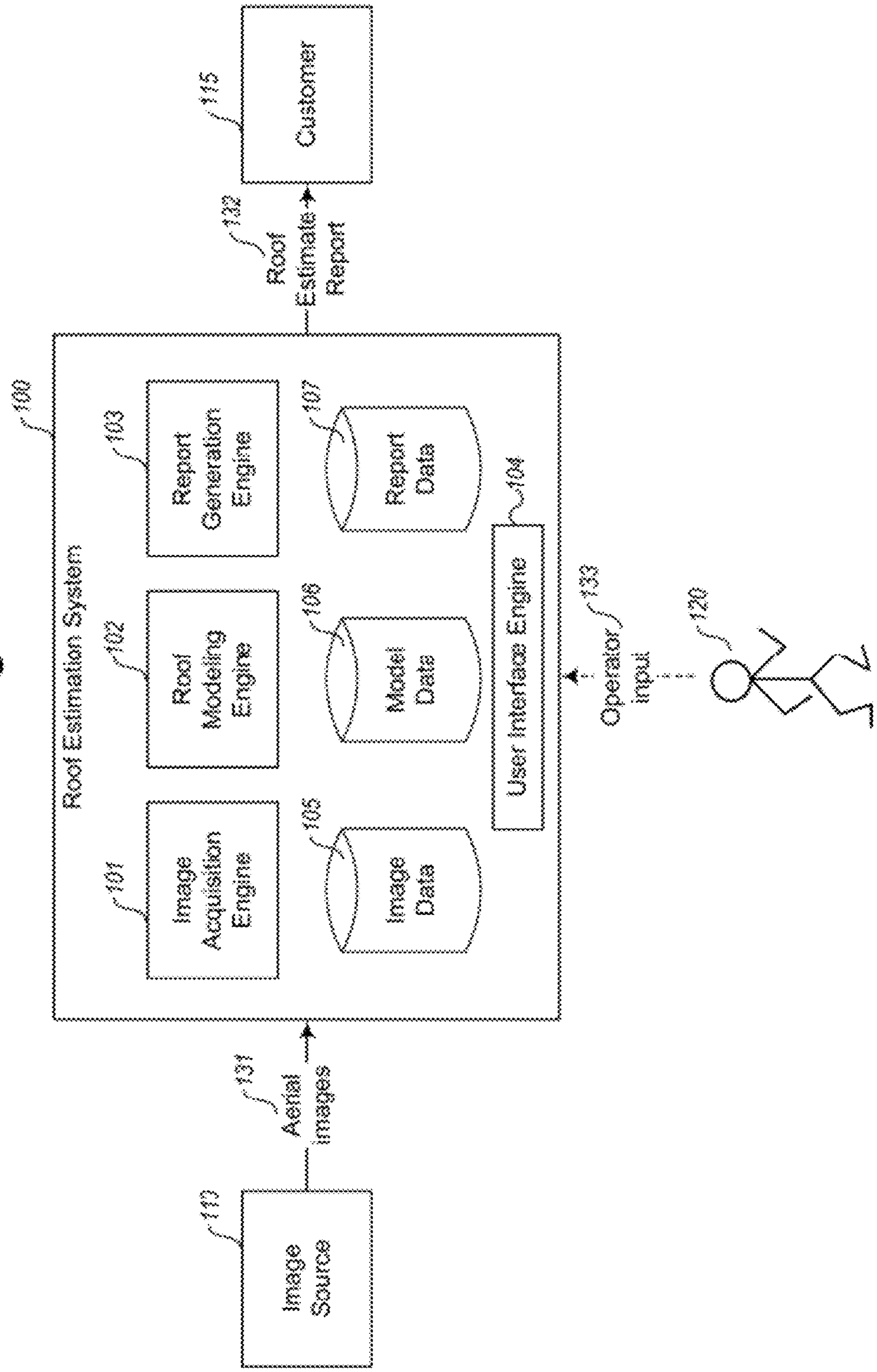
Fig. 1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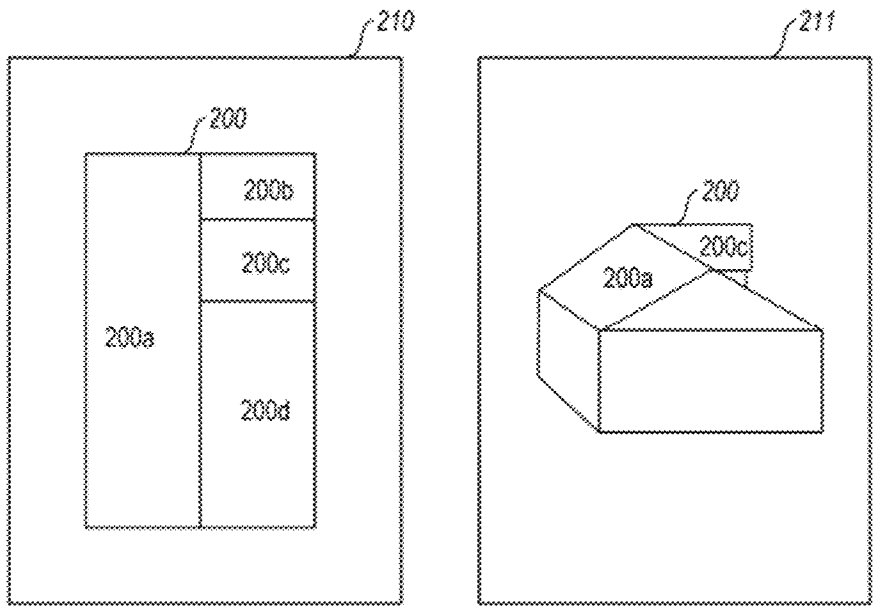
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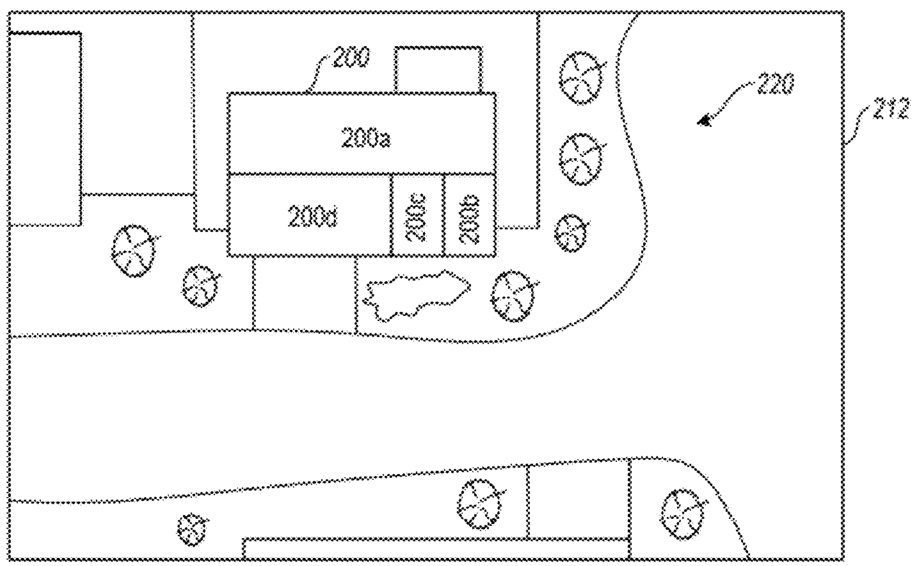
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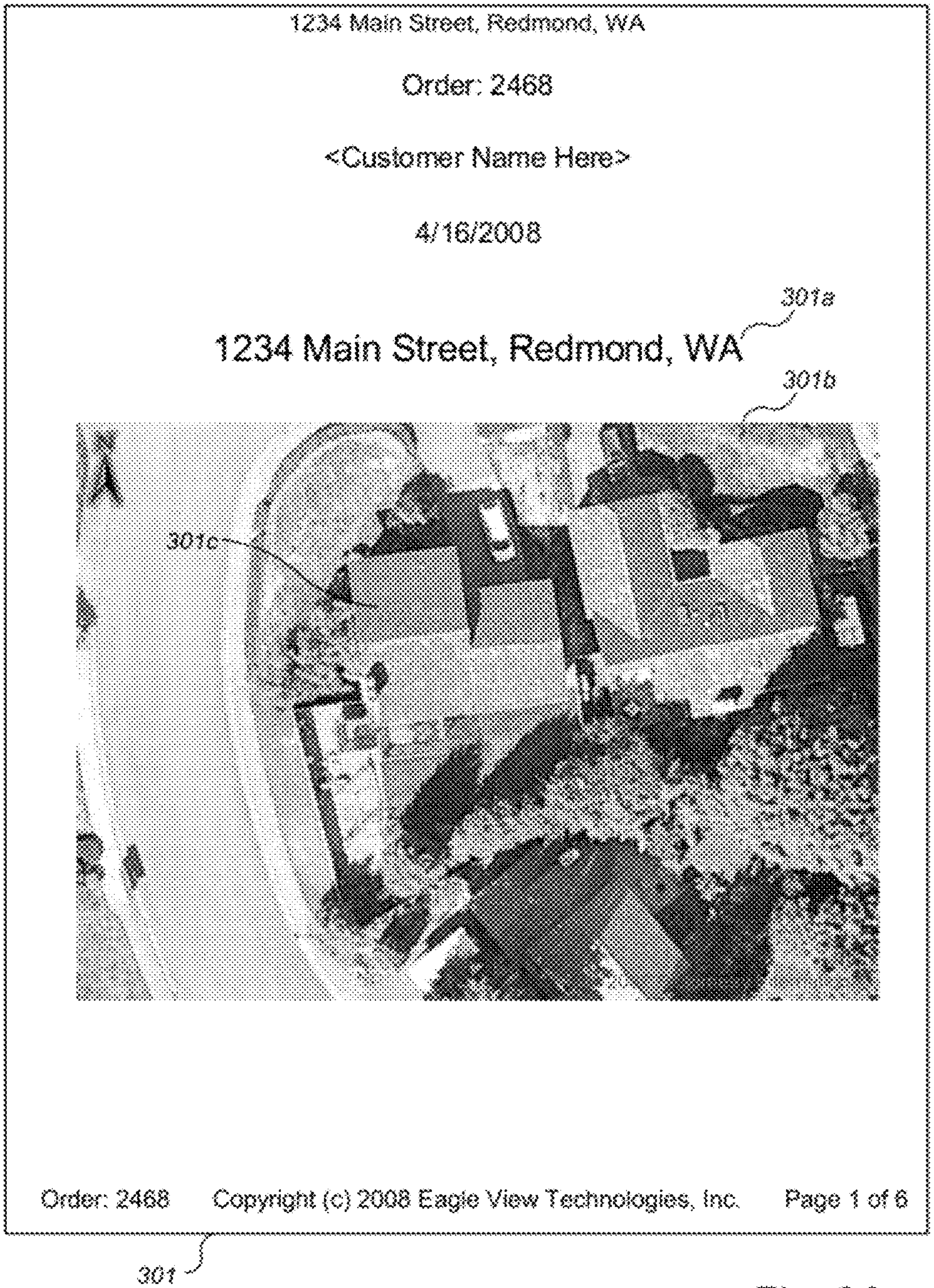
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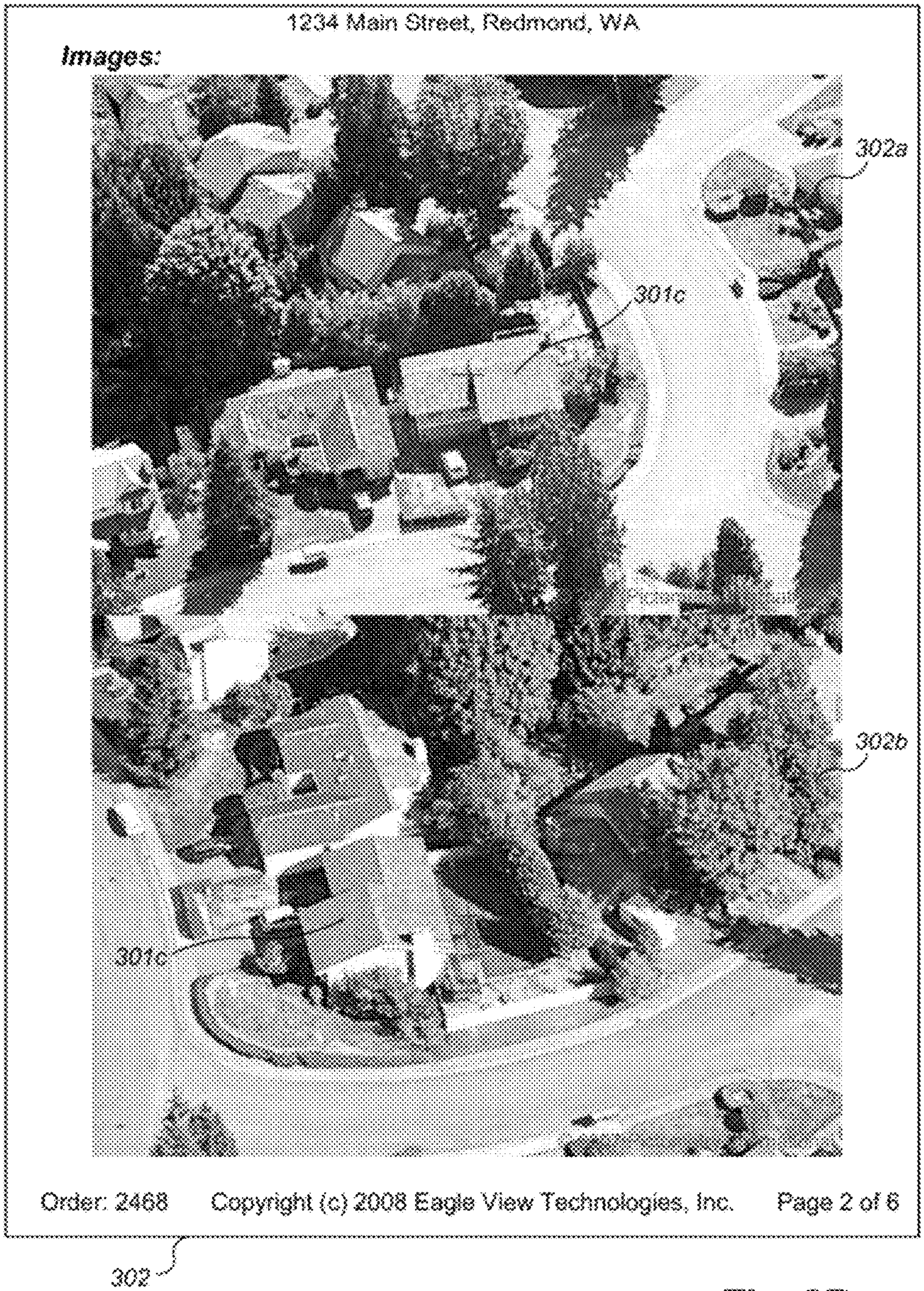
Page 1 of 6
301

Fig. 3A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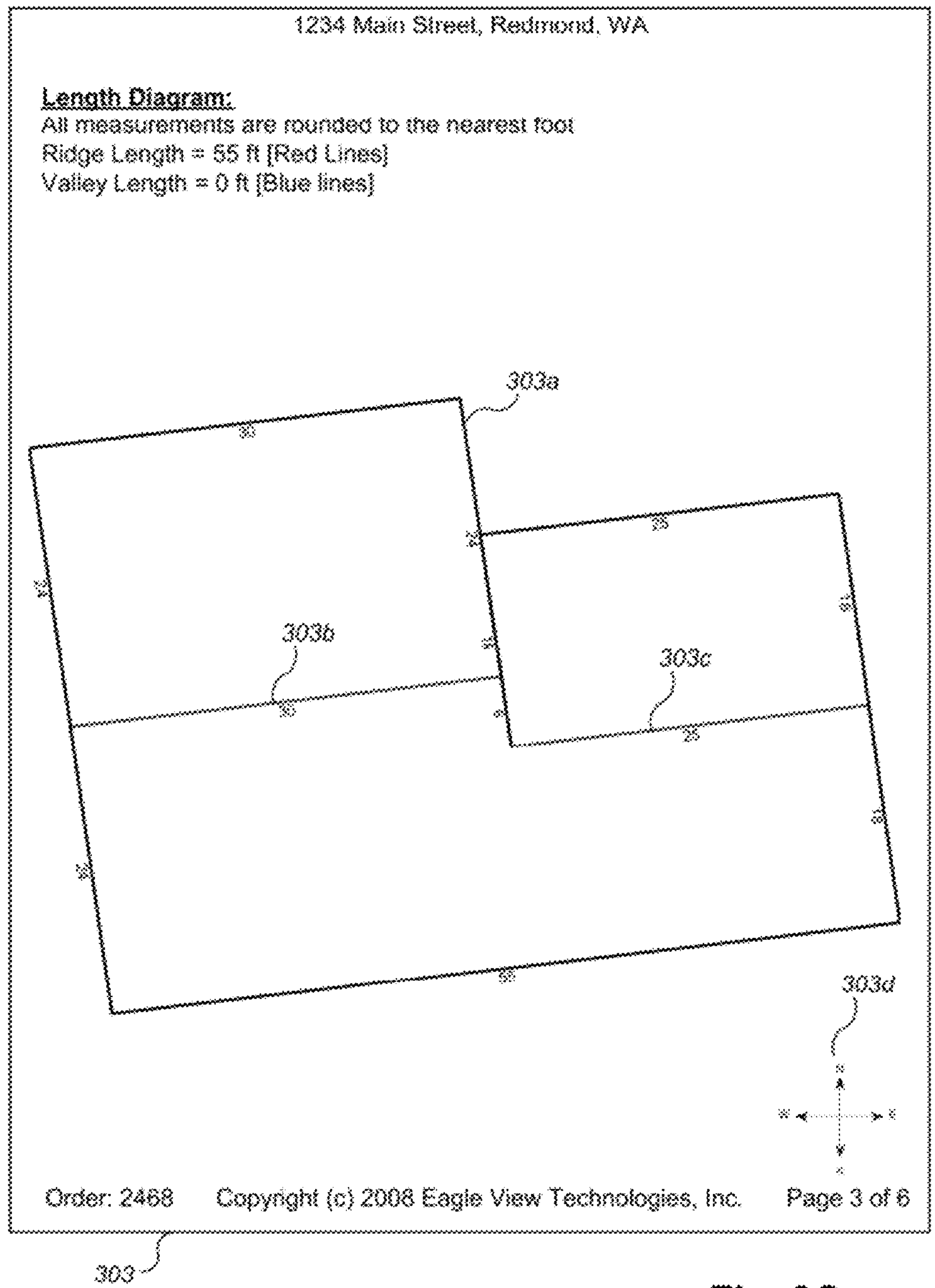
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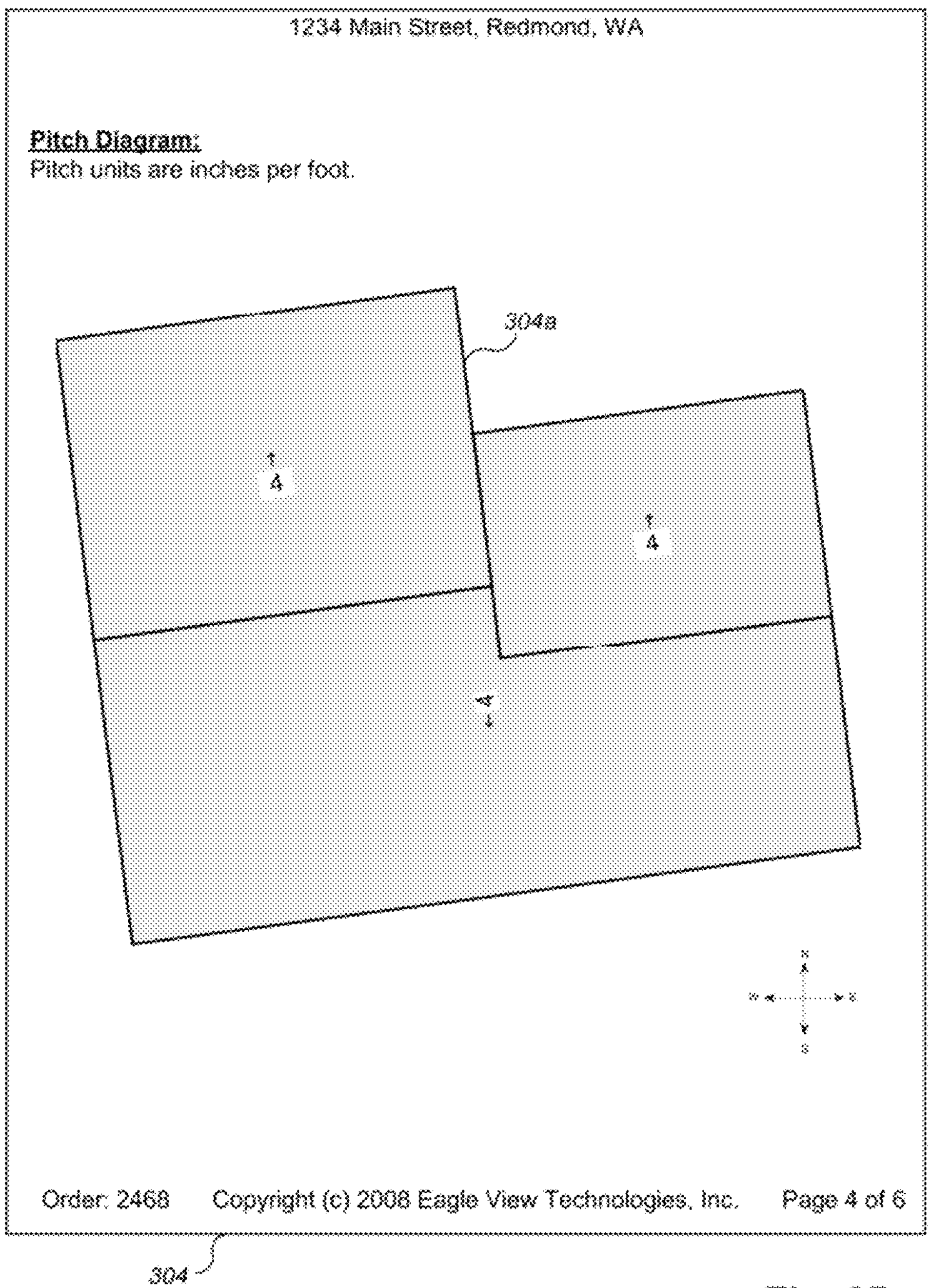
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 3 of 6
303

Fig. 3C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Pitch Diagram:
Pitch units are inches per foot.
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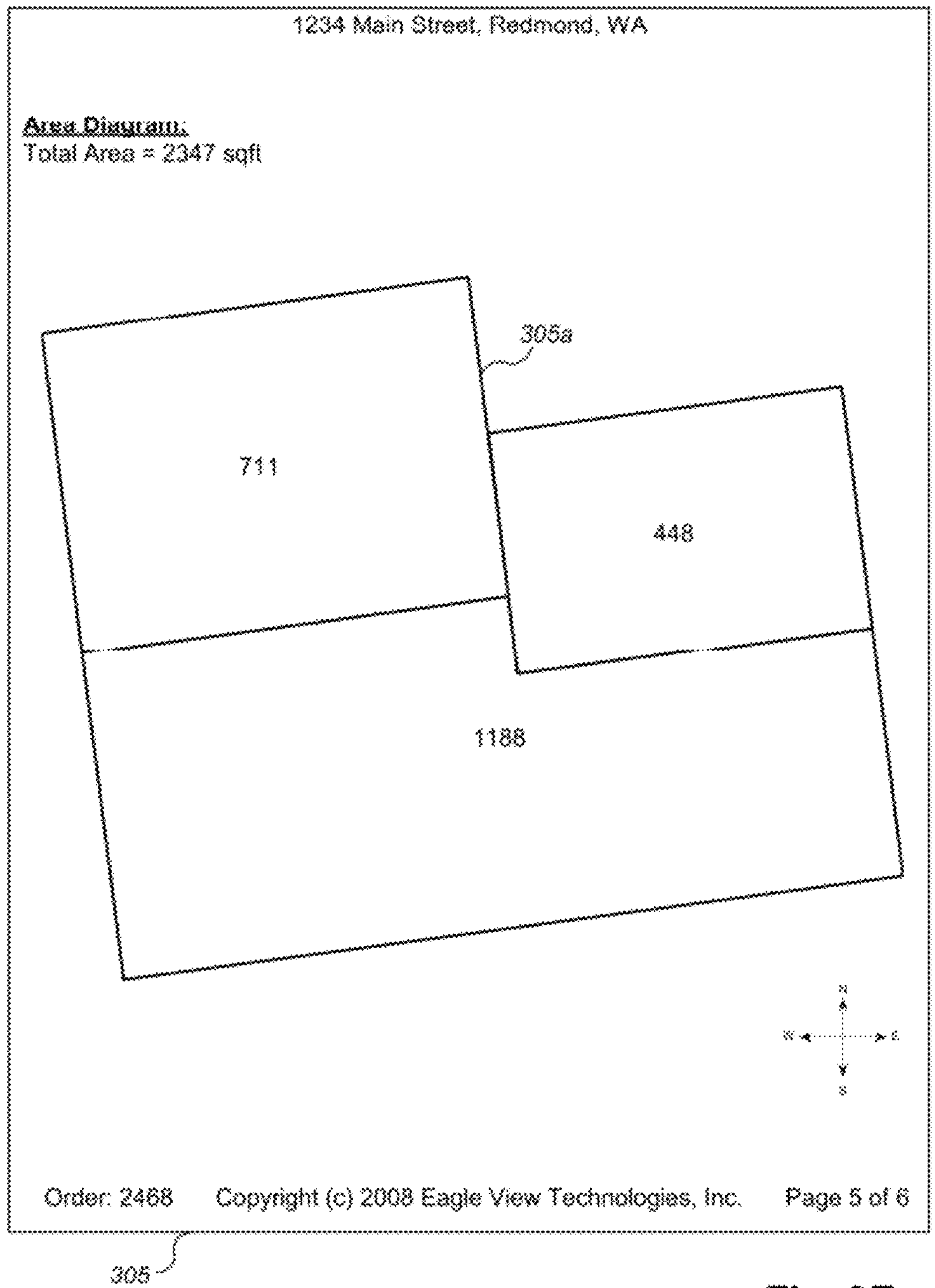
Order: 2468
Copyright (c) 2008 Eagle View Technologies, Inc.
Page 4 of 6
304

Fig. 3D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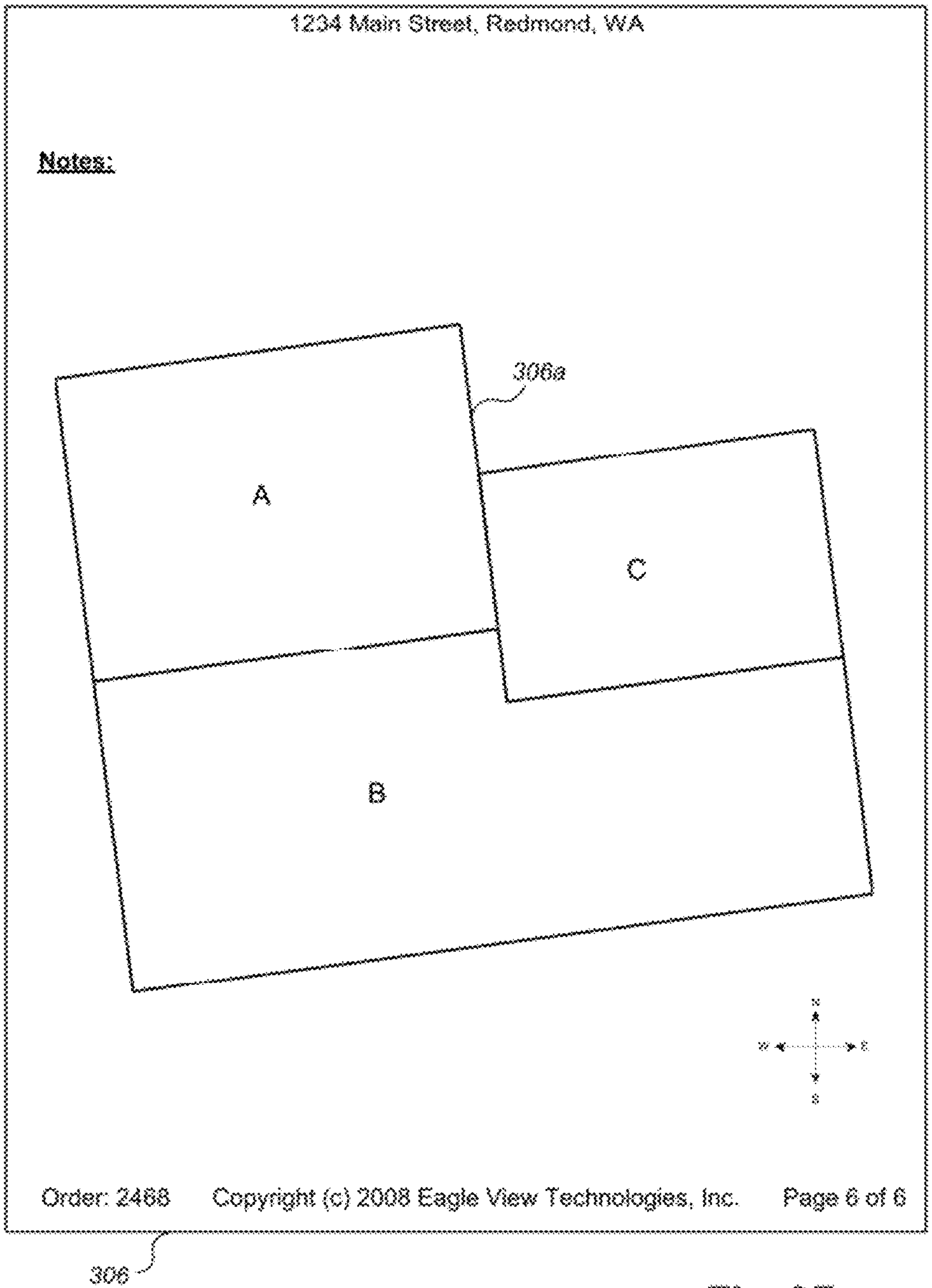
Page 5 of 6
305

Fig. 3E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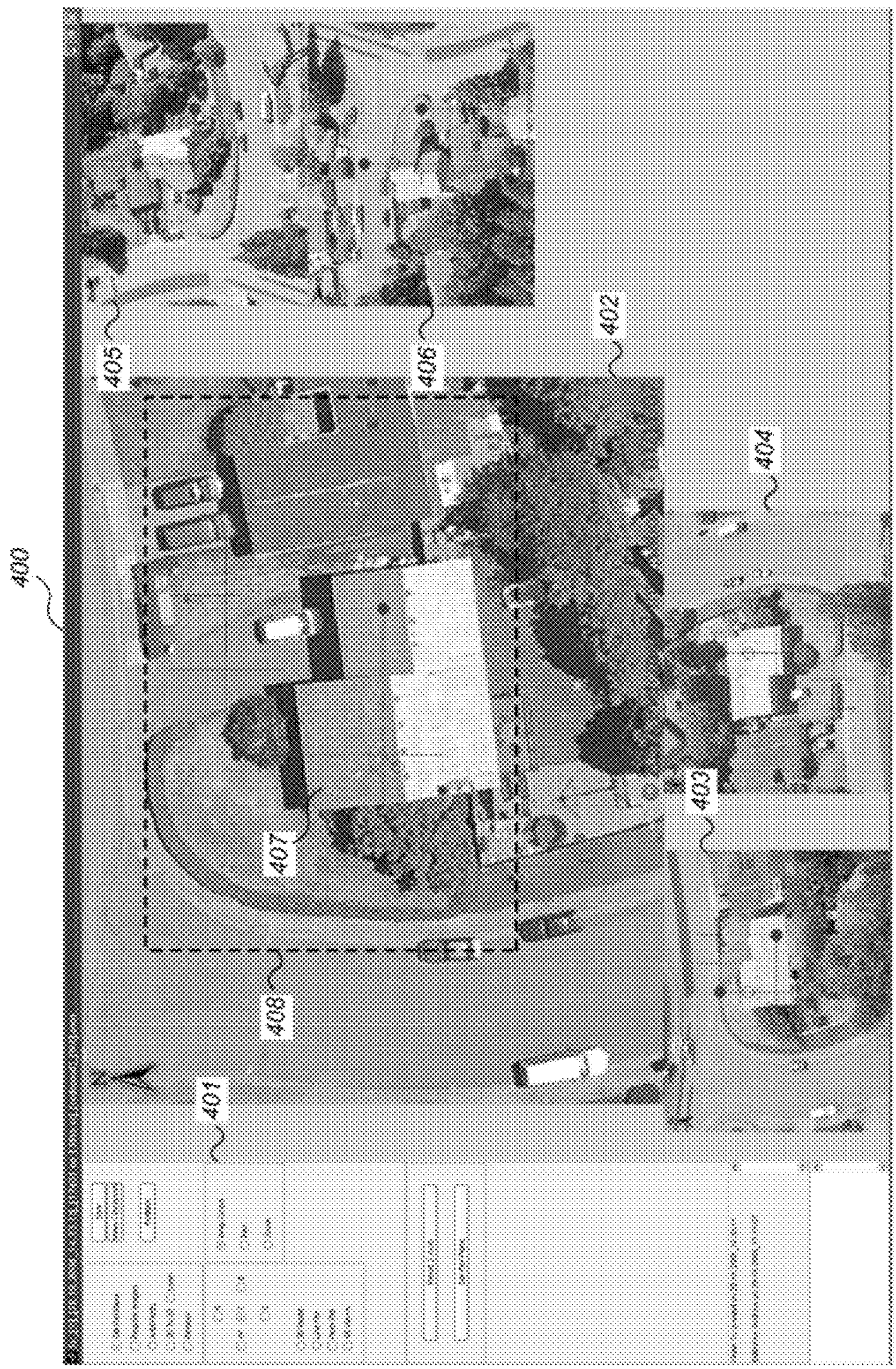

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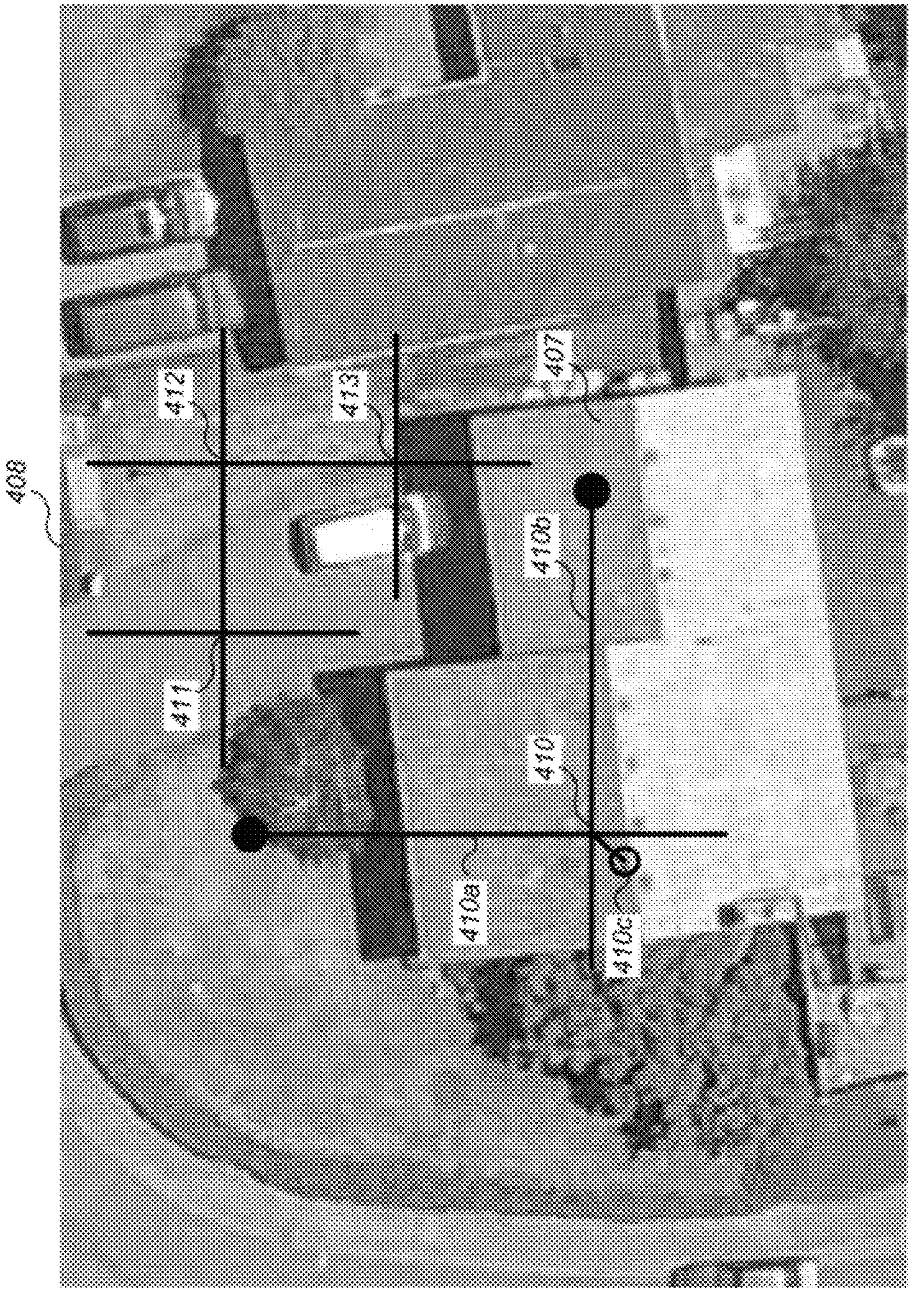

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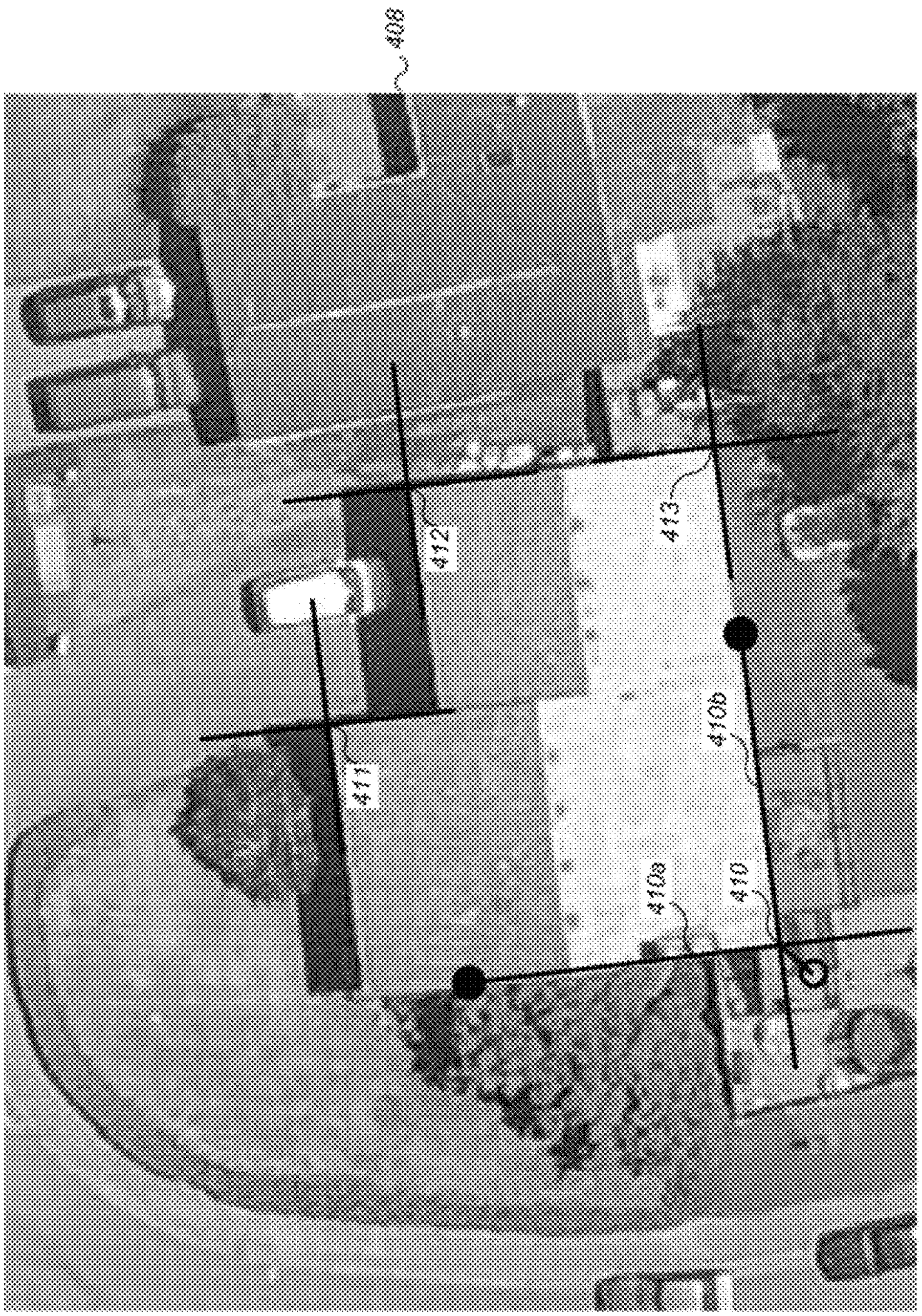

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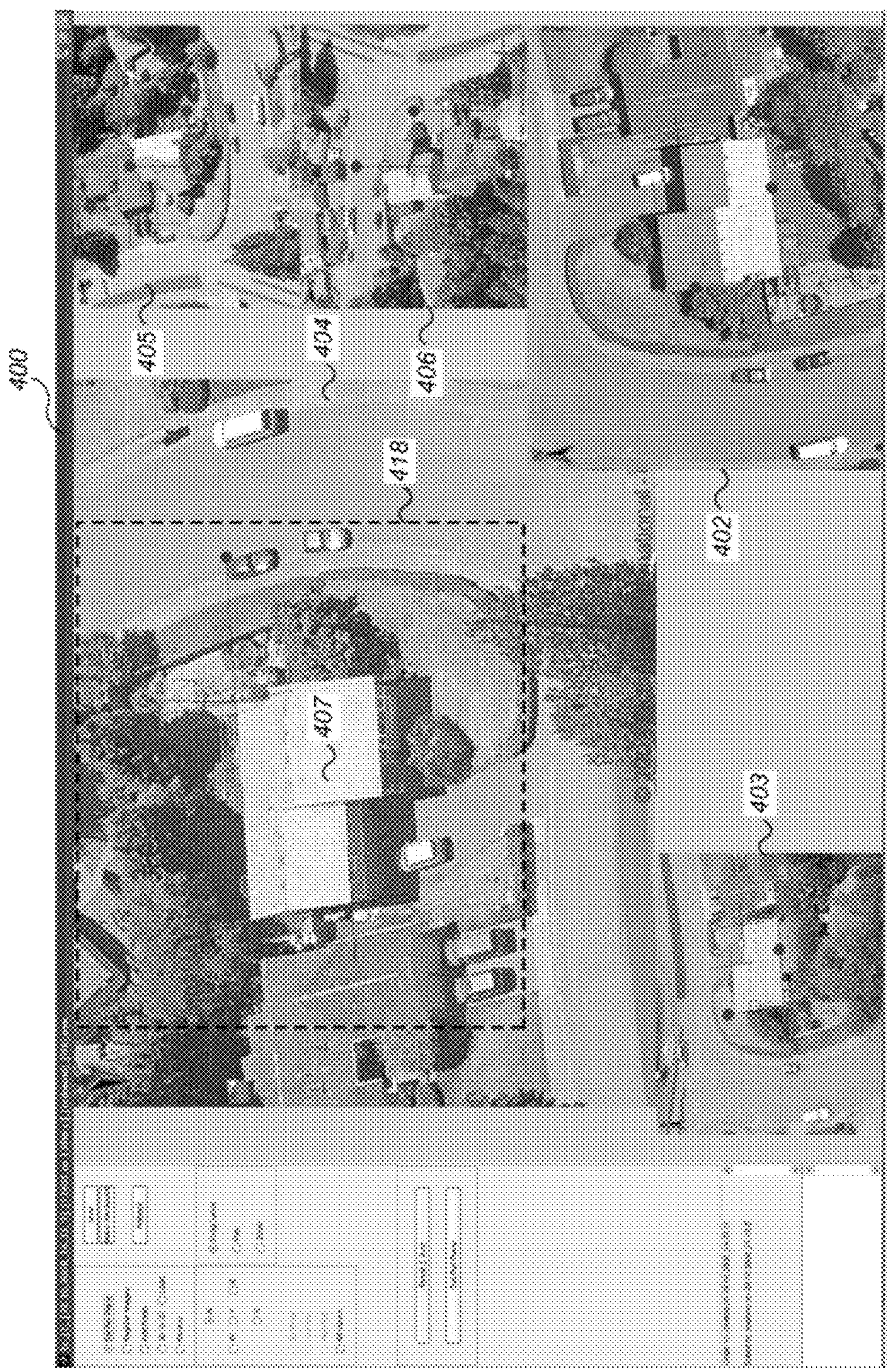

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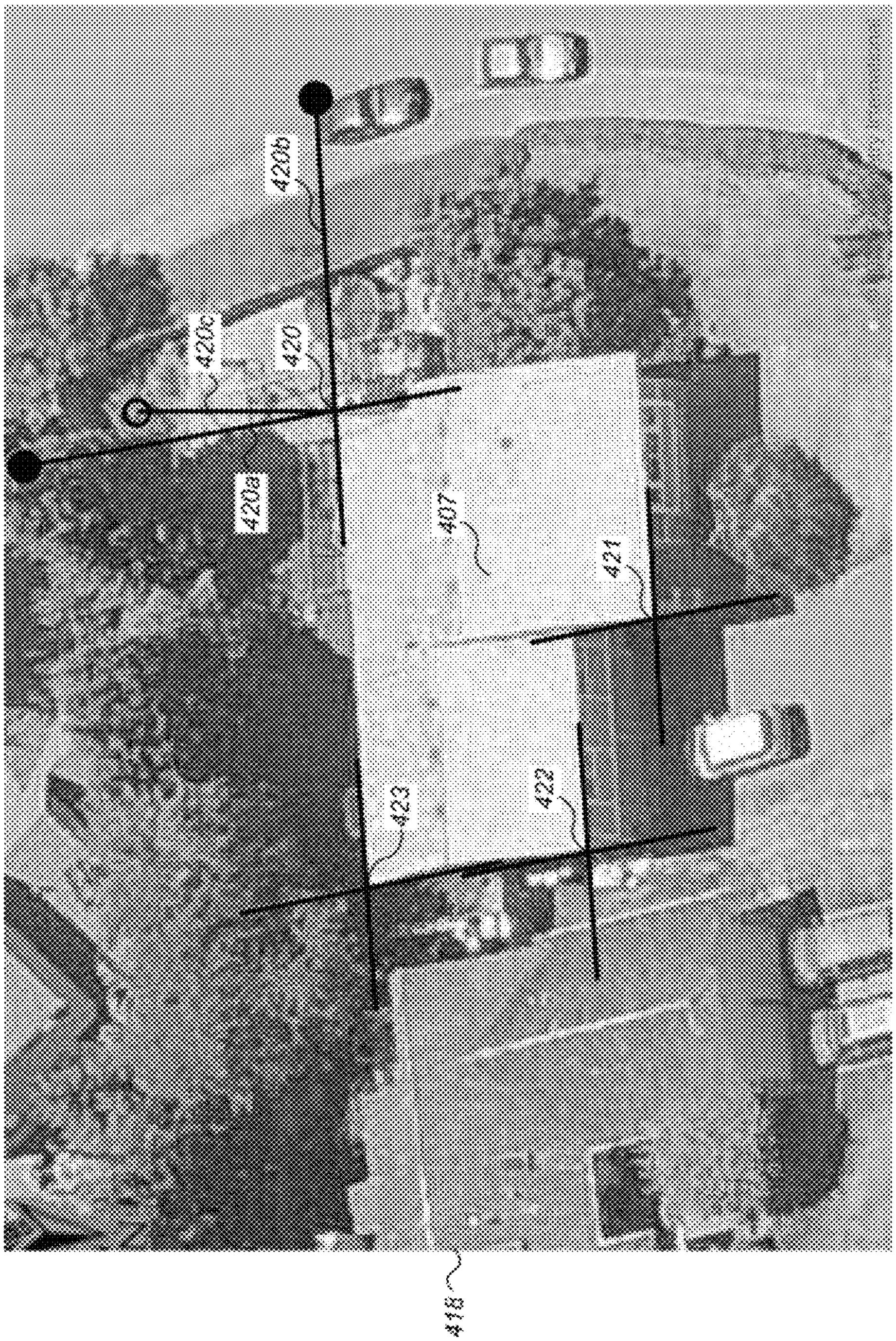
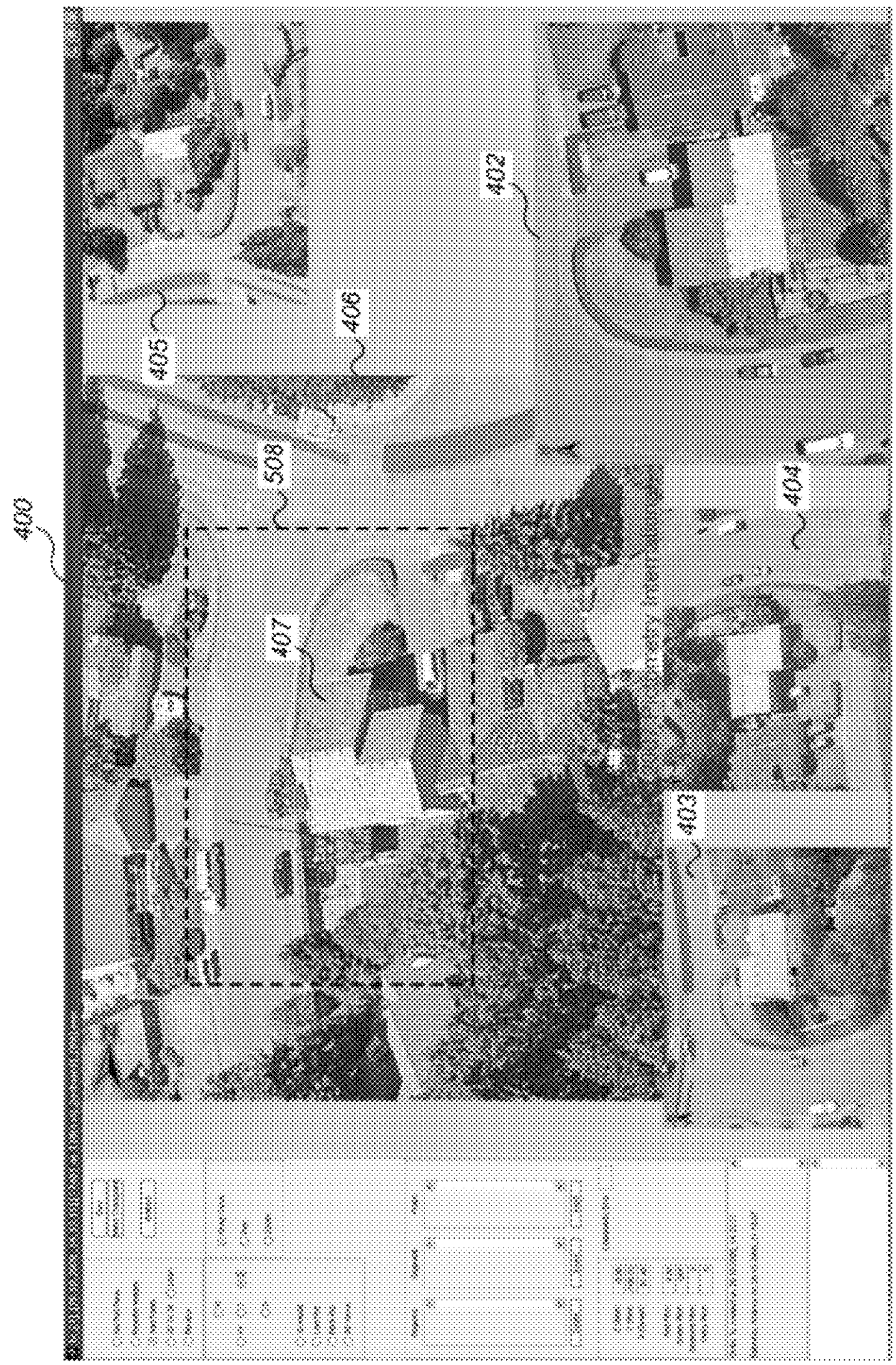


Fig. 4E

Fig. 4F



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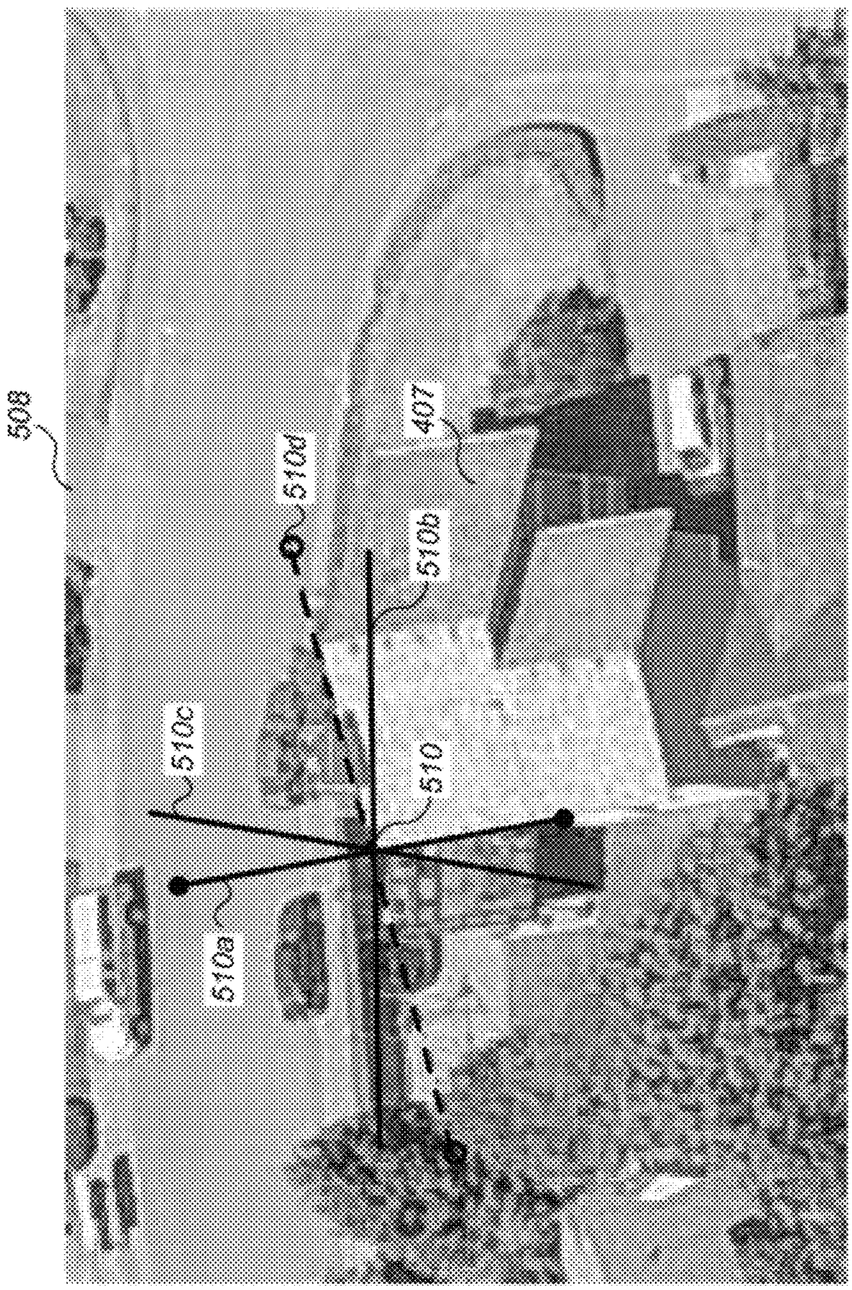

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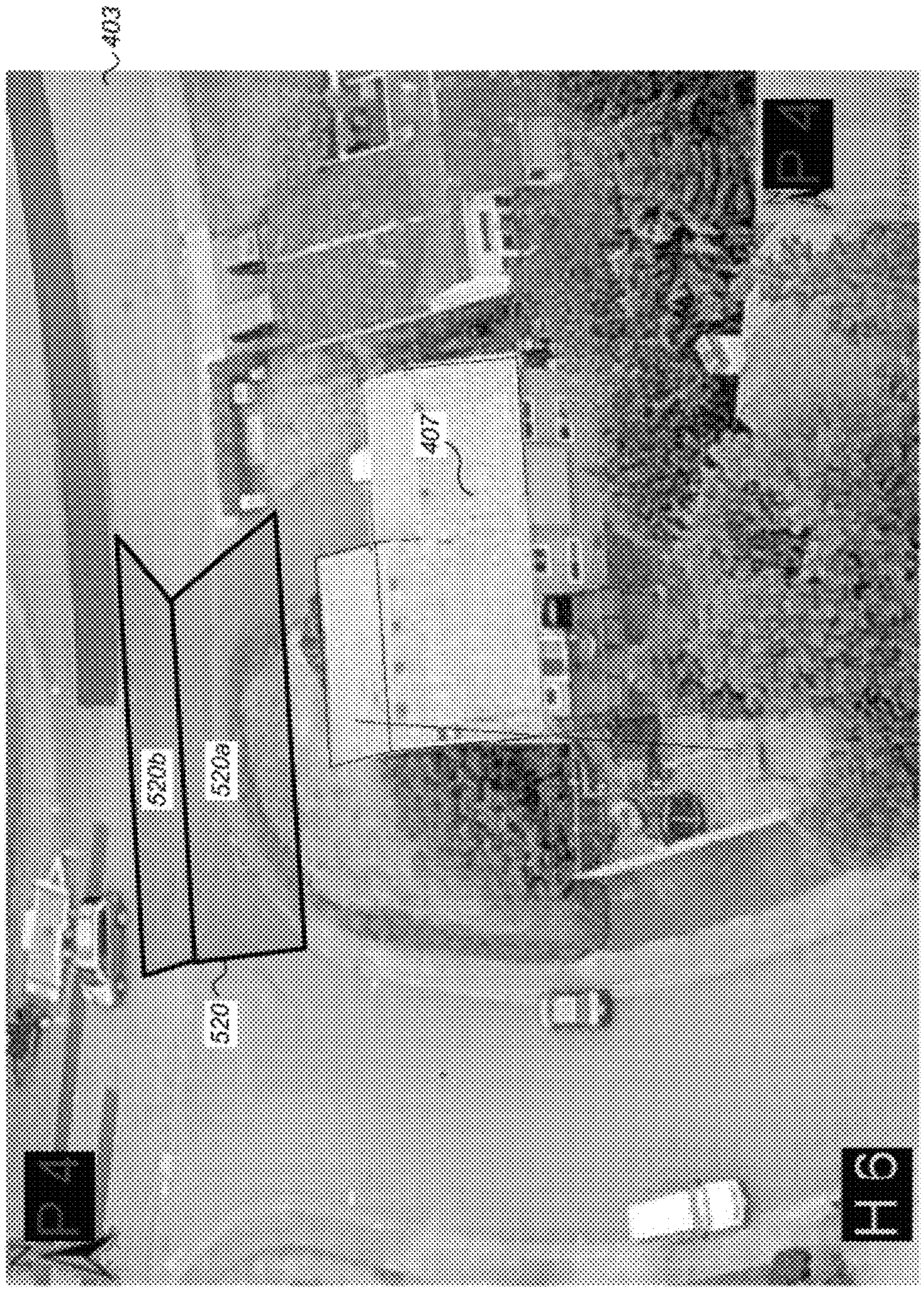

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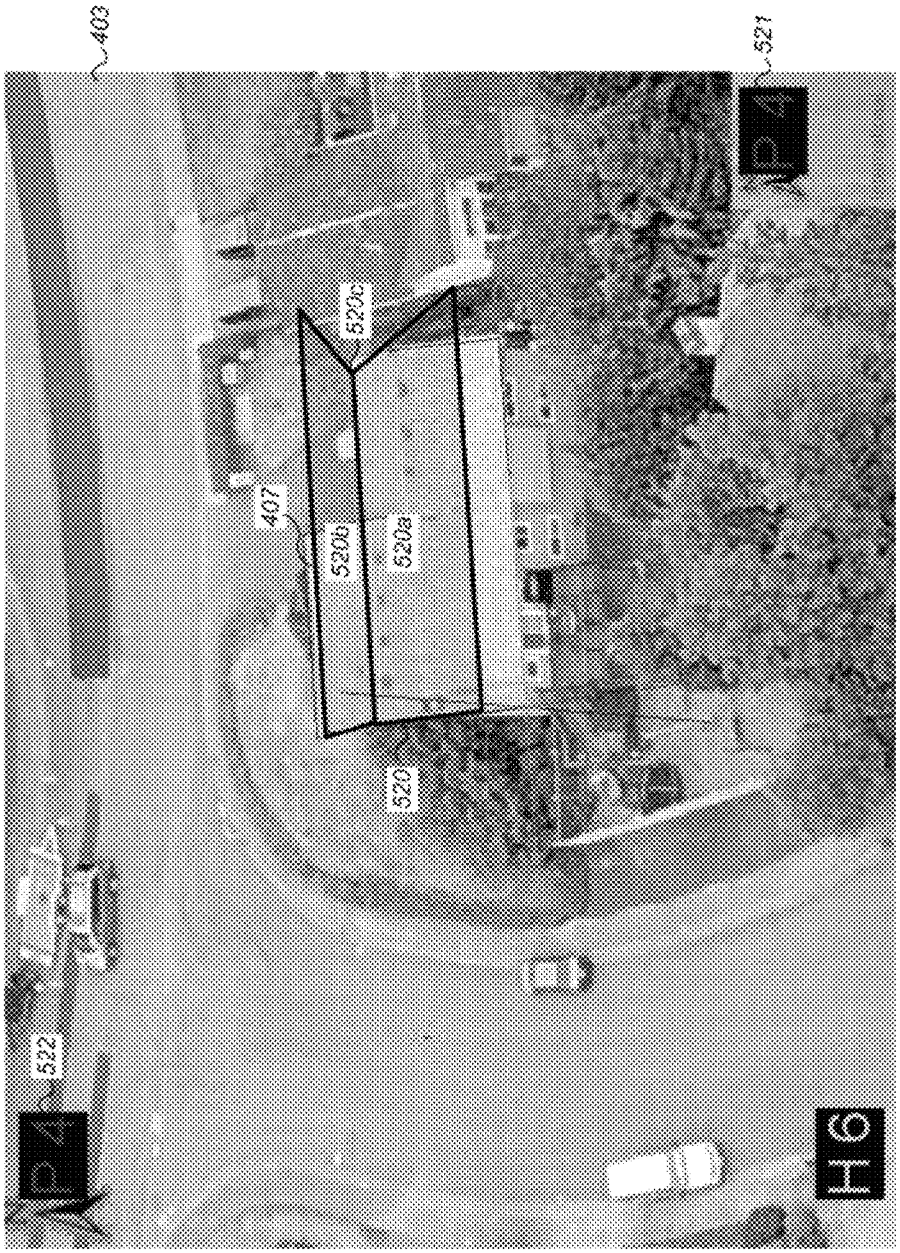

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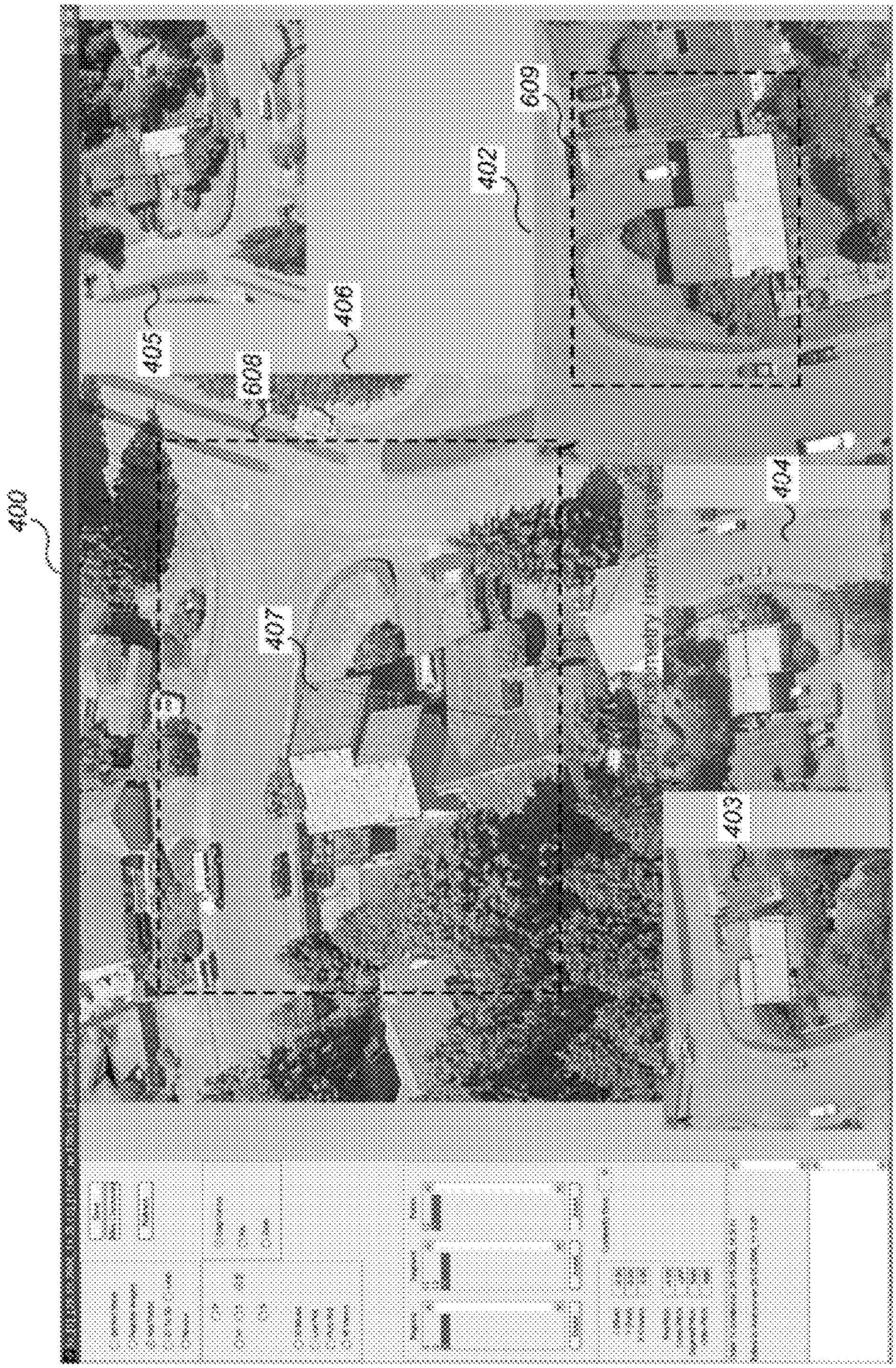

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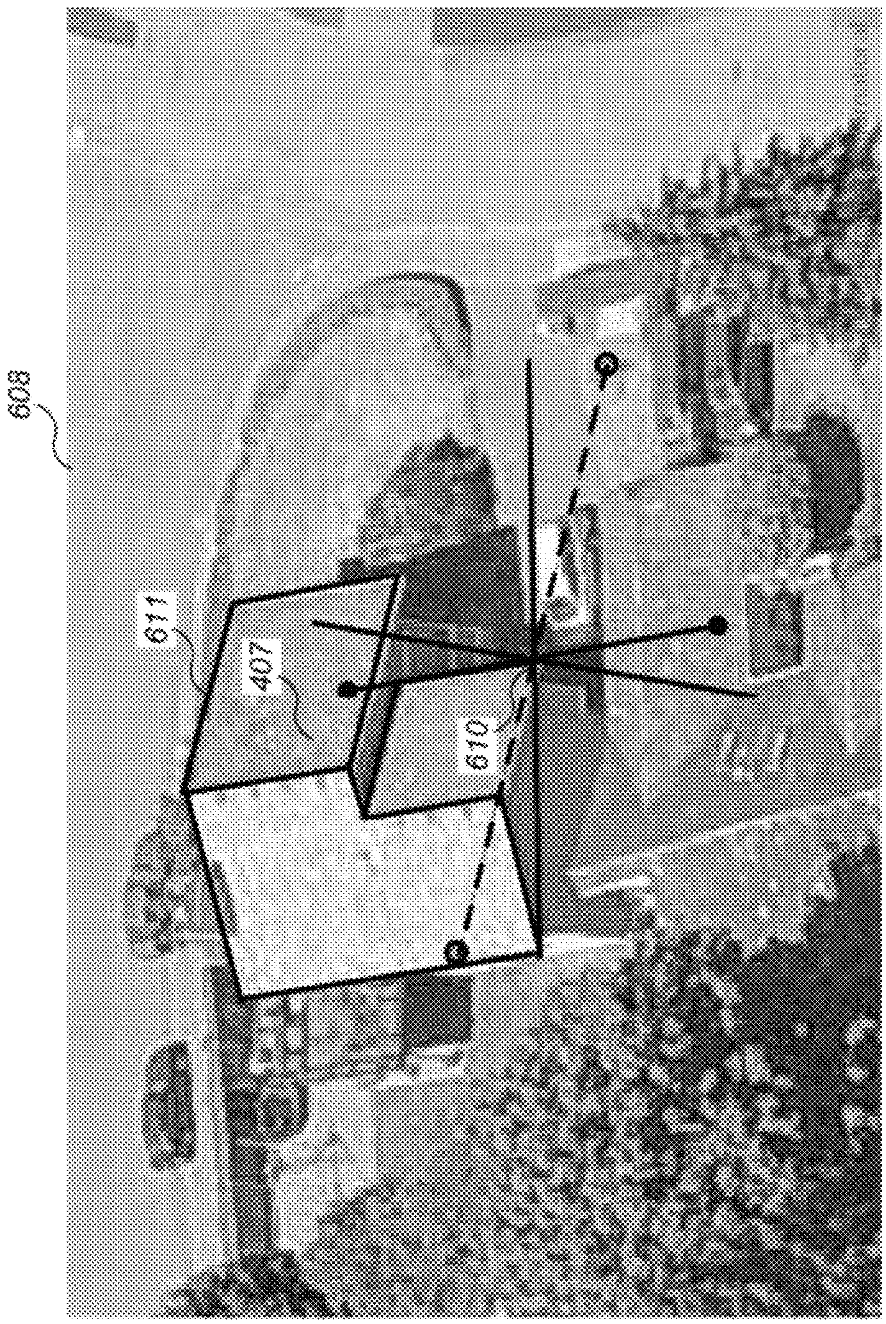

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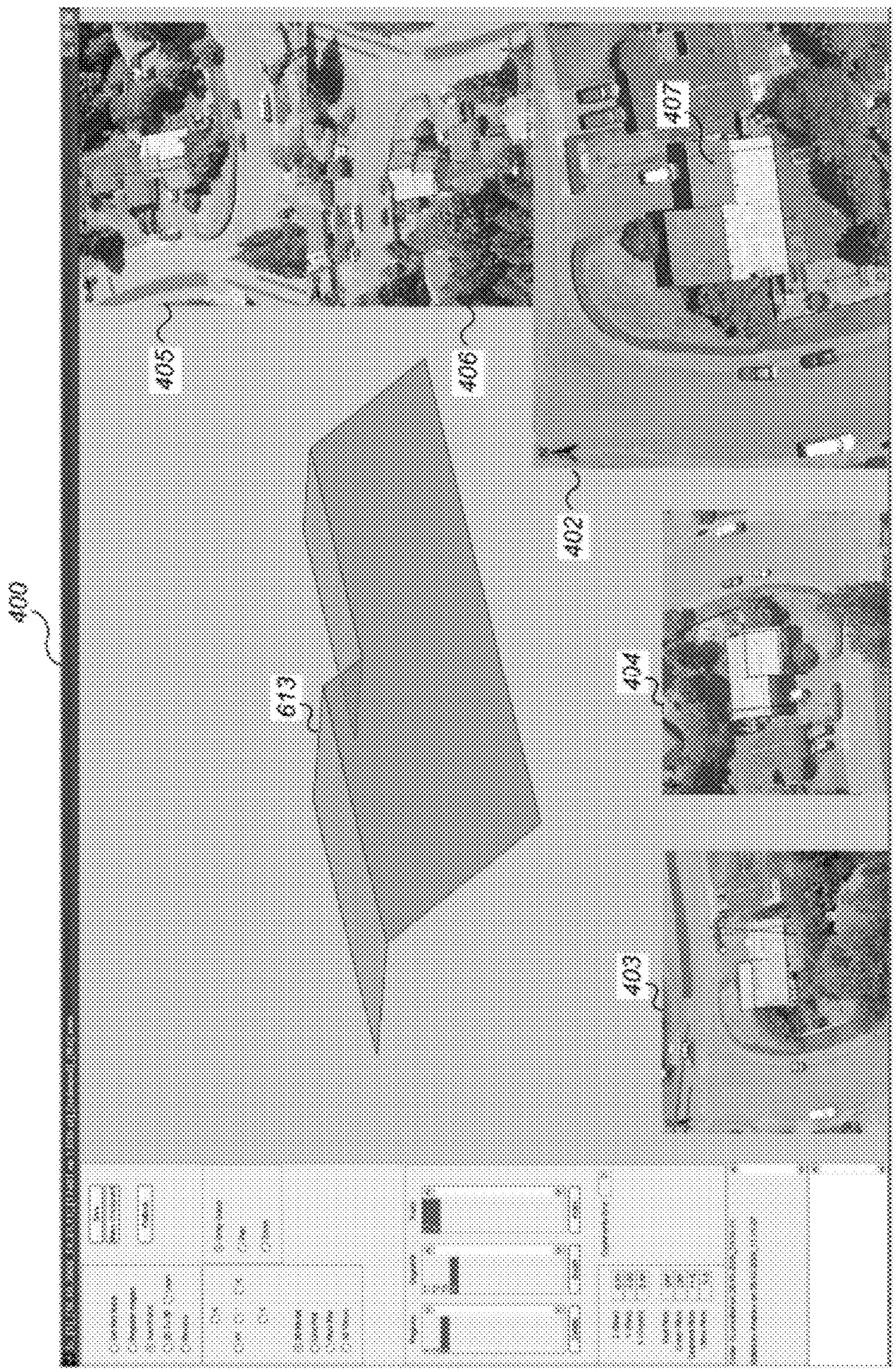

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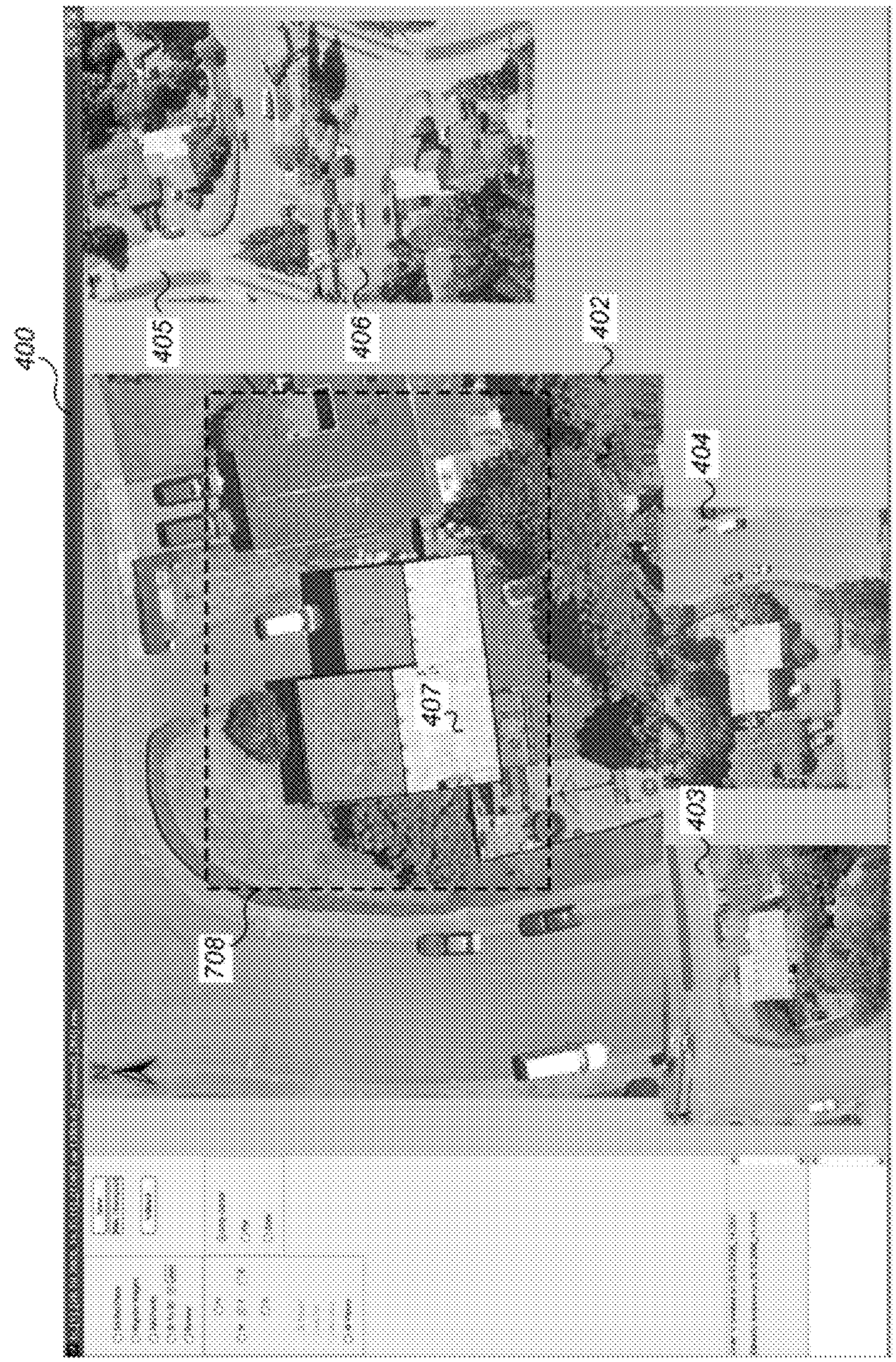

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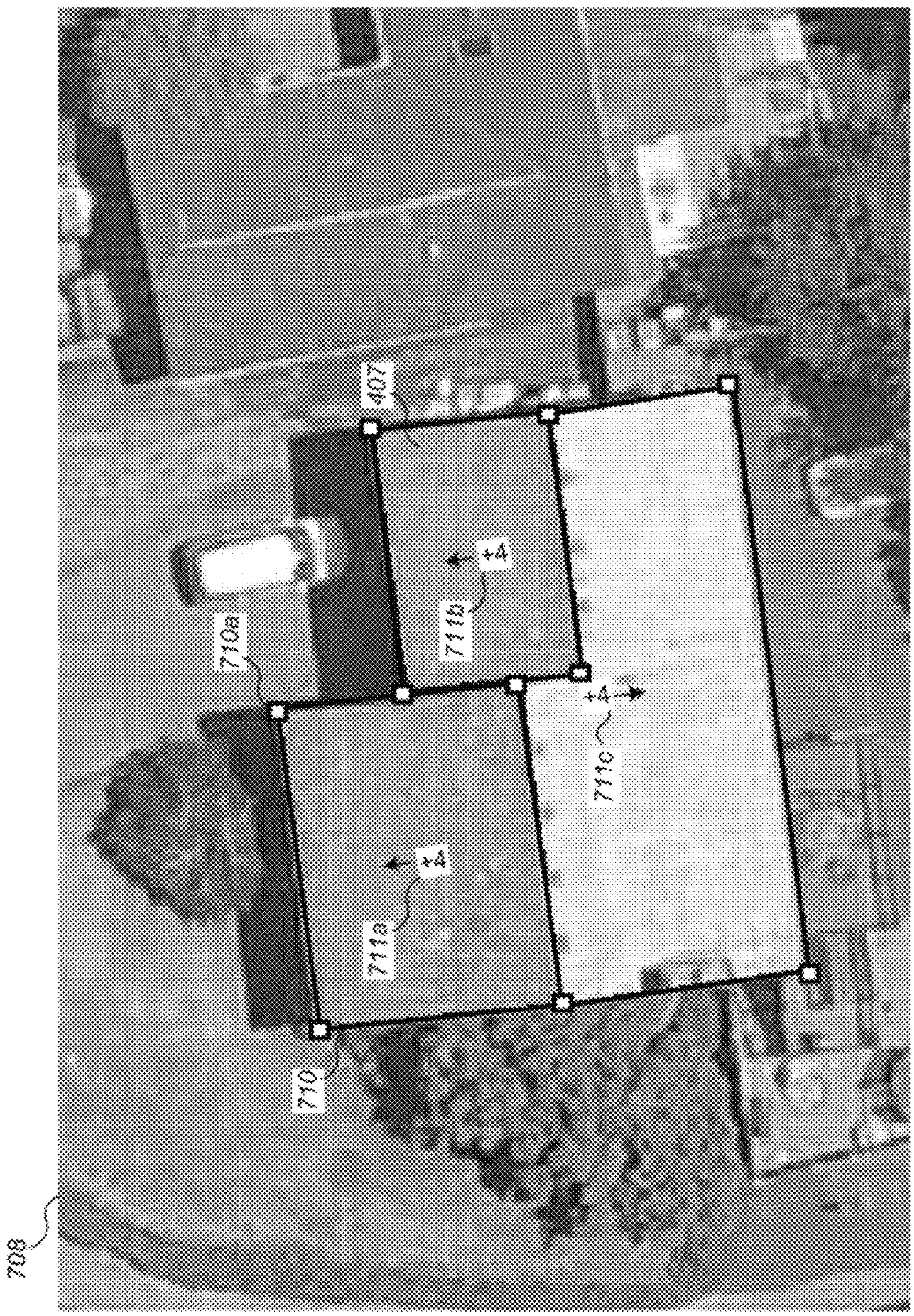

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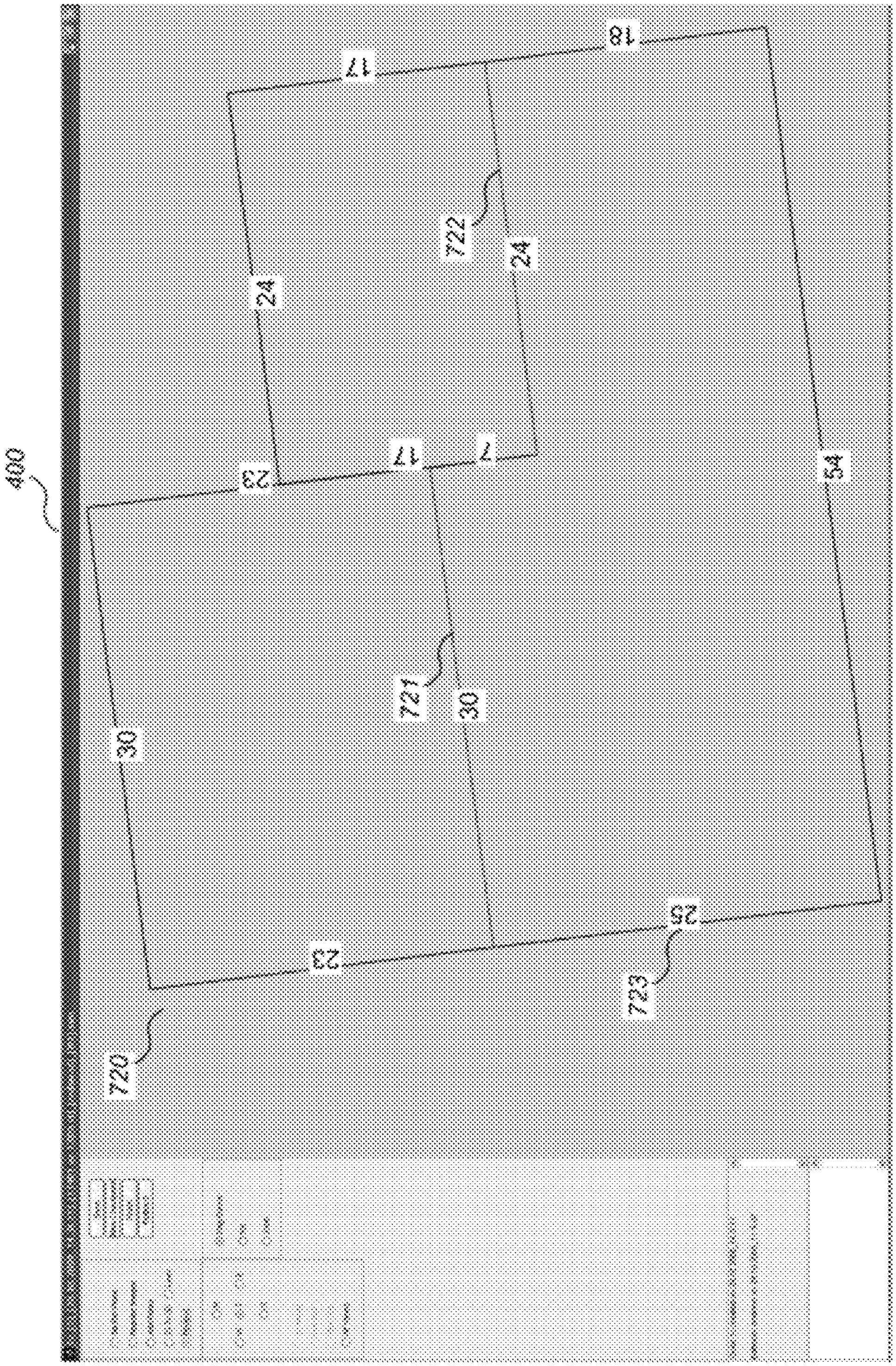

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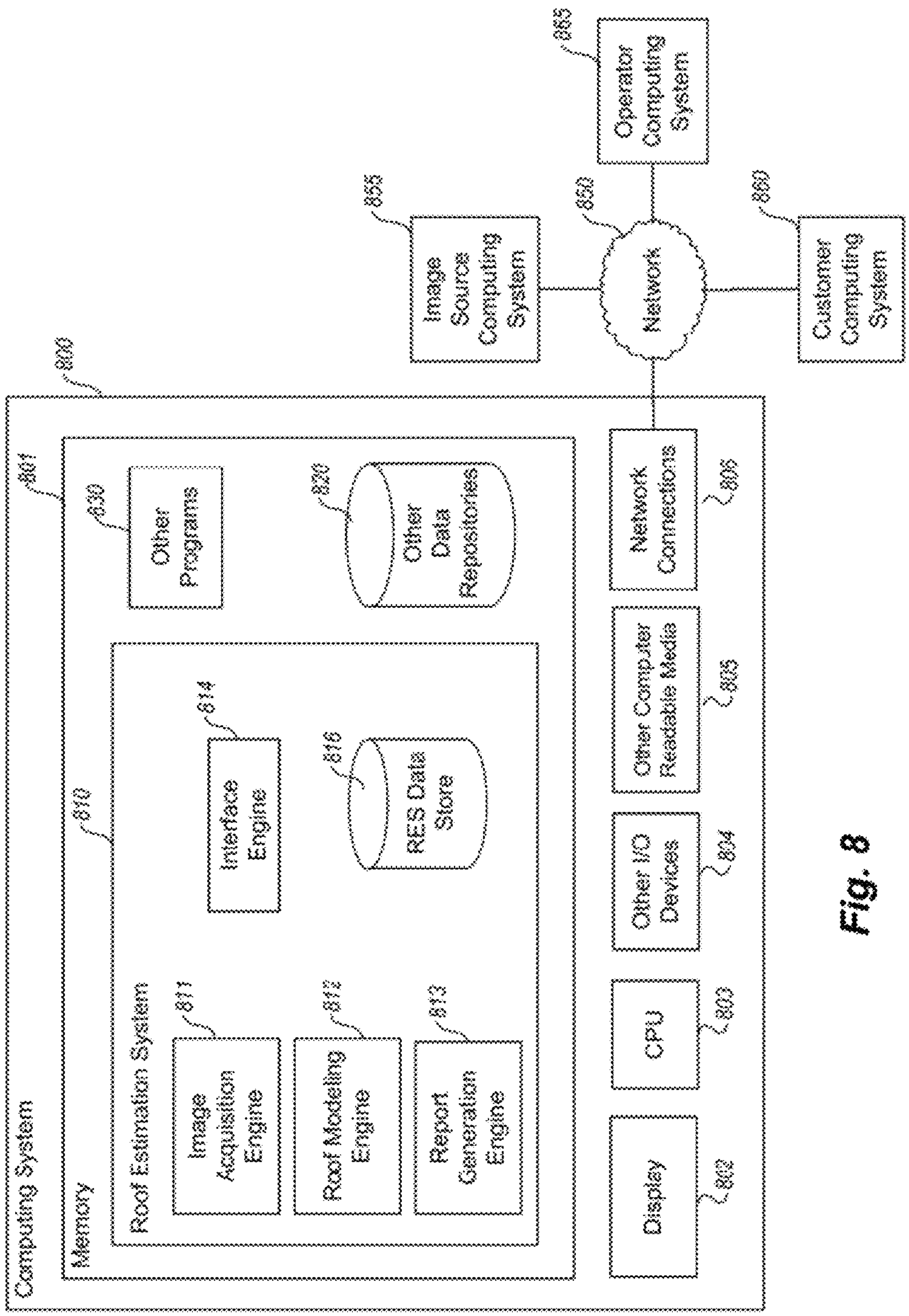
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Roof Modeling Engine
813
Report Generation Engine
814
Interface Engine
816
RES Data Store
830
Other Programs
820
Other Data Repositories
Display
802
CPU
803
Other I/O Devices
804
Other Computer Readable Media
805
Network Connections
806
850
Network
855
Image Source Computing System
865
Operator Computing System
860
Customer Computing System

Fig. 8

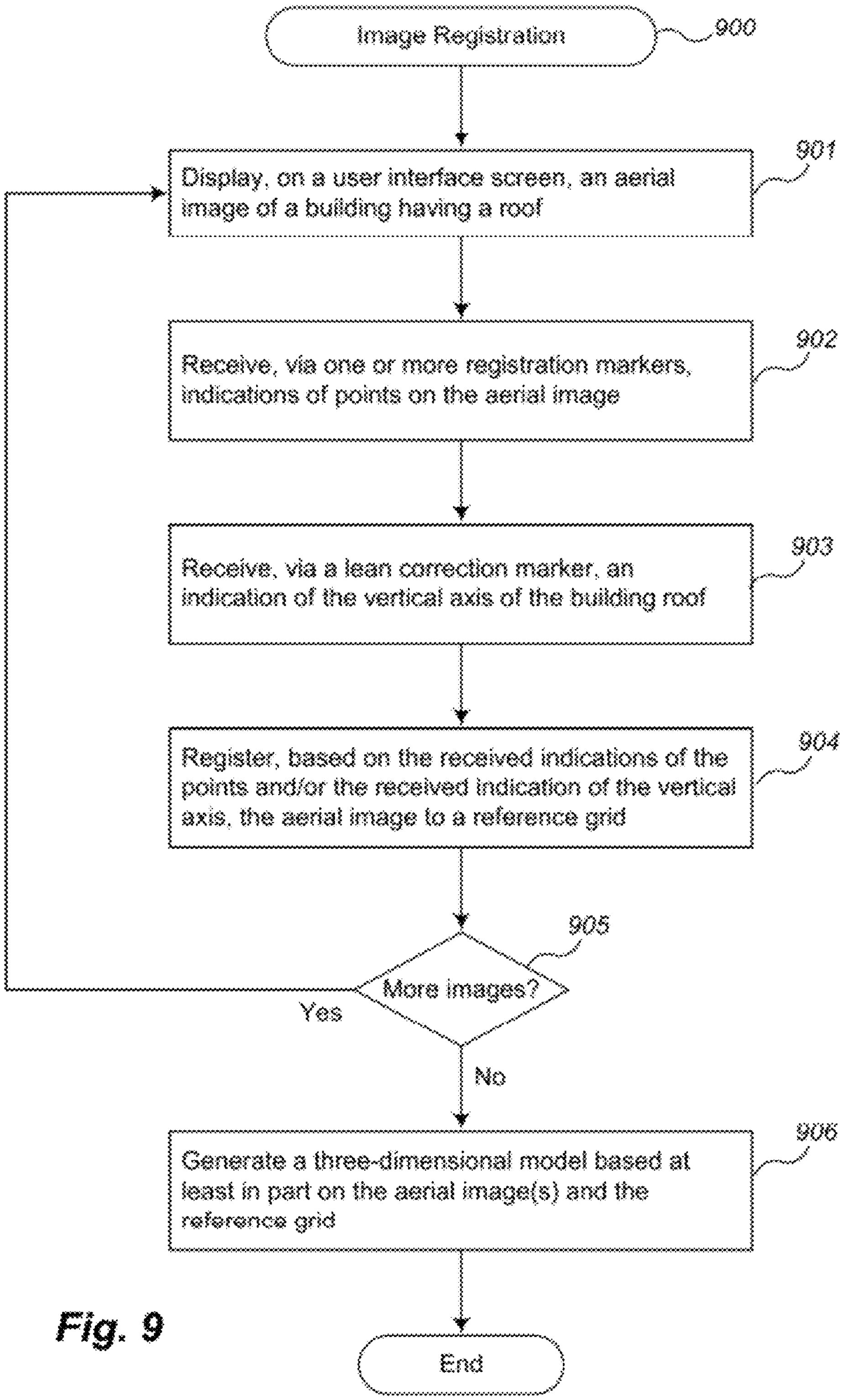
Image Registration
900
Display, on a user interface screen, an aerial image of a building having a roof
901
Receive, via one or more registration markers, indications of points on the aerial image
902
Receive, via a lean correction marker, an indication of the vertical axis of the building roof
903
Register, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid
904
More images?
905
Yes
No
Generate a three-dimensional model based at least in part on the aerial image(s) and the reference grid
906
End

Fig. 9

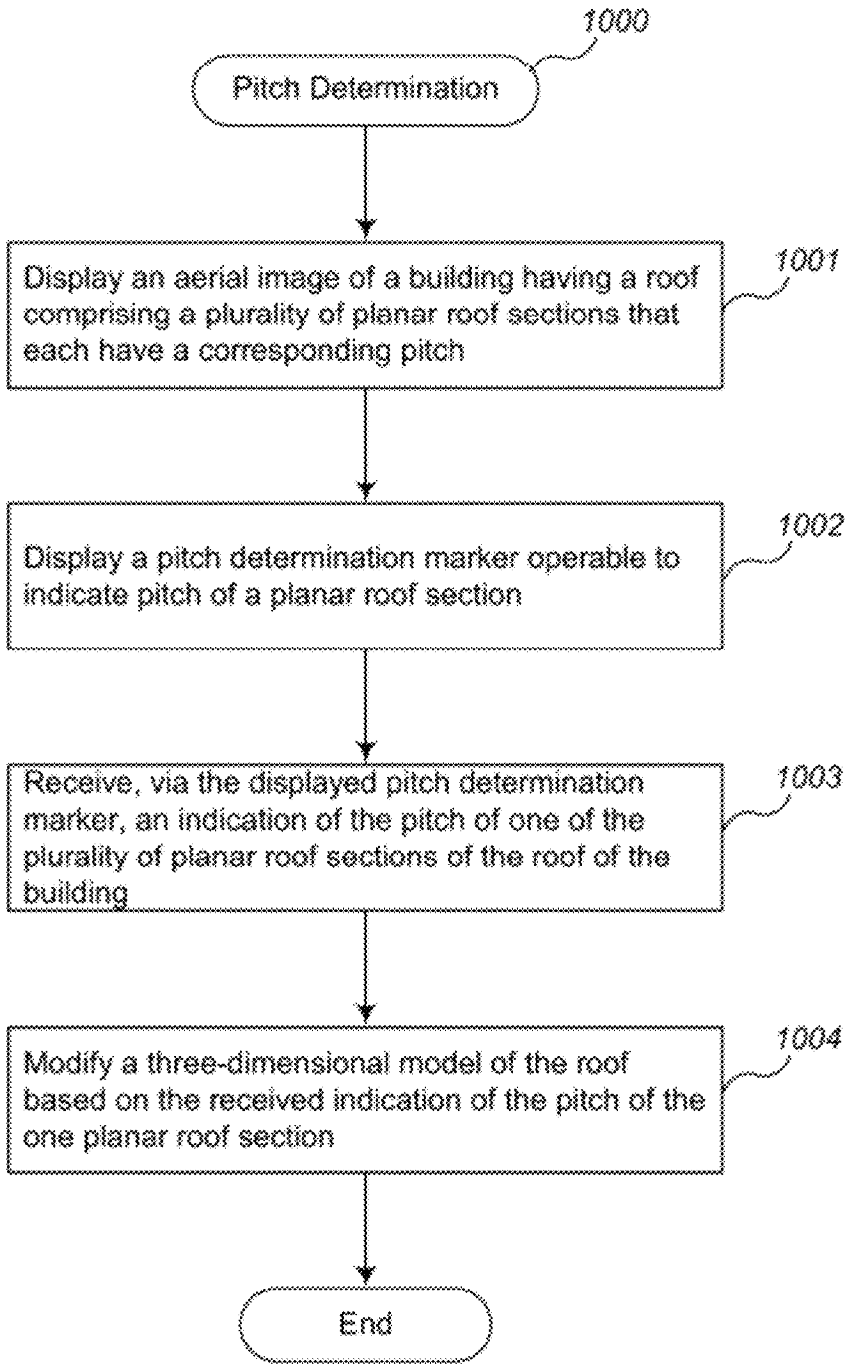
1000
Pitch Determination
1001
Display an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch
1002
Display a pitch determination marker operable to indicate pitch of a planar roof section
1003
Receive, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building
1004
Modify a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section
End

Fig. 10

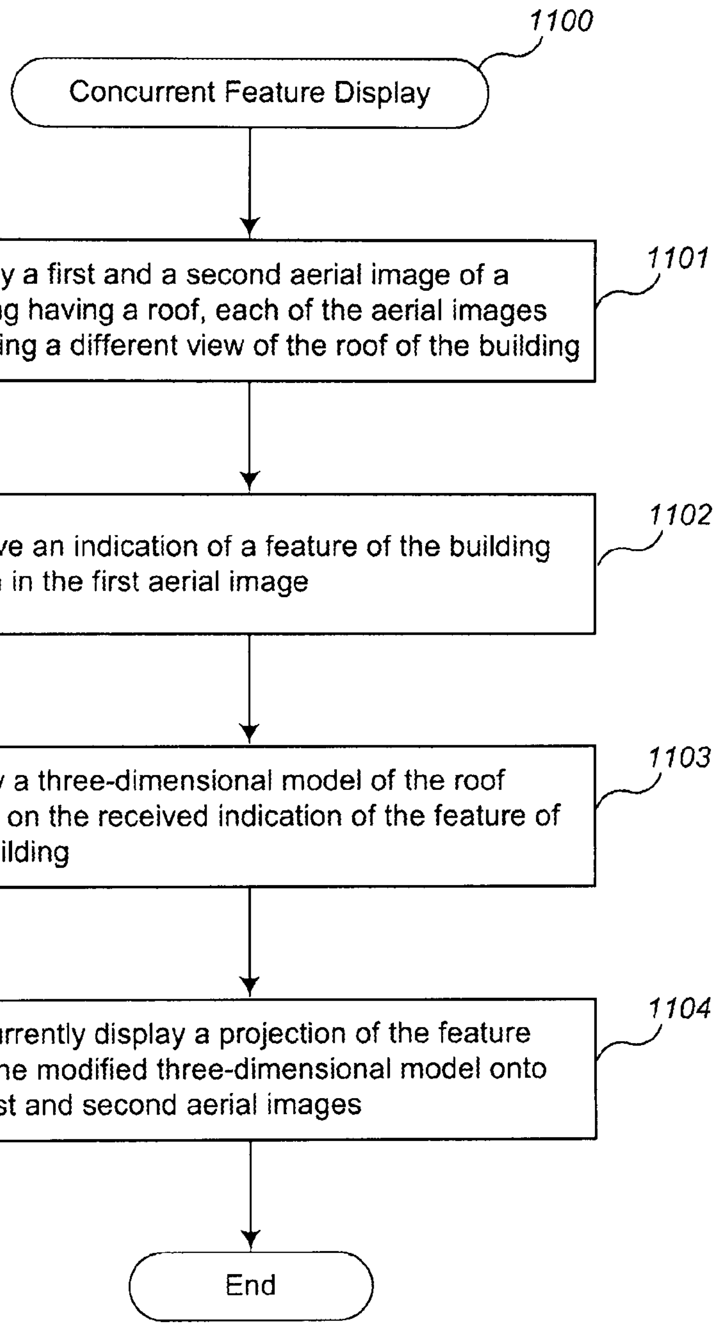
1100
Concurrent Feature Display
1101
Display a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building
1102
Receive an indication of a feature of the building shown in the first aerial image
1103
Modify a three-dimensional model of the roof based on the received indication of the feature of the building
1104
Concurrently display a projection of the feature from the modified three-dimensional model onto the first and second aerial images
End

Fig. 11

CONCURRENT DISPLAY SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/467,250, entitled "CONCURRENT DISPLAY SYSTEMS AND METHODS FOR AERIAL ROOF ESTIMATION", filed May 15, 2009 (which issued as U.S. Pat. No. 8,209,152) and claims the benefit of U.S. Provisional Patent Application No. 61/197,904, entitled "USER INTERFACE TECHNIQUES FOR ROOF ESTIMATION," filed Oct. 31, 2008, which applications are incorporated herein by reference in their entirety.

BACKGROUND

1. Field of the Invention:

This invention relates to systems and methods for estimating construction projects, and more particularly, to such systems and methods for determining roof measurement information based on one or more aerial images of a roof of a building.

2. Description of the Related Art:

The information provided below is not admitted to be part of the present invention, but is provided solely to assist the understanding of the reader.

Homeowners typically ask several roofing contractors to provide written estimates to repair or replace a roof on a house. Heretofore, the homeowners would make an appointment with each roofing contractor to visit the house to determine the style of roof, take measurements, and to inspect the area around the house for access and cleanup. Using this information, the roofing contractor then prepares a written estimate and then timely delivers it to the homeowner. After receiving several estimates from different rooting contractors, the homeowner then selects one.

There are factors that impact a roofing contractor's ability to provide a timely written estimate. One factor is the size of the roof contractor's company and the location of the roofing jobs currently underway. Most roof contractors provide roofing services and estimates to building owners over a large geographical area. Larger roof contractor companies hire one or more trained individuals who travel throughout the entire area providing written estimates. With smaller roofing contractors, the owner or a key trained person is appointed to provide estimates. With both types of companies, roofing estimates are normally scheduled for buildings located in the same area on a particular day. If an estimate is needed suddenly at a distant location, the time for travel and the cost of commuting can be prohibitive. If the roofing contractor is a small company, the removal of the owner or key person on a current job site can be time prohibitive.

Another factor that may impact the roofing contractor's ability to provide a written estimate is weather and traffic.

Recently, solar panels have become popular. In order to install solar panels, the roof's slope, geometrical shape, and size as well as its orientation with respect to the sun all must be determined in order to provide an estimate of the number and type of solar panels required. Unfortunately, not all roofs on a building are proper size, geometrical shape, or orientation for use with solar panels.

SUMMARY

These and other objects are met by the systems and methods disclosed herein that determine and provide roof measurement information about the sizes, dimensions, slopes and orientations of the roof sections of a building roof. Roof measurement information may be used to generate a roof estimate report that provides and graphically shows this information. A roof estimation system that practices at least some of the techniques described herein may include an image acquisition engine, a roof modeling engine, and a report generation engine. The roof estimation system is configured to generate a model of a roof of a building, based on one or more aerial images. In addition, the roof estimation system is configured to determine roof measurement information and generate a roof estimate report based on the generated model and/or the determined roof measurement information.

In some embodiments, the roof estimation system includes a user interface engine which provides access to at least some of the functions of the roof estimation system. In one embodiment, the user interface engine provides interactive user interface components operable by an operator to perform various functions related to generating a model of a roof of a building, including image registration, lean correction, pitch determination, feature identification, and model review and/or correction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system.

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. (Also shows lean correction.)

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment.

FIGS. **7**A-**7**C are screen displays illustrating roof model review in an example embodiment.

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment.

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment.

DETAILED DESCRIPTION

Embodiments described herein provide enhanced computer- and network-based methods, techniques, and systems for estimating construction projects based on one or more images of a structure. Example embodiments provide a Roof Estimation System ("RES") that is operable to provide a roof estimate report for a specified building, based on one or more aerial images of the building. In one embodiment, a customer of the RES specifies the building by providing an address of the building. The RES then obtains one or more aerial images showing at least portions of the roof of the building. Next, the RES generates a model of the roof of the building, which is then utilized to determine roof measurement information. The roof measurement information may include measurements such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc. The model of the roof and/or the roof measurement information is then used to generate a roof estimate report. The roof estimate report includes one or more line drawings of the roof of the building, which are annotated with information about the roof, such as lengths of the edges of sections of the roof, pitches of sections of the roof, areas of sections of the roof, etc.

Some embodiments of the roof estimation system include an interactive user interface configured to provide access to one or more of the functions of the roof estimation system. In one embodiment, the roof estimation system includes user interface controls that facilitate image registration, image lean correction, roof model generation, pitch determination, and roof model review. Image registration includes aligning, based at least in part on operator inputs, one or more images of a building roof to a set of reference points within a single three-dimensional ("3D") grid that is shared between the one or more images. Roof model generation includes generating a 3D model of a roof, based at least in part on operator inputs specifying various features and/or dimensional attributes of the roof. Roof model generation may further include the determination of the pitches of various planar sections of a roof. Roof model review includes display of a model of a roof, possibly in conjunction with one or more images of the roof, so that an operator may review the model for accuracy and possibly make adjustments and/or corrections to the roof model. In other embodiments, all or some of the functions of the roof estimation system may be performed automatically. For example, image registration may include automatically identifying building features for the placement of reference markers. Further, roof model generation may include automatically recognizing features, dimensional attributes, and/or pitches of various planar roof sections of the roof.

The described user interface is also configured to concurrently display roof features onto multiple images of a roof. For example, in the context of roof model generation, an operator may indicate a roof feature, such as an edge or a corner of a section of the roof, in a first image of the roof. As the roof estimation system receives the indication of the roof feature, the user interface concurrently displays that feature in one or more other images of the roof, so that the operator may obtain feedback regarding the accuracy of the roof model, the image registration, etc.

In the following, FIGS. **1**-**3** provide an overview of the operation of an example roof estimation system. FIGS. **4**-**7** provide additional details related an example interactive user interface provided by one embodiment of the roof estimation system. FIGS. **8**-**11** provide details related to roof estimation system implementation techniques.

1. Roof Estimation System Overview

FIG. **1** is a block diagram illustrating example functional elements of one embodiment of a roof estimation system. In particular, FIG. **1** shows an example Roof Estimation System ("RES") **100** comprising an image acquisition engine **101**, a roof modeling engine **102**, a report generation engine **103**, image data **105**, model data **106**, and report data **107**. The RES **100** is communicatively coupled to an image source **110**, a customer **115**, and optionally an operator **120**. The RES **100** and its components may be implemented as part of a computing system, as will be further described with reference to FIG. **8**.

More specifically, in the illustrated embodiment of FIG. **1**, the RES **100** is configured to generate a roof estimate report **132** for a specified building, based on aerial images **131** of the building received from the image source **110**. The image source **110** may be any provider of images of the building for which a roof estimate is being generated. In one embodiment, the image source **110** includes a computing system that provides access to a repository of aerial images of one or more buildings. In addition, the aerial images **131** may include images obtained via manned or unmanned aircraft (e.g., airplane, helicopter, blimp, drone, etc.), satellite, etc. Furthermore, the aerial images **131** may include images obtain via one or more ground-based platforms, such as a vehicle-mounted camera that obtains street-level images of buildings, a nearby building, a hilltop, etc. In some cases, a vehicle-mounted camera may be mounted in an elevated position, such as a boom. Example aerial images are described further with reference to FIGS. **2A**-**2B**.

The image acquisition engine **101** obtains one or more aerial images of the specified building by, for example, providing an indicator of the location of the specified building (e.g., street address, GPS coordinates, lot number, etc.) to the image source **110**. In response, the image source **110** provides to the image acquisition engine **101** the one or more aerial images of the building. The image acquisition engine **101** then stores the received aerial images as image data **105**, for further processing by other components of the RES **100**. Obtaining aerial images of a specified building may include various forms of geo-coding, performed by the image acquisition engine **101** and/or the image source **110**. In one embodiment, the image source geo-codes a provided street address into latitude and longitude coordinates, which are then used to look up (e.g., query a database) aerial images of the provided street address.

Next, the roof modeling engine **102** generates a model of the roof of the specified building. In the illustrated embodiment, the roof modeling engine **102** generates a three-dimensional ("3D") model, although in other embodiments, a two-dimensional (e.g., top-down roof plan) may be generated instead or in addition. Generating a model of the roof may generally include image calibration, in which the distance between two pixels on a given image is converted into a physical length. Image calibration may be performed automatically, such as based on meta-information provided along with the aerial images **131**.

A variety of automatic and semi-automatic techniques may be employed to generate a model of the roof of the building. In one embodiment, generating such a model is based at least in part on a correlation between at least two of the aerial images of the building. For example, the roof modeling engine **102** receives an indication of a corresponding feature that is shown in each of the two aerial images. In one embodiment, an operator **120**, viewing two or more images of the building, inputs an indication in at least some of the images, the indications identifying which points of the images correspond to each other for model generation purposes.

The corresponding feature may be, for example, a vertex of the roof of the building, the corner of one of the roof planes of the roof, a point of a gable or hip of the roof, etc. The corresponding feature may also be a linear feature, such as a ridge or valley line between two roof planes of the roof. In one embodiment, the indication of a corresponding feature on the building includes "registration" of a first point in a first aerial image, and a second point in a second aerial image, the first and second points corresponding the substantially the same point on the roof of the building. Generally, point registration may include the identification of any feature shown in both aerial images. Thus, the feature need not be a point on the roof of the building. Instead, it may be, for example, any point that is visible on both aerial images, such as on a nearby building (e.g., a garage, neighbor's building, etc.), on a nearby structure (e.g., swimming pool, tennis court, etc.), on a nearby natural feature (e.g., a tree, boulder, etc.), etc.

In some embodiments, the roof modeling engine **102** determines the corresponding feature automatically, such as by employing on one or more image processing techniques used to identify vertexes, edges, or other features of the roof. In other embodiments, the roof modeling engine **102** determines the corresponding feature by receiving, from the human operator **120** as operator input **133**, indications of the feature shown in multiple images of the building.

In one example embodiment, the RES **100** generates a model of the roof of the building in the following manner. First, a set of reference points are be identified in each of the images. These reference points are identified by the operator **120** utilizing a suitable input device, such as a mouse or joystick. The roof modeling engine **102** then uses these reference points and any acceptable algorithm to co-register the images and reconstruct the three-dimensional geometry of the object identified by the reference points. There are a variety of photogrammetric algorithms that can be utilized to perform this reconstruction. One such algorithm used by the RES **100** uses photographs taken from two or more view points to "triangulate" points of interest on the object in three-dimensional ("3D") space. This triangulation can be visualized as a process of projecting a line originating from the location of the photograph's observation point that passes through a particular reference point in the image. The intersection of these projected lines from the set of observation points to a particular reference point identifies the location of that point in 3D space. Repeating the process for all such reference points allows the software to determine a 3D volume suitable for building a 3D model of the structure. The choice of reconstruction algorithm depends on a number of factors such as the spatial relationships between the photographs, the number and locations of the reference points, and any assumptions that are made about the geometry and symmetry of the object being reconstructed. Several such algorithms are described in detail in textbooks, trade journals, and academic publications.

In addition, generating a model of the roof of a building may include correcting one or more of the aerial images for various imperfections. For example, the vertical axis of a particular aerial image sometimes will not substantially match the actual vertical axis of its scene. This will happen, for example, if the aerial images were taken at different distances from the building, or at a different pitch, roll, or yaw angles of the aircraft from which the images were produced. In such cases, an aerial image may be corrected by providing the operator **120** with a user interface control operable to adjust the scale and/or relative angle of the aerial image to correct for such errors. The correction may be either applied directly to the aerial image, or instead be stored (e.g., as an offset) for use in model generation or other functions of the RES **100**.

Generating a model of the roof of a building further includes the automatic or semi-automatic identification of features of the roof of the building. In one embodiment, one or more user interface controls may be provided, such that the operator **120** may indicate (e.g., draw, paint, etc.) various features of the roof, such as valleys, ridges, hips, vertexes, planes, edges, etc. As these features are indicated by the operator **120**, a corresponding three-dimensional ("3D") model may be updated accordingly to include those features. These features are identified by the operator based on a visual inspection of the images and by providing inputs that identify various features as valleys, ridges, hips, etc. In some cases, a first and a second image view of the roof (e.g., a north and east view) are simultaneously presented to the operator **120**, such that when the operator **120** indicates a feature in the first image view, a projection of that feature is automatically presented in the second image view. By presenting a view of the 3D model, simultaneously projected into multiple image views, the operator **120** is provided with useful visual cues as to the correctness of the 3D model and/or the correspondence between the aerial images.

In addition, generating a model of the roof of a building may include determining the pitch of one or more of the sections of the roof. In some embodiments, one or more user interface controls are provided, such that the operator **120** may accurately determine the pitch of each of the one or more roof sections. An accurate determination of the roof pitch may be employed (by a human or the RES **100**) to better determine an accurate cost estimate, as roof sections having a low pitch are typically less costly surfaces to repair and/or replace.

The generated model typically includes a plurality of planar roof sections that each correspond to one of the planar sections of the roof of the building. Each of the planar roof sections in the model has a number of associated dimensions and/or attributes, among them slope, area, and length of each edge of the roof section. Other information may include any information relevant to a roof builder or other entity having an interest in construction of, or installation upon, the roof. For example, the other information may include identification of valleys, ridges, rakes, eaves, or hip ridges of the roof and/or its sections; roof and/or roof section perimeter dimensions and/or outlines; measurements of step heights between different roof levels (e.g., terraces); bearing and/or orientation of each roof section; light exposure and/or shadowing patterns due to chimneys, other structures, trees, latitude, etc.; roofing material; etc? Once a 3D model has been generated to the satisfaction of the roof modeling engine **102** and/or the operator **120**, the generated 3D model is stored as model data **106** for further processing by the RES **100**. In one embodiment, the generated 3D model is then stored in a quality assurance queue, from which it is reviewed and possibly corrected by a quality control operator.

The report generation engine **103** generates a final roof estimate report based on a model stored as model data **106**, and then stores the generated report as report data **107**. Such a report typically includes one or more plan (top-down) views of the model, annotated with numerical values for the slope, area, and/or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof. The report may also include information about total area of the roof, identification and measurement of ridges and/or valleys of the roof, and/or different elevation views rendered from the 3D model (top, side, front, etc). An example report is illustrated and discussed with respect to FIGS. **3**A-**3**E, below.

In some embodiments, generating a report includes labeling one or more views of the model with annotations that are readable to a human user. Some models include a large number of small roof details, such as dormers or other sections, such that applying uniformly sized, oriented, and positioned labels to roof section views results in a visually cluttered diagram. Accordingly, various techniques may be employed to generate a readable report, including automatically determining an optimal or near-optimal label font size, label position, and/or label orientation, such that the resulting report may be easily read and understood by the customer **115**.

In addition, in some embodiments, generating a report includes automatically determining a cost estimate, based on specified costs, such as those of materials, labor, transportation, etc. For example, the customer **115** provides indications of material and labor costs to the RES **100**. In response, the report generation engine **103** generates a roof estimate report that includes a cost estimate, based on the costs provided by the customer **115** and the attributes of the particular roof, such as area, pitch, etc.

In one embodiment, the generated report is then provided to a customer. The generated report can be represented, for example, as an electronic file (e.g., a PDF file) or a paper document. In the illustrated example, roof estimate report **132** is transmitted to the customer **115**. The customer **115** may be or include any human, organization, or computing system that is the recipient of the roof estimate report **132**. For example, the customer **115** may be a property owner, a property manager, a roof construction/repair company, a general contractor, an insurance company, a solar power panel installer, a climate control (e.g., heating, ventilation, and/or air conditioning) system installer, a roof gutter installer, an awning installer, etc. Reports may be transmitted electronically, such as via a network (e.g., as an email, Web page, etc.) or by some shipping mechanism, such as the postal service, a courier service, etc.

In some embodiments, one or more of the models stored as model data **106** are provided directly to the customer or other computing system, without first being transformed into a report. For example, a model and/or roof measurement information based thereon may be exported and/or transmitted as a data file, in any suitable format, that may be consumed or otherwise utilized by some other computing system, such as a computer-aided design ("CAD") tool, a drawing program, a labor and material estimation software, a project management/estimation software, etc.

The RES **100** may be operated by various types of entities. In one embodiment, the RES **100** is operated by a roof estimation service that provides roof estimate reports to customers, such as roofing contractors, in exchange for payment. In another embodiment, the RES **100** is operated by a roof construction/repair company, to generate roof estimate reports that are used internally and/or provided to customers, such as property owners.

In addition, the RES **100** may be operated in various ways. In one embodiment, the RES **100** executes as a desktop computer application that is operated by the operator **120**. In another embodiment, the RES **100** executes as a network-accessible service, such as by a Web server, that may be operated remotely by the operator **120** and/or the customer **115**. Additional details regarding the implementation of an example roof estimation system are provided with respect to FIG. **8**, below.

FIGS. **2**A-**2**B illustrate aerial images of a building at a particular address. In the illustrated example, the aerial images are represented as stylized line drawings for clarity of explanation. As noted above, such aerial images may be acquired in various ways. In one embodiment, an aircraft, such as an airplane or helicopter is utilized to take photographs while flying over one or more properties. Such aircraft may be manned or unmanned. In another embodiment, a ground-based vehicle, such as a car or truck, is utilized to take photographs (e.g., "street view" photographs) while driving past one or more properties. In such an embodiment, a camera may be mounted on a boom or other elevating member, such that images of building roofs may be obtained. In another embodiment, photographs may be taken from a fixed position, such as a tall building, hilltop, tower, etc.

In particular, FIG. **2**A shows a top plan (top-down) aerial image **210** of a building **200**. The roof of the building **200** includes multiple planar roof sections **200***a*-**200***d*. FIG. **2**A also shows a second aerial image **211** providing a perspective (oblique) view of the building **200**. The roof sections **200***a* and **200***c* are also visible in image **211**.

FIG. **2**B shows a top-down, wide angle image **212** of the building **200**. The image **212** includes details of the surrounding areas **220** of the building **220**. Information about the surrounding areas **220** of the building **220** are in some embodiments used to determine additional cost factors related to a roof estimate. For example, the cleanup of, or access to, a worksite at building **220** may be complicated by various factors, including a substantial amount of landscaping; steeply sloped building sites; proximity to environmentally sensitive areas; etc. In such cases, the roof estimation system may automatically increase a cost factor in a corresponding roof estimate report.

In some embodiments, an aerial image has corresponding meta-information. Such meta-information may include details about the type of camera used (e.g., focal length, exposure, etc.), the position of the camera (e.g., GPS coordinates of the aircraft at the time the image was captured), the orientation of the camera (e.g., the angle of the camera), the time and/or date the image was captured, etc.

FIGS. **3**A-**3**F illustrate individual pages of an example roof estimate report generated by an example embodiment of a roof estimation system. As discussed with respect to FIG. **1**, a roof estimate report is generated by the roof estimation system based on one or more aerial images of a building. The roof estimate report may be based on a computer model (e.g., a 3D model) of the roof, and includes one or more views of the model. In this example, the various views of the model are presented as annotated line drawings, which provide information about the roof, such as the roof section areas, roof section edge lengths, roof section pitches, etc. The roof estimate report may be in an electronic format (e.g., a PDF file) and/or paper format (e.g., a printed report). In some embodiments, the roof estimate report may be in a format that may be consumed by a computer-aided design program.

FIG. **3**A shows a cover page **301** of the report and includes the address **301***a* of a building **301***c* and an overhead aerial image **301***b* of the building **301***c*.

FIG. **3**B shows a second page **302** of the report and includes two wide perspective (oblique) views **302***a* and **302***b* of the building **301***c* at the address with the surrounding areas more clearly shown.

FIG. **3**C shows a third page **303** of the report and includes a line drawing **303***a* of the building roof showing ridge lines **303***b* and **303***c*, and a compass indicator **303***d*. In addition, a building roof having valleys would result in a line drawing including one or more valley lines. The ridge and/or valley lines may be called out in particular colors. For example, ridge lines **303***b* and **303***c* may be illustrated in red, while valley lines may be illustrated in blue. The line drawing **303***a* is also annotated with the dimensions of the planar sections of the building roof. In this case, the dimensions are the lengths of the edges of the planar roof sections.

FIG. **3**D shows a fourth page **304** of the report and includes a line drawing **304***a* of the building roof showing the pitch of each roof section along with a compass indicator. The pitch in this example is given in inches, and it represents the number of vertical inches that the labeled planar roof section drops over 12 inches of horizontal run. The slope can be easily calculated from such a representation using basic trigonometry. The use of a numerical value of inches of rise per foot of run is a well known measure of slope in the roofing industry. A roof builder typically uses this information to assist in the repair and/or construction of a roof. Of course, other measures and/or units of slope may be utilized as well, including percent grade, angle in degrees, etc.

FIG. **3**E shows a fifth page **305** of the report and includes a line drawing **305***a* of the building roof showing the square footage of each roof section along with the total square foot area value. Of course, other units of area may be used as well, such as square meters or the number of "squares" of roofing material required for covering each roof section.

FIG. **3**F shows a fifth page **306** of the report and includes a line drawing **306***a* of the building roof where notes or comments may be written. The line drawing **306***a* includes a label for each roof section (shown here as "A", "B", "C"), such that comments may be conveniently related to specific roof sections.

In other embodiments, more or less information may be provided, or the illustrated information may be arranged in different ways. For example, the report may be provided in electronic form, such as a PDF file or a computer aided design software format. In some embodiments, the report may be "active" or editable, such that the user of the report may make changes to the report, based on on-site observations.

2. Roof Estimation System User Interface

FIGS. **4**A-**4**F, **5**A-**5**D, **6**A-**6**D, and **7**A-**7**C describe an example interactive user interface provided by one embodiment of the roof estimation system. As noted, the RES **100** described with reference to FIG. **1** includes a user interface engine **104** that is configured to provide access to one or more functions of the RES **100**, including image registration (described with respect to FIGS. **4**A-**4**F), roof pitch determination (described with respect to FIGS. **5**A-**5**D), roof model construction (described with reference to FIGS. **6**A-**6**D), and roof model review (described with respect to FIGS. **7**A-**7**C).

A. Image Registration

FIGS. **4**A-**4**F are screen displays illustrating image registration and image lean correction in an example embodiment. In particular, FIG. **4**A shows a user interface screen **400** that is utilized by an operator to generate a three dimensional model of a roof of a building. The user interface screen **400** shows a roof modeling project in an initial state, after the operator has specified an address of a building and after images of the building have been obtained and loaded into the roof estimation system.

The user interface screen **400** includes a control panel **401** and five images **402**-**406** of a building roof **407**. The control panel **401** includes user selectable controls (e.g., buttons, check boxes, menus, etc.) for various roof modeling tasks, such as setting reference points for the images, setting the vertical (Z) axis for the images, switching between different images, saving the model, and the like. Each of the images **402**-**406** provides a different view of the building roof **407**. In particular, images **402**-**406** respectively provide substantially top-down, south, north, west, and east views of the building roof **407**. Each image **402**-**406** includes four marker controls (also called "reference points" or "registration markers") that are used by the operator to set reference points in the image for purposes of image registration. The registration markers will be described further with respect to an enlargement of image portion **408** described with respect to FIGS. **4**B-**4**C, below.

FIGS. **4**B-**4**C show an enlarged view of image portion **408** during the process of image registration for image **402**, which provides a top-down view of the building roof **407**. As shown in FIG. **4**B, image portion **408** includes the building roof **407** and registration markers **410**-**413**. The markers **410**-**413** are interactive user interface controls that can be directly manipulated (e.g., moved, rotated, etc.) by the operator in order to specify points to use for purposes of image registration. In particular, image registration includes determining a transformation between each of one or more images and a uniform 3D reference grid. The uniform 3D reference grid is used as a coordinate system for a 3D model of the roof. By registering multiple images to the reference grid, an operator may indicate a roof feature on an image (such as a roof edge), which may then be translated from the coordinate system of the image to the coordinate system of the reference grid, for purposes of including of the indicated feature in the 3D model.

Marker **410** is an origin marker control, and includes arms **410***a*-**410***c*. Arms **410***a* and **410***b* are horizontal arms that are utilized to specify the X and Y axes (e.g., the horizontal plane) of the reference grid. Arm **410***c* is a vertical arm that may be utilized to specify the Z axis (e.g., the vertical axis) of the reference grid. The use of the vertical arm to specify the Z axis will be further described with respect to FIG. **4**E, below.

Typically, markers **410**-**413** are color coded, such that they may be distinguished from one another. For example, marker **411**-**413** may be respectively colored red, blue, and green. Origin marker **410** has a different appearance than markers **411**-**413**, so may be of any color. In other embodiments, markers **411**-**413** may be distinguished in other ways, such as by utilizing different sized dashed lines, different line thicknesses, etc. In still other embodiments, markers are not distinguished any way from each other, such as by being of uniform shape, color, etc.

FIG. **4**C shows image portion **408** with markers **410**-**413** after they have been placed by an operator. Typically, registration markers are placed at four spatially distributed corners of the roof. As shown in FIG. **4**C, the operator has placed markers **410**-**413** at four different corners of the building roof **407**. In particular, the operator first placed the origin marker **410** at the lower left corner of the building roof **407**, and has adjusted (e.g., rotated) the arms **410***a* and **410***b* to align with the major horizontal axes of the roof. By adjusting the arms **410***a* and **410***b* of the origin marker **410**, the rotational orientation of markers **411**-**413** is automatically adjusted by the roof estimation system. Next, the operator places markers **411**-**413** on some other corners of the roof. In general, the operator can place registration marker over any roof feature, but roof corners are typically utilized because they are more easily identified by the operator. After the operator is satisfied with the placement of markers **410**-**413**, the operator typically registers a next image of the building roof **407**, as will be described next.

FIGS. **4**D-**4**F illustrate image registration for image **404**, which provides a north view of the building roof **407**. In particular, FIG. **4**D shows the user interface screen **400** described with reference to FIG. **4**A. Here, image **402** has been minimized, while image **404** has been enlarged so that the operator may register that image by placing markers on image **404**, as will be described below with respect to an enlarged view of image portion **418**.

FIG. **4**E shows an enlarged view of image portion **418** during the process of image registration for image **404**. Image portion **418** includes the building roof **407** and registration markers **420**-**423**. Markers **420**-**423** respectively correspond to markers **410**-**413** described above. In particular, marker **420** is an origin marker control that includes arms **420***a*-**420***c*. Arms **420***a* and **420***b* are horizontal arms that are utilized to specify the X and Y axes of the reference grid. Arm **420***c* is a vertical arm that may be utilized to specify the Z axis of the reference grid.

In the example of FIG. **4**E, the operator has moved each of markers **420**-**423** to a corner of the roof **407**. Note that the markers **420**-**423** are moved to roof corners that correspond to those selected by the operator with markers **410**-**413**, as described with reference to FIG. **4**C. In particular, origin marker **420** has been moved to the corner of the roof **407** selected with origin marker **410** in image **408**; marker **421** has been moved to the corner selected with marker **411** in image **408**; marker **422** has been moved to the corner selected with marker **412** in image **408**; and marker **423** has been moved to the corner selected with marker **413** in image **408**. In addition, markers **420-423** have been rotated, by operator rotation of the origin marker **420**, to align with the major axes of the roof **407**.

As noted, the operator can utilize the origin marker **420** to specify the vertical axis of the reference grid. In particular, the operator can adjust (e.g., by dragging with a mouse or other pointing device) arm **420***c* of marker **420** to specify the vertical (Z) axis of the image. In some cases, aerial images may include some amount of lean, due to the orientation of the aircraft during image capture. For example, pitch, yaw, or roll of an aircraft during the course of image capture may result in images that are misaligned with respect to the vertical axis of the building and its roof. Typically, an operator may adjust arm **420***c* to line up with a feature of a building or roof that is known to be substantially vertical, such as a wall of a house or a chimney. Then, based on the angle of arm **420***c* with respect to the vertical axis of the image, the roof estimation system can determine a correction between the reference grid and the image.

FIG. **4**F shows an enlarged view of image portion **418** after registration of image **404**. Once the operator has placed and adjusted markers **420-423**, the operator may direct (e.g., by clicking a button) the roof estimation system to register the image to the reference grid, based on the positions and orientations of markers **420-423**. Once the roof estimation system registers the image, it provides the operator with feedback so that the operator may determine the correctness or accuracy of the registration.

In the example of FIG. **4**F, the operator has directed the roof estimation system to register image **404**, and the roof estimation system has updated image portion **418** with registration indicators **430-433**. Registration indicators **430-433** provide the operator with feedback so that the operator may judge the accuracy of the registration of image **404**.

Registration indicator **430** is an origin registration indicator that includes two arms **430***a*-**430***b* and three reference grid indicators **430***c*-**430***e*, shown as dashed lines. The reference grid indicators **430***c*-**430***e* show the vertical axis (**430***c*) and the two horizontal axes (**430***d* and **430***e*) of the reference grid determined based on the placement and orientation of the markers **420-423**. Arms **430***a* and **430***b* correspond to the placement of arms **420***a*-**420***c* of origin marker **420**. If the arms **430***a* and **430***b* do not substantially align with the corresponding reference grid indicators **430***e* and **430***d*, then the determined reference grid is out of alignment with the specified axes of the house. Typically, an operator will return to the view of FIG. **4**E to make adjustments to origin marker, such as adjusting one or more of the vertical or horizontal axes, in order to refine the registration of the image. Although the arms **430***a*-**430***b* and the reference grid indicators **430***c*-**430***e* are here illustrated as solid and dashed lines, in other embodiments they may be color coded. For example, arms **430***a*-**430***b* may be red, while reference grid indicators **430***c*-**430***e* may be blue.

Registration indicators **431-433** provide the operator with information regarding the accuracy of the placement of markers **421-423**. In particular, each registration indicator **431-433** includes a solid crosshairs and a reference indicator, shown for example as a dashed line **432***a*. The crosshair of a registration indicator corresponds to the placement of a marker. For example, the crosshairs of registration indicator **431** corresponds to the placement of marker **421** in FIG. **4**E. If the reference indicator intersects the center (or substantially near the center) of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is accurate. On the other hand, if the reference indicator does not intersect the center of the crosshairs of a registration indicator, then the operator knows that the placement of the corresponding marker is inaccurate. Typically, such an inaccuracy arises when the placement of markers in the top view of the roof does not agree with (correspond to) the placement of corresponding markers in another view of the roof. In such cases, the operator can return to the view of FIG. **4**C or **4**E to adjust the position of one or more markers.

After registering image **404**, the operator will proceed to register additional images of the building roof **407** utilizing a process similar to that described above. In this example, the operator will register images **403**, **405**, and **406**. Although the operator is here described as registering a total of five images, in other cases more or fewer images may be registered.

B. Roof Model Construction

FIGS. **5**A-**5**D and **6**A-**6**C generally illustrate aspects of the process of roof model generation based on multiple registered images. In particular, these figures illustrate the construction of a roof model by an operator. Model generation/construction may include identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. Each identified roof feature is incorporated by the roof estimation system into a 3D model of the roof, based on a translation between an image in which the feature is identified and the reference grid, as determined by the process described with reference to FIGS. **4**A-**4**F, above.

FIGS. **5**A-**5**D are screen displays illustrating pitch determination in an example embodiment. In particular, FIG. **5**A shows the user interface screen **400** after images **402-406** have been registered. In this example, the operator is using a pitch determination control (also called a "pitch determination marker" or "pitch determination tool") to specify the pitch of a planar roof section of the building roof **407** visible in image **406**. The pitch determination control will be further described in FIG. **5**B, below, with respect to an enlargement of image portion **508**.

FIG. **5**B shows an enlarged view of image portion **508** during the process of pitch determination for image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **5**B, the image portion **508** includes the building roof **407** and a pitch determination marker **510** (also called a "protractor tool"). The pitch determination marker **510** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**.

The pitch determination marker **510** includes arms **510***a*-**510***d*. Arms **510***a*-**510***c* are axes, which are automatically aligned, based on the registration of image **406**, with the major (X, Y, and Z) axes of the building roof. Arm **510***d* is a "protractor" arm that is adjustable by the operator to specify roof pitch.

The marker **510** is typically first moved by the operator to a convenient location on the building roof **407**, usually corner of a planar section of the roof **407**. Next, the operator adjusts arm **510***d* so that is substantially aligns with the sloped edge of the planar roof section. Then, the roof estimation system determines the pitch of the roof section, based on the configuration of the marker **510** with respect to the image and the reference grid.

After specifying the pitch of a planar roof section, the operator will typically specify other information about the planar roof section, such as its outline, as will be described with reference to FIGS. **6**A-**6**D. Note that as the operator provides additional information about the geometry of the roof **407**, the roof estimation system may automatically determine the pitch and/or other features of at least some of the other planar roof sections, based on the provided geometric information and/or assumptions about roof symmetry or other standard architectural practices.

FIG. **5**C shows a second type of pitch determination marker being used in the context of image **403** which provides a south perspective view of the building roof **407**. The illustrated pitch determination marker may be used in addition to, or instead of, the pitch determination marker **510** described with respect to FIGS. **5**A-**5**B, above. In particular, FIG. **5**C shows a pitch determination marker **520** (also called an "envelope tool") that includes surfaces **520***a* and **520***b*. The pitch determination marker **520** is an interactive user interface control that can be directly manipulated by the operator in order to specify the pitch of a section of the building roof **407**. In particular, the pitch determination marker **520** may be moved and/or adjusted so that it appears to lie substantially atop two adjacent planar sections of roof **407**.

FIG. **5**D shows the pitch determination marker **520** after the operator has used it to specify the pitch of two sections of roof **407**. Here, the operator has moved the marker **520** to a position in which the spine of the marker **520** is substantially aligned with the ridge line of roof **407**. Then, the operator has adjusted the angle of the surfaces **520***a* and **520***b* so that they appear to lie substantially atop corresponding sections of roof **407**. Then, the roof estimation system determines the pitch of the roof sections, based on the configuration of the marker **520** with respect to the image and the reference grid. Also illustrated are pitch indicators **521** and **522**. Pitch indicator **521** corresponds to the measured pitch of surface **520***a*, and pitch indicator **522** corresponds to the measured pitch of surface **520***b*. As the operator adjusts the angle of surfaces **520***a* and/or **520***b*, the corresponding pitch indicators **521**-**522** are automatically updated to reflect the determined pitch. In this example, the pitch of both surfaces is given as 4 inches of rise per foot of run.

The envelope pitch determination marker **520** may be adjusted in other ways, to specify pitches for types of roofs other than the gabled roof shown in image **403**. For example, when measuring pitch of roof sections that form a roof hip, point **520***c* may be manipulated by the operator, such as by dragging it to the left or right, to adjust the shape of the surfaces **520***a* and **520***b*, so that the surfaces align with the edges formed by the intersection of the sections that form the roof hip.

FIGS. **6**A-**6**D are screen displays illustrating model construction and concurrent display of operator specified roof features in an example embodiment. In particular, FIGS. **6**A-**6**D illustrate the construction of a three dimensional wire frame model of a building roof, based on the specification of roof features by an operator. In addition, FIGS. **6**A-**6**D illustrate the concurrent display of operator specified roof features in multiple views of a building roof.

FIG. **6**A shows the user interface screen **400** after images **402**-**406** have been registered, and after roof pitches have been determined. In this example, the operator is specifying sections of roof **407**, visible in image **406**, that are to be added to a 3D wire frame model of the roof **407** maintained by the roof estimation system. The specification of roof sections will be further described with reference to enlarged portion **608** of image **406** in FIG. **6**B, below. In addition, as the operator specifies roof sections in image **406**, the roof estimation system concurrently displays the specified roof sections in each of the other images **402**-**405**. The concurrent display of operator specified roof features will be further described with reference to enlarged portion **609** of image **402** in FIG. **6**C, below.

FIG. **6**B is an enlarged view of image portion **608** during the process of wire frame model construction in the context of image **406**, which provides an east perspective view of the building roof **407**. As shown in FIG. **6**B, the image portion **608** includes the building roof **407**, drawing tool **610**, and wire frame **611**. The drawing tool **610** (also called a "drawing marker" or a "drawing control") is an interactive user interface control that can be directly manipulated by the operator in order to specify roof features, such as edges, ridges, valleys, corners, etc. In the illustrated embodiment, the operator uses the drawing tool **610** to trace or outline planar sections of the roof **407**, leading to the generation of wire frame **611**. The drawing tool **610** may be used to establish a series of connected line segments that result in a closed polygon representing a planar roof section. As the operator specifies a planar roof section in this manner, the roof estimation system determines, based on the image and the reference grid, the geometry of the planar roof section, and includes (adds) the specified planar roof section in a 3D model that corresponds to roof **407**.

FIG. **6**C is an enlarged view of image portion **609** illustrating the concurrent display of operator specified roof features, in the context of image **402**, which provides a top plan view of the building roof **407**. As the operator specifies roof sections as described with respect to FIG. **6**B, the roof estimation system concurrently displays the specified roof features in one or more of the other images displayed by the user interface screen **400**. More specifically, image portion **609** includes building roof **407** and wire frame **612**. Wire frame **612** corresponds to wire frame **611** constructed by the operator with reference to FIG. **6**B, except that wire frame **612** is automatically displayed as a projection from the 3D model into the top-down view of image **402**. Changes that the operator makes to wire frame **611** are concurrently displayed by the roof estimation system as wire frame **612** in image portion **609**. For example, if a new planar roof section is added by the operator to wire frame **611**, the new planar roof section is automatically displayed in wire frame **612**. By concurrently displaying operator identified features in multiple views of building roof **407**, the operator obtains feedback regarding the correctness and/or accuracy of the 3D model or other aspects of the model generation process, such as image registration and pitch determination.

Generally, the roof estimation system can be configured to concurrently display any operator-identified features, such as corners, ridges, valleys, planar sections, and the like, in multiple views of a building.

Furthermore, the concurrently displayed wire frame **612** is an interactive user interface element, in that the operator can make changes to the wire frame **612**, which are then concurrently displayed in wire frame **611**. Wire frames similar to those described above are also projected by the roof estimation system into images **403**, **404**, and **405** displayed by the user interface screen **400**. In this manner, the operator can switch between various images of the building roof **407**, making refinements to the 3D model by adjusting the wire frame in whichever image is more convenient and/or provides a more suitable perspective/view of the model.

FIG. **6**D shows the user interface screen **400** during construction of a 3D model of the building roof **407**. In particular, the user interface **400** includes a shaded wire frame **613** representation of the 3D model constructed as described above. In this view, the operator can review the wire frame **613** in isolation from any images to determine whether the wire frame **613** accurately represents the building roof **407**. The wire frame **613** is an interactive user interface component, in that it can be directly manipulated (e.g., moved, rotated, resized, etc.). In some embodiments, manipulating the wire frame **613**, such as by changing its shape, results in corresponding changes in the underlying 3D model.

C. Roof Model Review

FIGS. **7**A-**7**C are screen displays illustrating roof model review in an example embodiment. In particular, FIGS. **7**A-**7**C illustrate various techniques to facilitate the review of a roof model by an operator. Reviewing the roof model may include reviewing roof section pitches (e.g., to determine whether they conform to the building roof and/or standard construction practices), reviewing the shape and/or location of the roof model (e.g., to determine whether it substantially conforms to the building roof), etc.

FIG. **7**A shows the user interface screen **400** after the operator has constructed a model of the roof **407** using one or more of the images **402**-**406**. In this example, a wire frame has been projected onto (superimposed upon) image **402** and annotated with roof section pitches, as will be described further with respect to enlarged portion **708** of image **402** in FIG. **7**B, below.

FIG. **7**B is an enlarged view of image portion **708** during the process of roof model review in the context of image **402**, which provides a substantially top plan view of the building roof **407**. As shown in FIG. **7**B, the image portion **708** includes a wire frame **710** and labels **711***a*-**711***c* that indicate pitches of corresponding sections of roof **407**. The wire frame **710** and the illustrated pitches are determined by the roof estimation system based on the pitch determination described with respect to FIGS. **5**A-**5**D, above, and the operator's specification of the wire frame model described with respect to FIGS. **6**A-**6**D, above.

The wire frame **710** includes multiple vertexes connected by line segments. Each vertex includes a handle, such as handle **710***a*. The handles may be directly manipulated (individually or in groups) by the operator to make adjustments/modifications to the wire frame **710**. For example, when an operator drags handle **710***a* to a new location, the ends of the two line segments connected to handle **710***a* will also move to the new location.

FIG. **7**C is an alternative view of the 3D model of roof **407** during the process of roof model review. In FIG. **7**C, the user interface screen **400** includes a wire frame **720** representation of the 3D model of the roof **407**. The wire frame **720** consists of multiple line segments corresponding to edges of planar roof sections. Each line segment is annotated with a label, such as label **723**, indicating the determined length of the corresponding roof section edge. Furthermore, some of the line segments indicate that they correspond to a particular roof feature. For example, line segments **721** and **722** may be colored (e.g., red) so as to indicate that they correspond to roof ridges. Other line segments may be differently colored (e.g., blue) so as to indicate a correspondence to roof valleys or other features. In addition, the wire frame **720** may be directly manipulated by the operator in order to make adjustments to the underlying model of the roof **407**. For example, the operator could increase or decrease the length of line segment **721**, resulting in a change in the corresponding feature of the 3D model of roof **407**.

Note that although the operator is shown, in FIGS. **5**-**7** above, operating upon a total of five images, in other cases, fewer images may be used. For example, in some cases fewer images may be available, or some images may provide obstructed views of the building roof, such as due to tree cover, neighboring buildings, etc.

3. Implementation Techniques

FIG. **8** is an example block diagram of a computing system for practicing embodiments of a roof estimation system. FIG. **8** shows a computing system **800** that may be utilized to implement a Roof Estimation System ("RES") **810**. One or more general purpose or special purpose computing systems may be used to implement the RES **810**. More specifically, the computing system **800** may comprise one or more distinct computing systems present at distributed locations. In addition, each block shown may represent one or more such blocks as appropriate to a specific embodiment or may be combined with other blocks. Moreover, the various blocks of the RES **810** may physically reside on one or more machines, which use standard inter-process communication mechanisms (e.g., TCP/IP) to communicate with each other. Further, the RES **810** may be implemented in software, hardware, firmware, or in some combination to achieve the capabilities described herein.

In the embodiment shown, computing system **800** comprises a computer memory ("memory") **801**, a display **802**, one or more Central Processing Units ("CPU") **803**, Input/Output devices **804** (e.g., keyboard, mouse, joystick, track pad, CRT or LCD display, and the like), other computer-readable media **805**, and network connections **806**. The RES **810** is shown residing in memory **801**. In other embodiments, some portion of the contents, some of, or all of the components of the RES **810** may be stored on and/or transmitted over the other computer-readable media **805**. The components of the RES **810** preferably execute on one or more CPUs **803** and generate roof estimate reports, as described herein. Other code or programs **830** (e.g., a Web server, a database management system, and the like) and potentially other data repositories, such as data repository **820**, also reside in the memory **801**, and preferably execute on one or more CPUs **803**. Not all of the components in FIG. **8** are required for each implementation. For example, some embodiments embedded in other software do not provide means for user input, for display, for a customer computing system, or other components.

In a typical embodiment, the RES **810** includes an image acquisition engine **811**, a roof modeling engine **812**, a report generation engine **813**, an interface engine **814**, and a roof estimation system data repository **816**. Other and/or different modules may be implemented. In addition, the RES **810** interacts via a network **850** with an image source computing system **855**, an operator computing system **865**, and/or a customer computing system **860**.

The image acquisition engine **811** performs at least some of the functions of the image acquisition engine **101** described with reference to FIG. **1**. In particular, the image acquisition engine **811** interacts with the image source computing system **855** to obtain one or more images of a building, and stores those images in the RES data repository **816** for processing by other components of the RES **810**. In some embodiments, the image acquisition engine **811** may act as an image cache manager, such that it preferentially provides images to other components of the RES **810** from the RES data repository **816**, while obtaining images from the image source computing system **855** when they are not already present in the RES data repository **816**. In other embodiments, images may be obtained in an "on demand" manner, such that they are provided, either by the image acquisition engine **811** or the image source computing system **855**, directly to modules of the RES **810** and/or the operator computing system **865**, without intervening storage in the RES data repository **816**.

The roof modeling engine **812** performs at least some of the functions of the roof modeling engine **102** described with reference to FIG. **1**. In particular, the roof modeling engine **812** generates a model based on one or more images of a building that are obtained from the RES data repository **816** or directly from the image source computing system **855**. As noted, model generation may be performed semi-automatically, based on at least some inputs received from the computing system **865**. In addition, at least some aspects of the model generation may be performed automatically, based on image processing and/or image understanding techniques. After the roof modeling engine **812** generates a model, it stores the generated model in the RES data repository **816** for further processing by other components of the RES **810**.

The report generation engine **813** performs at least some of the functions of the report generation engine **103** described with reference to FIG. **1**. In particular, the report generation engine **813** generates roof reports based on models stored in the RES data repository **816**. Generating a roof report may include preparing one or more views of a given 3D model of a roof, annotating those views with indications of various characteristics of the model, such as dimensions of sections or other features (e.g., ridges, valleys, etc.) of the roof, slopes of sections of the roof, areas of sections of the roof, etc. In some embodiments, the report generation engine **813** facilitates transmission of roof measurement information that may or may not be incorporated into a roof estimate report. For example, the roof generation engine **813** may transmit roof measurement information based on, or derived from, models stored in the RES data repository **816**. Such roof measurement information may be provided to, for example, third-party systems that generate roof estimate reports based on the provided information.

The interface engine **814** provides a view and a controller that facilitate user interaction with the RES **810** and its various components. For example, the interface engine **814** implements a user interface engine **104** described with reference to FIG. **1**. Thus, the interface engine **814** provides an interactive graphical user interface that can be used by a human user operating the operator computing system **865** to interact with, for example, the roof modeling engine **812**, to perform functions related to the generation of models, such as point registration, feature indication, pitch estimation, etc. In other embodiments, the interface engine **814** provides access directly to a customer operating the customer computing system **860**, such that the customer may place an order for a roof estimate report for an indicated building location. In at least some embodiments, access to the functionality of the interface engine **814** is provided via a Web server, possibly executing as one of the other programs **830**.

In some embodiments, the interface engine **814** provides programmatic access to one or more functions of the RES **810**. For example, the interface engine **814** provides a programmatic interface (e.g., as a Web service, static or dynamic library, etc.) to one or more roof estimation functions of the RES **810** that may be invoked by one of the other programs **830** or some other module. In this manner, the interface engine **814** facilitates the development of third-party software, such as user interfaces, plug-ins, adapters (e.g., for integrating functions of the RES **810** into desktop applications, Web-based applications, embedded applications, etc.), and the like. In addition, the interface engine **814** may be in at least some embodiments invoked or otherwise accessed via remote entities, such as the operator computing system **865**, the image source computing system **855**, and/or the customer computing system **860**, to access various roof estimation functionality of the RES **810**.

The RES data repository **816** stores information related the roof estimation functions performed by the RES **810**. Such information may include image data **105**, model data **106**, and/or report data **107** described with reference to FIG. **1**. In addition, the RES data repository **816** may include information about customers, operators, or other individuals or entities associated with the RES **810**.

In an example embodiment, components/modules of the RES **810** are implemented using standard programming techniques. For example, the RES **810** may be implemented as a "native" executable running on the CPU **803**, along with one or more static or dynamic libraries. In other embodiments, the RES **810** is implemented as instructions processed by virtual machine that executes as one of the other programs **830**. In general, a range of programming languages known in the art may be employed for implementing such example embodiments, including representative implementations of various programming language paradigms, including but not limited to, object-oriented (e.g., Java, C++, C#, Matlab, Visual Basic-.NET, Smalltalk, and the like), functional (e.g., ML, Lisp, Scheme, and the like), procedural (e.g., C, Pascal, Ada, Modula, and the like), scripting (e.g., Perl, Ruby, Python, JavaScript, VBScript, and the like), declarative (e.g., SQL, Prolog, and the like).

The embodiments described above may also use well-known synchronous or asynchronous client-server computing techniques. However, the various components may be implemented using more monolithic programming techniques as well, for example, as an executable running on a single CPU computer system, or alternatively decomposed using a variety of structuring techniques known in the art, including but not limited to, multiprogramming, multithreading, client-server, or peer-to-peer, running on one or more computer systems each having one or more CPUs. Some embodiments execute concurrently and asynchronously, and communicate using message passing techniques. Equivalent synchronous embodiments are also supported by an RES implementation. Also, other functions could be implemented and/or performed by each component/module, and in different orders, and by different components/modules, yet still achieve the functions of the RES.

In addition, programming interfaces to the data stored as part of the RES **810**, such as in the RES data repository **816**, can be available by standard mechanisms such as through C, C++, C#, and Java APIs; libraries for accessing files, databases, or other data repositories; through scripting languages such as XML; or through Web servers, FTP servers, or other types of servers providing access to stored data. For example, the RES data repository **816** may be implemented as one or more database systems, file systems, memory buffers, or any other technique for storing such information, or any combination of the above, including implementations using distributed computing techniques.

Also, the example RES **810** can be implemented in a distributed environment comprising multiple, even heterogeneous, computer systems and networks. For example, in one embodiment, the image acquisition engine **811**, the roof modeling engine **812**, the report generation engine **813**, the interface engine **814**, and the data repository **816** are all located in physically different computer systems. In another embodiment, various modules of the RES **810** are hosted each on a separate server machine and are remotely located from the tables which are stored in the data repository **816**. Also, one or more of the modules may themselves be distributed, pooled or otherwise grouped, such as for load balancing, reliability or security reasons. Different configurations and locations of programs and data are contemplated for use with techniques of described herein. A variety of distributed computing techniques are appropriate for implementing the components of the illustrated embodiments in a distributed manner including but not limited to TCP/IP sockets, RPC, RMI, HTTP, Web Services (XML-RPC, JAX-RPC, SOAP, and the like).

Furthermore, in some embodiments, some or all of the components of the RES are implemented or provided in other manners, such as at least partially in firmware and/or hardware, including, but not limited to one or more application-specific integrated circuits (ASICs), standard integrated circuits, controllers (e.g., by executing appropriate instructions, and including microcontrollers and/or embedded controllers), field-programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs), and the like Some or all of the system components and/or data structures may also be stored (e.g., as software instructions or structured data) on a computer-readable medium, such as a hard disk, a memory, a network, or a portable media article to be read by an appropriate drive or via an appropriate connection. The system components and data structures may also be stored as data signals (e.g., by being encoded as part of a carrier wave or included as part of an analog or digital propagated signal) on a variety of computer-readable transmission mediums, which are then transmitted, including across wireless-based and wired/cable-based mediums, and may take a variety of forms (e.g., as part of a single or multiplexed analog signal, or as multiple discrete digital packets or frames). Such computer program products may also take other forms in other embodiments. Accordingly, embodiments of this disclosure may be practiced with other computer system configurations.

FIG. **9** is an example flow diagram of an image registration routine provided by an example embodiment. The illustrated routine **900** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **900** facilitates image registration based upon operator indicated registration points and/or image lean corrections.

More specifically, the routine begins in step **901**, where it displays, on a user interface screen, an aerial image of a building having a roof. As part of the user interface screen, the routine also displays user interface controls such as markers that may be used by an operator for purposes of image registration and/or lean correction, as described with reference to FIG. **4**A, above.

In step **902**, the routine receives, via one or more registration markers, indications of one or more points on the aerial image. The registration markers are manipulated by the operator to specify points on the aerial image, as described with reference to FIGS. **4**A-**4**E. Typically, the points are visually identifiable features, such as corners of the roof of the building. For example, if the roof has four corners (e.g., a northwest, southwest, northeast, and southwest corner) the operator may place one registration marker on each of the four corners as shown in the aerial image. Then, the positions (e.g., coordinates on the aerial image) of the markers are transmitted to the routine for use in registering the aerial image, as described below.

In step **903**, the routine receives, via a lean correction marker, an indication of the vertical axis of the building roof. In at least some cases, the aerial image of the building is out of alignment with respect to the vertical axis of the building. This may be caused, for example, by pitch, roll, and/or yaw experienced by the aircraft during the process of photographing the building. To correct for such misalignment, the lean correction marker is manipulated by the operator to indicate a vertical axis of the building. Typically, the operator aligns the lean correction marker with known, substantially vertical feature of the building, such as a chimney, wall corner, etc., as described with reference to FIG. **4**E, above. After the operator has aligned the lean correction marker, the position (e.g., angle of the marker, coordinates of the endpoints of the marker, etc.) of the lean correction marker is transmitted to the routine for use in registering the aerial image, as described below.

Particular benefits may be obtained from lean correction performed in the context of an overhead, or "top down," view. An "overhead lean" occurs when the camera is not directly overhead with respect to the building when the photo is taken. In some cases, leans in excess of **5** degrees have been observed in "top down" photos. Furthermore, unlike oblique, perspective views, a top-down lean is typically less likely to include a convenient visual marker that provides sufficient angle to assess the lean direction and magnitude, such as the edge of the building or a tall chimney. An overhead lean affects the perceived location of the roof lines in a top down view. This effect is amplified as the pitch of the roof increases and/or as the vertical separation between disconnected roof sections increases. Without lean correction, superimposing a wire frame over the visible ridgelines (and other features of a building that reside at different elevations) may produce asymmetries in otherwise symmetric structures. Further, an absence of lean correction may introduce errors in pitch estimation, as the wire frame may not appear consistent between top and oblique view points. More specifically, without top view lean correction, the positions for the roof lines in an otherwise correct (i.e., accurate with respect to the actual geometry of the roof) wire frame will typically not line up on the visible roof lines in the overhead reference photo. This often leads the user (or software) to either introduce errors by incorrectly drawing the wire frame to the image lines or perform a subjective determination of where and how to shift the wire frame lines off the image lines to produce a correct model. Top view lean correction allows the roof estimation system to trace to, or substantially to, the actual roof lines seen in the top image while still producing an accurate wire frame model.

Image misalignment may be specified in other ways. For example, in other embodiments, the operator may instead rotate the image to a position in which the building appears to be in a substantially vertical position. Then, the angle of rotation of the image may be transmitted to the routine for use in registering the aerial image.

In step **904**, the routine registers, based on the received indications of the points and/or the received indication of the vertical axis, the aerial image to a reference grid. Registering the image to a reference grid may include determining a transformation between the reference grid and the image, based on the indicated points and/or the indicated vertical axis. Determining such a transformation may be based on other information as well, such as meta-information associated with the aerial image. In some embodiments, the aerial image has corresponding meta-information that includes image capture conditions, such as camera type, focal length, time of day, camera position (e.g., latitude, longitude, and/or elevation), etc.

In step **905**, the routine determines whether there are additional aerial images to be registered, and if so, returns to step **901**, else proceeds to step **906**. During execution of the loop of steps **901**-**905**, the operator typically indicates, for each registration marker, the same feature (e.g., corner) of the roof as shown in each of multiple images, such that the routine can register the multiple images to a single, uniform reference grid. Upon completion of the registration process, the routine has determined a uniform coordinate system for the multiple aerial images, for use during other phases of model construction, such as pitch determination or feature identification.

In step **906**, the routine generates a three-dimensional model based at least in part on the aerial image(s) and the reference grid. As discussed above with reference to FIGS. **5**A-**5**D and **6**A-**6**D, model generation includes identification of roof features shown in various images of the roof, such as edges, planar sections, vertexes, and the like, as well as determination of roof pitch and other dimensional attributes of the roof. In other embodiments, the routine performs other functions with the registered images, such as storing them for later use (e.g., by an automated model generation module), transmitting them to another computing (e.g., for use in a third-party design application), etc. After step **906**, the routine ends.

Note that in at least some embodiments, aspects of the routine **900** may be performed in an automated manner. For example, operations discussed above as being performed by an operator, such as the determination of the location of image registration points of step **902** and/or the indication of lean of step **903**, may be performed by automated image processing techniques.

FIG. **10** is an example flow diagram of a pitch determination routine provided by an example embodiment. The illustrated routine **1000** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1000** facilitates the determination of the pitch of a section of a roof, by displaying a pitch determination marker and modifying a 3D model of a roof based on an indication of roof pitch received via the pitch determination marker.

More specifically, the routine begins at step **1001** where it displays an aerial image of a building having a roof comprising a plurality of planar roof sections that each have a corresponding pitch. The aerial image is displayed in the context of a user interface screen, such as is described with reference to FIGS. **4**A-**6**C, above. The aerial images may be received from, for example, the image source computing system **855** and/or from the RES data repository **816** described with reference to FIG. **8**. As discussed above, aerial images may be originally created by cameras mounted on airplanes, balloons, satellites, etc. In some embodiments, images obtained from ground-based platforms (e.g., vehicle-mounted cameras) may be used instead or in addition.

In step **1002**, the routine displays a pitch determination marker operable to indicate pitch of a planar roof section. The pitch determination marker may be, for example, a pitch determination marker **510** ("protractor tool") or **520** ("envelope tool"), such as are respectively described with respect to FIGS. **5**B and **5**C, above. The routine displays the pitch determination marker by, for example, presenting it on a user interface screen displayed on a computer monitor or other display device. The pitch determination marker is a direct manipulation user interface control, in that an operator may manipulate it (e.g., adjust an angle, change its shape, alter its position, etc.) in order to indicate pitch of a planar roof section. Additional details regarding pitch determination controls are provided with respect to FIGS. **5**A-**5**D, above.

In step **1003**, the routine receives, via the displayed pitch determination marker, an indication of the pitch of one of the plurality of planar roof sections of the roof of the building. Receiving an indication of the pitch includes receiving an indication (e.g., via an event, callback, etc.) that the marker has been manipulated by the operator, and then determining an angle based on the shape and/or position of the marker. In some embodiments, such an indication may be received on an event driven basis, such as every time the marker is manipulated in some manner. In other embodiments, the routine may poll the marker from time to time to determine its current state. In addition, the operator may explicitly indicate that the current state of the marker is to be transmitted to the routine, such as by pressing a button or other indication.

In step **1004**, the routine modifies a three-dimensional model of the roof based on the received indication of the pitch of the one planar roof section. Modifying the 3D model of the roof includes associating the indicated pitch with a portion of the model corresponding to the one planar roof section. For example, the 3D model may include one or more data structures representing planar roof sections, and the indicated pitch may be included as part of the data structure representing the one planar roof section. In some embodiments, the 3D model may not at this point include representations of the planar roof sections, such as because the operator has not yet specified them. In such a case, the routine may store the indicated pitch in association with the location and orientation at which the pitch was specified by the operator, as determined from the aerial image. Then, at a later time, when the operator specifies a roof section that has the same orientation as the stored pitch and that includes or is near the stored location, the roof estimation system can store the indicated pitch in association with the specified roof section.

After step **1004**, the routine ends. In other embodiments, the routine may instead return to step **1001**, to determine the pitch for another planar roof section (of the same or different roof).

FIG. **11** is an example flow diagram of concurrent feature display routine provided by an example embodiment. The illustrated routine **1100** may be provided by, for example, execution of the roof estimation system **810** described with respect to FIG. **8**. The illustrated routine **1100** concurrently displays operator indicated features in multiple aerial images of a building roof.

More specifically, the routine begins in step **1101**, where it displays a first and a second aerial image of a building having a roof, each of the aerial images providing a different view of the roof of the building. The aerial images are displayed in the context of a user interface screen, such as is described with reference to FIGS. **6**A-**6**C, above.

In step **1102**, the routine receives an indication of a feature of the building shown in the first aerial image. The indication is typically received via a user interface control, such as a drawing tool or marker, upon its manipulation by an operator. For example, the operator may manipulate a drawing tool in order to specify one or more features of the building roof, such as a corner on the roof, an edge of the roof, an outline of a section of the roof, etc. In one embodiment, the operator utilizes a drawing tool to indicate roof section corner points and roof section edges connecting those corner points. Additional details regarding feature indication are provided with respect to FIGS. **6**A-**6**C, above.

In step **1103**, the routine modifies a three-dimensional model of the roof based on the received indication of the feature of the building. Modifying the 3D model may include adding or updating the indicated feature to a wire frame model of the roof. For example, if the indicated feature is a roof section corner point, the corner point will be added to the 3D model, along with the location (e.g., the X, Y, and Z position of the point) of the point. The location of the point is automatically determined based on a translation of the position of the point in the image to a point in the uniform reference grid associated with the image. If the indicated feature is a roof section edge, the edge will be added to the 3D model, such as by associating the edge with two points corresponding to the end points of the edge. Higher-level features can also be indicated. For example, a planar roof section may be indicated by "closing" a sequence of two or more connected line segments, to create a closed polygon that represents the outline or perimeter of the planar roof section.

In step **1104**, the routine concurrently displays a projection of the feature from the modified three-dimensional model onto the first and second aerial images. In one embodiment, displaying the feature from the modified three-dimensional model includes projecting the three-dimensional model onto both the first and second aerial images. For example, if the first image (for which the indicated feature was received) provides a west view of the building, and the second image provides an east view of the building, the routine will concurrently display a projection of the indicated feature from the 3D model onto both the first and second images. The projection of the indicated feature into the second image is based at least in part on a translation from the position of the feature in the reference grid to a position in the second image. In addition, the concurrent display onto two or more images occurs at substantially the same time (within a short time interval, at times that are substantially coincident) as the indication of the feature of the building in step **1102**, giving the operator the illusion that as they are indicating a feature in the first image, the feature is being simultaneously projected into the second image.

After step **1104**, the routine ends. In other embodiments, the routine may instead return to step **1101**, to perform an interactive loop of steps **1101-1104** with the operator, so that the routine can concurrently display multiple features as they are indicated by the operator. Note that in such an embodiment, each iteration of the loop of steps **1101-1104** may be performed at near real-time speeds, so as to provide a fluid, interactive model generation experience for the operator enabling the operator to drag, draw, or otherwise indicate/manipulate features in a first image and view the results of their work concurrently projected into a second image.

All of the above U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, including but not limited to U.S. Provisional patent application No. 61/197,904, entitled "USER INTERFACE SYSTEMS AND METHODS FOR ROOF ESTIMATION," filed Oct. 31, 2008, are incorporated herein by reference, in their entireties.

From the foregoing it will be appreciated that, although specific embodiments have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the present disclosure. For example, the methods, systems, and techniques for generating and providing roof estimate reports discussed herein are applicable to other architectures other than the illustrated architecture or a particular roof estimation system implementation. Also, the methods and systems discussed herein are applicable to differing network protocols, communication media (optical, wireless, cable, etc.) and devices (such as wireless handsets, electronic organizers, personal digital assistants, portable email machines, game machines, pagers, navigation devices such as GPS receivers, etc.). Further, the methods and systems discussed herein may be utilized by and/or applied to other contexts or purposes, such as by or for solar panel installers, roof gutter installers, awning companies, HVAC contractors, general contractors, and/or insurance companies.

The invention claimed is:

1. A computer-implemented method in a roof estimate report system including at least one processor and a memory coupled to the at least one processor, the method comprising:

displaying, by the at least one processor of the roof estimate report system, a plurality of aerial images of a roof at the same time on a single display, each of the aerial images providing a different view, taken from a different angle of the same roof;

displaying, by the at least one processor of the roof estimate report system, respective line drawings representing features of the roof, the respective line drawings overlying a first and a second aerial image of the plurality of aerial images of the roof on the single display, the line drawing overlying the first aerial image of the roof having features in common with the line drawing overlying the second aerial image of the roof;

in response to user input, changing, by the at least one processor of the roof estimate report system, the line drawing representing a feature of the roof that overlies the first aerial image of the roof;

correlating, by the at least one processor of the roof estimate report system, a location of the feature on the roof represented by the line drawing that has been changed to a location of a corresponding feature represented by the line drawing overlying the second aerial image;

based on the correlation, changing, by the at least one processor of the roof estimate report system, the corresponding feature in the line drawing overlying the second aerial image according to the change of the line drawing representing the feature of the roof that overlies the first aerial image; and

generating and outputting a roof estimate report using a report generation engine, wherein the roof estimate report includes one or more top plan views of a model of the roof annotated with numerical values for corresponding slope, area, or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof.

2. The method of claim **1** further comprising, before the displaying the respective line drawings, modifying a three-dimensional model of the roof based on a received indication of a roof feature by adding a planar roof section to the three-dimensional model.

3. The method of claim **2** wherein the indicated roof feature is at least one of: a point on the roof, a section of the roof, a ridgeline of the roof, a valley of the roof, a rake edge of the roof, an eave of the roof, a hip ridge of the roof, an edge of a section of the roof, and a corner of a section of the roof.

4. The method of claim **1** wherein the displaying the respective line drawings comprises:

displaying the respective line drawing overlying the first aerial image at a first time; and

displaying the respective the line drawing overlying the second aerial image at a second time that is substantially coincident to the first time.

5. The method of claim **1** further comprising receiving an indication of one of the features of the roof at a first time, and wherein the displaying the respective line drawings occurs at a second time that is substantially coincident to the first time.

6. The method of claim **1** wherein the displaying the respective line drawings includes initiating display of a line on the first and second image.

7. The method of claim **1** wherein the first image provides a substantially top plan view of the roof of the building, and wherein the second image provides a perspective view of the roof of the building.

8. The method of claim **1** wherein the first image provides a first perspective view of the roof of the building and the second image provides a second perspective view of the roof of the building.

9. The method of claim **1** further comprising:

transmitting roof measurement information based at least in part on the change of the line drawing representing a feature of the roof that overlies the first aerial image of the roof.

10. The method of claim **1** further comprising:

displaying a marker operable to specify a point on an image;

receiving, via the marker, an indication of a point on the first aerial image; and

registering, based on the received indication of the point, the aerial image to a reference grid corresponding to a three-dimensional model of the roof.

11. The method of claim **1** further comprising:

displaying a lean correction marker operable to indicate a vertical axis of an aerial image;

receiving, via the lean correction marker, an indication of a vertical axis of the first aerial image; and

registering, based on the received indication of the vertical axis, the first aerial image to a reference grid corresponding to a three-dimensional model of the roof.

12. A computing system for generating a roof estimate report, the computing system comprising:

a memory;

at least one processor coupled to the memory; and

a roof estimation module that is stored on the memory and that is configured, when executed by at least one processor of the computing system for generating the roof estimate report, to:

substantially concurrently display a projection of a roof feature onto first and second aerial images as a line drawing of the roof feature;

overlay the line drawing of the roof feature on corresponding locations of the feature on the first and second aerial images;

in response to user input causing modification of the line drawing overlaid on the first aerial image, make corresponding changes to the line drawing overlaid on the second aerial image; and

generate and output a roof estimate report using a report generation engine, wherein the roof estimate report includes one or more top plan views of a model of the roof annotated with numerical values for corresponding slope, area, or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof.

13. The computing system of claim **12** wherein the roof estimation module includes an interactive roof modeling user interface.

14. The computing system of claim **12** wherein the computing system is a desktop computer and the roof estimation module is part of an interactive roof modeling program executing on the computing system.

15. The computing system of claim **12** wherein the roof estimation module is part of a network accessible roof modeling program executing on the computing system.

16. A non-transitory computer-readable storage medium, having computer executable instructions stored thereon that, when executed by at least one computer processor, cause the at least one processor to enable a computing system to generate a roof estimate report for a building having a roof, by performing a method comprising:

substantially concurrently displaying a projection of a roof feature as a line drawing of the feature onto a first aerial image of the roof that provides a first view of the roof of the building and onto a second aerial image that provides a second view of the roof of the building;

overlaying the line drawing on corresponding locations of the feature on the first and second aerial images;

in response to user input causing modification of the line drawing overlaid on the first aerial image, making corresponding changes to the line drawing overlaid on the second aerial image; and

generating and outputting a roof estimate report using a report generation engine, wherein the roof estimate report includes one or more top plan views of a model of the roof annotated with numerical values for corresponding slope, area, or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof.

17. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises modifying a three-dimensional model of the roof by adding a planar roof section to the three-dimensional model.

18. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises receiving an indication of the feature of the building by receiving position information of the feature in the first aerial image, and wherein substantially concurrently displaying the projection of the feature includes:

translating the received position information into position information of the feature in a three-dimensional model; and

translating the position information of the feature in the three-dimensional model into position information of the feature in the second aerial image.

19. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature comprises:

displaying the feature in the first aerial image at a first time; and

displaying the feature in the second aerial image at a second time that is within two seconds of the first time.

20. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature includes displaying the projection of the feature substantially concurrently with receiving an indication of the feature of the building.

21. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature includes displaying the projection of the feature at substantially the same time as receiving an indication of the feature of the building.

22. The non-transitory computer-readable storage medium of claim **16** wherein the method is performed iteratively, and the method further comprising:

providing an operator with an interactive model generation experience.

23. The non-transitory computer-readable storage medium of claim **16** wherein displaying the projection of the feature includes initiating display of a line on the first and second image.

24. The non-transitory computer-readable storage medium of claim **16** wherein the first image provides a perspective view of the roof of the building, and wherein the second image provides a substantially top plan view of the roof of the building.

25. The non-transitory computer-readable storage medium of claim **16** wherein the method further comprises:

modifying a three dimensional model of the roof based at least on the modification of the line drawing overlaid on the first aerial image; and

generating a roof estimate report based at least in part on the modified three-dimensional model.

26. A computer-implemented method in a roof estimate report system including a computer system and a memory coupled to the computer system, the method comprising:

displaying, by the computer system of the roof estimate report system, a first aerial image of a roof on a single display;

displaying, by the computer system of the roof estimate report system, a second aerial image of the same roof on the same single display, the second aerial image providing a different view than the first aerial image, taken from a different angle of the same roof;

displaying, by the computer system of the roof estimate report system, a first line drawing representing features of the roof overlaid on the first aerial image of the roof;

displaying, by the computer system of the roof estimate report system, a second line drawing representing features of the roof overlaid on the second aerial image of the roof, the second line drawings having features in common with and that correspond to features in the first line drawing;

in response to user input, changing, a line in the first line drawing representing a feature of the roof that overlies the first aerial image of the roof;

changing, by the computer system of the roof estimate report system, a line in the second line drawing that corresponds to the same feature in the first line drawing that was changed by the user, the change in the second line drawing being made by the computer system in response to the change that was made by the user in the first line drawing; and

generating and outputting a roof estimate report using a report generation engine, wherein the roof estimate report includes one or more top plan views of a model of the roof annotated with numerical values for corresponding slope, area, or lengths of the edges of at least some of the plurality of planar roof sections of the model of the roof.

27. The method of claim **26** wherein the roof feature is at least one of:

a ridgeline of the roof, a valley of the roof, a rake edge of the roof, an eave of the roof, a hip ridge of the roof, and an edge of a section of the roof.

28. The method of claim **26** wherein the step of displaying, by the computer system of the roof estimate report system, a second line drawing representing features of the roof overlaid on the second aerial image of the roof comprises:

displaying the second line drawing after the first line drawing has been displayed.

29. The method of claim **26** wherein the step of changing, by the computer system of the roof estimate report system, a feature in the second line drawing overlying the second aerial image comprises:

changing the second line drawing at a time that is substantially concurrent to the time the changes are being made by the user in the first line drawing.

30. The method of claim **26** further comprising:

displaying the second line drawing overlying the second aerial image on the same display concurrently with displaying the first line drawing overlying the first aerial image of the roof on the same, single display.

31. The method of claim **26** further comprising:

displaying the second line drawing overlying the second aerial image on the same display at a later time, after the displaying of the first line drawing overlying the first aerial image of the roof on the display.

32. The method of claim **26** wherein the first image provides a substantially top plan view of the roof of the building, and the second image provides an oblique view of the roof of the building.

33. The method of claim **26** wherein the first image provides a first oblique view from a first compass bearing of the roof of the building, and the second image provides a second oblique view from a second compass bearing of the roof of the building.

34. The method of claim **26** further comprising:

displaying roof measurement information on the same display concurrently with the first line drawing being displayed.

35. The method of claim **34** wherein the step of displaying roof measurement information on the same display concurrently with the first line drawing being displayed comprises:

displaying the roof measurement information in a location that overlays the line drawing itself.

36. The method of claim **26** further comprising:

displaying a wire frame model of the roof in isolation from any images of the roof on the same display.

37. The method of claim **26** further comprising:

modifying a wire frame model of the roof based on input received from a user; and

making, by the computer system of the roof estimate report system, corresponding changes in a 3D model of the roof based on the changes made by the user to the wire frame model.

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EXHIBIT 11

Substitute for form 1449A/PTO

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Use as many sheets as necessary)

Sheet 1 of 3

Complete if Known	
Application Number	13/397,325
Filing Date	02/15/2012
First Named Inventor	James Edward Loveland
Art Unit	3661
Examiner Name	Unassigned
Attorney Docket Number	97171-00143

U. S. PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
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	18	US-2010/0114537	05/06/2010	Pershing	

FOREIGN PATENT DOCUMENTS

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Sheet 2 of 3

Complete if Known	
Application Number	13/397,325
Filing Date	02/15/2012
First Named Inventor	James Edward Loveland
Art Unit	3661
Examiner Name	Unassigned
Attorney Docket Number	97171-00143

U. S. PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	19	US-2010/0179787	07/15/2010	Pershing, et al.	
	20	US-2010/0296693	11/25/2010	Thornberry, et al.	
	21	US-2011/0096083	04/28/2011	Schultz	
	22	US-2011/0187713	08/04/2011	Pershing, et al.	
	23	US-2004/0263514	12/30/2004	Jin, et al.	
	24	US-2001/0027404	10/04/2001	Loveland	
	25	US-2005/0102394	05/12/2005	Loveland	
	26	US-2007/0067191	03/22/2007	Loveland	
	27	US-6,037,945	03/14/2000	Loveland	
	28	US-6,810,383	10/26/2004	Loveland	
	29	US-6,816,819	11/09/2004	Loveland	
	30	US-6,826,539	11/30/2004	Loveland	
	31	US-6,829,584	12/07/2004	Loveland	
	32	US-8,145,578	03/27/2012	Pershing, et al.	
	33	US-2012/0007982	01/12/2012	Giuffrida, et al.	
	34	US-7,873,238	01/18/2011	Schultz, et al.	
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Application Number	13/397,325
Filing Date	02/15/2012
First Named Inventor	James Edward Loveland
Art Unit	3661
Examiner Name	Unassigned
Attorney Docket Number	97171-00143

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	35	"Xactimate 27 – Aerial Sketch," Internet printout from http://www.xactware.com/solutions/claims-estimating/27-3/aerial-sketch, 2012 (3 pages)	

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Xactware: Verisk Insurance Solutions Announces Expansion of Imagery Database

Accelerates collection of aerial imagery and related data for structures across the United States

August 04, 2015 10:11 ET | **Source:** Xactware

LEHI, Utah, Aug. 4, 2015 (GLOBE NEWSWIRE) -- Verisk Insurance Solutions, a leading data analytics provider to the property/casualty insurance industry, today announced it has reached long-term agreements with a range of leading U.S. aerial imagery and data-capturing firms to accelerate the collection of high-quality imagery and data for Property InSight™. By ramping up the collection of imagery and data, Verisk Insurance Solutions and its Xactware business are ensuring robust geographic coverage with high-quality imagery and data captured specifically for the needs of the property insurance industry and other building professionals. Verisk Insurance Solutions is a Verisk Analytics (Nasdaq:VRSK) business.

Xactware uses proprietary algorithms to process the high-quality imagery and data to provide property professionals with detailed information about the exterior of a structure, including roof and exterior plans with all dimensions; 3D property models; hazards, property conditions, and analysis of building materials; a landscaping plan; plans and information for windows, doors, decks, swimming pools, and outbuildings; high-resolution aerial images; and much more.

Property InSight can be used by all types of building professionals for a wide range of purposes, including remote exterior building inspections and risk assessment; creating reconstruction estimates after a damaging event; determining the squares of roofing for roof replacement; and much more, including information used to estimate siding, rain gutters and downspouts, soffit and fascia, awnings, and so on.

Property InSight helps significantly reduce the time property professionals typically spend at a site measuring, determining quantities, and assessing the types of materials used.

"This accelerated timetable will significantly speed our work to expand the reach and quality of Property InSight," said Jim Loveland, president and CEO of Xactware. "The demand for high-quality imagery and for data captured specifically for property workflows continues to grow. This initiative strengthens our coverage in many key areas in the United States with higher-quality information at a faster pace."

This latest initiative is the most recent step in ongoing efforts to extend Verisk's leadership in multispectral, multitiered imagery solutions to serve the needs of property professionals, and it builds on the addition of world-renowned geospatial experts from AMS Geomatics to the Verisk Insurance Solutions geospatial team earlier this year.

"Collecting high-quality, reliable data for Property InSight is a key component of the database," said

Jeffrey C. Taylor, vice president of Geospatial and Pricing Solutions at Verisk Insurance Solutions. "This latest initiative illustrates our long-term commitment to the highest-quality imagery and data that will provide our customers with the best possible information about structures for making robust decisions in a cost-effective way."

Property InSight data can be requested through the Xactimate® claims-estimating solution, the XactAnalysis® claims management network, or the 360Value® insurance-to-value underwriting solution.

To learn more about Property InSight, visit Xactware.com/property-insight.

About Verisk Insurance Solutions

A Verisk Analytics (Nasdaq:VRSK) business, Verisk Insurance Solutions is a leading source of information about property/casualty insurance risk. Drawing upon vast experience in data management, security, and predictive modeling to serve its clients, Verisk Insurance Solutions includes the industry-leading brands of ISO, AIR Worldwide, and Xactware. In the United States and around the world, Verisk Insurance Solutions helps customers protect people, property, and financial assets. For more information, visit www.verisk.com/insurance.

Contact:

Giuseppe Barone/Colleen Finley
MWW Group (for Verisk Insurance Solutions)
201-507-9500

gbarone@mww.com

cfinley@mww.com

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www.xactware.com/.../new-**aerial-sketch**-makes-drawing-roof-plans-faster- and-easier/
Feb 16, 2012 ... The latest release of Xactware's **Aerial Sketch**™ roof-dimensioning product uses high-resolution aerial images for a selected address to detect ...
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Xactimate 27.5 - **Aerial Sketch** | Xactware (https://www.xactware.com/en-
https://www.xactware.com/en-au/solutions/claims.../**aerial-sketch**/

The latest release of Xactware's **Aerial Sketch**™ roof-dimensioning product uses high-resolution aerial images for a selected address to detect and automatically ...
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(https://www.xactware.com/en-au/solutions/claims-estimating/xactimate/27-5/aerial-sketch/)

Solutions - **Aerial Sketch** Rate Agreement | Xactware (http://www.xactware.com/en-
www.xactware.com/en-us/solutions/**aerial-sketch**-rate-agreement/
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*Some corporate contracted rates may be less. The charge for your order will appear on your invoice as "**Aerial Sketch** Usage." Xactware does not manage and ...
Labeled Xactware
(http://www.xactware.com/en-us/solutions/aerial-sketch-rate-agreement/)

Upcoming Webcasts - **Aerial Sketch**: Revolutionary Roof ... (https://www.xactware.com/en-
https://www.xactware.com/.../**aerial-sketch**-revolutionary-roof-dimensioning- in-four-easy-steps/
Earlier this year, Xactware introduced **Aerial Sketch**™ — a new tool that streamlines the roof-dimensioning process through the use of high-resolution aerial ...
Labeled Xactware
(https://www.xactware.com/en-nz/resources/webcasts/upcoming-webcasts/aerial-sketch-revolutionary-roof-dimensioning-in-four-easy-steps/)

News - Xactware Releases **Aerial Sketch** for Xactimate | Xactware
www.xactware.com/.../xactware-releases-**aerial-sketch**-for-xactimate/

Feb 18, 2011 ... The new **Aerial Sketch**™ tool in the latest version of Xactware's industry-leading property repair estimating solution helps insurers and ...
Labeled Xactware

Xactimate 27.5 - **Aerial Sketch** Details | Xactware (http://www.xactware.com/en-
www.xactware.com/en-au/solutions/claims.../**aerial-sketch**/details/

Estimators use **Aerial Sketch** to download aerial images, trace roof features, and create fully dimensioned roof plans that can be used to estimate repair costs.
Labeled Xactware
(http://www.xactware.com/en-au/solutions/claims-estimating/xactimate/27-5/aerial-sketch/details/)

Aerial Sketch Scenario Training Course Outline (https://www.xactware.com/training/self-
https://www.xactware.com/.../**aerial-sketch**-scenario-training-course-outline
Aerial Sketch Scenario Training Course Outline. **Aerial Sketch** Scenario Training. 01 - Importing Your Image; 02 - Setting Up Your Image; 03 - Drawing the Roof ...

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Solutions - **Aerial Sketch** Fee Agreement | Xactware (http://www.xactware.com/en-
www.xactware.com/en-gb/solutions/**aerial-sketch**-fee-agreement1/
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Xactimate 27.5 - **Aerial Sketch** FAQ | Xactware (http://www.xactware.com/en-
www.xactware.com/en-au/solutions/claims...5/**aerial-sketch**/faqs/
Xactimate is the most used and trusted replacement cost estimating software for the insurance repair industry.
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News - New XactRemodel Includes **Aerial Sketch** | Xactware (http://www.xactware.com/en-
www.xactware.com/en.../new-xactremodel-includes-**aerial-sketch**/
Apr 5, 2012 ... Xactware's new release of XactRemodel® includes **Aerial Sketch**®, a patent- pending tool that helps remodelers quickly draw plans of existing ...
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- HR Departments (/index.php?option=com_k2&view=item&layout=item&id=5517&Itemid=894)
- Retail (/index.php?option=com_k2&view=item&layout=item&id=1568&Itemid=871)
- Commercial Real Estate (/index.php?option=com_k2&view=item&layout=item&id=2273&Itemid=911)
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www.xactware.com/en-us/solutions/.../**property-insight**/overview/

Property InSight is a comprehensive data package that provides detail about the exterior of a structure including roof and exterior diagrams with the ...
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Property InSight - FAQs | Xactware (http://www.xactware.com/en-us/solutions/property-
www.xactware.com/en-us/solutions/property.../**property-insight**/faqs/
A. **Property InSight** is a data solution from Xactware that offers quick delivery of in-depth property data directly into Xactware products. The data includes a native ...
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Property InSight - About | Xactware (http://www.xactware.com/en-us/solutions/property-
www.xactware.com/en-us/solutions/...data/**property-insight**/about/

Xactware **Property InSight** is the fast, easy way to learn crucial details about a structure that will save you time and help provide faster and more detailed service.
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News - Xactware's **Property InSight** Is Now Available | Xactware
www.xactware.com/.../xactwares-**property-insight**-is-now-available/
Feb 10, 2015 ... Xactware today announced that **Property InSight**™ is now available for all residential, commercial, and agricultural structures in the United ...
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Property InSight - Features | Xactware (http://www.xactware.com/en-us/solutions/property-
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Property InSight provides comprehensive property data that includes all dimensions and slopes. The native Xactimate Sketch included with **Property InSight** can ...
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Xactware's **Property InSight** team uses advanced technologies to extract detailed dimensions and roof information including the length, perimeter, slope, area, ...
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Roof InSight is the quick and painless way to seamlessly get roof dimensions and data into an estimate. And each **Roof InSight** data package is fully guaranteed.
Labeled Xactware

Roof InSight - FAQs | Xactware (http://www.xactware.com/en-us/solutions/roof-data/roof-insight/faqs/)
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A. **Roof InSight** offers estimators quick and seamless delivery of comprehensive roof data directly into Xactimate in the native Sketch format. It includes the roof ...
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www.xactware.com/en-us/solutions/roof-data/**roof-insight**/about/

Roof InSight provides a set of five high-quality aerial images of a roof – top down, and one for each of the cardinal compass points – prior to the damage.
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Roof InSight - Roof InSight Test | Xactware (http://www.xactware.com/en-us/solutions/roof-
www.xactware.com/en-us/solutions/.../**roof-insight**/**roof-insight**-test/


Roof InSight is coming soon in the next Xactimate update. When it comes to delivering effective insight on the dimensions and characteristics of a roof, collecting ...
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Roof InSight - Xactware **Roof InSight** License Agreement | Xactware
www.xactware.com/.../**roof-insight**/xactware-**roof-insight**-license-agreement/
AS A CONDITION TO YOUR LICENSE TO USE **ROOF INSIGHT** AS FURTHER DEFINED HEREIN, YOU MUST AGREE TO THE FOLLOWING ADDENDUM TO ...
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Roof InSight - St. Louis Missouri Tornado | Xactware (http://www.xactware.com/en-
www.xactware.com/en-us/solutions/roof.../**roof-insight**/saint-louis/

(http://www.xactware.com/en-us/solutions/roof-data/roof-insight/saint-louis/)
April 10 Missouri: Before and After. When they strike heavily populated areas, even smaller tornadoes wreak havoc for homeowners. On April 10, 2013 an F2 ...
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Roof InSight - Guarantee | Xactware (http://www.xactware.com/en-us/solutions/roof-
www.xactware.com/en-us/solutions/roof.../**roof-insight**/**roof-insight**/
... **Roof InSight** Guarantee. **Roof Insight** Guarantee. If for any reason you are not satisfied with your Xactware **Roof InSight**, contact us to receive a full credit.
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1 2 3 4 5 6 7 8 9 10

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CIVIL COVER SHEET

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. *(SEE INSTRUCTIONS ON NEXT PAGE OF THIS FORM.)*

I. (a) PLAINTIFFS

EAGLE VIEW TECHNOLOGIES, INC.,
PICTOMETRY INTERNATIONAL CORP.

(b) County of Residence of First Listed Plaintiff: Snohomish County, WA
(EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorneys *(Firm Name, Address, and Telephone Number)*
Liza M. Walsh
Connell Foley, One Newark Center, 1085 Raymond Blvd., 19th Floor
Newark, NJ 07102 lwalsh@connellfoley.com

DEFENDANTS

XACTWARE SOLUTIONS, INC.,
VERISK ANALYTICS, INC.

County of Residence of First Listed Defendant: ______
(IN U.S. PLAINTIFF CASES ONLY)

NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE TRACT OF LAND INVOLVED

Attorneys *(If Known)*

II. BASIS OF JURISDICTION *(Place an "X" in One Box Only)*

☐ 1 U.S. Government Plaintiff
☒ 3 Federal Question *(U.S. Government Not a Party)*
☐ 2 U.S. Government Defendant
☐ 4 Diversity *(Indicate Citizenship of Parties in Item III)*

III. CITIZENSHIP OF PRINCIPAL PARTIES *(Place an "X" in One Box for Plaintiff and One Box for Defendant)* *(For Diversity Cases Only)*

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated *or* Principal Place of Business In This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated *and* Principal Place of Business In Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. NATURE OF SUIT *(Place an "X" in One Box Only)*

CONTRACT
☐ 110 Insurance
☐ 120 Marine
☐ 130 Miller Act
☐ 140 Negotiable Instrument
☐ 150 Recovery of Overpayment & Enforcement of Judgment
☐ 151 Medicare Act
☐ 152 Recovery of Defaulted Student Loans (Excludes Veterans)
☐ 153 Recovery of Overpayment of Veteran's Benefits
☐ 160 Stockholders' Suits
☐ 190 Other Contract
☐ 195 Contract Product Liability
☐ 196 Franchise

REAL PROPERTY
☐ 210 Land Condemnation
☐ 220 Foreclosure
☐ 230 Rent Lease & Ejectment
☐ 240 Torts to Land
☐ 245 Tort Product Liability
☐ 290 All Other Real Property

TORTS

PERSONAL INJURY
☐ 310 Airplane
☐ 315 Airplane Product Liability
☐ 320 Assault, Libel & Slander
☐ 330 Federal Employers' Liability
☐ 340 Marine
☐ 345 Marine Product Liability
☐ 350 Motor Vehicle
☐ 355 Motor Vehicle Product Liability
☐ 360 Other Personal Injury
☐ 362 Personal Injury - Medical Malpractice

PERSONAL INJURY
☐ 365 Personal Injury - Product Liability
☐ 367 Health Care/ Pharmaceutical Personal Injury Product Liability
☐ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
☐ 370 Other Fraud
☐ 371 Truth in Lending
☐ 380 Other Personal Property Damage
☐ 385 Property Damage Product Liability

CIVIL RIGHTS
☐ 440 Other Civil Rights
☐ 441 Voting
☐ 442 Employment
☐ 443 Housing/ Accommodations
☐ 445 Amer. w/Disabilities - Employment
☐ 446 Amer. w/Disabilities - Other
☐ 448 Education

PRISONER PETITIONS
Habeas Corpus:
☐ 463 Alien Detainee
☐ 510 Motions to Vacate Sentence
☐ 530 General
☐ 535 Death Penalty
Other:
☐ 540 Mandamus & Other
☐ 550 Civil Rights
☐ 555 Prison Condition
☐ 560 Civil Detainee - Conditions of Confinement

FORFEITURE/PENALTY
☐ 625 Drug Related Seizure of Property 21 USC 881
☐ 690 Other

LABOR
☐ 710 Fair Labor Standards Act
☐ 720 Labor/Management Relations
☐ 740 Railway Labor Act
☐ 751 Family and Medical Leave Act
☐ 790 Other Labor Litigation
☐ 791 Employee Retirement Income Security Act

IMMIGRATION
☐ 462 Naturalization Application
☐ 465 Other Immigration Actions

BANKRUPTCY
☐ 422 Appeal 28 USC 158
☐ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
☐ 820 Copyrights
☒ 830 Patent
☐ 840 Trademark

SOCIAL SECURITY
☐ 861 HIA (1395ff)
☐ 862 Black Lung (923)
☐ 863 DIWC/DIWW (405(g))
☐ 864 SSID Title XVI
☐ 865 RSI (405(g))

FEDERAL TAX SUITS
☐ 870 Taxes (U.S. Plaintiff or Defendant)
☐ 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
☐ 375 False Claims Act
☐ 400 State Reapportionment
☐ 410 Antitrust
☐ 430 Banks and Banking
☐ 450 Commerce
☐ 460 Deportation
☐ 470 Racketeer Influenced and Corrupt Organizations
☐ 480 Consumer Credit
☐ 490 Cable/Sat TV
☐ 850 Securities/Commodities/ Exchange
☐ 890 Other Statutory Actions
☐ 891 Agricultural Acts
☐ 893 Environmental Matters
☐ 895 Freedom of Information Act
☐ 896 Arbitration
☐ 899 Administrative Procedure Act/Review or Appeal of Agency Decision
☐ 950 Constitutionality of State Statutes

V. ORIGIN *(Place an "X" in One Box Only)*

☒ 1 Original Proceeding
☐ 2 Removed from State Court
☐ 3 Remanded from Appellate Court
☐ 4 Reinstated or Reopened
☐ 5 Transferred from Another District *(specify)*
☐ 6 Multidistrict Litigation

VI. CAUSE OF ACTION

Cite the U.S. Civil Statute under which you are filing *(Do not cite jurisdictional statutes unless diversity)*:
35 U.S.C. 271

Brief description of cause:
Patent Infringement

VII. REQUESTED IN COMPLAINT:

☐ CHECK IF THIS IS A CLASS ACTION UNDER RULE 23, F.R.Cv.P.

DEMAND $

CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ Yes ☐ No

VIII. RELATED CASE(S) IF ANY

(See instructions): JUDGE ______ DOCKET NUMBER ______

DATE: 09/23/2015

SIGNATURE OF ATTORNEY OF RECORD: s/ Liza M. Walsh

FOR OFFICE USE ONLY

RECEIPT # ______ AMOUNT ______ APPLYING IFP ______ JUDGE ______ MAG. JUDGE ______