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APPLICATION NUMBER: ***13/424,054***
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	6338.157
First Inventor	Chris Thornberry
Title	A Method and System for Quick Squar
Express Mail Label No.	Electronically Transmitted

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. ☐ **Fee Transmittal Form** (e.g., PTO/SB/17)
2. ☑ **Applicant claims small entity status.** See 37 CFR 1.27.
3. ☑ **Specification** [*Total Pages* 36] Both the claims and abstract must start on a new page *(For information on the preferred arrangement, see MPEP 608.01(a))*
4. ☑ **Drawing(s)** (*35 U.S.C. 113*) [*Total Sheets* 9]
5. **Oath or Declaration** [*Total Sheets* _____]
   a. ☑ Newly executed (original or copy)
   b. ☐ A copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional with Box 18 completed)*
      i. ☐ DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) name in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. ☐ **Application Data Sheet.** See 37 CFR 1.76
7. ☐ **CD-ROM or CD-R** in duplicate, large table or Computer Program *(Appendix)* ☐ Landscape Table on CD
8. **Nucleotide and/or Amino Acid Sequence Submission** *(if applicable, items a. – c. are required)*
   a. ☐ Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies); or
      ii. ☐ Paper
   c. ☐ Statements verifying identity of above copies

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ACCOMPANYING APPLICATION PARTS

9. ☐ **Assignment Papers** (cover sheet & document(s))
   Name of Assignee _____
10. ☐ **37 CFR 3.73(b) Statement** *(when there is an assignee)* ☐ **Power of Attorney**
11. ☐ **English Translation Document** *(if applicable)*
12. ☐ **Information Disclosure Statement** (PTO/SB/08 or PTO-1449) ☐ Copies of citations attached
13. ☐ **Preliminary Amendment**
14. ☐ **Return Receipt Postcard** (MPEP 503) *(Should be specifically itemized)*
15. ☐ **Certified Copy of Priority Document(s)** *(if foreign priority is claimed)*
16. ☐ **Nonpublication Request** under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or equivalent.
17. ☐ Other: _____

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in the first sentence of the specification following the title, or in an Application Data Sheet under 37 CFR 1.76:*

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: .....

Prior application information: *Examiner* _____ *Art Unit:* _____

19. CORRESPONDENCE ADDRESS

☑ The address associated with Customer Number: 30589 ***OR*** ☑ Correspondence address below

Name	Dunlap Codding, P.C.				
Address	P.O. Box 16370				
City	Oklahoma City	State	Oklahoma	Zip Code	73113
Country	USA	Telephone	405-607-8600	Email	dsorocco@dunlapcodding.com

Signature		Date	03/19/2012
Name (Print/Type)	Douglas J. Sorocco	Registration No. (Attorney/Agent)	43,145

This collection of information is required by 37 CFR 1.53(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**
If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Electronically Transmitted: March 19, 2012 **Utility**

A Method and System for Quick Square Roof Reporting

Cross-Reference to Related Applications

[0001] Not Applicable.

Background

[0002] Residential and/or commercial property owners approaching a major roofing project may be unsure of the amount of material needed and/or the next step in completing the project. Generally, such owners contact one or more contractors for a site visit. Each contractor must physically be present at the site of the structure in order to make a determination on material needs and/or time. The time and energy for providing such an estimate becomes laborious and may be affected by contractor timing, weather, contractor education, and the like. Estimates may be varied even between contractors in determination of estimated square footage causing variance in supply ordering as well. Additionally, measuring an actual roof may be costly and potentially hazardous – especially with steeply pitched roofs. Completion of a proposed roofing project may depend on ease in obtaining a simplified roofing estimate and/or obtaining reputable contractors for the roofing project.

[0003] Images are currently being used to measure objects and structures within the images, as well as to be able to determine geographic locations of points within the image when preparing estimates for a variety of construction projects, such as roadwork, concrete work, and roofing. Estimating construction projects using software may increase speed at which an estimate can be prepared, and may reduce labor and fuel costs associated with on-site visits.

Brief Description of the Several Views of the Drawings

[0004] Like reference numerals in the figures represent and refer to the same or similar 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:

[0005] FIG. 1 is a schematic diagram of an embodiment of a roof estimator reporting system according to the instant disclosure.

[0006] FIG. 2 is a block diagram of an embodiment of one or more memory according to the instant disclosure.

[0007] FIG. 3 is an exemplary embodiment of a program logic according to the instant disclosure.

[0008] FIG. 4 is another exemplary embodiment of a program logic according to the instant disclosure.

[0009] FIG. 5 is yet another exemplary embodiment of a program logic according to the instant disclosure.

[0010] FIG. 6 is a further exemplary embodiment of a program logic according to the instant disclosure.

[0011] FIG. 7 is an exemplary slope factor chart for determining pitch factors according to the instant disclosure.

[0012] FIG. 8 is an exemplary embodiment of a roofing report presentation page according to the instant disclosure.

Detailed Description of Inventive Concept

[0013] Before explaining at least one embodiment of the inventive concept disclosed herein in detail, it is to be understood that the inventive concept 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 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 any way.

[0014] In the following detailed description of embodiments of the inventive concept, numerous specific details are set forth in order to provide a more thorough understanding of the inventive concept. It will be apparent to one of ordinary skill in the art, however, that the inventive concept within the disclosure may be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the instant disclosure.

[0015] Referring now to the drawings, and in particular to FIG. 1, shown therein and designated by a reference numeral 100 is an exemplary computer system 100 constructed in accordance with the present disclosure. The system 100 can be a system or systems that are able to embody and/or execute the logic of the processes described herein. The logic embodied in the form of software instructions, or firmware may be executed on any appropriate hardware which may be a dedicated system or systems.

[0016] As used herein, the terms "network-based", "cloud-based" and any variations thereof, are intended to include the provision of configurable computational resources on demand via interfacing with a computer and/or computer network, with software and/or data at least partially located on the computer and/or computer network, by pooling processing power of two or more networked processors.

[0017] As used herein, the terms "comprises", "comprising", "includes", "including", "has", "having", or any other variation thereof, are intended to be non-exclusive inclusions. For example, a process, method, article, or apparatus that comprises a set of elements is not limited to only those elements but may include other elements not expressly listed or even inherent to such process, method, article, or apparatus.

[0018] As used in the instant disclosure, the terms "provide", "providing", and variations thereof comprise displaying or providing for display a webpage (e.g., roofing webpage) to one or more user terminals interfacing with a computer and/or computer network(s) and/or allowing the one or more user terminal(s) to participate, such as by interacting with one or more mechanisms on a webpage (e.g., roofing webpage) by sending and/or receiving signals (e.g., digital, optical, and/or the like) via a computer network interface (e.g., Ethernet port, TCP/IP port, optical port, cable modem, and combinations thereof). A user may be provided with a web page in a web browser, or in a software application, for example.

[0019] As used herein, the term "roof request", "roofing request", "roofing order", and any variations thereof may comprise a feature of the graphical user interface or a feature of a software application, allowing a user to indicate to a host system that the

user wishes to place an order, such as by interfacing with the host system over a computer network and exchanging signals (e.g., digital, optical, and/or the like), with the host system using a network protocol, for example. Such mechanism may be implemented with computer executable code executed by one or more processors, for example, with a button, a hyperlink, an icon, a clickable symbol, and/or combinations thereof, that may be activated by a user terminal interfacing with the at least one processor over a computer network, for example.

[0020] Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by anyone of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0021] In addition, the use of the "a" or "an" are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the inventive concept. This description should be read to include one or more, and the singular also includes the plural unless it is obvious that it is meant otherwise.

[0022] Finally, as used herein any reference to "one embodiment" or "an embodiment" means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The appearance of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

[0023] Referring now to FIG. 1, shown therein is an exemplary embodiment of a roof estimator reporting system 100 according to the instant disclosure. The system

100 comprises two or more host systems 102 and 126 interfacing and/or communicating with one or more user terminals 104 via a network 106.

[0024] The one or more user terminals 104 may be implemented as a personal computer, a smart phone, network-capable TV set, TV set-top box, a tablet, an e-book reader, a laptop computer, a desktop computer, a network-capable handheld device, a video game console, a server, a digital video recorder, a DVD-player, a Blu-Ray player and combinations thereof, for example. In an exemplary embodiment, the user terminal 104 may comprise an input device 122, an output device 124, a processor (not shown) capable of interfacing with the network 106, processor executable code (not shown), and a web browser capable of accessing a website and/or communicating information and/or data over a network, such as the network 106. As will be understood by persons of ordinary skill in the art, the one or more user terminals 104 may comprise one or more non-transient memories comprising processor executable code and/or software applications, for example.

[0025] The input device 122 may be capable of receiving information input from a user and/or other processor(s), and transmitting such information to the user terminal 104 and/or to the host system 102. The input device 122 may be implemented as a keyboard, a touchscreen, a mouse, a trackball, a microphone, a fingerprint reader, an infrared port, a slide-out keyboard, a flip-out keyboard, a cell phone, a PDA, a video game controller, a remote control, a fax machine, a network interface, and combinations thereof, for example.

[0026] The output device 124 may output information in a form perceivable by a user and/or other processor(s). For example, the output device 124 may be a server, a

computer monitor, a screen, a touchscreen, a speaker, a website, a TV set, a smart phone, a PDA, a cell phone, a fax machine, a printer, a laptop computer, and combinations thereof. It is to be understood that in some exemplary embodiments, the input device 122 and the output device 124 may be implemented as a single device, such as, for example, a touchscreen or a tablet. It is to be further understood that as used herein the term user is not limited to a human being, and may comprise a computer, a server, a website, a processor, a network interface, a human, a user terminal, a virtual computer, and combinations thereof, for example.

[0027] The system 100 may include one or more host systems. For example, FIG. 1 illustrates system 100 having two host systems 102 and 126. The host systems 102 and 126 may be partially or completely network-based or cloud based, and not necessarily located in a single physical location. Each of the host systems 102 and 126 may further be capable of interfacing and/or communicating with the one or more user terminals 104 via the network 106, such as by exchanging signals (e.g., digital, optical, and/or the like) via one or more ports (e.g., physical or virtual) using a network protocol, for example. Additionally, each host system 102 and 126 may be capable of interfacing and/or communicating with other host systems directly and/or via the network 106, such as by exchanging signals (e.g., digital, optical, and/or the like) via one or more ports.

[0028] In some embodiments, host systems 102 and 126 may be independently controlled by separate entities. Host system 102 may be controlled by a first company and host system 126 may be controlled by a second company distinct from the first company. For example, host system 102 may be controlled by a roofing material

supplier and host system 126 may be controlled by a roofing report company. The roofing material supplier may be a separate entity from the roofing report company.

[0029] The host system 102 may be referred to hereinafter as the "first host system" and the host system 126 may be referred to hereinafter as the "second host system". The first host system 102 may comprise one or more processors 108 working together, or independently to, execute processor executable code, one or more memories 110 capable of storing processor executable code, one or more input devices 112, and one or more output devices 114. Each element of the first host system 102 may be partially or completely network-based or cloud-based, and not necessarily located in a single physical location.

[0030] The one or more processors 108 may be implemented as a single or plurality of processors 108 working together, or independently to execute the logic as described herein. Exemplary embodiments of the one or more processors 108 include a digital signal processor (DSP), a central processing unit (CPU), a field programmable gate array (FPGA), a microprocessor, a multi-core processor, and/or combinations thereof. The one or more processors 108 may be capable of communicating with the one or more memories 110 via a path (e.g., data bus). The one or more processors 108 may be capable of communicating with the input devices 112 and the output devices 114.

[0031] The one or more processors 108 may be further capable of interfacing and/or communicating with the one or more user terminals 104 via the network 106. For example, the one or more processors 108 may be capable of communicating via the network 106 by exchanging signals (e.g., digital, optical, and/or the like) via one or more

physical or virtual ports using a network protocol. It is to be understood that in certain embodiments using more than one processor 108, the one or more processors 108 may be located remotely from one another, located in the same location, or comprising a unitary multi-core processor (not shown). The one or more processors 108 may be capable of reading and/or executing processor executable code and/or of creating, manipulating, altering, and/or storing computer data structures into one or more memories 110.

[0032] The one or more memories 110 may be capable of storing processor executable code. Additionally, the one or more memories 110 may be implemented as a conventional non-transient memory 110, such as, for example, random access memory (RAM), a CD-ROM, a hard drive, a solid state drive, a flash drive, a memory card, a DVD-ROM, a floppy disk, an optical drive, and/or combinations thereof. It is to be understood that while one or more memories 110 may be located in the same physical location as the first host system 102, the one or more memories 110 may be located remotely from the first host system 102, and may communicate with the one or more processor 108 via the network 106. Additionally, when more than one memory 110 is used, a first memory 110 may be located in the same physical location as the first host system 102, and additional memories 110 may be located in a remote physical location from the first host system 102. The physical location(s) of the one or more memories 110 may be varied. Additionally, one or more memories 110 may be implemented as a "cloud memory" (i.e., one or more memory 110 may be partially or completely based on or accessed using the network 106).

[0033] The one or more input devices 112 may transmit data to the processors 108, and may be implemented as a keyboard, a mouse, a touchscreen, a camera, a cellular phone, a tablet, a smart phone, a PDA, a microphone, a network adapter, and/or combinations thereof. The input devices 112 may be located in the same physical location as the first host system 102, or may be remotely located and/or partially or completely network-based.

[0034] The one or more output devices 114 may transmit information from the processor 108 to a user, such that the information may be perceived by the user. For example, the output devices 114 may be implemented as a server, a computer monitor, a cell phone, a tablet, a speaker, a website, a PDA, a fax, a printer, a projector, a laptop monitor, and/or combinations thereof. The output device 114 may be physically co-located with the first host system 102, or may be located remotely from the first host system 102, and may be partially or completely network based (e.g., website). As used herein, the term "user" is not limited to a human, and may comprise a human, a computer, a host system, a smart phone, a tablet, and/or combinations thereof, for example.

[0035] The first host system 102 may directly communicate with the second host system 126 and/or communicate via network 106. Generally, the first host system 102 may include one or more processors 108 capable of executing a first set of processor executable code and the second host system 126 may include one or more processors 128 capable of executing a second set of processor executable code.

[0036] The second host system 126 may further comprise one or more memories 130 capable of storing processor executable code, one or more input devices 132, and

one or more output devices 134. Each element of the second host system 126 may be partially or completely network-based or cloud based, and not necessarily located in a single physical location.

[0037] The one or more processors 128 may be implemented as a single or a plurality of processors 128 working together to execute the logic described herein. Exemplary embodiments of the one or more processors 128 include a digital signal processor (DSP), a central processing unit (CPU), a field programmable gate array (FPGA), a microprocessor, a multi-core processor, and/or combinations thereof. The one or more processors 128 may be capable of communicating with the one or more memories 130 via a path (e.g., data bus). The one or more processors 128 may be capable of communicating with the input devices 132 and the output devices 134.

[0038] The one or more processors 128 may be further capable of interfacing and/or communicating with the one or more user terminals 104 via the network 106. For example, the one or more processors 128 may be capable of communicating via the network 106 by exchanging signals (e.g., digital, optical, and/or the like) via one or more physical or virtual ports using a network protocol. It is to be understood that in certain embodiments using more than one processor 128, the one or more processors 128 may be located remotely from one another, located in the same location, or comprising a unitary multi-core processor (not shown). The one or more processors 128 may be capable of reading and/or executing processor executable code and/or of creating, manipulating, altering, and/or storing computer data structures into one or more memories 130.

[0039] The one or more memories 130 may be capable of storing processor executable code. Additionally, the one or more memories 130 may be implemented as a conventional non-transient memory 130, such as, for example, random access memory (RAM), a CD-ROM, a hard drive, a solid state drive, a flash drive, a memory card, a DVD-ROM, a floppy disk, an optical drive, and/or combinations thereof. It is to be understood that while one or more memories 130 may be located in the same physical location as the second host system 126, the one or more memories 130 may be located remotely from the second host system 126, and may communicate with the one or more processor 128 via the network 106. Additionally, when more than one memory 130 is used, a first memory 130 may be located in the same physical location as the second host system 126, and additional memories 130 may be located in a remote physical location from the second host system 126. The physical location(s) of the one or more memories 130 may be varied. Additionally, one or more memories 130 may be implemented as a "cloud memory" (i.e., one or more memory 130 may be partially or completely based on or accessed using the network 106).

[0040] The input devices 132 may transmit data to the processors 128, and may be implemented as a keyboard, a mouse, a touchscreen, a camera, a cellular phone, a tablet, a smart phone, a PDA, a microphone, a network adapter, and/or combinations thereof. The input devices 132 may be located in the same physical location as the second host system 126, or may be remotely located and/or partially or completely network-based.

[0041] The output devices 134 may transmit information from the processors 128 to a user, such that the information may be perceived by the user. For example, the

output devices 134 may be implemented as a server, a computer monitor, a cell phone, a tablet, a speaker, a website, a PDA, a fax, a printer, a projector, a laptop monitor, and/or combinations thereof. The output devices 134 may be physically co-located with the second host system 126, or may be located remotely from the second host system 126, and may be partially or completely network based (e.g., website).

[0042] The network 106 may permit bi-directional communication of information and/or data between the first host system 102, the second host system 126 and/or user terminals 104. The network 106 may interface with the first host system 102, the second host system 126, and the user terminals 104 in a variety of ways. For example, the network 106 may interface by optical and/or electronic interfaces, and/or may use a plurality of network topographies and/or protocols including, but not limited to, Ethernet, TCP/IP, circuit switched paths, and/or combinations thereof. For example, the network 106 may be implemented as the World Wide Web (or Internet), a local area network (LAN), a wide area network (WAN), a metropolitan network, a wireless network, a cellular network, a GSM-network, a CDMA network, a 3G network, a 4G network, a satellite network, a radio network, an optical network, a cable network, a public switched telephone network, an Ethernet network, and/or combinations thereof. Additionally, the network 106 may use a variety of network protocols to permit bi-directional interface and/or communication of data and/or information between the first host system 102, the second host system 126, and/or one or more user terminals 104.

[0043] Referring to FIGS. 1 and 2, the one or more memories 110 may store processor executable code and/or information comprising a user database 136, a contractor database 137, a first image database 138 and program logic 139. The

processor executable code may be stored as a data structure, such as a database and/or a data table, for example.

[0044] The user database 136 may include information about customers engaging with the first host system 102. For example, one or more customers may access the first host system 102 through the one or more user terminals 104. The first host system 102 may provide a roof request website to the user terminal 104. The roof request website may be directed by the one or more processors 108. The processor 108 may also direct the one or more customers to a login/registration portion of the website.

[0045] In some embodiments, customers may register a user profile with the first host system 102. The user profile may be created and/or stored in the user database 136 by the processor 108. For example, the customer may be prompted by the processor 108 to provide login credentials (e.g., username and/or password). Login credentials may allow the processor 108 to authenticate the customer against the user database 136. In this manner, the first host system 102 may access the user profile in the user database 136. The user profile may include information including, but not limited to, demographic information including, but not limited to, name, age, address, billing account information, username, password, behavioral information, experience, gender, and/or the like.

[0046] If user authentication is successful, the user profile may be accessed by the processor 108. If the user authentication fails, the customer may be returned to the login/registration page, where the customer may be prompted for a username and

password again. Optionally, the processor 108 may block a customer from entering a username and/or password after a preset number of failed authentication attempts.

[0047] In some embodiments, customers may be prompted by the processor 108 to provide information for a user profile without registration and/or authentication using a username and/or password. The user profile may be created and/or stored in the user database 136 by the processor 108. For example, the processor 108 may prompt the customer to provide demographic information (e.g., name, address, billing account information, and the like), and store the information in a user profile for the customer using a unique customer identification.

[0048] The contractor database 137 may comprise information about roofing contractors within a given geographic location. Each roofing contractor may be associated with a contractor profile having information including, but not limited to, roofing contractor business name, roofing contractor owner name, address, experience level, age of contractor business, review information, and the like. In some embodiments, the contractor profile may include a geographical category assignment identification (ID). For example, the contractor profile may be assigned a numerical or alphabetical identification based on geographic location of the business.

[0049] In some embodiments, the contractor profile may include review information. The review information may include positive and/or negative feedback relating to each contractor. For example, the review information may be based on prior customer feedback of customers using the system 100. Review information may also be obtained from one or more outside databases (e.g., Yelp, Google review, and/or the like).

[0050] One or more contractors may provide a contractor profile via the first host system 102. For example, one or more contractors may access the roof review website of the first host system 102 via the user terminal 104. The processor 108 may direct the contractor via the roof review website to a login/registration portion of the website. If the contractor has previously registered with the first host system 102, the contractor may be prompted by the processor 108 to provide login credentials (e.g., username and/or password), which may allow the processor 108 to authenticate the contractor against the contractor database 137.

[0051] If the contractor is not registered with the first host system 102, the first host system 102 may prompt the contractor to provide information via the one or more user terminals 104 to create a contractor profile. Alternatively, the contractor profiles may be provided in the contractor database 137 without information provided by each contractor. For example, a user of the first host system 102 may provide information via the input device 112, the network 106, and/or the like, setting up a contractor profile without direct knowledge of the contractor.

[0052] The one or more memories 110 may include the image database 138. The image database 138 may store geo-referenced imagery. Such imagery may be represented by a single pixel map, and/or by a series of tiled pixel maps that when aggregated recreate the image pixel map. Imagery may include nadir, ortho-rectified and/or oblique geo-referenced images. The one or more processors 108 may provide the images via the image database 138 to customers at the one or more user terminals 104. Customers, using the user terminals 104, may provide geographic location information associated with a roof request using the geo-referenced images provided by

the one or more processors 108. For example, a customer may be provided a geo-referenced image to validate the location of a structure (e.g., roof). In some embodiments, the customer may be able to select the structure (e.g., via a drag-and-drop user interface) to pinpoint a location of the structure within the image. Selection of the structure may provide location information (e.g., latitude/longitude coordinate, or and the like) of the structure to the first host system 102. For simplicity, the description will provide for a roof as the structure of interest. However, is should be apparent that other structures of buildings and/or landscapes may be used in accordance with the present disclosure.

[0053] The one or more memories 110 may further store processor executable code and/or instructions, which may comprise the program logic 139. The program logic 139 may comprise processor executable instructions and/or code, which when executed by the processor 108, may cause the processor 108 to generate, maintain, provide, and/or host a website providing one or more roofing requests, for example. The program logic 139 may further cause the processor 108 to collect user information and/or contractor information, create user profiles and/or contractor profiles, provide users one or more geo-referenced images, and allow one or more users to validate a location of the roof as described herein.

[0054] The one or more processors 108 may generate, maintain, or provide one or more roofing orders to the second host system 126. For example, the one or more processors 108 may provide the one or more roofing orders to the second host system 126 by copying information obtained and/or stored in one or more memories 110. The

roofing orders may include contractor profile, user profile, user validated images, a unique ordering ID, and/or the like.

[0055] The one or more memories 130 of the second host system 126 may store processor executable code and/or information comprising an order database 140, a second image database 141 and the program logic 142. The processor executable code may be stored as a data structure, such as a database and/or a data table, for example.

[0056] The order database 140 may include information about a roofing order placed by a customer and copied by the first host system 102. For example, a roofing order may include contractor profile, user profile, user validated images, a unique ordering ID, and/or the like. The second host system 126 may access the order database 140 to provide a roofing report as described in detail herein.

[0057] The one or more memories 130 of the second host system 126 may also include a second image database 141. The second image database 141 may provide additional nadir, ortho-rectified, and/or oblique geo-referenced and/or non-geo-referenced images for use in providing a roofing report as described in detail herein. Alternatively, the image database 138 and the image database 141 may be the same database.

[0058] The one or more memories 130 of the second host system 126 may further store processor executable code and/or instructions, which may comprise program logic 142. The program logic 142 may comprise processor executable instructions and/or code, which when executed by the one or more processors 128, may cause the one or more processors 128 to generate, maintain, and/or provide a website

or series of websites for providing roofing reports. The program logic 142 may further cause the one or more processors 128 to allow one or more users to participate in executing a roofing report via the input devices 132.

[0059] Referring to FIG. 3, shown therein is an exemplary flow chart 144 of program logic 139 for creating a roof report order which may be used with the first host system 102 according to the instant disclosure. Program logic 139 may comprise executable code, which when executed by the one or more processors 108 may cause the one or more processors 108 to execute one or more of the following:

[0060] The program logic 139 may provide for one or more user terminals 104 interfacing with the processor 108 over the network 106 to provide one or more roofing request website pages allowing customers to place a roofing request order. Each order is generally a request of the customer to provide estimated square footage of a specific roof. Additionally, each order may also include a request for contractor information and/or a bid request for estimate costs and associated features of materials, supplies, physical labor, and the like.

[0061] Generally, in a step 145, customers using one or more user terminals 104 may provide user information to the first host system 102. The user information may then be used to prepare one or more user profiles for use in preparing the roofing report. Additionally, program logic 139 may generate a unique identification number and/or alpha numeric character to associate with the user profile.

[0062] The user information may include a location of the roof provided by the customer. For example, the customer may provide a residential and/or commercial address of the roof. One or more processors 108 may direct customers to validate the

location of the roof using user terminals 104, in step 146. For example, processors 108 may provide one or more images via the image database 138. The images may be geo-referenced images illustrating portions or all of the roof. The program logic 139 may cause the processor 108 to provide users the one or more geo-referenced images, and allow the customer to validate the location of the roof. For example, the customer may be able to use a drag-and-drop element provided by the program logic 139 via user terminal 104 to select the roof within the one or more geo-referenced images. Selection of the roof within the one or more geo-referenced images may provide one or more validated images and a validated location of the roof. In some embodiments, the geographic location may include coordinates, and validation of the geographic location may be provided by a customer by altering one or more coordinates of the geographic location. Customers may alter the one or more coordinates by methods including, but not limited to, manual manipulation, drag-and-drop elements, and the like.

[0063] It should be understood that validation of the geo-referenced images may be provided by the second host system 126 via the one or more processors 128 in lieu of, or in combination with host system 102. For example, the first host system 102 may direct customers to the second host system 126 wherein the one or more processors 128 of the second host system 126 provide geo-referenced images from image database 141 to the customer for validation of one or more roof and/or roofing structures. As such, in some embodiments, only the second host system 126 provides geo-referenced images in the image database 141.

[0064] The first host system 102 may determine contractor availability within a region of interest about the validated location of the roof as shown in step 147. For

example, program logic 139 may extract the validated location and compare the validated location against location of contractors in a region of interest. The region of interest may be determined by the customer via user terminal and/or the region of interest may be a pre-programmed determination. For example, the region of interest may be a five mile radius about the validated location. Contractor availability may include contractors having a contractor profile within the contractor database 137. Contractors within the contractor database 137 may be provided with a copy of the roofing report as described herein.

[0065] The program logic 139 may direct the one or more processors 108 to create and/or store a roofing order for the customer as shown in step 148. Additionally, the program logic 139 may direct one or more processors to transfer the roofing order to the second host system 126.

[0066] FIG. 4 illustrates a flow chart 149 of an exemplary embodiment of the program logic 139 and/or 142 for processing a roof report order which may be used with the system 100 according to the instant disclosure. The program logic 139 comprises processor executable code, that when executed by the processor 108, may cause the processor 108 to execute one or more of the following:

[0067] The program logic 139 may include a step 150 wherein one or more user terminals 104 interfacing with the processor 108 over the network 106 may be provided with one or more websites having a mechanism allowing a customer to request a roof report. The customer may provide the request to the first host system 102 using the one or more websites, in a step 152. Prior to providing customer information, the customer may be notified that the first host system 102 may distribute any contact

information provided by the customer to contractors provided within the first host system 102. The one or more processors 108 may provide the customer an option for agreeing to terms of service (e.g., distribution of their contact information), in a step 154.

[0068] In a step 156, the roof report request website may include queries regarding customer information including, but not limited to, customer name, address, address of the roof, billing information, and the like. The customer information may be provided by the one or more processors 108 and stored in the one or more memories 110. For example, the customer information may be provided by processors 108 as a user profile and stored in the user database 136 of the one or more memories 110.

[0069] Customers may be able to select the desired roof, location, and/or the like on the one or more websites provided by the processor 108 over the network 106, in step 158. For example, the customer may use the one or more user terminals 104 to provide a geographical location (e.g., address, latitude/longitude coordinates, or the like), a geo-referenced image, and/or an element within a geo-referenced image. Once the geographical location of the roof is selected, the processor 108 may provide a verification web page or similar mechanism for customer review and/or approval of a proposed order, in a step 160. The first host system 102 may receive the proposed order via the processor 108, store the order and/or transfer the order to the second host system 126 for processing, in a step 162. The processor 108 may provide a confirmation webpage or similar mechanism informing the customer of a successful order placement, in a step 164.

[0070] FIG. 5 illustrates a flow chart 169 of an exemplary embodiment of the program logic 139 and/or 142 for providing a roof report which may be used with the

system 100 according to the instant disclosure. Generally, processing of the proposed order may be provided using the second host system 126. The program logic 142 comprises processor executable code, that when executed by the processor 128, may cause the processor 128 to execute one or more of the following:

[0071] The second host system 126 may receive the proposed order via the one or more processors 108 of the first host system 102. Generally, the validity of the location of the roof provided by the customer may be determined, in a step 170. In a step 172, the second host system 126 may determine if the location of the roof provided by the customer exists. If the location is not found, the customer may be further contacted by the second host system 126 and/or the first host system 102 requesting resubmission or additional information for the proposed order, in a step 174. Additionally, in a step 176, the second host system 126 may determine if corresponding imagery within image database 141 exists for the location provided by the customer. If there is no corresponding imagery, the customer may be further contacted by the second host system 126 and/or the first host system 102 with a status message indicating no suitable imagery of the roof currently exists, in a step 178.

[0072] The second host system 126 may further process and review the order, in a step 180. An exemplary series of steps for implementing step 180 is shown in a flow chart 188 illustrated in FIG. 6. For example, the one or more processors 128 of the second host system 126 may receive the proposed order, in a step 190. The one or more processors 128 may extract order related information and images. Generally, a user may access a roof report website provided by the one or more processors 128 to review and/or process the proposed order. For example, the user may access the roof

report website using the input devices 132 and the output devices 134 to review and/or process the proposed order.

[0073] In some embodiments, using the input devices 132 and/or the output devices 134, the user may provide additional details to the proposed order regarding the roof including, but not limited to, identification of areas of the roof (e.g., eaves, drip edges, ridges, and the like), pitch, distance, angle, and/or the like.

[0074] The footprint of the roof may be determined, in step 192. For example, the footprint of the roof may be determined using systems and methods including, but not limited to, those described in U.S. Patent Publication No. 2010/0179787, U.S. Patent Publication No. 2010/0110074, U.S. Patent Publication No. 2010/0114537, U.S. Patent Publication No. 2011/0187713, U.S. Patent No. 8,078,436, and U.S. Serial No. 12/090,692, all of which are incorporated by reference herein in their entirety.

[0075] In some embodiments, the one or more processors 128 may provide one or more websites to the user for evaluation of multiple oblique images to provide the footprint of the roof. For example, the user and/or the processors 128 may identify edges of the roof. Two-dimensional and/or three-dimensional information regarding the edges (e.g., position, orientation, and/or length) may be obtained from the images. Using the two-dimensional and/or three-dimensional information (e.g., position orientation, and/or length), line segments may be determined with multiple line segments forming at least a portion of the footprint of the roof.

[0076] The footprint may provide a two-dimensional boundary and/or outline of the roof. In a step 194, a predominant pitch value for the roof may be determined. In some embodiments, a predominant pitch value may be determined using the footprint

as a boundary of the roof. The predominant pitch may be a weighted average of individual pitch factors for two or more portions of the roof. FIG. 7 illustrates an exemplary slope factor chart for determining pitch factors. For example, a first portion of the roof (e.g., 60% of the roof) may be at a 6:12 pitch. The 6:12 pitch corresponds to 1.1180 as the pitch factor). A second portion of the roof (e.g. 40% of the roof) may be at a 4:12 pitch. The 4:12 pitch corresponds to 1.0541 as the pitch factor. Thus, the weighted value of the first portion of the roof having 6:12 pitch is:

(Pitch Factor) * (Percentage of roof) = First Weighted Value **EQ. 1**

1.1180 * 0.6 = 0.6708

The weighted value of the second portion of the roof having 4:12 pitch is:

(Pitch Factor) * (Percentage of roof) = Second Weighted Value **EQ. 2**

1.0541 * 0.4 = 0.42164

The sum of 0.6708 and 0.42164 is 1.09244 as the total weighted pitch value. A total weighted pitch value of 1.09244 is closest to a pitch factor of 1.0833 in the table in FIG. 7. This pitch factor corresponds to a 5:12 pitch. As such, the predominant pitch in this scenario would be 5:12. Using the predominant pitch and outer dimensions provided by the footprint, an estimated area of the roof may be determined, in a step 196.

[0077] In some embodiments, the user may review and reevaluate the estimated area of the roof obtained. For example, using the system and methods described

herein, the user may review the steps for obtaining the footprint, the predominant pitch value, and/or estimated area. Additionally, the user may provide for a review report. The review report may comprise feedback to the one or more processors 128 regarding errors, concerns, and/or the like.

[0078] Referring to FIGS. 1, 6 and 8, in a step 184 and 186, a customer and/or contractor may receive a roof report 200. FIG. 8 illustrates an exemplary embodiment of a roof report 200 provided in accordance with the present disclosure. The program logic 139 may provide for one or more user terminals 104 interfacing with the processor 108 over the network 106 to provide one or more roofing report website pages allowing customers and/or contractors to view the roof report 200.

[0079] Generally, roofing reports within the industry are detailed with data sets regarding pitch, total area, eave length, hip ridge length, valley length, number of box vents, and the like. The roof report 200 may be streamlined to generally include data sets such as customer information 202, roofing 204, estimated area detail 206, and contractor(s) 208. The customer information data set 202 may include the customer name, customer contact information, and the like. The roofing data set 204 may include one or more nadir images of the roof and one or more oblique images of the roof. The estimated area detail 206 may provide the total estimated roof area as determined using the second host system 126 described herein. The contractor data set 208 may include one or more contractor names and associated contractor contact information for the one or more contractor names.

[0080] The roof report 200 may be distributed using the first host system 102 and/or the second host system 126 to the one or more user terminals 104. For

example, the roof report 200 may be distributed using the first host system 102 to a contractor at a first user terminal 104 and the roof report 200 may be distributed using the first host system 102 to the customer at a second user terminal 104.

[0081] In some embodiments, the first host system 102 and/or the second host system 126 may distribute the roof report 200 to one or more recipients in addition to, or in lieu of, the customer. For example, the roof report 200 may be distributed to recipients including, but not limited to, roof material suppliers (e.g., small roofing companies, Lowes, Home Depot, and the like), insurance companies, real estate agencies, home services and/or cleaning companies, insulation companies, auditing companies, and/or contractors. Contractors and/or suppliers may be associated with residential and/or commercial building elements and/or services including, but not limited to, fireplaces, pool sales, fencing, lawn maintenance, gardening, pavement resurfacing, decking, sunrooms, roofing, guttering, custom Christmas light designs, siding, windows, doors, garage doors, and the like.

[0082] In some embodiments, additional data sets may be included within the roof report 200. For example, data sets may include, but are not limited to, weather data, insurance/valuation data, census data, school district data, real estate data, and the like.

[0083] Weather data sets may be provided by one or more databases storing information associated with weather (e.g., inclement weather). A weather data set within the roof report 200 may include, but is not limited to, hail history information and/or location, wind data, severe thunderstorm data, hurricane data, tornado data, and/or the like. In some embodiments, the one or more databases providing weather

information may be hosted by a separate system (e.g., LiveHailMap.com) and provide information to the first host system 102 and/or the second host system 126. The weather data set may be included within the roof report 200 and provided to the customer and/or other parties. In some embodiments, weather data sets may be provided within a report as described herein without the addition of roof related information (e.g., roofing data set 204).

[0084] Insurance and/or valuation data sets may be provided by one or more databases storing information associated with housing insurance and/or valuation. An insurance and/or valuation data set may include, but is not limited to, insured value of the home, insurance premium amount, type of residence (e.g., multi-family, single family), number of floors (e.g., multi-floor, single-floor), building type, and/or the like. In some embodiments, the one or more databases may be hosted by a separate system (e.g., Bluebook, MSB, 360Value) and provide information to the first host system 102 and/or the second host system 126.

[0085] The insurance and/or valuation data set may be included within the roof report 200 and provided to the customer and/or other parties. For example, during underwriting of a home, an insurance company may be able to request the roof report 200 on a home that is recently purchased. The information within the roof report 200 may be integrated with insurance information provided by an insurance database and used to form a quote report. The quote report may be sent to the customer and/or insurance company. Alternatively, the roof report 200 may be solely sent to the insurance company with the insurance company using the information to formulate a quote.

[0086] In another example, the roof report 200 may be used in an insurance claim. In the case of a catastrophe of a customer, one or more databases may be used to provide an insurance dataset with claim information in the roof report 200. For example, an insurance database having a policy in force (PIF) and a weather database may be used to correlate information regarding an insurance claim for a particular roof. This information may be provided within the roof report 200.

[0087] Real estate and/or census data sets may also be including within the roof report. The real estate and/or census data sets may be provided by one or more databases having detailed information of a home. For example, a real estate data set may include, but is not limited to, the homeowner's name, the purchase price of the home, number of times the home has been on the market, the number of days the home has been on the market, the lot size, and/or the like. The census data set may include information concerning the number of residents within the home. In some embodiments, the one or more databases may be hosted by a separate system (e.g., Core Logic) and provide information to the first host system 102 and/or the second host system 126 to provide data sets as described herein. The real estate data set may be included within the roof report 200 and provided to the customer and/or other parties.

[0088] The roof reports 200 may include roofing data as described herein; however, system 100 may be used to provide other information to a customer and/or other party without roof related information (e.g., roofing data set 204). For example, in a real estate transaction, one or more databases in host system 102 and/or host system 126 may include recent home sales over time in one or more geographic areas. The footprint of each home and home valuation may be provided in one or more databases

within host system 102 and/or host system 126. Using the systems and methods described herein, a customer (e.g., homeowner) may request a report determining approximate sales price of a home using the footprint and/or valuation versus comparables within the geographic area. The report may provide an approximate sale price of the home. In some embodiments, demographics of the homeowners may be used and stored in one or more databases. The demographic information may be used for potential advertising and/or comparables within the geographic area.In another example, using systems and methods as described herein, a report may be provided for housecleaning and/or home services area (e.g., fireplace cleaning, pool sales, fencing, lawn maintenance/gardening, pavement resurfacing, decking, sunrooms, roofing, guttering, custom Christmas light designs, siding, windows, doors, garage doors, and the like). For example, using a footprint of a home, number of stories within a home, and the like, a determination of average square footage within a home may be determined. This information may be used to formulate a price quote for cleaning services.

[0089] Other services related to roofing may be provided within the roof report 200. For example, using the square footage of the roofing footprint, a price quote may be generated on the cost of insulation for the roof (e.g., energy efficiency, insulation replacement, and the like). Additionally, audits may be performed using information within one or more databases. For example, using the roofing area of a home, historically paid insurance claims for comparables, and validation of payment for a specific claim for the home, a comparison may be made to determine whether the

service payment for the specific claim was within a certain threshold. Auditing, it should be understood, may be applied to other areas as described herein as well.

[0090] Although the terms "home" and "house" are used herein, it should be noted that the systems and methods in the present disclosure may be applied to any residential and/or commercial building or structure.

[0091] 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 purposed 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 scope and spirit of the inventive concept(s) disclosed herein and defined by the appended claims.

What is claimed is:

1. A set of instructions stored on one or more computer readable medium for running on one or more computer systems, comprising:

instructions for identifying a geographic location of a roof;

instructions for determining contact information of one or more contractors within a region of interest of the geographic location of the roof; and,

instructions for determining a footprint of the roof;

instructions for determining predominant pitch of the roof;

instructions for determining an estimated roofing area based on the predominant pitch and the footprint of the roof.

2. The set of instructions of claim 1, further comprising instructions for providing a roof report, wherein the roof report includes one or more ortho images of the roof, one or more oblique images of the roof, the estimated roofing area and contact information of one or more contractor within the region of interest of the geographic location of the roof.

3. The set of instructions of claim 2, wherein the roof report includes contact information of the customer.

4. The set of instructions of claim 1, wherein the one or more computer readable medium comprises a first computer readable medium of a first host system and a second computer readable medium of a second host system.

5. The set of instructions of claim 1, wherein instructions for identifying the geographic location of the roof further comprises instructions for obtaining contact information of a customer.

6. The set of instructions of claim 1, wherein the one or more computer readable medium further comprises instructions for receiving customer input to validate geographic location of the roof.

7. The set of instructions of claim 6, wherein the geographic location includes coordinates and validation of the geographic location includes instructions for receiving customer input to alter one or more coordinates of the geographic location.

8. The set of instructions of claim 1, wherein instructions for identifying a geographic location of the roof includes identifying one or more edges of the roof in an image.

9. The set of instructions of claim 1, wherein instructions for determining a footprint of the roof further comprises:

instructions for identifying edges of the roof;

instructions for determining three-dimensional information of the edges including position, orientation and length using multiple oblique images from multiple cardinal directions; and,

instructions for determining, automatically, one or more line segments forming a portion of a footprint of the roof utilizing position and orientation of the edges.

10. The set of instructions of claim 1, wherein determining the predominant pitch includes determining a plurality of pitch values, the predominant pitch based on the plurality of pitch values.

11. The set of instructions of claim 10, wherein each pitch value is associated with an estimated percentage of roof area to provide an average pitch value.

12. The set of instructions of claim 1, further comprising:

instructions for providing the roof report to one or more contractors, the contractor located within the region of interest of the geographic location of the roof.

13. A system, comprising:

two or more host systems, each host system having one or more computer readable medium; the first host system storing a set of instructions that when executed by one or more processors causes the one or more processors to:

identify a geographic location of a roof;

determine contact information of at least one contractor within a region of interest about the geographic location of the roof;

the second host system storing a set of instructions that when executed by one or more processors causes the one or more processors to:

determine a footprint of the roof;

determine a predominant pitch;

determine an estimated roofing area based on the predominant pitch and the footprint of the roof; and,

provide a roof report, wherein the roof report includes one or more ortho images of the roof, one or more oblique images of the roof, the estimated roofing area and contact information of one or more contractors within the region of interest.

ABSTRACT

A set of instructions stored on one or more computer readable medium for running on one or more computer systems is described herein. The set of instructions generally may include instructions for identifying a geographic location of a roof, instructions for determining contact information of one or more contractors within a region of interest of the geographic location of the roof, instructions for determining a footprint of the roof, instructions for determining predominant pitch of the roof, and/or instructions for determining an estimated roofing area based on the predominant pitch and the footprint of the roof.

Electronically Filed: 03/19/2012
Title: A Method and System for Quick
Square Roof Reporting
Inventor: Chris Thornberry
Attorney: Marc A. Brockhaus Dkt. No. 6338.157
SHEET 1 OF 9 FORMAL DRAWINGS

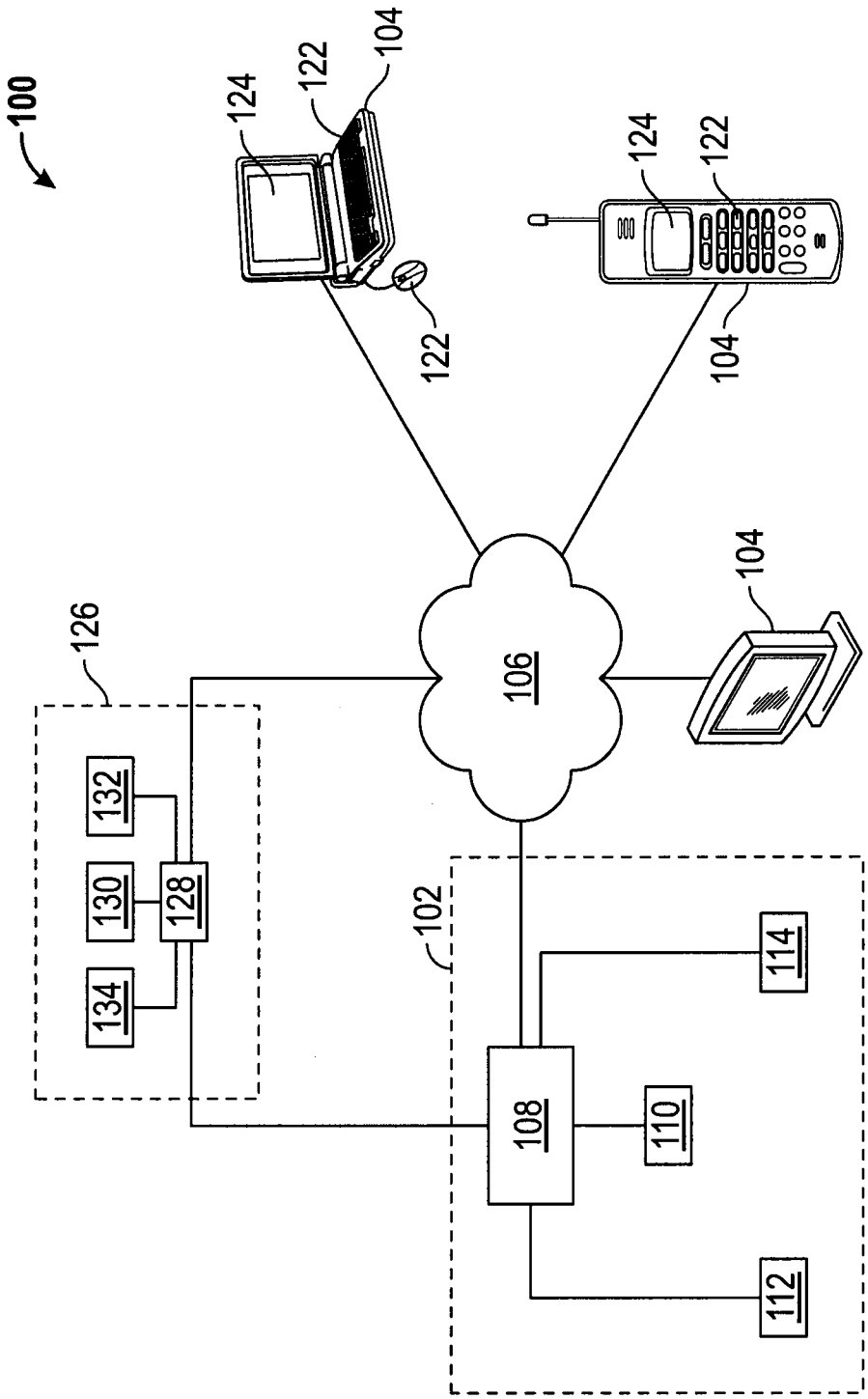


FIG. 1

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Inventor: Chris Thornberry
Attorney: Marc A. Brockhaus Dkt. No. 6338.157
SHEET 2 OF 9 FORMAL DRAWINGS

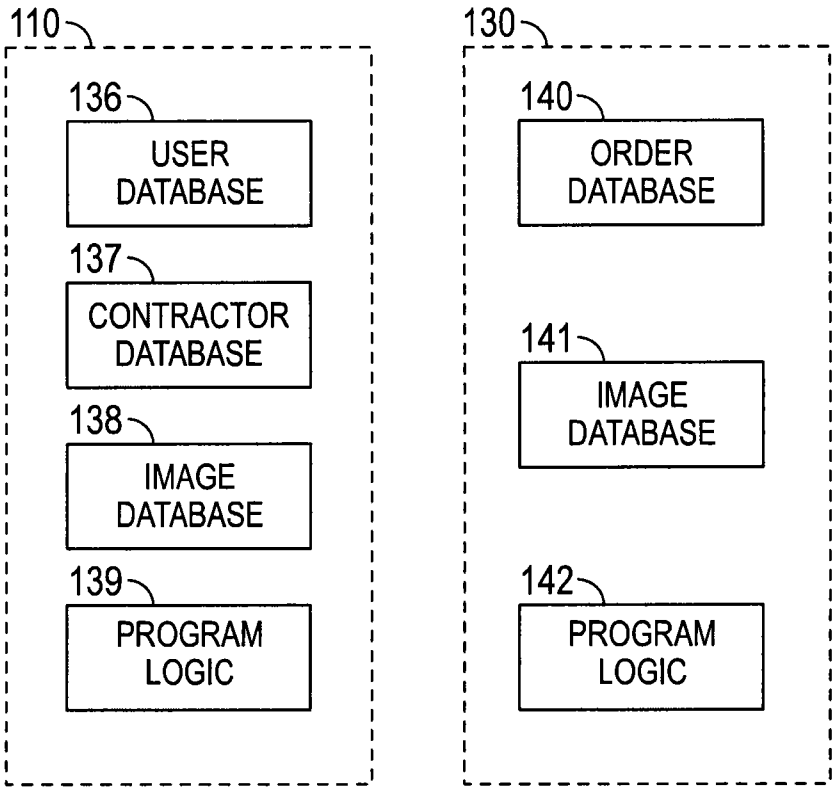


FIG. 2

Electronically Filed: 03/19/2012
Title: A Method and System for Quick Square Roof Reporting
Inventor: Chris Thornberry
Attorney: Marc A. Brockhaus Dkt. No. 6338.157
SHEET 3 OF 9 FORMAL DRAWINGS

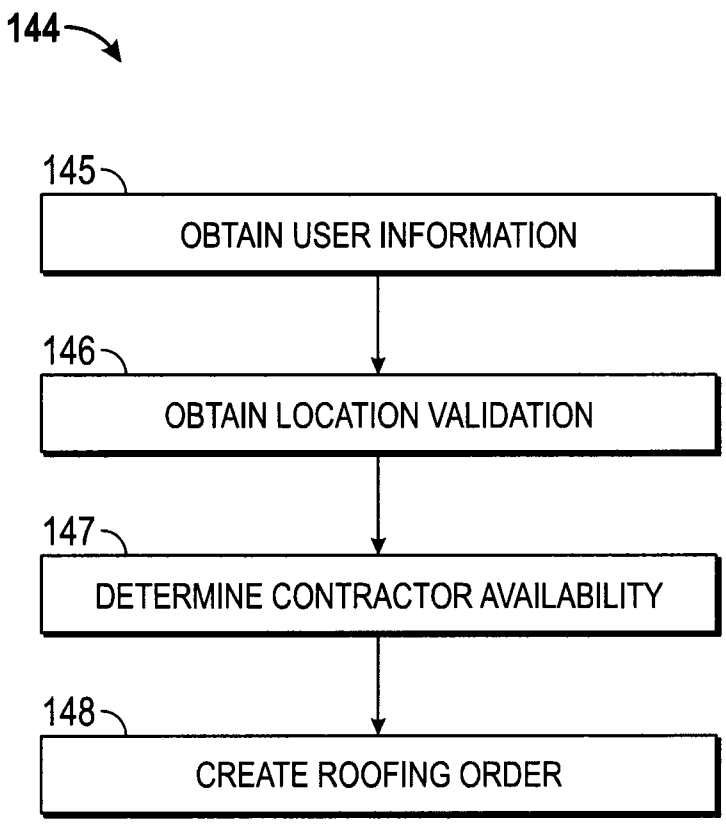


FIG. 3

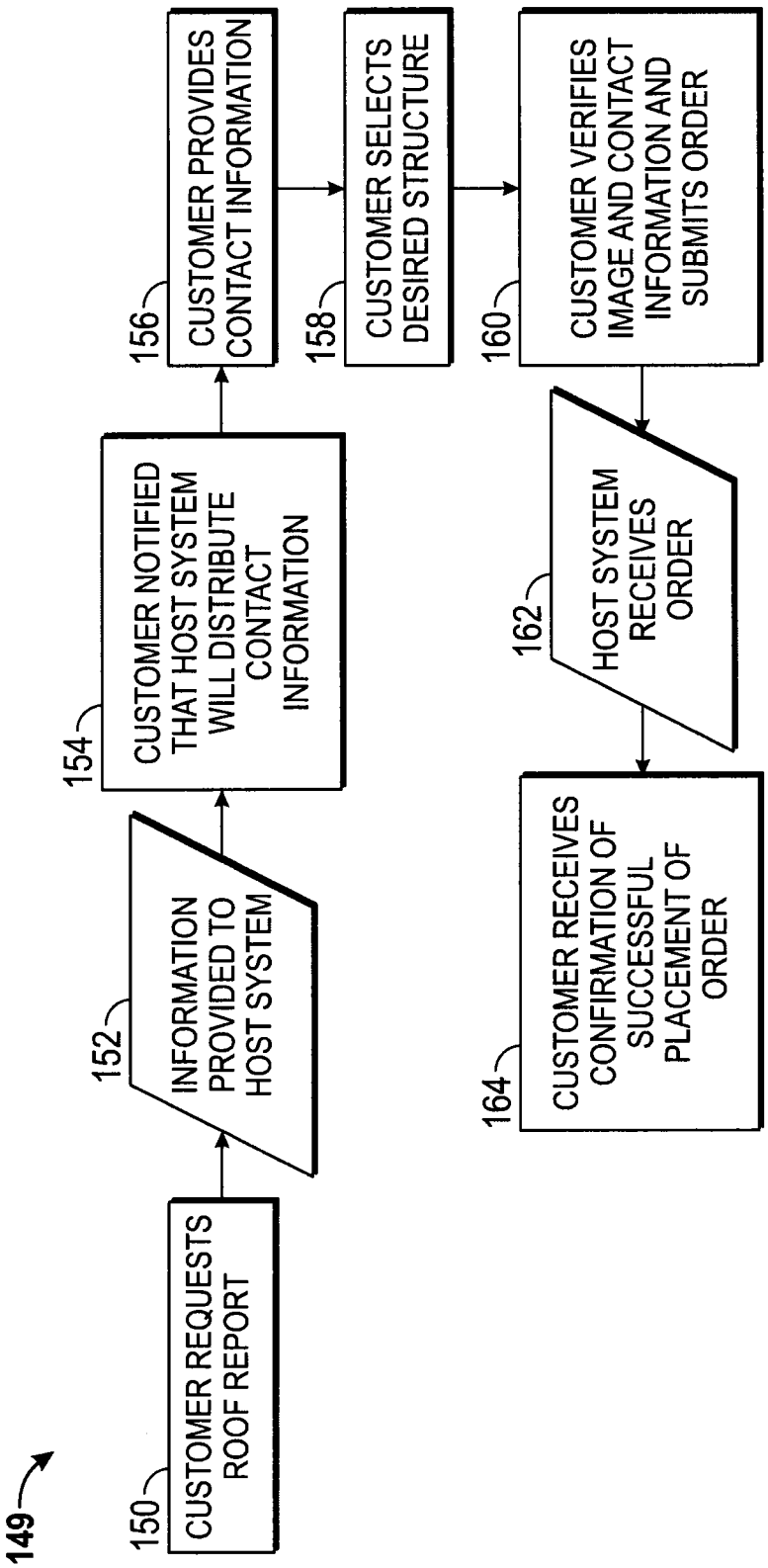

149
150
CUSTOMER REQUESTS ROOF REPORT
152
INFORMATION PROVIDED TO HOST SYSTEM
154
CUSTOMER NOTIFIED THAT HOST SYSTEM WILL DISTRIBUTE CONTACT INFORMATION
156
CUSTOMER PROVIDES CONTACT INFORMATION
158
CUSTOMER SELECTS DESIRED STRUCTURE
160
CUSTOMER VERIFIES IMAGE AND CONTACT INFORMATION AND SUBMITS ORDER
162
HOST SYSTEM RECEIVES ORDER
164
CUSTOMER RECEIVES CONFIRMATION OF SUCCESSFUL PLACEMENT OF ORDER

FIG. 4

Electronically Filed: 03/19/2012
Title: A Method and System for Quick Square Roof Reporting
Inventor: Chris Thornberry
Attorney: Marc A. Brockhaus Dkt. No. 6338.157
SHEET 5 OF 9 FORMAL DRAWINGS

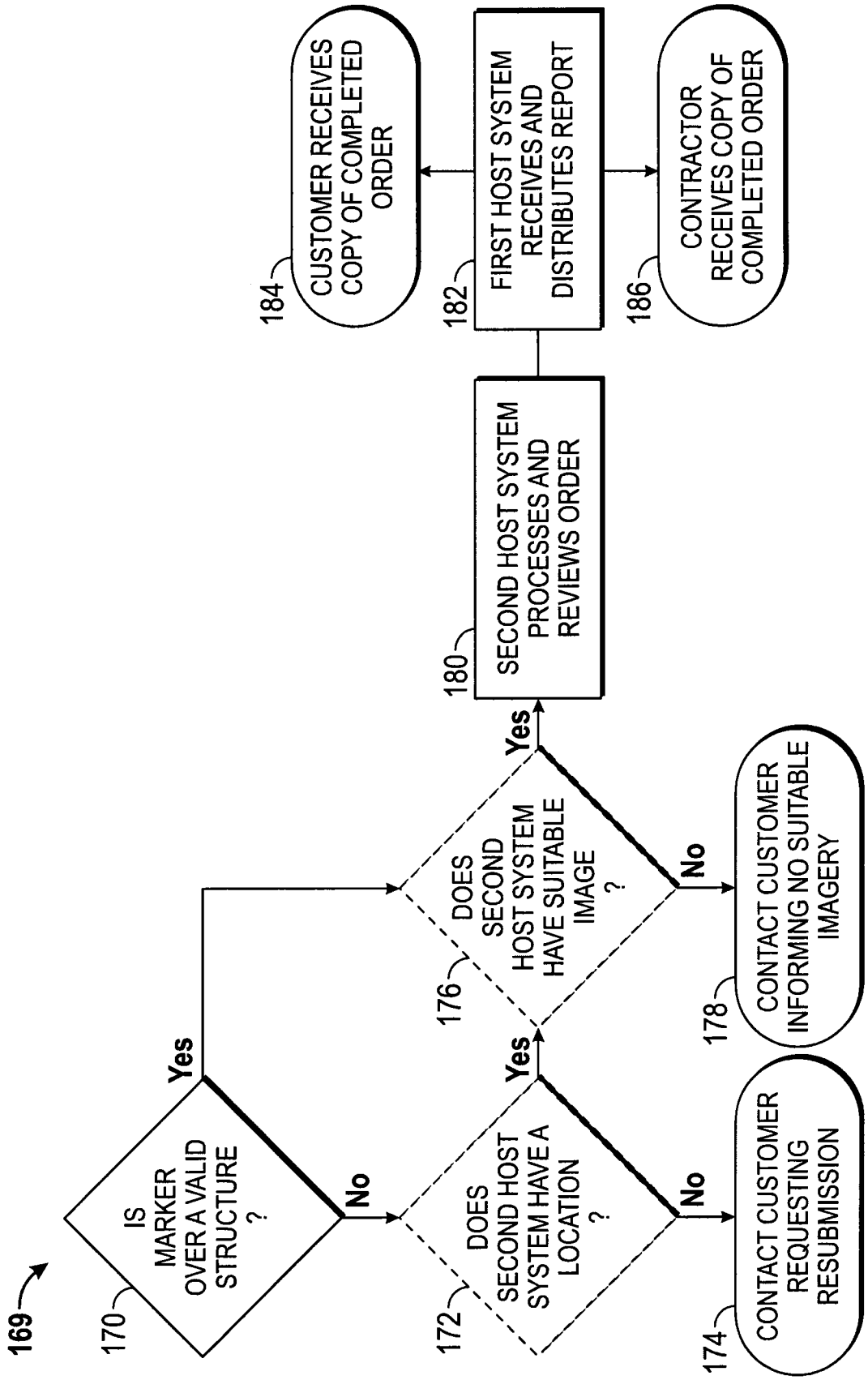


FIG. 5

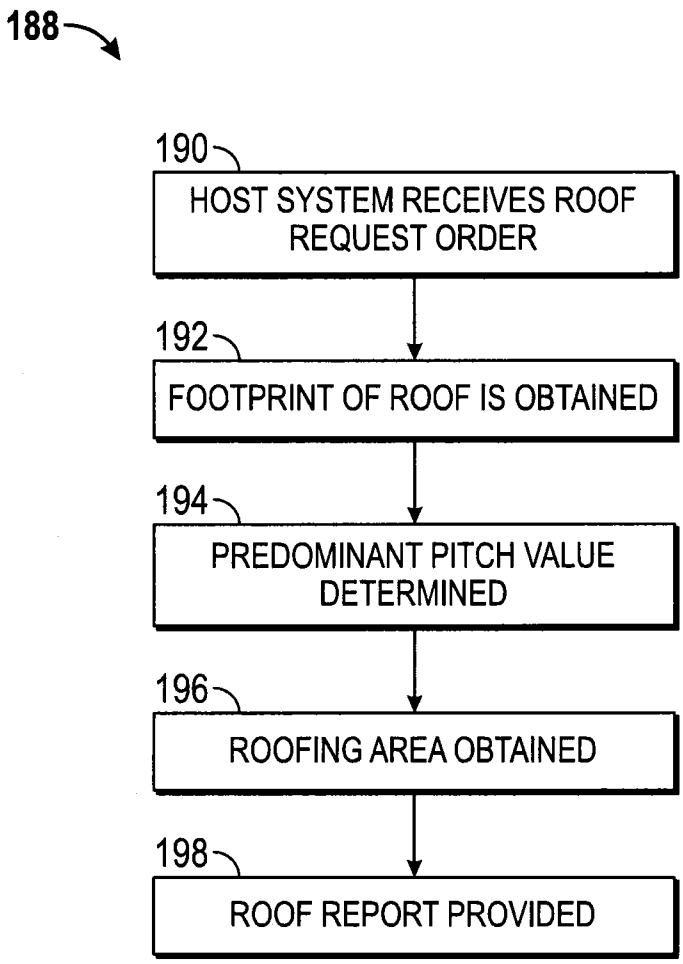

188
190
HOST SYSTEM RECEIVES ROOF REQUEST ORDER
192
FOOTPRINT OF ROOF IS OBTAINED
194
PREDOMINANT PITCH VALUE DETERMINED
196
ROOFING AREA OBTAINED
198
ROOF REPORT PROVIDED

FIG. 6

Slope Factor Chart

Pitch of Roof	1:12	2:12	3:12	4:12	5:12	6:12	7:12	8:12	9:12	10:12	11:12	12:12
Slope Factor	1.0035	1.0138	1.0308	1.0541	1.0833	1.1180	1.1577	1.2019	1.2500	1.3017	1.3566	1.4142

(A) x (Slope Factor) = (B)

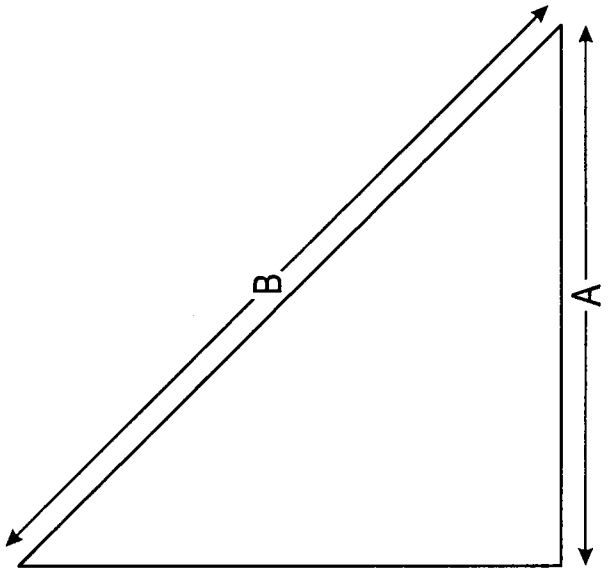
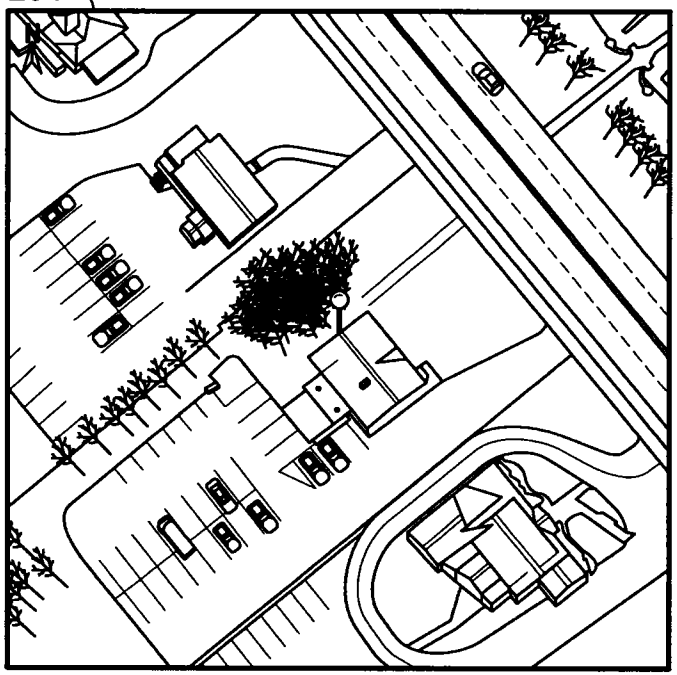


FIG. 7

0046



200

202

John Homeowner
1440 Monroe Ave
Rochester NY, 14618
123-456-7890
homeowner@gaf.com

Congratulations!

You have received a Pictometry Roof Squares Report compliments of GAF. This report provides an estimate of the number of squares on your roof.

REPORT DETAILS : INTRODUCTION

HOMEOWNER

202

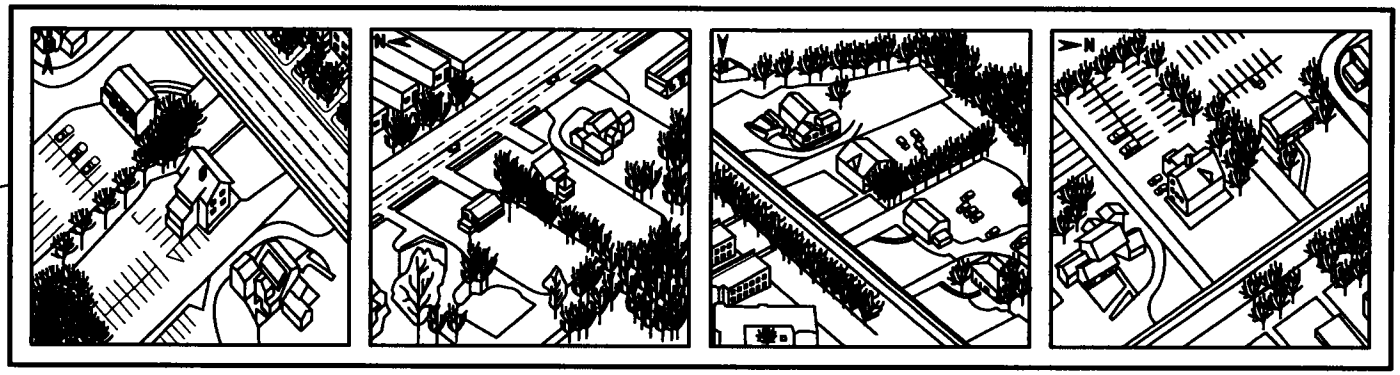
John Homeowner	Order # : PIC-000012840
1440 Monroe Ave	Phone : 123-456-7890
Rochester NY, 14618	Email : homeowner@gaf.com

REPORT BY
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FIG. 8

GAF



200

204

206 Your roof is estimated at **20.2 squares***+/- 10%

A copy of your report is being sent to the following GAF Master Elite Contractors who will be able to provide a quotation for installation services.

208

Contractor 1

123 Main Street
Anywhere, MY 11735
800Contractor1

Contractor 2

456 Main Street
Anywhere, MY 107470
800Contractor2

*DISCLAIMER: The information contained in this report is for estimating purposes, and should be verified by a roofing professional. Use of this report is subject to terms and conditions found at www.pictometry.com/roof.

REPORT DETAILS : INTRODUCTION

HOMEOWNER

John Homeowner
1440 Monroe Ave
Rochester NY, 14618

Order # : PIC-000012840
Phone : 123-456-7890
Email : homeowner@gaf.com

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FIG. 8 (Continued)

Electronically Filed: 03/19/2012
Title: A Method and System for Quick Square Roof Reporting
Inventor: Chris Thornberry
Attorney: Marc A. Brockhaus Dkt. No. 6338.157
SHEET 9 OF 9 FORMAL DRAWINGS

Doc Code: Oath
Document Description: Oath or declaration filed

PTO/SB/01 (04-09)
Approved for use through 01/31/2014. OMB 0651-0032
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DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

☐ Declaration Submitted With Initial Filing OR ☐ Declaration Submitted After Initial Filing (surcharge (37 CFR 1.16(f)) required)

Attorney Docket Number	6338.157
First Named Inventor	Chris Thornberry
COMPLETE IF KNOWN	
Application Number	
Filing Date	
Art Unit	
Examiner Name	

I hereby declare that: (1) Each inventor's residence, mailing address, and citizenship are as stated below next to their name; and (2) I believe the inventor(s) named below to be the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention titled:

A Method and System for Quick Square Roof Reporting

(Title of the Invention)

the application of which

☑ is attached hereto

OR

☐ was filed on (MM/DD/YYYY) _____ as United States Application Number or PCT International Application Number _____ and was amended on (MM/DD/YYYY) _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified application, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

Authorization To Permit Access To Application by Participating Offices

☑ If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the above-identified patent application is filed access to the above-identified patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the above-identified patent application is filed to have access to the above-identified patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the above-identified patent application with respect to: 1) the above-identified patent application-as-filed; 2) any foreign application to which the above-identified patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the above-identified patent application; and 3) any U.S. application-as-filed from which benefit is sought in the above-identified patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing the Authorization to Permit Access to Application by Participating Offices.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 21 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

DECLARATION — Utility or Design Patent Application

Claim of Foreign Priority Benefits

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or (f), or 365(b) of any foreign application(s) for patent, inventor's or plant breeder's rights certificate(s), or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent, inventor's or plant breeder's rights certificate(s), or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application number(s) are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

PTO/SB/01 (04-09)
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DECLARATION — Utility or Design Patent Application

Direct all correspondence to: ☑ The address associated with Customer Number: 30589 OR ☑ Correspondence address below

Name
Dunlap Codding, P.C.

Address
P.O. BOX 16370

City	State	Zip
Oklahoma City	Oklahoma	73113

Country	Telephone	Email
USA	405+607-8600	mbrockhaus@dunlapcodding.com

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available. Petitioner/applicant is advised that documents which form the record of a patent application (such as the PTO/SB/01) are placed into the Privacy Act system of records DEPARTMENT OF COMMERCE, COMMERCE-PAT-7, System name: *Patent Application Files*. Documents not retained in an application file (such as the PTO-2038) are placed into the Privacy Act system of COMMERCE/PAT-TM-10, System name: *Deposit Accounts and Electronic Funds Transfer Profiles*.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

NAME OF SOLE OR FIRST INVENTOR: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Chris T.	Thornberry

Inventor's Signature | Date

Residence: City	State	Country	Citizenship
Indianapolis	IN	USA	US

Mailing Address
10825 Cyrus Dr.

City	State	Zip	Country
Indianapolis	IN	46231	USA

☐ Additional inventors or a legal representative are being named on the _____ supplemental sheet(s) PTO/SB/02A or 02LR attached hereto

PTO/SB/02A (07-07)
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DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet

Page _____ of _____

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle (if any))	Family Name or Surname		
Dale R.	Thornberry		
Inventor's Signature			Date
Carmel Residence: City	IN State	USA Country	US Citizenship
13890 Wildcat Dr. Mailing Address			
Carmel City	IN State	46033 Zip	US Country

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle (if any))	Family Name or Surname		
Inventor's Signature			Date
Residence: City	State	Country	Citizenship
Mailing Address			
City	State	Zip	Country

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle (if any))	Family Name or Surname		
Inventor's Signature			Date
Residence: City	State	Country	Citizenship
Mailing Address			
City	State	Zip	Country

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 21 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 (1-800-786-9199) and select option 2.

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	A Method and System for Quick Square Roof Reporting
First Named Inventor/Applicant Name:	Chris T. Thornberry
Filer:	Douglas John Sorocco/Lori Radford
Attorney Docket Number:	6338.157

Filed as Small Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility filing Fee (Electronic filing)	4011	1	95	95
Utility Search Fee	2111	1	310	310
Utility Examination Fee	2311	1	125	125
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**530**

Electronic Acknowledgement Receipt

EFS ID:	12339736
Application Number:	13424054
International Application Number:	
Confirmation Number:	7006
Title of Invention:	A Method and System for Quick Square Roof Reporting
First Named Inventor/Applicant Name:	Chris T. Thornberry
Customer Number:	30589
Filer:	Douglas John Sorocco/Lori Radford
Filer Authorized By:	Douglas John Sorocco
Attorney Docket Number:	6338.157
Receipt Date:	19-MAR-2012
Filing Date:	
Time Stamp:	17:47:18
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$530
RAM confirmation Number	5228
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1	Transmittal of New Application	6338157_Transmittal.pdf	83267 7a3acd648d608fd8386f9b8fb24a1fb9e37e3892	no	1
Warnings:					
Information:					
2		6338157_Application.pdf	1419540 2380d4ad7f6b5d90a72efeeef0732b5a4168a220	yes	36

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Specification	1	31
	Claims	32	35
	Abstract	36	36

Warnings:					
Information:					
3	Drawings-only black and white line drawings	6338157_Drawings.pdf	238837 ee6a67544ab794c288074a4d846e875617149066	no	9
Warnings:					
The page size in the PDF is too large. The pages should be 8.5 x 11 or A4. If this PDF is submitted, the pages will be resized upon entry into the Image File Wrapper and may affect subsequent processing					
Information:					
4	Oath or Declaration filed	6338157_Declaration.pdf	216172 8df3667379527af582e25b8dd60a2273db64e1f6	no	4
Warnings:					
Information:					
5	Fee Worksheet (SB06)	fee-info.pdf	33024 346ae01cd114e96938544dd20be689d784dac761	no	2
Warnings:					
Information:					
			Total Files Size (in bytes):	1990840	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

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United States Patent and Trademark Office
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/424,054	03/19/2012	Chris T. Thornberry	6338.157

CONFIRMATION NO. 7006

30589
DUNLAP CODDING, P.C.
PO BOX 16370
OKLAHOMA CITY, OK 73113

IMPROPER AUTHORIZATION LETTER



Date Mailed: 04/02/2012

Title: Method and System for Quick Square Roof Reporting

Improper Submission of Authorization to Permit Access to Application by Participating Offices under 37 CFR 1.14(h)

The Authorization to Permit Access to Application by Participating Offices under 37 CFR 1.14(h) (authorization to permit access) on 03/19/2012 in application number 13/424,054 is not accepted because of the reason(s) listed below:

- The authorization to permit access was not properly signed. If applicant still wishes to provide authorization to permit access under 37 CFR 1.14(h), applicant must submit a properly signed authorization (e.g., PTO/SB/39).

Any authorization should be submitted prior to filing a subsequent foreign application with a participating intellectual property office in which priority is claimed to the above-identified U.S. application to ensure that it is likely that the participating foreign intellectual property office will be successful in its attempt to retrieve a copy of the U.S. priority application from the Office.

/mkibret/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

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UNITED STATES DEPARTMENT OF COMMERCE
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
13/424,054	03/19/2012	3633	530	6338.157	13	2

CONFIRMATION NO. 7006

30589
DUNLAP CODDING, P.C.
PO BOX 16370
OKLAHOMA CITY, OK 73113

FILING RECEIPT

OC000000053453110

Date Mailed: 04/02/2012

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Chris T. Thornberry, Indianapolis, IN;
Dale R. Thornberry, Carmel, IN;

Power of Attorney: None

Domestic Priority data as claimed by applicant

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)

If Required, Foreign Filing License Granted: 03/30/2012

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/424,054**

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****

Title

Method and System for Quick Square Roof Reporting

Preliminary Class

052

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as

set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/424,054

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	95		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	310		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	125		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	13 minus 20 =	*	x 30 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	2 minus 3 =	*	x 125 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	530		TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
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Alexandria, Virginia 22313-1450
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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/424,054	03/19/2012	Chris T. Thornberry	6338.157

CONFIRMATION NO. 7006

30589
DUNLAP CODDING, P.C.
PO BOX 16370
OKLAHOMA CITY, OK 73113

FORMALITIES LETTER



Date Mailed: 04/02/2012

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The oath or declaration is unsigned.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- A surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.16(f) of $**65** for a small entity in compliance with 37 CFR 1.27, must be submitted.

SUMMARY OF FEES DUE:

Total fee(s) required within **TWO MONTHS** from the date of this Notice is $**65** for a small entity
- $**65** Surcharge.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

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Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

Doc Code: TRAN.LET

Document Description: Transmittal Letter

PTO/SB/21 (07-09)
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TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Application Number	13/424,054
Filing Date	03/19/2012
First Named Inventor	Chris Thornberry
Art Unit	3633
Examiner Name	
Attorney Docket Number	6338.157

Total Number of Pages in This Submission

ENCLOSURES *(Check all that apply)*

- ☐ Fee Transmittal Form
  - ☐ Fee Attached
- ☐ Amendment/Reply
  - ☐ After Final
  - ☐ Affidavits/declaration(s)
- ☑ Extension of Time Request
- ☐ Express Abandonment Request
- ☐ Information Disclosure Statement
- ☐ Certified Copy of Priority Document(s)
- ☐ Reply to Missing Parts/ Incomplete Application
  - ☐ Reply to Missing Parts under 37 CFR 1.52 or 1.53
- ☐ Drawing(s)
- ☐ Licensing-related Papers
- ☐ Petition
- ☐ Petition to Convert to a Provisional Application
- ☐ Power of Attorney, Revocation Change of Correspondence Address
- ☐ Terminal Disclaimer
- ☐ Request for Refund
- ☐ CD, Number of CD(s) _____
  - ☐ Landscape Table on CD
- ☐ After Allowance Communication to TC
- ☐ Appeal Communication to Board of Appeals and Interferences
- ☐ Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- ☐ Proprietary Information
- ☐ Status Letter
- ☑ Other Enclosure(s) (please Identify below):
  See Remarks

Remarks

ELECTRONICALLY TRANSMITTED:
1. SB21 Transmittal Form (1 pg);
2. SB22 Extension of Time (1 pg); and
3. SB01 Declaration (4 pgs).

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	DUNLAP CODDING, P.C.		
Signature	Marc Brockhaus		
Printed name	Marc A. Brockhaus		
Date	07/11/2012	Reg. No.	40,923

CERTIFICATE OF TRANSMISSION/MAILING

I hereby certify that this correspondence is being facsimile transmitted to the USPTO or deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on the date shown below:

Signature	Marc Brockhaus		
Typed or printed name	Marc A. Brockhaus	Date	07/11/2012

This collection of information is required by 37 CFR 1.5. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and1.14. This collection is estimated to 2 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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PETITION FOR EXTENSION OF TIME UNDER 37 CFR 1.136(a)	Docket Number (Optional) 6338.157
Application Number 13/424,054	Filed 03/19/2012
For METHOD AND SYSTEM FOR QUICK SQUARE ROOF REPORTING	
Art Unit 3633	Examiner

This is a request under the provisions of 37 CFR 1.136(a) to extend the period for filing a reply in the above identified application.

The requested extension and fee are as follows (check time period desired and enter the appropriate fee below):

		Fee	Small Entity Fee	
☐	One month (37 CFR 1.17(a)(1))	$150	$75	$_____
☑	Two months (37 CFR 1.17(a)(2))	$560	$280	$ 280.00
☐	Three months (37 CFR 1.17(a)(3))	$1270	$635	$_____
☐	Four months (37 CFR 1.17(a)(4))	$1980	$990	$_____
☐	Five months (37 CFR 1.17(a)(5))	$2690	$1345	$_____

☑ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check in the amount of the fee is enclosed.

☑ Payment by credit card. Form PTO-2038 is attached.

☐ The Director has already been authorized to charge fees in this application to a Deposit Account.

☐ The Director is hereby authorized to charge any fees which may be required, or credit any overpayment, to Deposit Account Number _____.

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

I am the

☐ applicant/inventor.

☐ assignee of record of the entire interest. See 37 CFR 3.71. Statement under 37 CFR 3.73(b) is enclosed (Form PTO/SB/96).

☑ attorney or agent of record. Registration Number 40,923

☐ attorney or agent under 37 CFR 1.34. Registration number if acting under 37 CFR 1.34 _____

Marc Brockhaus — Signature

07/11/2012 — Date

Marc A. Brockhaus — Typed or printed name

405-607-8600 — Telephone Number

NOTE: Signatures of all the inventors or assignees of record of the entire interest or their representative(s) are required. Submit multiple forms if more than one signature is required, see below.

☐ Total of _____ forms are submitted.

This collection of information is required by 37 CFR 1.136(a). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 6 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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Doc Code: Oath
Document Description: Oath or declaration filed

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DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

☐ Declaration Submitted With Initial Filing OR ☑ Declaration Submitted After Initial Filing (surcharge (37 CFR 1.16(f)) required)

Attorney Docket Number	6338.157
First Named Inventor	Chris Thornberry
COMPLETE IF KNOWN	
Application Number	13/424,054
Filing Date	03/19/2012
Art Unit	3633
Examiner Name	

I hereby declare that: (1) Each inventor's residence, mailing address, and citizenship are as stated below next to their name; and (2) I believe the inventor(s) named below to be the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention titled:

A Method and System for Quick Square Roof Reporting

(Title of the Invention)

the application of which

☐ is attached hereto

OR

☑ was filed on (MM/DD/YYYY) 03/19/2012 as United States Application Number or PCT International Application Number 13/424,054 and was amended on (MM/DD/YYYY) _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified application, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

Authorization To Permit Access To Application by Participating Offices

☑ If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the above-identified patent application is filed access to the above-identified patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the above-identified patent application is filed to have access to the above-identified patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the above-identified patent application with respect to: 1) the above-identified patent application-as-filed; 2) any foreign application to which the above-identified patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the above-identified patent application; and 3) any U.S. application-as-filed from which benefit is sought in the above-identified patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing the Authorization to Permit Access to Application by Participating Offices.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 21 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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DECLARATION — Utility or Design Patent Application

Claim of Foreign Priority Benefits

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or (f), or 365(b) of any foreign application(s) for patent, inventor's or plant breeder's rights certificate(s), or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent, inventor's or plant breeder's rights certificate(s), or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application number(s) are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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DECLARATION — Utility or Design Patent Application

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Name: Dunlap Codding, P.C.

Address: P.O. BOX 16370

City	State	Zip
Oklahoma City	Oklahoma	73113

Country	Telephone	Email
USA	405+607-8600	mbrockhaus@dunlapcodding.com

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available. Petitioner/applicant is advised that documents which form the record of a patent application (such as the PTO/SB/01) are placed into the Privacy Act system of records DEPARTMENT OF COMMERCE, COMMERCE-PAT-7, System name: *Patent Application Files*. Documents not retained in an application file (such as the PTO-2038) are placed into the Privacy Act system of COMMERCE/PAT-TM-10, System name: *Deposit Accounts and Electronic Funds Transfer Profiles*.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

NAME OF SOLE OR FIRST INVENTOR: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Chris T.	Thornberry

Inventor's Signature: [signature] Date: 7/11/02

Residence: City	State	Country	Citizenship
Indianapolis	IN	USA	US

Mailing Address: 10825 Cyrus Dr.

City	State	Zip	Country
Indianapolis	IN	46231	USA

☐ Additional inventors or a legal representative are being named on the _____ supplemental sheet(s) PTO/SB/02A or 02LR attached hereto

PTO/SB/02A (07-07)
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DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet

Page _____ of _____

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle (if any))	Family Name or Surname		
Dale R.	Thornberry		
Inventor's Signature			Date 7/11/2012
Carmel Residence: City	IN State	USA Country	US Citizenship
13890 Wildcat Dr. Mailing Address			
Carmel City	IN State	46033 Zip	US Country

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle (if any))	Family Name or Surname		
Inventor's Signature			Date
Residence: City	State	Country	Citizenship
Mailing Address			
City	State	Zip	Country

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle (if any))	Family Name or Surname		
Inventor's Signature			Date
Residence: City	State	Country	Citizenship
Mailing Address			
City	State	Zip	Country

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 21 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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Electronic Patent Application Fee Transmittal

Application Number:	13424054
Filing Date:	19-Mar-2012
Title of Invention:	Method and System for Quick Square Roof Reporting
First Named Inventor/Applicant Name:	Chris T. Thornberry
Filer:	Marc Alan Brockhaus/Lori Radford
Attorney Docket Number:	6338.157

Filed as Small Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Late filing fee for oath or declaration	2051	1	65	65
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension - 2 months with $0 paid	2252	1	280	280
Miscellaneous:				
			Total in USD ($)	**345**

Electronic Acknowledgement Receipt

EFS ID:	13230528
Application Number:	13424054
International Application Number:	
Confirmation Number:	7006
Title of Invention:	Method and System for Quick Square Roof Reporting
First Named Inventor/Applicant Name:	Chris T. Thornberry
Customer Number:	30589
Filer:	Marc Alan Brockhaus/Lori Radford
Filer Authorized By:	Marc Alan Brockhaus
Attorney Docket Number:	6338.157
Receipt Date:	11-JUL-2012
Filing Date:	19-MAR-2012
Time Stamp:	19:11:41
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$345
RAM confirmation Number	8318
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1	Transmittal Letter	6338157_Transmittal07112012.pdf	66328 6c94df5cbce3eb1481ba304545e5e7ff17fffe59	no	1
Warnings:					
Information:					
2	Extension of Time	6338157_Extension.pdf	63328 d8ea90b22ad019378ace7df774ab83bd9bb39815	no	1
Warnings:					
Information:					
3	Oath or Declaration filed	6338157_Declaration07112012.pdf	251984 3f589b28c803f22ee67b83a9dabf3fbd193da95e	no	4
Warnings:					
Information:					
4	Fee Worksheet (SB06)	fee-info.pdf	32029 2131307dbefada77aaa4974ed33c73dc9a1cf6c2	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	413669		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
13/424,054	03/19/2012	3633	595	6338.157	13	2

CONFIRMATION NO. 7006

30589
DUNLAP CODDING, P.C.
PO BOX 16370
OKLAHOMA CITY, OK 73113

UPDATED FILING RECEIPT

OC000000055427640

Date Mailed: 07/18/2012

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Chris T. Thornberry, Indianapolis, IN;
Dale R. Thornberry, Carmel, IN;

Power of Attorney: None

Domestic Priority data as claimed by applicant

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)

Permission to Access - A proper **Authorization to Permit Access to Application by Participating Offices** (PTO/SB/39 or its equivalent) has been received by the USPTO.

If Required, Foreign Filing License Granted: 03/30/2012

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/424,054**

Projected Publication Date: 09/19/2013

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****

Title

Method and System for Quick Square Roof Reporting

Preliminary Class

052

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

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This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage, facilitate, and accelerate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/424,054

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	95		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	310		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	125		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	13 minus 20 =	*	x 30 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	2 minus 3 =	*	x 125 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	530		TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/424,054	03/19/2012	Chris T. Thornberry	6338.157

CONFIRMATION NO. 7006

30589
DUNLAP CODDING, P.C.
PO BOX 16370
OKLAHOMA CITY, OK 73113

PUBLICATION NOTICE

OC000000063889186

Title: Method and System for Quick Square Roof Reporting

Publication No.US-2013-0246204-A1
Publication Date:09/19/2013

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Office of Public Records. The Office of Public Records can be reached by telephone at (703) 308-9726 or (800) 972-6382, by facsimile at (703) 305-8759, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently http://pair.uspto.gov/. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/424,054	03/19/2012	Chris T. Thornberry	6338.157	7006

30589 7590 04/16/2014

DUNLAP CODDING, P.C.
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EXAMINER	
ZIMMERMAN, MATTHEW E	
ART UNIT	PAPER NUMBER
3684	

MAIL DATE	DELIVERY MODE
04/16/2014	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Office Action Summary	Application No. 13/424,054	Applicant(s) THORNBERRY ET AL.	
	Examiner MATTHEW ZIMMERMAN	Art Unit 3684	AIA (First Inventor to File) Status No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE *3* MONTHS FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *09/19/2013*.

☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

4)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims*

5)☒ Claim(s) *1-13* is/are pending in the application.

5a) Of the above claim(s) _____ is/are withdrawn from consideration.

6)☐ Claim(s) _____ is/are allowed.

7)☒ Claim(s) *1-13* is/are rejected.

8)☐ Claim(s) _____ is/are objected to.

9)☐ Claim(s) _____ are subject to restriction and/or election requirement.

* If any claims have been determined allowable, you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to PPHfeedback@uspto.gov.

Application Papers

10)☐ The specification is objected to by the Examiner.

11)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

Certified copies:

a)☐ All b)☐ Some** c)☐ None of the:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

** See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)

2) ☐ Information Disclosure Statement(s) (PTO/SB/08a and/or PTO/SB/08b) Paper No(s)/Mail Date _____.

3) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____ .

4) ☐ Other: _____.

1. The present application is being examined under the pre-AIA first to invent provisions.

DETAILED ACTION

Status of Claims

2. Claim(s) 1-13 have been examined.

Claim Rejections - 35 USC § 101

3. 35 U.S.C. 101 reads as follows:

> Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title.

4. Claims 1-13 are rejected under 35 U.S.C. 101 because the claimed invention is directed to non-statutory subject matter. The claimed invention is drawn to a computer program per se. A computer program per se is abstract instructions and not a machine or apparatus; nor is it a process as the instructions are not “acts” being performed. As such, the claimed invention is not directed to one of the four statutory categories of invention, but instead directed to nonstatutory functional descriptive material. It is noted that computer programs embodied on a computer readable medium or other structure, which would permit the functionality of the program to be realized, would be directed to a product and be within a statutory category of invention, so long as the computer readable medium is not disclosed as non-statutory subject matter per se (e.g., signals or carrier waves).

Claim Rejections - 35 USC § 102

5. The following is a quotation of the appropriate paragraphs of pre-AIA 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

6. Claims 1-13 are rejected in the alternative under pre-AIA 35 U.S.C. 102(b) as being anticipated by Como (US 2002/00897332).

Referring to Claims 1-12, Como teaches a set of instructions stored on one or more computer readable medium for running on one or more computer systems comprising instructions (*see Como Fig. 1B-1C and ¶¶0090-91*). The Examiner notes that the instructions are nowhere stated as computer executable instructions and may simply be instructions in English to perform the recited steps (ex., an instruction for identifying a geographic location of a roof may comprise "Please tell the user to write his address on a sheet of paper"). Therefore the instructions are treated as non-functional descriptive material and given little to no patentable weight.

Referring to Claim 13, Como teaches a system comprising two or more host systems, each host system having one or more computer readable medium; the first host system storing a set of instructions (*see Como Fig. 1B-1C and ¶¶0090-91*) and the second host system storing asset of instructions (*see Como Fig. 1B-1C and ¶¶0090-91*). The Examiner notes that the instructions are nowhere stated as computer executable instructions and may simply be instructions in English to perform the recited steps (ex., an instruction for identifying a geographic location of a roof may comprise

"Please tell the user to write his address on a sheet of paper"). The Examiner notes that the processors may in fact be human processors such as data entry specialists and not necessarily "computer processors." Therefore the instructions are treated as non-functional descriptive material and given little to no patentable weight.

Claim Rejections - 35 USC § 103

7. The following is a quotation of pre-AIA 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

8. Claims 1-13 are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over Thornberry (US 2010/0296693) in view of Como (US 2002/0087332).

Referring to Claim 1, Thornberry teaches a set of instructions stored on one or more computer readable medium for running on one or more computer systems, comprising:

- instructions for identifying a geographic location of a roof (*see Thornberry Fig. 4A-B*);
- instructions for determining a footprint of the roof (*see Thornberry Fig. 5A-7D and ¶¶0104-112*);

- instructions for determining predominant pitch of the roof (*see Thornberry Fig. 5A-7D and ¶¶0090-98*);
- instructions for determining an estimated roofing area based on the predominant pitch and the footprint of the roof (*see Thornberry Fig. 5A-7D and ¶¶0104-112*).

Thornberry does not explicitly teach instructions for determining contact information of one or more contractors within a region of interest of the geographic location of the roof. However, Como teaches instructions for determining contact information of one or more contractors within a region of interest of a designated geographical location (*see Como ¶¶0095-96 and Fig. 12A*). It would have been obvious to one of ordinary skill in the art at the time of invention to apply the concept of determining contact information of one or more contractors in a designated geographical location to the geographical location of the roof because it would increase sales as these contractors may thus receive business from the consumer for a new roof. In addition, the results would be predictable. Specifically, Tornberry would continue to determine an estimated roofing area except that now it would also provide a list of contractors in the geographical location of the roof.

Referring to Claim 2, the combination teaches the set of instructions of claim 1, further comprising instructions for providing a roof report, wherein the roof report includes one or more ortho images of the roof, one or more oblique images of the roof, the estimated roofing area and contact information of one or more contractor within the region of interest of the geographic location of the roof (*see Thornberry Fig. 5A-7D and*

¶¶0101-102; in addition, and in the alternative, the Examiner notes that the instructions are non-functional descriptive material and given little to no patentable weight).

Referring to Claim 3, the combination teaches the set of instructions of claim 2, wherein the roof report includes contact information of the customer (*see Thornberry Fig. 5A-7D, an address, claim #, order #, etc*).

Referring to Claim 4, the combination teaches the set of instructions of claim 1, wherein the one or more computer readable medium comprises a first computer readable medium of a first host system and a second computer readable medium of a second host system (*see Thornberry ¶¶0089,36, the Examiner notes that the first and second computers can be interpreted as the same computer*).

Referring to Claim 5, the combination teaches the set of instructions of claim 1, wherein instructions for identifying the geographic location of the roof further comprises instructions for obtaining contact information of a customer (*see Thornberry Fig. 4C-D*).

Referring to Claim 6, the combination teaches the set of instructions of claim 1, wherein the one or more computer readable medium further comprises instructions for receiving customer input to validate geographic location of the roof (*see Thornberry Fic. 4C-D*).

Referring to Claim 7, the combination teaches the set of instructions of claim 6, wherein the geographic location includes coordinates and validation of the geographic location includes instructions for receiving customer input to alter one or more coordinates of the geographic location (*see Thornberry Fig. 4C-D*).

Referring to Claim 8, the combination teaches the set of instructions of claim 1, wherein instructions for identifying a geographic location of the roof includes identifying one or more edges of the roof in an image (*see Thornberry Fig. 6*).

Referring to Claim 9, the combination teaches the set of instructions of claim 1, wherein instructions for determining a footprint of the roof further comprises:

- instructions for identifying edges of the roof (*see Thornberry ¶0112*);
- instructions for determining three-dimensional information of the edges including position, orientation and length using multiple oblique images from multiple cardinal directions (*see Thornberry ¶0112, ¶0029, ¶0125, ¶0100*);
- instructions for determining, automatically, one or more line segments forming a portion of a footprint of the roof utilizing position and orientation of the edges (*see Thornberry ¶0089*).

Referring to Claim 10, the combination teaches the set of instructions of claim 1, wherein determining the predominant pitch includes determining a plurality of pitch values, the predominant pitch based on the plurality of pitch values (*see Thornberry ¶0098*).

Referring to Claim 11, the combination teaches the set of instructions of claim 10, wherein each pitch value is associated with an estimated percentage of roof area to provide an average pitch value (*see Thornberry ¶0098*).

Referring to Claim 12, the combination teaches the set of instructions of claim 1, further comprising: instructions for providing the roof report to one or more contractors, the contractor located within the region of interest of the geographic location of the roof.

The Examiner notes that this is non-functional descriptive material and given little to no patentable weight.

Referring to Claim 13, Thornberry teaches a system comprising:

- two or more host systems, each host system having one or more computer readable medium the first host system storing a set of instructions that when executed by one or more processors causes the one or more processors to (*see Thornberry ¶¶0089,36*):
    - identifying a geographic location of a roof (*see Thornberry Fig. 4A-B*);
- the second host system storing a set of instructions that when executed by one or more processors causes the one or more processors to (*see Thornberry ¶¶0089,36*):
    - determining a footprint of the roof (*see Thornberry Fig. 5A-7D and ¶¶0104-112*);
    - determining predominant pitch of the roof (*see Thornberry Fig. 5A-7D and ¶¶0090-98*);
    - determining an estimated roofing area based on the predominant pitch and the footprint of the roof (*see Thornberry Fig. 5A-7D and ¶¶0104-112*).
    - provide a roof report, wherein the roof report includes one or more ortho images of the roof, one or more oblique images of the roof, the estimated roofing area and contact information of one or more contractors within the region of interest (*see Thornberry Fig. 5A-7D*

and ¶¶0101-102; in addition, and in the alternative, the Examiner notes that the instructions are non-functional descriptive material and given little to no patentable weight).

Thornberry does not explicitly teach determining contact information of one or more contractors within a region of interest of the geographic location of the roof. However, Como teaches determining contact information of one or more contractors within a region of interest of a designated geographical location (*see Como ¶¶0095-96 and Fig. 12A*). It would have been obvious to one of ordinary skill in the art at the time of invention to apply the concept of determining contact information of one or more contractors in a designated geographical location to the geographical location of the roof because it would increase sales as these contractors may thus receive business from the consumer for a new roof. In addition, the results would be predictable. Specifically, Tornberry would continue to determine an estimated roofing area except that now it would also provide a list of contractors in the geographical location of the roof.

Conclusion

Any inquiry concerning this communication or earlier communications from the examiner should be directed to MATTHEW ZIMMERMAN whose telephone number is (571)270-5278. The examiner can normally be reached on Mon-Fri 9:00am-5:00pm.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Jason B. Dunham can be reached on (571) 272-8109. The fax phone

number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/MATTHEW ZIMMERMAN/
Primary Examiner, Art Unit 3684

Notice of References Cited	Application/Control No. 13/424,054	Applicant(s)/Patent Under Reexamination THORNBERRY ET AL.	
	Examiner MATTHEW ZIMMERMAN	Art Unit 3684	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2010/0296693	11-2010	Thornberry et al.	382/100
*	B	US-2002/0087332	07-2002	Como, Brian	705/1
	C	US-			
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
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	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	0	"20100296693" and footprint	US-PGPUB; USPAT	OR	ON	2014/04/11 21:30
L2	2	"20100296693" and computer	US-PGPUB; USPAT	OR	ON	2014/04/11 21:45
L3	2	"20100296693" and edge	US-PGPUB; USPAT	OR	ON	2014/04/11 21:53
L4	2	"20100296693" and oblique	US-PGPUB; USPAT	OR	ON	2014/04/11 21:54
L5	2	"20100296693" and orientation	US-PGPUB; USPAT	OR	ON	2014/04/11 21:55
L6	2	"20100296693" and automatic	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 21:57
L7	2	"20100296693" and automatic$3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 21:57
L8	2	"20100296693" and (seller contrator retailer merchant vendor)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:01
L9	22521	705/26.1-27.2.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:06
L11	11	(thornberry near2 chris).in. (thornberry near2 dale).in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:06
L12	45261	(image and roof)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:06
L13	10	11 and 12	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:06
L18	2	"20060200311"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:08
L19	372	(find$3 locat$3 determin$3) with (contractor near3 location)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:10
L20	171240	"705".clas.	US-PGPUB; USPAT; USOCR; FPRS; EPO;	OR	ON	2014/04/11 22:10

			JPO; DERWENT; IBM_TDB			
L21	108	19 and 20	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:10
L22	38	(find$3 locat$3 determin$3) adj2 (contractor near3 location)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:11
L23	7	(find$3 locat$3 determin$3) adj2 (contractor adj2 location)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:11
L24	31	(find$3 locat$3 determin$3) adj2 (contractor adj5 location)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:11
L25	17	20 and 24	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:11
L26	1	"20020087332" and location	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:14
L27	17755	705/26.1,26.5,27.1.ccls. G06Q30/0621 G06Q30/0641	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:24
L29	596	(estimat$3 same roof$3 same (size area footprint))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:24
L30	5	27 and 29	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:25
L33	99	(estimat$3 same roof$3 same (size area footprint)) and aerial	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:25
L34	1	27 and 33	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/11 22:25
S6	1	13/424054	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:17
S7	10	"20100179787" "20100110074" "20100114537" "20110187713" "8078436".pn. 12/090692	US-PGPUB; USPAT	OR	ON	2014/04/10 17:33
S9	21	aerial adj roof adj estimat$4	US-PGPUB; USPAT	OR	ON	2014/04/10 17:35
S10	4	(US-20100114537-$ or US-20100179787-$ or US-20100110074-$).did. or (US-	US-PGPUB; USPAT	OR	ON	2014/04/10 17:37

		8078436-$).did.				
S11	23	predominant adj pitch	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:37
S12	0	S10 and S11	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:37
S13	3	(predominant adj pitch) and roof	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:38
S14	4	S10 and pitch	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:39
S15	8079	pitch near4 averag$3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:42
S16	0	S10 and S15	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:42
S17	1	S15 and S7	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 17:42
S18	2	"20100114537" and pitch	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/04/10 21:51
S19	5	"8078436".pn. "8145840".pn. "8209152".pn. "8515125".pn. "8515198".pn.	US-PGPUB; USPAT	OR	ON	2014/04/11 16:46
S20	5	"8078436".pn. "8170840".pn. "8209152".pn. "8515125".pn. "8515198".pn.	US-PGPUB; USPAT	OR	ON	2014/04/11 16:46
S21	5	"8078436".pn. "8170840".pn. "8209152".pn. "8515198".pn. "8401222".pn.	US-PGPUB; USPAT	OR	ON	2014/04/11 16:47
S22	2	"20100296693"	US-PGPUB; USPAT	OR	ON	2014/04/11 16:48
S23	2	"20100296693" and pitch	US-PGPUB; USPAT	OR	ON	2014/04/11 16:49
S24	1	"20130246204" and (pitch same averag$3)	US-PGPUB; USPAT	OR	ON	2014/04/11 16:58

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L10	6384	705/26.1-27.2.ccls.	USPAT; UPAD	OR	ON	2014/04/11 22:06
L14	3	(thornberry near2 chris).in. (thornberry near2 dale).in.	USPAT; UPAD	OR	ON	2014/04/11 22:07

L15	13851	(image and roof)	USPAT; UPAD	OR	ON	2014/04/11 22:07
L16	3	14 and 15	USPAT; UPAD	OR	ON	2014/04/11 22:07
L17	0	"20060200311"	USPAT; UPAD	OR	ON	2014/04/11 22:08
L28	3932	705/26.1,26.5,27.1.ccls. G06Q30/0621 G06Q30/0641	USPAT; UPAD	OR	ON	2014/04/11 22:24
L31	172	(estimat$3 same roof$3 same (size area footprint))	USPAT; UPAD	OR	ON	2014/04/11 22:25
L32	1	28 and 31	USPAT; UPAD	OR	ON	2014/04/11 22:25

4/ 11/ 2014 10:26:24 PM
C:\ Users\ mzimmerman1\ Documents\ EAST\ Workspaces\ 13424054.wsp

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13424054	THORNBERRY ET AL.
	Examiner	Art Unit
	MATTHEW ZIMMERMAN	3684

CPC- SEARCHED		
Symbol	Date	Examiner
G06Q30/0621	4/11/2014	MZ
G06Q30/0641	4/11/2014	MZ

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner
705	26.1,26.5,27.1	4/11/2014	MZ

SEARCH NOTES		
Search Notes	Date	Examiner

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner
705	26.1,27.1,26.5	4/11/2014	MZ

Electronically Transmitted: August 15, 2014 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application No:	13/424,054	Conf. No. 7006
Inventors:	Chris T. Thornberry, Dale R. Thornberry	
Filed:	Mar. 19, 2012	
TC/A.U.:	3684	
Examiner:	ZIMMERMAN, MATTHEW E.	
Title:	Method and System for Quick Square Roof Reporting	
Docket No.:	6338.157	
Customer No.:	30589	

Mail Box Non-Fee Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

RESPONSE

The following is being submitted in response to the Office Action dated April 16, 2014:

Amendments to the Specification begin on page 2 of this paper.

Amendments to the Claims begin on page **3** of this paper.

Remarks/Arguments begin on page **10** of this paper.

Amendments to the Specification

Please replace paragraph [0074] with the following amended paragraph:

[0074] The footprint of the roof may be determined, in step 192. For example, the footprint of the roof may be determined using systems and methods including, but not limited to, those described in U.S. Patent Publication No. 2010/0179787, U.S. Patent Publication No. 2010/0110074, U.S. Patent Publication No. 2010/0114537, U.S. Patent Publication No. 2011/0187713, U.S. Patent No. 8,078,436, and U.S. Serial No. ~~12/090,692~~ 12/909,692, all of which are incorporated by reference herein in their entirety

Amendments to the Claims

This listing of claims will replace all prior versions, and listings of claims in the application.

Listing of Claims:

1. (Currently Amended) ~~A set of instructions stored on one~~ One or more non-transitory computer readable medium storing a set of computer executable instructions for running on one or more computer systems that when executed cause the one or more computer systems to~~, comprising: instructions for identifying~~ identify a geographic location of a roof; ~~instructions for determining~~ determine contact information of one or more contractors within a region of interest of the geographic location of the roof; ~~and, instructions for determining~~ determine a footprint of the roof; ~~instructions for determining~~ determine predominant pitch of the roof; and ~~instructions for determining~~ determine an estimated roofing area based on the predominant pitch and the footprint of the roof.

2. (Currently Amended) The one or more non-transitory computer readable medium storing a set of computer executable instructions for running on one or more computer systems of claim 1, that when executed further cause the one or more computer systems to ~~set of instructions of claim 1, further comprising instructions for providing~~ provide a roof report, wherein the roof report includes one or more ortho images of the roof, one or more oblique images of the roof, the

estimated roofing area and the contact information of one or more contractor within the region of interest of the geographic location of the roof.

3. (Currently Amended) The one or more non-transitory computer readable medium ~~set of instructions~~ of claim 2, wherein the roof report includes contact information of the customer.

4. (Currently Amended) The one or more non-transitory computer readable medium ~~set of instructions~~ of claim 1, wherein the one or more non-transitory computer readable medium comprises a first non-transitory computer readable medium of a first host system and a second non-transitory computer readable medium of a second host system.

5. (Currently Amended) The one or more non-transitory computer readable medium ~~set of instructions~~ of claim 1, wherein ~~instructions for~~ identifying the geographic location of the roof further comprises ~~instructions for~~ obtaining contact information of a customer.

6. (Currently Amended) The one or more non-transitory computer readable medium storing a set of computer executable instructions for running on one or more computer systems of claim 1, that when executed further cause the one or more computer systems to ~~set of instructions of claim 1, wherein the one or more~~

~~computer readable medium further comprises instructions for receiving~~ receive customer input to validate geographic location of the roof.

7. (Currently Amended) The one or more non-transitory computer readable medium ~~set of instructions~~ of claim 6, wherein the geographic location includes coordinates and validation of the geographic location includes instructions for receiving customer input to alter one or more coordinates of the geographic location.

8. (Currently Amended) The one or more non-transitory computer readable medium ~~set of instructions~~ of claim 1, wherein ~~instructions for~~ identifying a geographic location of the roof includes identifying one or more edges of the roof in an image.

9. (Currently Amended) The one or more non-transitory computer readable medium storing a set of computer executable instructions for running on one or more computer systems of claim 1, that when executed further cause the one or more computer systems to ~~set of instructions of claim 1, wherein instructions for determining a footprint of the roof further comprises: instructions for identifying~~ identify edges of the roof; ~~instructions for determining~~ determine three-dimensional information of the edges including position, orientation and length using multiple oblique images from multiple cardinal directions; and, ~~instructions~~

~~for determining~~ determine, automatically, one or more line segments forming a portion of a footprint of the roof utilizing position and orientation of the edges.

10. (Currently Amended) The one or more non-transitory computer readable medium ~~set of instructions~~ of claim 1, wherein determining the predominant pitch includes determining a plurality of pitch values, the predominant pitch based on the plurality of pitch values.

11. (Currently Amended) The one or more non-transitory computer readable medium ~~set of instructions~~ of claim 10, wherein each pitch value is associated with an estimated percentage of roof area to provide an average pitch value.

12. (Currently Amended) The one or more non-transitory computer readable medium storing a set of computer executable instructions for running on one or more computer systems of claim 1, that when executed further cause the one or more computer systems to ~~set of instructions of claim 1, further comprising: instructions for providing~~ provide the roof report to one or more contractors, the contractor located within the region of interest of the geographic location of the roof.

13. (Currently Amended) A system, comprising:

two or more host systems, each host system having one or more non-transitory computer readable medium; the non-transitory computer readable medium of

the first host system storing a set of computer executable instructions that when executed by one or more processors causes the one or more processors to:

identify a geographic location of a roof;

determine contact information of at least one contractor within a region of interest about the geographic location of the roof;

the non-transitory computer readable medium of the second host system storing a set of computer executable instructions that when executed by one or more processors causes the one or more processors to:

determine a footprint of the roof;

determine a predominant pitch;

determine an estimated roofing area based on the predominant pitch and the footprint of the roof; and,

provide a roof report, wherein the roof report includes one or more ortho images of the roof, one or more oblique images of the roof, the estimated roofing area and contact information of one or more contractors within the region of interest.

14. (New) A roofing estimate method, comprising:

receiving, by at least one computer processor from a user via a user terminal, a geographic location of a roof;

providing to the user, with the computer processor, imagery of the roof based on the geographic location of the roof;

providing, with the computer processor, an estimated roofing area based at least on a predominant pitch and a footprint of the roof, the footprint of the roof determined at least in part using at least one image of the roof; and

providing, with the computer processor, contact information of one or more roofing contractors within a region of interest of the geographic location of the roof.

15. (New) The roofing estimate method of claim 14, further comprising:

providing, with the computer processor, a roof report, wherein the roof report includes one or more ortho images of the roof, one or more oblique images of the roof, the estimated roofing area and the contact information of one or more contractor within the region of interest of the geographic location of the roof.

16. (New) The roofing estimate method of claim 14, wherein the footprint of the roof is determined at least in part with oblique images of the roof.

17. (New) The roofing estimate method of claim 14, wherein the predominant pitch value of the roof based at least in part on the footprint of the roof as a boundary of the roof.

18. (New) The roofing estimate method of claim 14, wherein the predominant pitch is based on a weighted average of individual pitch factors for two or more portions of the roof.

REMARKS

This is intended to be a complete response to the Office Action mailed April 16, 2014, in which claims 1- 13 are rejected. Claims 1-13 remain pending in the application and have been amended. Claims 14-18 are newly submitted claims that are believed to be generally consistent with the subject matter set forth in original claims 1-13.

In the specification, paragraph [0074] has been amended to correct a typographical error.

Based on the preceding amendments and the following remarks, Applicants respectfully request the withdrawal of the rejections and the issuance of a timely notice of allowance for claims 1- 18.

Claim Amendments

Applicants respectfully submit that the amendments to claims 1-13 and new claims 14-18 do not introduce any new matter. Written description and enablement support for the claims can be found, for example, in paragraphs [0015], [0029]-[0031], [0053], [0058], [0069], and [0074]-[0076] of the above-referenced patent application as originally filed. Therefore, no new matter is added by the amendments and the new claims.

Claim Rejection – 35 U.S.C. § 101

Claims 1-13 were rejected under 35 U.S.C. § 101 as being directed to non-statutory subject matter. The Examiner noted that computer programs embodied on a computer readable medium or other structure, which would permit the functionality of the program to be realized, would be directed to a

product and be within a statutory category of invention, so long as the computer readable medium is not disclosed as non-statutory subject matter per se (e.g., signals or carrier waves). To clarify the scope of the claims, the claims have been amended to be directed to "one or more non-transitory computer readable storage medium." The term "non-transitory computer-readable medium" comprises all types of computer-readable media, with the sole exception being a transitory, propagating signal.

In light of the foregoing, reconsideration and withdrawal of the rejection of claims 1-13 under 35 U.S.C. § 101 is respectfully requested.

Claim Rejection – 35 U.S.C. § 102(b)

Claims 1-13 were rejected under 35 U.S.C. § 102(b) as being anticipated by Como (US Patent Publication No. 2002/00897332), hereinafter "Como". For the reasons set forth below, Applicants respectfully submit that the currently pending claims are not anticipated over the cited reference.

The Examiner noted that "the instructions are nowhere stated as computer executable instructions and may simply be instructions in English to perform the recited steps" and therefore treated the instructions as "non-functional descriptive material given little to no patentable weight" (Office Action page 3). Claims 1-13 have been amended to recite "computer executable" instructions, as supported at least in paragraphs [0015], [0053], and [0058] of the application. Therefore, Applicants respectfully submit that the entirety of the claims should be given

patentable weight[1]. Como teaches a system and method for enabling a user on a network to locate contractors in at least one designated location. [See Abstract]. Como also generally refers to "[r]oofing, siding and sheet metal work." [See Paragraph [0030]] However, Como does not teach computer executable instructions for identifying a geographic location of a roof, determining a footprint of the roof, determining a predominant pitch of the roof, and determining an estimated roofing area based on the predominant pitch and the footprint of the roof, as recited in independent claims 1 and 13. Because Como does not teach each and every feature of claims 1 and 13, Como does not anticipate such claims under 35 U.S.C. §102(b).

Further, because claims 2-12 include each and every feature of independent claim 1, Como also does not anticipate claims 2-12.

In light of the foregoing, reconsideration and withdrawal of the rejection of claims 1-13 under 35 U.S.C. § 102(b) is respectfully requested.

Claim Rejection – 35 U.S.C. § 103(a)

Claims 1-13 were rejected under 35 U.S.C. § 103(a) as being unpatentable as obvious over Thornberry (US Patent Publication No. 2010/0296693), hereinafter "Thornberry", in view of Como (US Patent Publication

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[1] See MPEP §2111.05 "When determining the scope of a claim directed to a computer-readable medium containing certain programming, the examiner should first look to the relationship between the programming and the intended computer system. Where the programming performs some function with respect to the computer with which it is associated, a functional relationship will be found. For instance, a claim to computer-readable medium programmed with attribute data objects that perform the function of facilitating retrieval, addition, and removal of information in the intended computer system, establishes a functional relationship such that the claimed attribute data objects are given patentable weight. See *Lowry*, 32 F.3d at 1583-84, 32 USPQ2d at 1035.

No. 2002/00897332), hereinafter "Como". Applicants respectfully submit that the currently pending claims are not made obvious by the cited references.

For example, Thornberry does not disclose, teach, or even suggest, determining a predominant pitch, or determining an estimated roofing area based on the predominant pitch and the footprint of the roof, as recited in part in independent claims 1 and 13. The Examiner cites to Thornberry Figs. 5A-7D and paragraphs [0090]-[0098] as disclosing instructions for determining predominant pitch of the roof. However, these sections of Thornberry disclose determining "pitch direction," also described as "vector direction corresponding to roof pitch" (see paragraphs [0089]-[0090] and FIG. 5E), not "predominant pitch."

Examples of pitch direction vectors are shown in FIG. 5E as arrows "pointing in the downward direction, corresponding to the direction of rain flow" (paragraph [0089]). Thornberry describes an example of computer programming to determine pitch direction in paragraphs [0090]-[0098]. For example, see paragraph [0092] describing determining pitch direction for a section of roof running from a single ridge line parallel to a perimeter line – where pitch direction "runs from the ridge towards the perimeter." Also see paragraph [0097]-[0098] describing finding pitch direction "for completely enclosed shapes where all sides are valleys at the intersection of multiple planes" by taking an average slope and averaging the slope direction of the planes whose pitch runs into the plane in question and then using "that direction as the pitch direction for the plane." Therefore, Thornberry discloses how to determine "pitch direction," not "predominant pitch."

The Examiner cites to Thornberry Figs. 5A-7D and paragraphs [0104]-[0112] as disclosing "determining an estimated roofing area based on the predominant pitch and the footprint of the roof." However, as previously discussed, Thornberry does not determine predominant pitch, and therefore cannot determine an estimated roofing area based on predominant pitch and footprint of the roof. Nowhere does Thornberry disclose using predominant pitch to calculate area.

Additionally, because dependent claims 2-12 include each and every feature of independent claim 1, Thornberry also does not render claims 2-12 obvious under 35 U.S.C. §103(a).

Further, Applicants respectfully submit that the Como reference does not supply the deficiencies of Thornberry, for the reasons set forth above. The arguments and comments concerning Como will not be reiterated herein, but such are deemed relevant to the Examiner's rejection of claims 1-13 and are therefore incorporated herein by reference.

In light of the foregoing, reconsideration and withdrawal of the rejection of claims 1-13 under 35 U.S.C. § 103(a) is respectfully requested.

CONCLUSION

The foregoing is intended to be a complete response to the Office Action dated April 16, 2014. Applicants respectfully request reconsideration and withdrawal of the rejections set forth in the Office Action and a timely notice of allowance for all of the pending claims 1-18. Should the Examiner have any questions or comments regarding the foregoing, or any other matter, the undersigned would welcome a telephonic interview with the Examiner.

Respectfully Submitted,



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Attorney for Applicants

Electronic Patent Application Fee Transmittal

Application Number:	13424054
Filing Date:	19-Mar-2012
Title of Invention:	Method and System for Quick Square Roof Reporting
First Named Inventor/Applicant Name:	Chris T. Thornberry
Filer:	Marc Alan Brockhaus/Lori Radford
Attorney Docket Number:	6338.157

Filed as Small Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Extension - 1 month with $0 paid	2251	1	100	100

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
			Total in USD ($)	**100**

Electronic Acknowledgement Receipt

EFS ID:	19880842
Application Number:	13424054
International Application Number:	
Confirmation Number:	7006
Title of Invention:	Method and System for Quick Square Roof Reporting
First Named Inventor/Applicant Name:	Chris T. Thornberry
Customer Number:	30589
Filer:	Marc Alan Brockhaus/Lori Radford
Filer Authorized By:	Marc Alan Brockhaus
Attorney Docket Number:	6338.157
Receipt Date:	15-AUG-2014
Filing Date:	19-MAR-2012
Time Stamp:	16:22:11
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$100
RAM confirmation Number	2441
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1	Transmittal Letter	6338157_Transmittal08152014.pdf	65950 f96bd34cdb8a066c006a66a60b1b657ed81be736	no	1
Warnings:					
Information:					
2	Extension of Time	6338157_Extension08152014.pdf	62085 28629ce69fa8d43c40765d2e853e5ae20d1500c4	no	1
Warnings:					
Information:					
3		6338157_Response08152014.pdf	441924 a90f21e54f8a10e1f8320f1bbff41a437cc57ad9	yes	15

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Amendment/Req. Reconsideration-After Non-Final Reject	1	1
	Claims	2	9
	Abstract	10	15

Warnings:					
Information:					
4	Fee Worksheet (SB06)	fee-info.pdf	30357 26b572197b62f271e0dfece2ab98ed7c5f6ab412	no	2
Warnings:					
Information:					
			Total Files Size (in bytes):	600316	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Doc Code: TRAN.LET

Document Description: Transmittal Letter

PTO/SB/21 (07-09)
Approved for use through 07/31/2012. OMB 0651-0031
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TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission

Application Number	13/424,054
Filing Date	03/19/2012
First Named Inventor	Chris T. Thornberry
Art Unit	3684
Examiner Name	Matthew E. Zimmerman
Attorney Docket Number	6338.157

ENCLOSURES *(Check all that apply)*

- ☐ Fee Transmittal Form
  - ☐ Fee Attached
- ☑ Amendment/Reply
  - ☐ After Final
  - ☐ Affidavits/declaration(s)
- ☑ Extension of Time Request
- ☐ Express Abandonment Request
- ☐ Information Disclosure Statement
- ☐ Certified Copy of Priority Document(s)
- ☐ Reply to Missing Parts/ Incomplete Application
  - ☐ Reply to Missing Parts under 37 CFR 1.52 or 1.53
- ☐ Drawing(s)
- ☐ Licensing-related Papers
- ☐ Petition
- ☐ Petition to Convert to a Provisional Application
- ☐ Power of Attorney, Revocation Change of Correspondence Address
- ☐ Terminal Disclaimer
- ☐ Request for Refund
- ☐ CD, Number of CD(s) _____
  - ☐ Landscape Table on CD
- ☐ After Allowance Communication to TC
- ☐ Appeal Communication to Board of Appeals and Interferences
- ☐ Appeal Communication to TC **(Appeal Notice, Brief, Reply Brief)**
- ☐ Proprietary Information
- ☐ Status Letter
- ☑ Other Enclosure(s) (please Identify below):
  See Remarks

Remarks

ELECTRONICALLY TRANSMITTED:
1. SB21 Transmittal Form (1 pg);
2. SB22 Extension of Time (1 pg); and
3. Response (15 pgs).

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	DUNLAP CODDING, P.C.		
Signature	Marc Brockhaus		
Printed name	Marc A. Brockhaus		
Date	08/15/2014	Reg. No.	40,923

CERTIFICATE OF TRANSMISSION/MAILING

I hereby certify that this correspondence is being facsimile transmitted to the USPTO or deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on the date shown below:

Signature	Marc Brockhaus		
Typed or printed name	Marc A. Brockhaus	Date	08/15/2014

This collection of information is required by 37 CFR 1.5. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and1.14. This collection is estimated to 2 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PTO/AIA/22 (03-13)
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PETITION FOR EXTENSION OF TIME UNDER 37 CFR 1.136(a)

Docket Number (Optional): 6338.157

Application Number: 13/424,054 | Filed: 03/19/2012

For: Chris T. Thornberry

Art Unit: 3684 | Examiner: Matthew E. Zimmerman

This is a request under the provisions of 37 CFR 1.136(a) to extend the period for filing a reply in the above-identified application.

The requested extension and fee are as follows (check time period desired and enter the appropriate fee below):

		Fee	Small Entity Fee	Micro Entity Fee	
☑	One month (37 CFR 1.17(a)(1))	$200	$100	$50	$ 100.00
☐	Two months (37 CFR 1.17(a)(2))	$600	$300	$150	$
☐	Three months (37 CFR 1.17(a)(3))	$1,400	$700	$350	$
☐	Four months (37 CFR 1.17(a)(4))	$2,200	$1,100	$550	$
☐	Five months (37 CFR 1.17(a)(5))	$3,000	$1,500	$750	$

☑ Applicant asserts small entity status. See 37 CFR 1.27.

☐ Applicant certifies micro entity status. See 37 CFR 1.29.
Form PTO/SB/15A or B or equivalent must either be enclosed or have been submitted previously.

☐ A check in the amount of the fee is enclosed.

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WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

I am the

☐ applicant.

☑ attorney or agent of record. Registration number 40,923.

☐ attorney or agent acting under 37 CFR 1.34. Registration number _____.

Marc Brockhaus — Signature

08/15/2014 — Date

Marc A. Brockhaus — Typed or printed name

405-607-8600 — Telephone Number

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. Submit multiple forms if more than one signature is required, see below*.

☐ * Total of _____ forms are submitted.

This collection of information is required by 37 CFR 1.136(a). The information is required to obtain or retain a benefit by the public, which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 6 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Mail Stop PCT, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number	Filing Date	☐ To be Mailed
13/424,054	03/19/2012	

ENTITY: ☐ LARGE ☒ SMALL ☐ MICRO

APPLICATION AS FILED – PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	

APPLICATION AS AMENDED – PART II

AMENDMENT **08/15/2014**

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
Total (37 CFR 1.16(i))	* 18	Minus	** 20	= 0	X $40 =	0
Independent (37 CFR 1.16(h))	* 3	Minus	***3	= 0	X $210 =	0
☐ Application Size Fee (37 CFR 1.16(s))						
☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
					TOTAL ADD'L FEE	0

AMENDMENT

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
☐ Application Size Fee (37 CFR 1.16(s))						
☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
					TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

LIE
/Davina Butler/

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ELECTRONICALLY FILED ON: October 20, 2014

Doc code: IDS

Doc description: Information Disclosure Statement (IDS) Filed

Substitute for form PTO/SB/08a **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** **(Not for submission under 37 CFR 1.99)**	Application Number	13/424,054
	Filing Date	03/19/2012
	First Named Inventor	Chris T. Thornberry
	Art Unit	3684
	Examiner Name	ZIMMERMAN, MATTHEW E.
	Attorney Docket Number	6338.157

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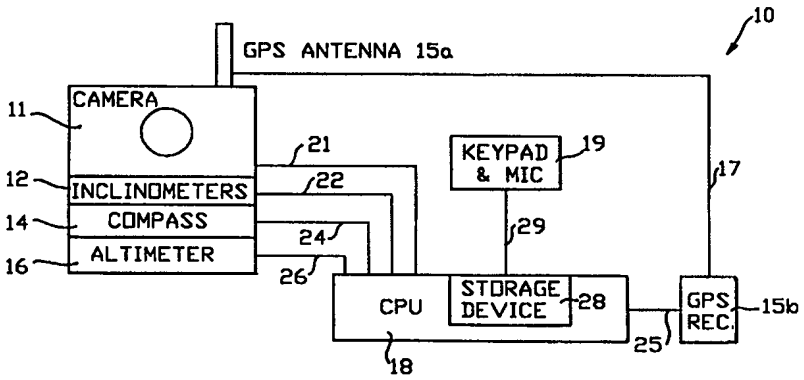
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(57) Abstract

In accordance with the present invention, there is provided an image capture and georeferencing unit. The unit comprises in combination, a portable camera (11) with a GPS antenna and receiver (15b) that captures global coordinates, a compass (14) for determining the direction and an inclinometer (12) for the photographic angle. The camera and other instruments feed image and shot data to a CPU (18), where the shot data is analyzed, mathematically interpolated and reconciled with known constants. The image and shot data are stored in memory (28). The "shot data" analyzed by the computer includes camera parameters such as camera: location, latitude, longitude and altitude, time, bearing, depression angle/pitch or azimuth, roll and yaw. The portable camera and data–gathering instruments move together and, therefore, function as a single unit that provides precise, accurate data and digitized photographic image information, despite topographical changes and/or altitude variations of the camera. Exact digital representations with precise coordinates are instantly available for precise reconnaissance purposes. The photographic shot data is mathematically adjusted (trigonometrically) to coordinate the points on the ground plane with the points in the image plane in order to produce an automatically computationally georeferenced digital image. Elevation data may be used to corroborate or enhance the accuracy of the trigonometric interpolations.

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DIGITAL-IMAGE MAPPING

FIELD OF THE INVENTION

The present invention pertains to the capture and automatic georeferencing of a camera and/or images captured by the camera by utilizing a portable camera and data unit and, more particularly, to a system and method of obtaining precisely located, oblique, digitized land images, taking into account diverse topography and varying camera angles, including changes in heading, roll and yaw.

BACKGROUND OF THE INVENTION

Aerial photography of land images for reconnaissance purposes is well known, as illustrated in United States Patent No. 5,247,356 (issued to John A. Ciampa on September 21, 1993), entitled METHOD AND APPARATUS FOR MAPPING AND MEASURING LAND. This patent teaches that coordinates of a land location can be calculated and combined with photographic information about the terrain. The global position and the elevation information are converted into digitized form, along with the image information and then stored in computer memory.

One of the problems of such aerial-photography methodology is that photographs must be taken over landscapes of relatively flat terrain, while a plane's altitude is generally parallel with the landscape, or at aircraft altitudes where topographical variations are generally minimized in the angular calculations. The inability of the prior art of aerial photographic systems to coordinate image information with collateral measurements has often required the use of expensive

flight platforms, preordained flight paths and orthogonal camera angles.

In order to obtain exact geographic coordinates of any land image, it is no longer necessary to stabilize the camera, flight path and elevation, as previously calculated in the aforementioned patent. Due to additional data and calculations, the camera may now be freed up, regardless of topographical changes and changes of camera angles with respect to this changing topography.

The present invention combines into a single unit a portable camera with a data unit containing a Global Position Satellite (GPS) antenna/receiver, including but not limited to differential GPS or other type GPS system, a compass and inclinometer. The data unit provides camera coordinates and triaxial angle data, which are combined with the digital representations of the photographic image. Trigonometric formulas correlate to the image pixel and corresponding ground coordinates. An iterative algorithm, as is well known in fuzzy logic and optimization routines, is used to compensate for the changes and variations in the landscape topography. This is accomplished by using known Digital Elevation Models (DEM) that are furnished by the United States Geophysical Survey (USGS) or other digital terrain models captured as a result of laser signals. In addition the system's mathematical algorithms take account of the differences in measurements of known objects such as cars and distribute these differences to fixed variables which has the effect of raising, lowering, tilting or reshaping a virtual ground plane that compensates for differences caused by elevation. The particular camera to be utilized with this invention may be an analog, digital video or still digital

camera. The camera may be carried by an operator who is on foot or in a land, sea or air craft.

The inclinometer, the GPS antenna/receiver and a compass are affixed to the camera so that they move together as a unit. The inclinometer detect changes in the depression angle and the roll angles of the camera. The photographic data is attached to the image file and is transferred to a small microprocessor (CPU), where the storage device can be a PCMCIA memory card. The microprocessor processes and links the shot data from the instruments with a digital image file. All of the data regarding depression angle, global position, heading (or bearing) and image are interpolated and combined with the shot time. This digitized image and other information are then stored in a spatially managed image file mosaic software, whereby images can be retrieved based on their map location or from a gallery or "contact sheet" of digital miniature thumbnails.

The method of the invention comprises the following steps. The image is first digitally captured by a "digital" camera or other digitizing device, along with the aforementioned shot data. "Shot data" is then analyzed by the computer, including location (i.e., latitude, longitude and altitude); camera bearing or heading (the compass direction in which the lens is pointing); the camera depression angle or azimuth; and the camera roll (i.e., the yaw of the camera, with respect to its horizontal axis). The shot data is then mathematically adjusted (trigonometrically) to coordinate the points on the ground plane with the points in the image plane, so as to produce an automatically computationally georeferenced digital image. Elevation data may be used to corroborate or enhance the accuracy of the trigonometric interpolation. The result of all of this

processing provides an image, or a portion thereof, from which can be obtained geographic coordinates of any point on the ground and/or ground measurements taken between any two points in the image. This "georeferencing" of each image also determines its placement in a series of adjacent images, so that each image can be depicted as a "tile" within a "mosaic" of tiled images. Each image, in addition to its georeference, is processed so as to contain a discrete sequential identifier, the date and the time. Many images of the same landscape may be taken by using different angles and camera positions, each of which is accessible by means of a graphical user interface. Trigonometric processing also takes into account fixed variables, such as lens focal length, the size of the image plane, the number of pixels in the X-Y axes (horizontal and vertical planes) and the size of the pixels.

It is the object of the present invention to provide an improved oblique aerial-photography system so that any person without special "photo-interpreting" skills may conduct electronic field studies of land and building, as well as ground-based visual inventories.

It is another object of this invention to provide a portable photography system that combines into a single operational unit a photographic camera with a GPS antenna/receiver that captures global coordinates, a compass for determining camera direction and inclinometer for calculating the photographic angle.

It is a further object of this invention to provide a digital photographic imaging system that "georeferences" each geographical image, so that each image, or part thereof, can be depicted as a "tile" within a "mosaic" of tiled images.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided an image capture and georeferencing unit. The unit comprises in combination, a portable camera with a Global Position Satellite (GPS) antenna/receiver that captures global coordinates, a compass for determining the direction and an inclinometer for calculating the photographic angle. The camera and other instruments feed image and shot data to a CPU, where the shot data is analyzed, mathematically interpolated and reconciled with known constants. The image and shot data are then stored in memory. The "shot data" analyzed by the computer includes camera location (i.e., latitude, longitude and altitude), time, camera bearing (the compass direction in which the lens is pointing), the camera depression or azimuth, and camera roll (i.e., the yaw of the camera with respect to its horizontal axis). The portable camera and data-gathering instruments move together and, therefore, function as a single unit that provides precise, accurate data and digitized photographic image information, despite topographical changes and/or altitude variations of the camera. They also provide precise data on the GPS location of the camera and its altitude with respect to the ground. Exact digital representations with precise coordinates are instantly available for precise reconnaissance purposes. The photographic shot data is mathematically adjusted (trigonometrically) to coordinate the points on the ground plane with the points in the image plane in order to produce an automatically computationally georeferenced digital image. Elevation data may be used to corroborate or enhance the accuracy of the trigonometric interpolations.

The result of all of this processing provides an image,

or a portion thereof, from which can be obtained geographic coordinates of any point on the ground and/or measurements on the ground taken between any two points in the image. The "georeferencing" of each image also determines its placement in a series of adjacent images, so that each image can be depicted as a "tile" within a "mosaic" of tiled images. Each image, in addition to its georeference, is processed so as to contain a discrete sequential identifier, the date and the time. Many images of the same landscape may be taken by using different angles and camera positions, each of which is accessible by means of a graphical user interface. Processing adjusts the shot data to compensate for fixed camera data, such as the lens focal length, the size of the image plane, the number of pixels in the X-Y axes (horizontal and vertical planes) and the size of the pixels.

BRIEF DESCRIPTION OF THE DRAWINGS

A complete understanding of the present invention may be obtained by reference to the accompanying drawings, when considered in conjunction with the subsequent detailed description, in which:

FIGURE 1 illustrates a schematic, block diagram of the camera and instruments of this invention;

FIGURE 2 depicts a flow diagram of the processing method used in the system shown in FIGURE 1, in which an image is captured, digitized and combined with shot data and other georeferencing information, and thereafter stored for future use;

FIGURE 3 shows a flow diagram of the image file management software of the inventive system depicted in FIGURE

1; and

FIGURES 4 A-C illustrate the inventive technique used to mathematically calculate the georeference at each pixel of the image; and

FIGURES 5 A-B illustrate a schematic view of the inventive technique used to mathematically reconcile the shot data with Digital Elevation Models and/or other known "ground truth".

DESCRIPTION OF THE PREFERRED EMBODIMENT

Generally speaking, the invention features an imaging system, including a novel combination of a portable camera, GPS receiver, bearing compass and inclinometer(s). All of the components move and function as a single unit, so that, despite changes in the depression and the roll angles of the camera, each digital image is captured, along with shot data, which becomes automatically, computationally georeferenced.

Now referring to FIGURE 1, an imaging system 10 of this invention is illustrated. The system combines a camera 11 with an inclinometer 12, a compass 14, an optional altimeter 16 and a Global Position Satellite (GPS) antenna/receiver, 15a and 15b, respectively. The particular camera 11 that can be utilized with this invention may be a databack film camera that is capable of affixing shot time and subsequent digitization. The camera 11 can also be an analog, a digital video or a still digital camera. The camera 11, inclinometer 12, compass 14, optional altimeter 16 and GPS receiver 15b are each individually connected to a CPU processor 18 containing a fixed or removable memory 28 (such as a PCMCIA card) via respective lines 21, 22, 24, 26 and 25. The

GPS antenna 15a is connected to the GPS receiver 15b via line 17. Also connected to the CPU processor 18 are an optional key-pad-and microphone 19 via line 29. The key-pad-and-microphone 19 can be used to enter comments or additional information with respect to the photographed site. Where altitude provided by the GPS is adequate, the altimeter 16 may be dispensed with. Where comments are impractical, the key-pad-and-microphone 19 may also be dispensed with.

The invention reflects the discovery that in addition to camera location, it is necessary to factor into the calculations the changes in the elevation of the depicted land, the depression and the bearing of the camera, with respect to this encompassed land. The compass 14 provides camera heading or bearing information; the GPS antenna/receiver 15a and 15b provide the camera position information (latitude, longitude and altitude); the inclinometers 12 provide the depression and roll angles; and the optional altimeter laser or other 16 provides additional altitude information. As an alternative to or in addition to instrumental measurements of land, the system may computationally deduce elevations within the image by assessing deficiencies in measurements of known objects such as cars. These variables are combined with the digital image, plane measurements, focal length, and pixel data to give a georeferenced image down to the pixel level.

The instrument's shot data are recorded and used to coordinate the points on the ground plane with the points in the image plane in order to produce a georeference for each pixel. DEM data are used to corroborate or enhance the accuracy of the trigonometric interpolations. The result of all of this processing provides an image, or a portion thereof, from which

can be obtained geographic coordinates of any point on the ground and/or measurements on the ground taken between any two points in the image. The "georeferencing" of each image also determines its placement in a series of adjacent images, so that each image can be depicted as a "tile" within a "mosaic" of tiled images. Each image, in addition to its georeference, is processed so as to contain a discrete sequential identifier, the date and the time. Many images of the same landscape may be taken by using different angles and camera positions, each of which is accessible by means of a graphical user interface. Processing adjusts the shot data to compensate for the lens focal length, the size of the image plane, the number of pixels in the X-Y axes (horizontal and vertical plans) and the size of the pixels.

The GPS antenna/receiver 15a and 15b can be obtained from, among others, Trimble Navigation Systems of Sunnyvale, California. A fluxgate compass 14 and inclinometers 12 are available from, among others, KVH Industries, Inc., of Middletown, Rhode Island.

In processing the information, the CPU 18 accesses Digital Elevation Model (DEM) data from a database in order to adjust the image data for topographical variations. The position variables (camera X, Y and Z coordinates) are obtained from the Global Position Satellite (GPS) receiver. The pointing variables (camera heading or bearing) are obtained from the compass 14, and the depression and the roll information are obtained from the inclinometers 12.

The processing assumes a simple, pin-hole camera model. The ground position of the photographed image can be defined by simple triangular, trigonometric processing of the depression

angle ϕ_D, the size of the image plane and the focal length (FL) of the camera as shown in FIGURE 4A. A pixel location (P_x, P_y) of a particular point selected on a displayed image can be processed for a particular depression angle by calculating the inverse tangent of the angle as shown in FIGURE 4B.

Referring to FIGURE 4C, assuming a northerly direction, the angle ϕ_D (depression angle) is offset by the arctangent (film height [y] * (row containing focal axis [F_y] -row of selected pixel [P_y])/2* image plane height [Z] * focal length [FL]) resulting in angle ϕ_p. The angle ϕ_p is subtracted from the recorded depression angle ϕ_p and denoted as ρ_v relative to the point on the ground immediately below the camera, with camera altitude above the ground "Z" (height). The northerly distance to the selected point [P_x, P_y] is Z* sin ($\pi/_2$ - ρ_v). The east-west distance is calculated from the (column of selected pixel [P_x] -focal axis column [F_x]/$_2$)*film width [x]/image plane width [x_1].

east-west distance = Camera Z*cos ϕ/2*focal length * sin ρ_v

When the direction is other than north, a simple rotation is made on the point to establish the ground location. The true location is then obtained by translating the ground location of the camera into its recorded position.

Ground location for terrain "T" that is not flat is adjusted by using DEM data and an iterative algorithm, well known in the art of optimization routines. The processor 18 uses the algorithm and the point [g_1] assumed for a flat terrain as shown in FIGURE 5A. The processor accesses the DEM data for that point and obtains the elevation [g_2] as shown in FIGURE 5B. The process is complete if the elevation at that camera location is

the same as that of the selected point. Otherwise, the camera elevation is modified to account for the difference in the ground elevation of the selected point. The revised value is then used to estimate the ground location (G_3). The iterative algorithm continues to revise the estimate until it converges to within acceptable limits. The algorithm is modified to adjust for roll of the camera by transforming pixel coordinates to a new set of coordinates. The transformation is a simple rotation about focal axis "F" by well-known mathematical methods.

$$T\mu = [\cos \mu \ \sin \mu \ ] \ - \ \sin\mu \ \cos \mu$$

The data points provided by the DEM are sampled along the ground every 30 meters in an orthogonal grid bounded by g_2 and g_1, as shown. Intermediate points are obtained by interpolation, such as by using bilinear interpolation or bicubic splines.

The position of the camera and the pointing angles are subject to a small degree of error and, therefore, may be reconciled with measured ground truth other than DEM data. This is accomplished by locating or measuring discrete objects in several images and then modifying the collected data so as to obtain more accurate estimates.

Referring to FIGURE 2, a flow chart 100 is illustrated for the image-and-data-capture process of this invention. An image is captured by camera 12, step 101; the image information is converted to digital form, step 102. The camera altitude, ground location, tilt, depression angle and heading (bearing) are then obtained, as shown in step 103. The information from steps 102 and 103 is then combined, step 104. The data is then adjusted according to focal length, pixel size, pixel location

and focal axis, as previously explained with reference to FIGURE 4, step 105. The result of all of the processing provides an image, or a portion thereof, from which can be obtained geographic coordinates on the ground and/or ground measurements taken between any two image points. The "georeferencing" of each image determines its placement in a series of adjacent images, so that each image can be depicted as a "tile" within a "mosaic" of tiles images, step 106. The DEM data is then used to adjust the image data for variations in the terrain, step 107. The image data is then compressed for storage purposes, step 108.

Referring to FIGURE 3, a flow chart 200 illustrates in more detail the DEM adjustment process for the data obtained in FIGURE 2. A tile from the mosaic is obtained, steps 201 and 202. In conjunction with the selection, an associated DEM elevation file is accessed, step 203. The accessed data is then combined and the digitized data decompressed, step 204. The image and adjoining images are then displayed, step 206. Certain features of the images are selected, step 207, and the horizontal or vertical measurements are selected for review, step 208. Different images are reviewed, step 210, and the end points are measured, step 209. The ground points are then estimated, step 211, and compared with the DEM data, step 212. If the elevation estimate is different, the elevation is revised, step 214, and entered via line 215. A new estimate is made via return loop 205, and the re-entering of step 211. After a few iterations, the decision is made, step 212, to report distance between points, step 217 via line 216. When the estimate is found accurate, the actual distance between the selected ground points is made, step 217. The process is then repeated via return loop 220, in order to obtain the distance values for other selected

points and tiles.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

What is claimed is:

1. An image georeferencing system, comprising:

a portable, data-capturing device affixed to a camera, with said camera providing an image, said portable, data-capturing device and said camera being carried by hand or upon an aerial surveillance vehicle or other craft, said portable, data-capturing device providing data for computationally generating a georeference, and being independently operative of any aeronautical instruments, said portable, data-capturing device further including at least one inclinometer for determining depression angle, a means for determining heading or bearing of said data-capturing device and a global position satellite antenna/receiver for obtaining georeferencing information, said at least one inclinometer and said global position satellite antenna/receiver being movable as a single unit; and

a processor operatively connected to said portable, data-capturing device and said camera, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device, said processor computationally generating a georeference of any object within said image, in which said object can be located and measured therewithin.

2. The imaging georeferencing system in accordance with claim 1, further comprising an altimeter connected to said processor for determining additional altitude data of said portable, data-capturing device.

3. The imaging georeferencing system in accordance with claim 1, further comprising a key pad connected to said processor for entering pilot information into said processor.

4. The imaging georeferencing system in accordance with claim 1, further comprising a microphone connected to said processor for entering comments into said processor.

5. An image georeferencing system, comprising:

a camera for providing an image in combination with a georeferencing, data-capturing device and inclinometer, said combination carried by hand or upon an aerial surveillance vehicle or other craft, said georeferencing, data-capturing device capturing data for computationally generating a georeference of any object within said image; and

a processor connected to said camera and georeferencing, data-capturing device combination, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device and processing said captured data for computing a georeference of any object within said image.

6. The image georeferencing system in accordance with claim 5, wherein said camera and georeferencing, data-capturing device combination comprises at least one inclinometer for determining depression angle, a means for determining heading of said image and a global position satellite antenna/receiver for obtaining georeferencing information with respect to said image, said at least one inclinometer and said global position satellite

antenna/receiver being movable as a single unit, with each being connected to said processor.

7. The image georeferencing system in accordance with claim 6, further comprising an altimeter connected to said processor for determining additional altitude data.

8. The image georeferencing system in accordance with claim 5, further comprising a key pad connected to said processor for entering comments into said processor.

9. The image georeferencing system in accordance with claim 5, further comprising a microphone connected to said processor for entering comments into said processor.

10. A method of computationally georeferencing images, comprising the steps of:

a) capturing an image of terrain to provide digitized image information;

b) combining said digitized image information with shot data from instrumental data and camera data;

c) analyzing said combined digitized image and said shot data;

d) obtaining information with respect to image location data, including at least one of a group of location data including variations in camera latitude, longitude, altitude, camera bearing, camera depression angle, roll and yaw; and

e) adjusting information obtained in step (b) and utilizing information obtained in step (d) to coordinate points on a ground plane with points in an image plane to produce

a georeferenced digital image of the terrain.

11. The method in accordance with claim 10, further comprising the step of:

f) utilizing digital elevation model data to enhance accuracy of image and georeferencing information obtained in step (b).

12. The method in accordance with claim 10, further comprising the step of:

f) processing said information obtained in step (b) to provide an image, or a portion thereof, that can be spatially located by using geographic coordinates and/or measurements taken between any two points.

13. The method in accordance with claim 10, further comprising the step of:

f) depicting combined image information and georeferencing information as a "tile" within a "mosaic" of tiled images, with each image, in addition to its respective georeference, being processed so as to contain a discrete sequential identifier, date and time.

14. The method in accordance with claim 10, further comprising the step of:

f) capturing a multiplicity of images of the same terrain in accordance with step (a) by using different angles and capture positions to provide different points of view of the same scene, each of which being accessible by means of a graphical user interface.

15. The method in accordance with claim 10, further comprising the steps of:

f) obtaining information with respect to lens focal length, size of image plane, number of pixels in horizontal and vertical planes, and size of pixels; and

g) processing said image information in step (a) with respect to said information obtained in step (f) to adjust said image information.

16. A method of aerial surveillance of terrain, comprising the steps of:

f) aerially capturing an image of terrain to provide image information;

g) combining said image information with shot data as georeferencing variables;

h) analyzing said combined image and said georeferencing variables;

i) obtaining information with respect to image location data, including at least one of a group of location data including variations in camera latitude, longitude, altitude, camera bearing, camera depression angle, roll and yaw; and

j) adjusting information obtained in step (b) and utilizing information obtained in step (d) to coordinate points on a ground plane with points in an image plane to produce an exact image of the terrain.

17. The method in accordance with claim 16, further comprising the step of:

f) utilizing digital elevation model data to enhance accuracy of image and georeferencing information obtained in step (b).

18. The method in accordance with claim 16, further comprising the step of:

f) processing said information obtained in step (b) to provide an image, or a portion thereof, that can be spatially located by using geographic coordinates and/or make known geographic coordinates of the ground at any point depicted in the image and/or ground measurements taken between any two points of the image.

19. The method in accordance with claim 16, further comprising the step of:

f) depicting combined image information and georeferencing information as a "tile" within a "mosaic" of tiled images, with each image, in addition to its respective georeference, being processed so as to contain a discrete sequential identifier, date and time.

20. The method in accordance with claim 16, further comprising the step of:

f) taking a multiplicity of images of the terrain in accordance with step (a) by using different angles and capture positions to provide multiple views, accessible by means of a window-like, graphical user interface.

21. The method in accordance with claim 16, further comprising the steps of:

f) obtaining information with respect to lens focal length, size of image plane, number of pixels in horizontal and vertical planes, and size of pixels; and

g) processing said image information obtained in step (a) with respect to said information obtained in step (f) to adjust said image information.

22. An image georeferencing system comprising

a camera for providing an image in combination with a georeferencing, data-capturing device, said combination carried by hand or upon an aerial surveillance vehicle or other craft, said georeferencing, data-capturing device capturing data for computationally generating and recording a georeference of the camera for each captured image; and further comprising a device selected from the group consisting of an inclinometer, means for determining heading or bearing of the camera.

23. The image georeferencing system of claim 22 further comprising a processor connected to said camera and georeferencing, data-capturing device combination, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device and processing said captured data for computing a georeference of any object within said image.

24. The image georeferencing system of claim 23 wherein said camera further comprising means for recording the depression and roll angle of the camera for each image captured by the camera.

25. The image georeferencing system of claim 23 wherein said camera further comprising means for recording the altitude of the camera for each image captured by the camera.

26. The image georeferencing system of claim 23 wherein said georeference data is obtained by a global position system antenna and receiver connected to the processing unit.

27. The image georeferencing system of claim 26 wherein said processing unit is within said camera.

28. The image georeferencing system of claim 24 wherein said angle means is an inclinometer connected to the processing unit.

29. The image georeferencing system of claim 25 wherein said altitude means is an altimeter connected to the processing unit.

30. A digital mapping system, comprising:

a portable data-capturing device affixed to a camera, said camera providing an image, said portable data-capturing device and said camera being carried by hand or upon an aerial surveillance vehicle or other craft for providing a pixel-based image, said portable data-capturing device providing data for computationally generating a georeference for each pixel of said pixel-based image, said data-capturing device being independently operative of any aeronautical instruments, said portable data-capturing device further including at least one inclinometer for determining declination angel, a means for determining heading or bearing of said image-capturing device and a global position satellite antenna/receiver for obtaining georeferencing information, said at least one inclinometer and

said global position satellite antenna/receiver being movable as a single unit; and

a processor operatively connected to said portable data-capturing device and said camera, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device, said processor computationally generating a georeference of each pixel and any object within said image, wherein said object can be located and measured within said image.

31. The imaging georeferencing system in accordance with claim 30, further comprising a key pad connected to said processor for entering pilot information into said processor.

32. The imaging georeferencing system in accordance with claim 30, further comprising a microphone connected to said processor for entering comments into said processor.

33. An image georeferencing system in accordance with claim 30, further comprising:

a camera for providing an image in combination with a georeferencing, data-capturing device and inclinometer, said combination carried by hand or upon an aerial surveillance vehicle or other craft, said georeferencing, data-capturing device capturing data for computationally generating a georeference of any object within said image; and

a processor connected to said camera and georeferencing, data-capturing device combination, said processor comprising data storage means, including digital elevation

information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device and processing said captured data for computing a georeference of any object within said image.

34. A digital mapping system, comprising:

a camera for providing a pixel-based image in combination with a georeferencing data-capturing device, said combination carried by hand or upon an aerial surveillance vehicle or other craft, said georeferencing data-capturing device capturing data for computationally generating a georeference of each pixel and any object within said image; and

a processor connected to said camera and georeferencing data-capturing device combination, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said image-capturing device, and processing said captured data for computing a georeference of each pixel and any object within said image.

35. The image georeferencing system in accordance with claim 34, wherein said camera and georeferencing, data-capturing device combination comprises at least one inclinometer for determining depression angle, a means for determining heading of said image and a global position satellite antenna/receiver for obtaining georeferencing information with respect to said image, said at least one inclinometer and said global position satellite antenna/receiver being movable as a single unit, with each being connected to said processor.

36. The image georeferencing system in accordance with claim 35, further comprising an altimeter connected to said processor for determining additional altitude data.

37. The image georeferencing system in accordance with claim 34, further comprising a key pad connected to said processor for entering comments into said processor.

38. The image georeferencing system in accordance with claim 34, further comprising a microphone connected to said processor for entering comments into said processor.

39. A method of digitally mapping terrain, comprising the steps of:

a) capturing a pixel-based image of terrain to provide digitized image information;

b) capturing georeferencing information;

c) combining said digitized image information with said captured georeferencing information; and

d) processing said combined digitized image information and said captured georeferencing information in order to generate a georeference of each pixel and any object within said image of said terrain, whereby said object can be located within said image of terrain.

40. The method in accordance with claim 39, further comprising the step of:

f) utilizing digital elevation model data to enhance accuracy of image and georeferencing information obtained in step (b).

41. The method in accordance with claim 39, further comprising the step of:

f) processing said information obtained in step (b) to provide an image, or a portion thereof, that can be spatially located by using geographic coordinates and/or measurements taken between any two points.

42. The method in accordance with claim 39, further comprising the step of:

f) depicting combined image information and georeferencing information as a "tile" within a "mosaic" of tiled images, with each image, in addition to its respective georeference, being processed so as to contain a discrete sequential identifier, date and time.

43. The method in accordance with claim 39, further comprising the step of:

f) capturing a multiplicity of images of the same terrain in accordance with step (a) by using different angles and capture positions to provide different points of view of the same scene, each of which being accessible by means of a graphical user interface.

44. The method in accordance with claim 39, further comprising the steps of:

f) obtaining information with respect to lens focal length, size of image plane, number of pixels in horizontal and vertical planes, and size of pixels; and

g) processing said image information in step (a)

with respect to said information obtained in step (f) to adjust said image information.

45. A method of aerial surveillance of terrain, comprising the steps of:

a) aerially capturing a[n] pixel-based image of terrain to provide image information;

b) combining said image information with georeferencing information; and

c) processing said combined image and said georeferencing information, in order to generate a georeference of each pixel and any object within said image of terrain, whereby said object can be located within said image of terrain.

46. The method in accordance with claim 45, further comprising the step of:

f) utilizing digital elevation model data to enhance accuracy of image and georeferencing information obtained in step (b).

47. The method in accordance with claim 45, further comprising the step of:

f) processing said information obtained in step (b) to provide an image, or a portion thereof, that can be spatially located by using geographic coordinates and/or make known geographic coordinates of the ground at any point depicted in the image and/or ground measurements taken between any two points of the image.

48. The method in accordance with claim 45, further

comprising the step of:

f) depicting combined image information and georeferencing information as a "tile" within a "mosaic" of tiled images, with each image, in addition to its respective georeference, being processed so as to contain a discrete sequential identifier, date and time.

49. The method in accordance with claim 45, further comprising the step of:

f) taking a multiplicity of images of the terrain in accordance with step (a) by using different angles and capture positions to provide multiple views, accessible by means of a window-like, graphical user interface.

50. The method in accordance with claim 45, further comprising the steps of:

f) obtaining information with respect to lens focal length, size of image plane, number of pixels in horizontal and vertical planes, and size of pixels; and

g) processing said image information obtained in step (a) with respect to said information obtained in step (f) to adjust said image information.

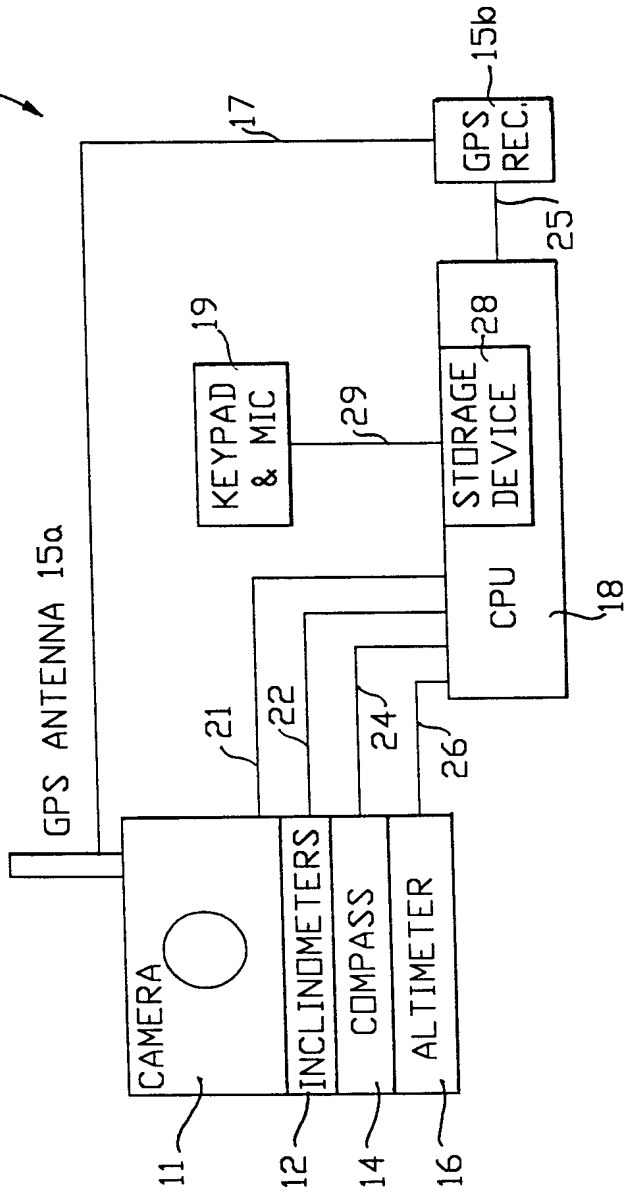

10
15b
GPS REC.
17
25
19
KEYPAD & MIC
29
28
STORAGE DEVICE
CPU
18
GPS ANTENNA 15a
21
22
24
26
CAMERA
INCLINOMETERS
COMPASS
ALTIMETER
11
12
14
16

FIG. 1

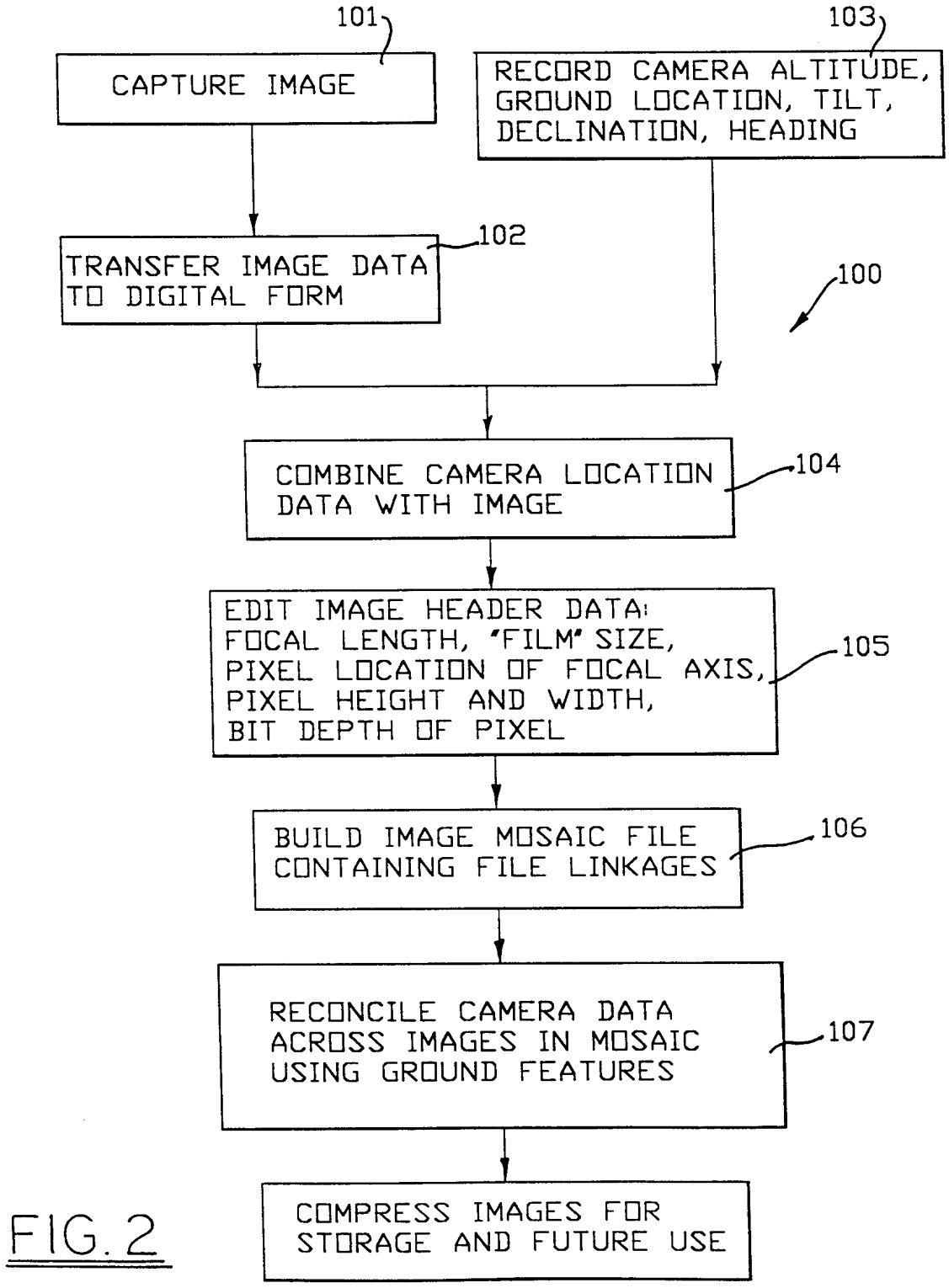

101
CAPTURE IMAGE
103
RECORD CAMERA ALTITUDE, GROUND LOCATION, TILT, DECLINATION, HEADING
TRANSFER IMAGE DATA TO DIGITAL FORM
102
100
COMBINE CAMERA LOCATION DATA WITH IMAGE
104
EDIT IMAGE HEADER DATA: FOCAL LENGTH, "FILM" SIZE, PIXEL LOCATION OF FOCAL AXIS, PIXEL HEIGHT AND WIDTH, BIT DEPTH OF PIXEL
105
BUILD IMAGE MOSAIC FILE CONTAINING FILE LINKAGES
106
RECONCILE CAMERA DATA ACROSS IMAGES IN MOSAIC USING GROUND FEATURES
107
COMPRESS IMAGES FOR STORAGE AND FUTURE USE

FIG. 2

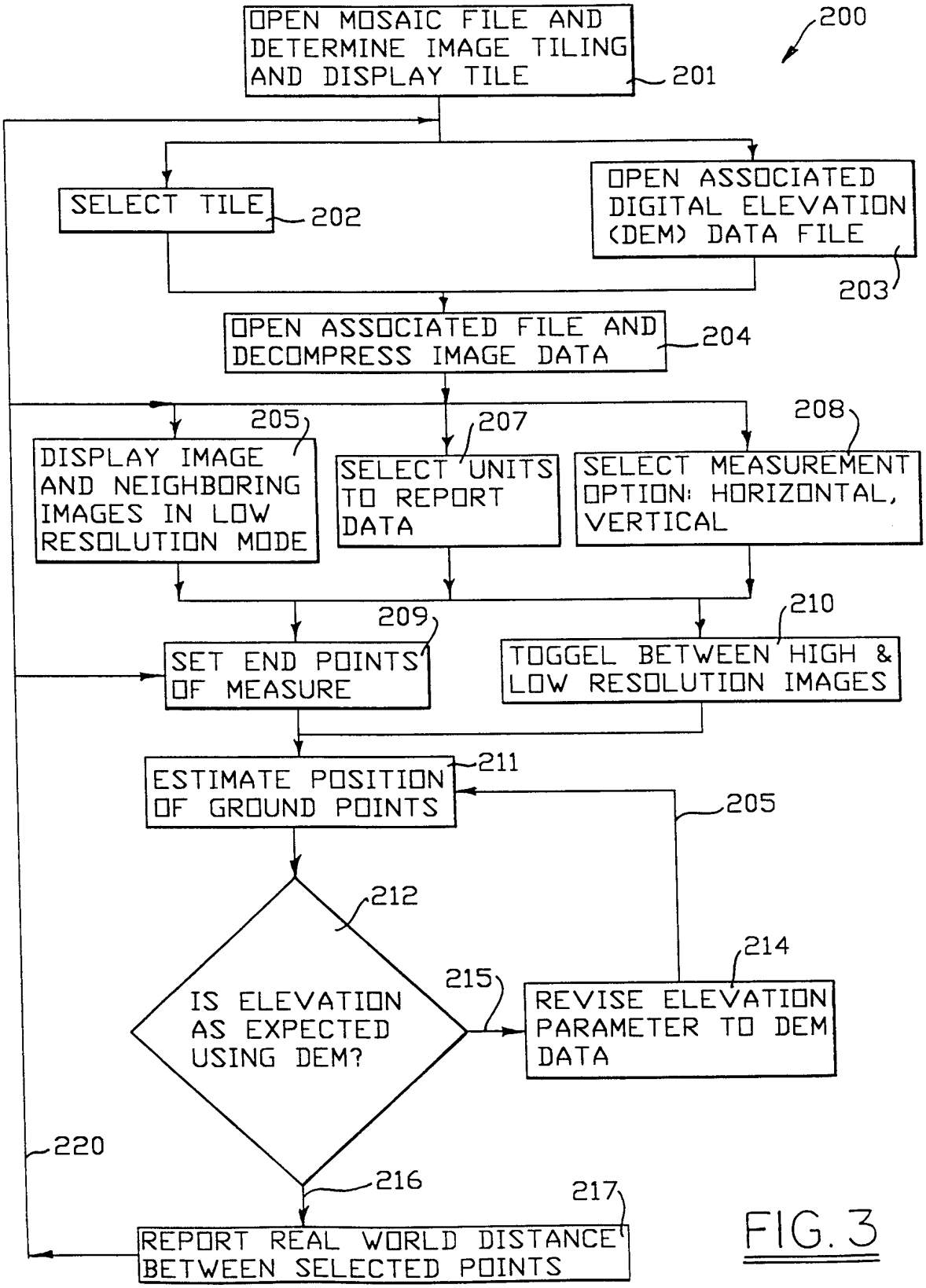

OPEN MOSAIC FILE AND DETERMINE IMAGE TILING AND DISPLAY TILE
201
200
SELECT TILE
202
OPEN ASSOCIATED DIGITAL ELEVATION (DEM) DATA FILE
203
OPEN ASSOCIATED FILE AND DECOMPRESS IMAGE DATA
204
205
DISPLAY IMAGE AND NEIGHBORING IMAGES IN LOW RESOLUTION MODE
207
SELECT UNITS TO REPORT DATA
208
SELECT MEASUREMENT OPTION: HORIZONTAL, VERTICAL
209
SET END POINTS OF MEASURE
210
TOGGEL BETWEEN HIGH & LOW RESOLUTION IMAGES
211
ESTIMATE POSITION OF GROUND POINTS
205
212
IS ELEVATION AS EXPECTED USING DEM?
215
214
REVISE ELEVATION PARAMETER TO DEM DATA
220
216
217
REPORT REAL WORLD DISTANCE BETWEEN SELECTED POINTS

FIG. 3

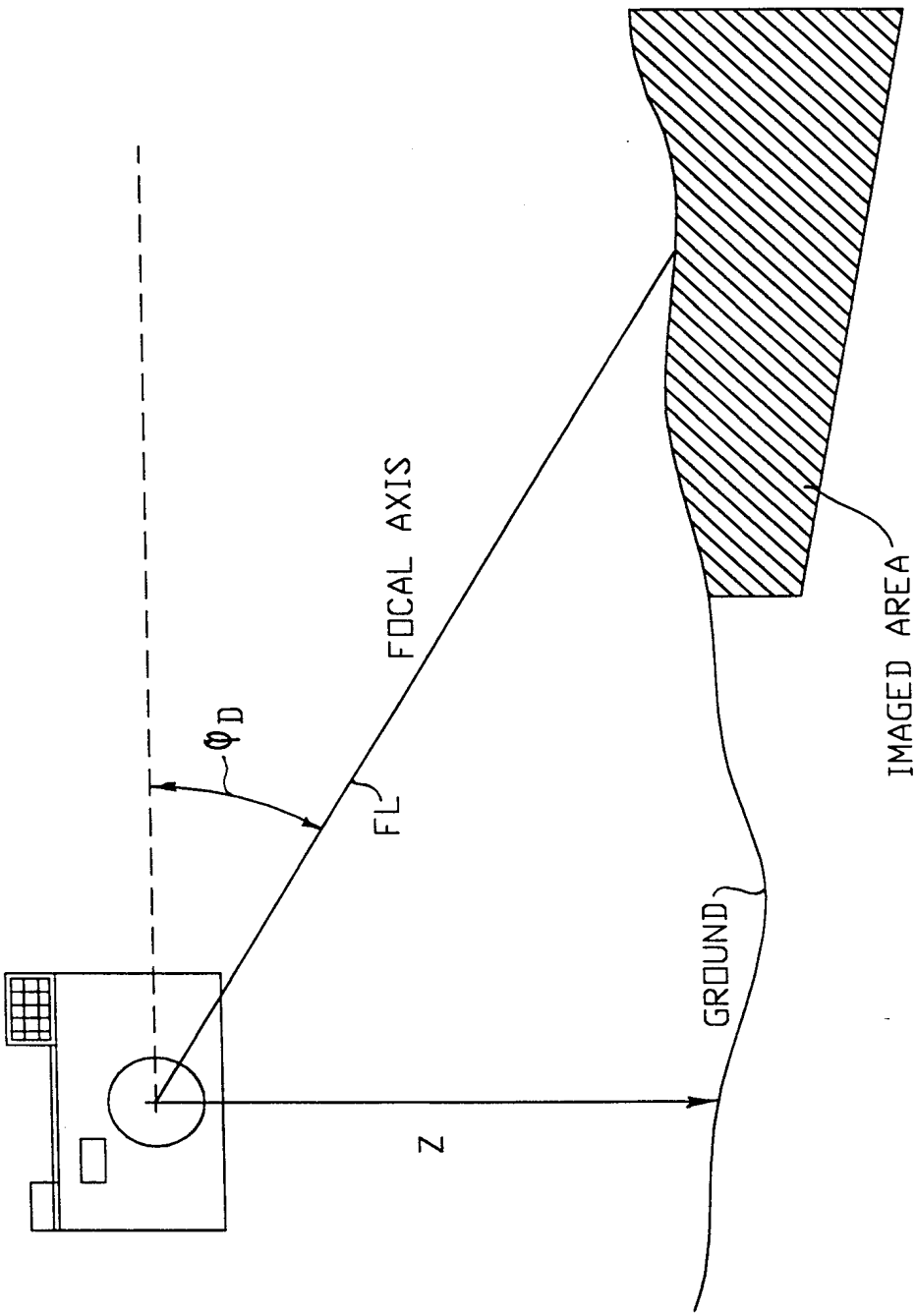


FIG. 4(a)

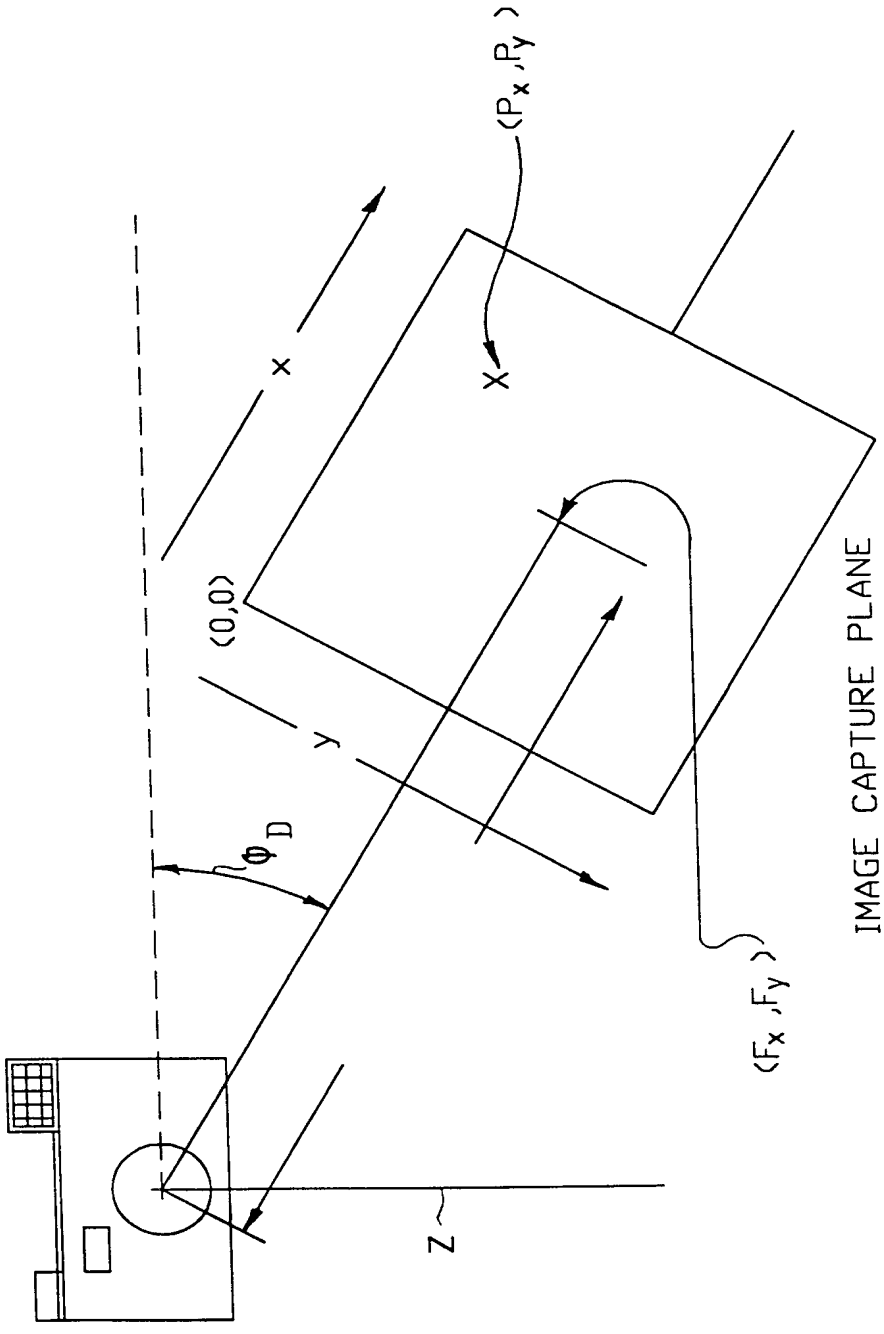


FIG. 4(b)

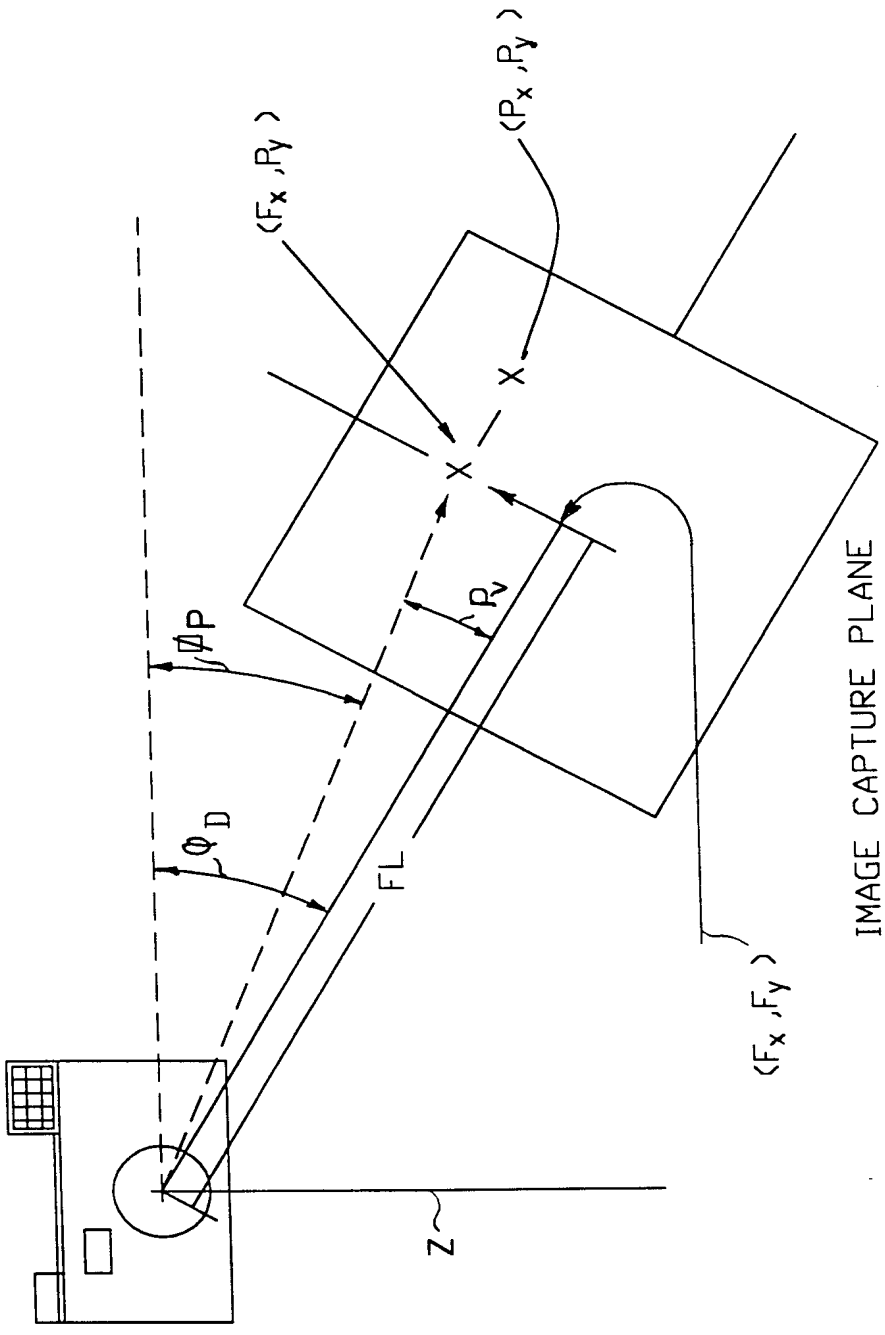


FIG. 4(c)

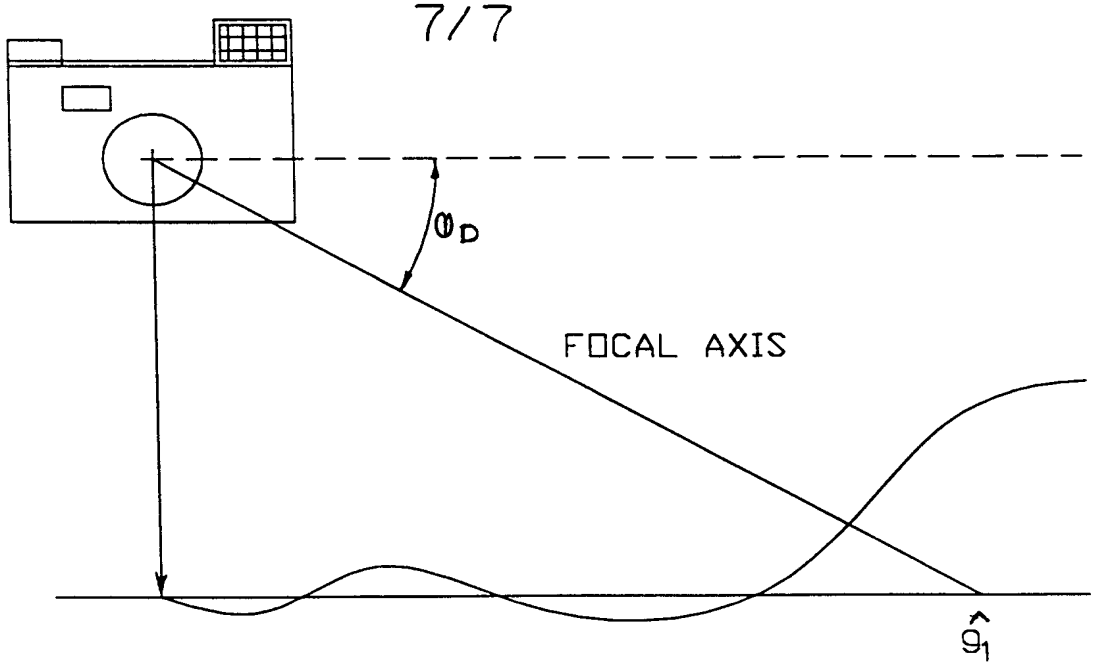


FIG. 5(a)

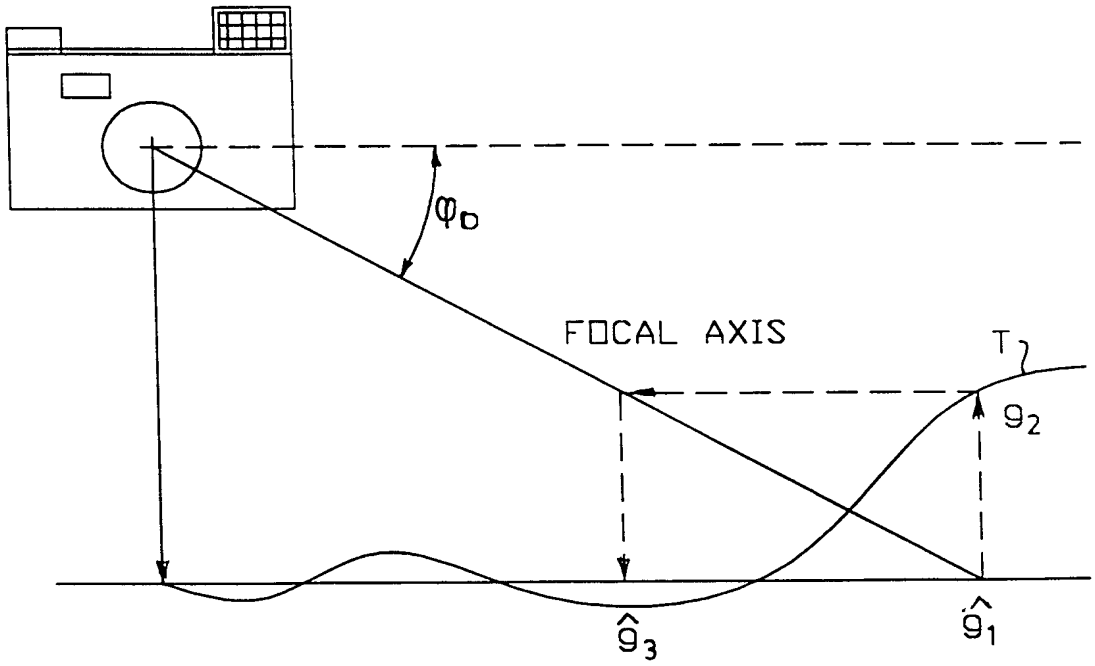


FIG. 5(b)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/20809

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :Please See Extra Sheet.
US CL :348/143,144,145,148, 373; 354/106; 364/420
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 348/143,144,145,148, 373; 354/106; 364/420

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,467,271 A (ABEL et al.) 14 November 1995, col. 3-30 and Figs. 1-8	10-21, 22-38
Y	US, A, 5,467,271 A (ABEL et al.) 14 November 1995, col. 3-30 and Figs. 1-8	1-9, 22-38
Y	US, A, 5,508,736 A (COOPER) 16 April 1996, col. 3-6 and Fig. 1	1-9, 22-38
A	US, A, 5,506,644 A (SUZUKI et al.) 09 April 1996, Figs. 3 and 9	None

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 NOVEMBER 1998	28 JAN 1999

Name and mailing address of the ISA/US	Authorized officer
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INTERNATIONAL SEARCH REPORT

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PCT/US98/20809

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (5):

H04N 7/18, 9/47, 5/225; G03B 17/24; G01V 1/00; G01W 1/10; G06F 17/00; G06G 7/48

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(30) Priority Data:
09/264,594 8 March 1999 (08.03.99) US

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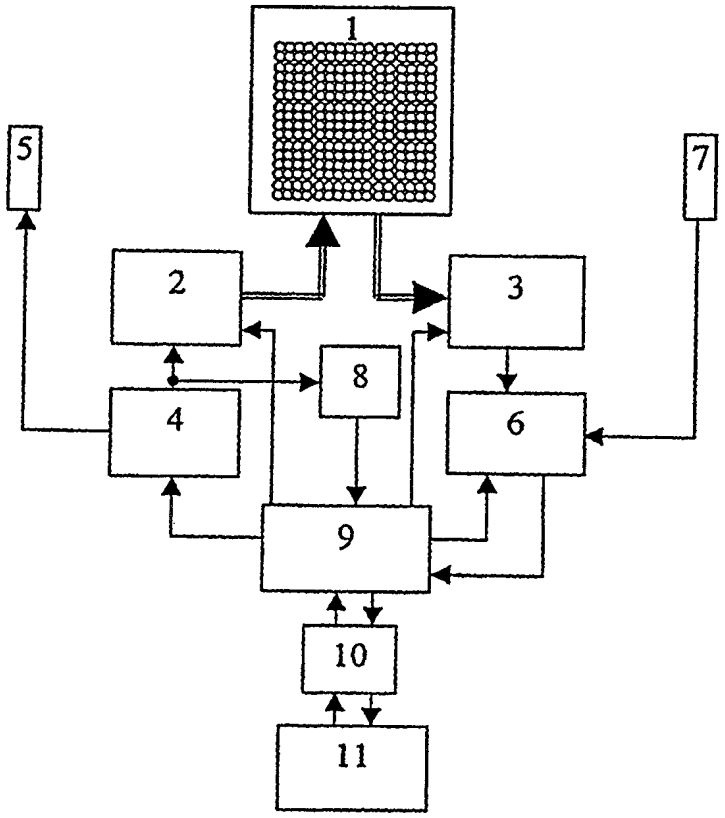
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(54) Title: ELECTRIC MAMMOGRAPH

(57) Abstract

The electric mammograph is an electrical impedance tomograph device for obtaining three–dimensional images of the conductivity distribution in biological tissues. A planar array of electrodes (1) is put in contact with the tissues of interest. An AC source (4) is connected to a single remotely attached electrode (5, 7) and to one of the planar array electrodes (1). Potential differences between the at rest electrodes in the planar array and a second remote at rest electrode (7, 5) are measured. The images are reconstructed using a modified back projection method.



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ELECTRIC MAMMOGRAPH

Technical Field

The invention is in the field of medical tomography, and in particular relates to a method and apparatus for the visualization and diagnosis of pathologic changes in breast tissues and other organs near the surface of the human body.

Background Art

It is known that electrical conductivity of many tumors, and in particular the malignant tumors of the mammary gland, significantly differs from the conductivity of surrounding sound tissues. This fact may be used for the detection and localization of such tumors.

Some devices are known for visualizing the spatial distribution of conductivity (impedance) in the human body, e.g., electrical impedance tomographs. (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph," International application PCT/RU97/00398.) In an electrical impedance tomograph, the source of alternating electric current is connected to pairs of electrodes placed along a line on the surface of a body and measurements of the potential differences are made on the other pairs of electrodes. The results of measurements obtained from various combinations of electrodes are used to reconstruct the conductivity distribution with the help of a computer. A three-dimensional distribution of conductivity, however, is not possible with this type of tomograph. Furthermore, its resolution falls significantly from the periphery to the center of contour of the electrodes. Consequently, it is not an adequate device for the diagnosis of mammary gland tumors.

An electroimpedance mammograph device, purporting

to yield a three-dimensional impedance distribution has also been described. (A. Nowakovsky, J. Wortek, and J. Stelter, "A Technical University of Gdansk Electroimpedance Mammograph," Proc. IX Int. Conf. Electrical Bio-Impedance, Heidelberg, 1995, p. 434-437; J. Wortek, J. Stelter, A. Nowakovsky, "Impedance mammograph 3D phantom studies," Proc. X Int. Conf. Electrical Bio-Impedance, Barcelona, 1998, p. 521-524.) This device contains a compact set of electrodes that are placed on the inner surface of a rigid hemisphere, multiplexers that are connected to the source of alternating electric current, and a device for measuring the potential difference between various pairs of electrodes. The measured potential differences are sent to a computer to reconstruct and display the three-dimensional impedance distribution inside the hemisphere. The serviceability of this device based on actual measurements on the human body have not yet been published.

A number of limitations for this device are apparent. The arrangement of electrodes on the hemisphere surface limits the application of the device because the contact with all the electrodes can be provided only for a breast of a definite size. The device also has no means to measure the quality of each contact, nor any means to correct the reconstruction calculations if any of the electrodes have insufficient contact with the body. This decreases the validity of the data. The electric current source and the measuring device are connected to pairs of electrodes placed on the hemisphere, requiring four multiplexers. When the number of electrodes is large, these multiplexers become the most complicated and expensive parts of the device. These multiplexers are also the largest source of spurious signals due to channel-to-channel crosstalk. Only 64 electrodes were used in the prototype. This is obviously insufficient for obtaining satisfactory resolution.

However, further increasing this number is problematical because of the difficulty of commutation by the chosen measuring circuit.

When a safe level of electrical current is used, the measured potential differences are small because of the small distances between electrodes. This decreases the signal-to-noise ratio and the display quality. This effect only gets worse with an increasing number of electrodes. The algorithm for image reconstruction is based on the perturbation method. It requires a calculation time of ten minutes on a workstation for a system of 64 electrodes (Nowakovsky). For 180 electrodes, the minimum necessary for practical applications, about ten hours are required for the calculations based on the estimations of the authors. This amount of time is not feasible for clinical practice.

Other attempts at obtaining three-dimensional electrical impedance images of a body have involved multi-dimensional electrode arrays that surround or partially surround the object being imaged. The reconstruction algorithms used and the methodology of making measurements were also different than those of the present invention. These efforts include U. S. Patents 5,284,142, 5,351,697, 4,263,920, 4,486,835, and 4,539,640.

A goal of the present invention is to provide a new method and apparatus for electric mammography with greater reliability and accuracy of measurements, higher resolution, and increased computational speed. This invention is particularly applicable to the clinical diagnosis of breast tumors and other subsurface areas.

Disclosure of the Invention

The electric mammograph is a device for the measurement and three-dimensional (3-D) reconstruction of the conductivity distribution in biological tissues for clinical diagnoses.

It consists of a compact array of electrodes positioned over the tissue being measured, two additional electrodes spaced apart from the array of electrodes, a source of alternating (AC) current, a means to measure potential difference, and computing means to reconstruct and visualize the resulting conductivity distribution.

Brief Description of the Drawings

The invention is illustrated in the following drawings.

FIG. 1 is a block diagram of the electric mammograph.

FIG. 2 shows the arrangement of the apparatus when conducting a mammograph examination.

FIG. 3 is a block diagram of the algorithm used for the three-dimensional conductivity distribution reconstruction.

FIG. 4 is a photograph of the apparatus

FIG. 5 is a sample electric mammogram.

Description of Preferred Embodiments

A block diagram of the components of the electric mammograph is shown in FIG. 1. A compact array of cylindrical protruding electrodes **1** is arranged in a rigid dielectric plane. The example shown has 256 electrodes. The output multiplexer **2** is connected to the electrode array **1** and is the means by which the alternating current (AC) source **4** is connected to one of the cylindrical electrodes in the array. The input multiplexer **3** serves to connect one of the non-activated or "rest" electrodes of the array to the potential difference measuring unit **6**. The microprocessor **9** and the computer **11,** connected via cables **10,** determine which electrode is activated and which of the rest electrodes is being measured at any given time.

Two single remote electrodes, **5** and **7**, are attached to the extremities of the patient. One remote electrode **5** is connected directly to the AC source. The other remote electrode **7**

is connected directly to the potential difference detector **6**. The AC source is connected to a voltage threshold detector **8**. The operation of the electric mammograph is controlled by a microprocessor/computer means. It gets inputs from the potential difference detector **6** and the threshold detector **8** and outputs to the two multiplexers **2**, **3**, the potential difference detector, and the AC source. The first remote electrode **5** connected to the AC source and the second remote electrode **7** are located on a patient's extremities, e.g., one on each wrist as shown in FIG. 2.

In the prior art methods of obtaining a tomographic image of a human body, a series of contact electrodes were placed on the surface of the patent's body. A source of electric current was connected sequentially to pairs of electrodes causing current to flow through the body. Measurements were then made of potential differences between pairs of other "non-activated" electrodes.

In the present invention, the output multiplexer **2** switches a single lead from the AC source to "activate" a single electrode in the electrode array **1** at a time, instead of activating pairs of electrodes in prior art devices. The second "activated" electrode is the remote electrode **5** that is always "on". Switching a single lead at a time reduces the spurious couplings arising from channel-to-channel penetration of signals in the multiplexer. It also simplifies the device and reduces its cost. The same is true for the input multiplexer **3**. The potential difference detector measures the difference between the selected array electrode and the remote rest electrode **7**. For a given rest electrode, the output multiplexer **2** sequences through all the other electrodes in the compact set while the potential difference detector makes its measurements. Then the rest electrode is switched and the output multiplexer sequence repeated.

Using the two singular electrodes **5**, **7** also increase the amplitude of the measured signals due to the increased distance between the points where the potentials are measured. This increases the signal-to-noise ratio and the accuracy of the measurements. The distance of these singular electrodes from the electrode array allows one to assume that the unperturbed equipotential surfaces of electric field are spherical in the examination area. It simplifies and speeds up the conductivity reconstruction calculations.

The method of back projection along equipotential surfaces of the electric field is used to reconstruct the 3-D conductivity distribution. It is assumed that in the case where the electric current is injected through one of the electrodes of the compact set of electrodes arranged in a planar array and the remote common electrode, equipotential surfaces near the two-dimensional set of electrodes are spherical. The procedure of back projection is reduced to the following. For some point with coordinates (X, Y, Z) inside the object under visualization, the distance is determined between this point and the injecting electrode of the compact array. This distance is equal to the radius r of the equipotential surface containing the point where the conductivity is reconstructed. Knowing this radius, it is possible to determine the line of intersection of the equipotential surface with the surface on which the electrodes are arranged. When the electrodes are arranged on the plane, given by equation $z=0$, this line is the circle lying in the (x, y) plane having its center at the point where the injecting electrode is located, and having radius r. Conductivity S (in arbitrary units) at the chosen point is calculated according to the equation:

$$S(x,y,z)=1+W_1(z)\sum_i \frac{1}{\int_{L(x,y,z,i)} W_2(l)dl} \int_{L(x,y,z,i)} W_2(l)(E_r(l)-E_m(l))/E_r(l)dl$$

where i – is the number of the injecting electrode, $L(x,y,z,i)$ - is the line of intersection of the equipotential surface with the surface on which the electrodes are arranged (circle with radius r). The components of the electric field vector $\vec{E}_m$ are first calculated at the nodes of the grid between the electrodes as the potential differences between adjacent electrodes in the x and y directions. Then these components are linearly interpolated to the current point of integration on the line L and the magnitude of this vector E_m is calculated.

The reference intensity of the electric field E_r corresponds to a homogeneous medium and is calculated numerically. Weighting coefficient $W_1(z)$ corrects the decrease of sensitivity with depth. In the present invention, the empirical equation $W_1=(z+\alpha)/(z+\beta), \alpha<<\beta$ is used for it. The weighting coefficient W_2 provides a relatively greater contribution to the calculated conductivity of those points on line L, which are located closer to the point at which the conductivity is reconstructed. In the present device, the equation: $W_2=1/R^4=1/\left((x-x_l)^2+(y-y_l)^2+z^2\right)^2$ is used, where R is the

distance between the point where the conductivity is reconstructed and the current point on the line along which integration is being carried out; the index *l* refers to the coordinates of this point.

The method of back projection is the fastest method used in electrical impedance tomography reconstruction. Its use, however, for reconstructing the static conductivity distribution for the 3-D case is only possible by a proper choice of the projected values.

In addition, the synthesized reference data set E_r must be used. This is obtained by approximating the real measured potentials according to the method of Korjenevsky. (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph," Russian Federation patent application N 96123647/14.)

In many cases it is difficult to obtain sufficient contact of all the electrodes with the patient's body. Consequently, the threshold detector **8** of the output voltage is used to determine whether the electrode being measured at any particular moment has sufficient contact with the body. The compact set of electrodes is arranged on a rigid dielectric plane and every electrode is a conducting protrusion from the plane. This arrangement permits an examination of a mammary gland regardless of its size. During an examination, this plane of electrodes is pressed against the breast, flattening it toward the chest. This increases the number of electrodes having contact with the body and decreases the thickness of the tissue layer to be measured. The protrusion of the electrodes improves their electrical contact with the body.

One or more of the electrodes on the periphery of the plane may not have contact with the body, depending on the size of the examined object. These electrodes are detected with the help

of the threshold detector of the output voltage mentioned above. The values of the potential differences measured from electrodes that have insufficient body contact cannot be used directly in the process of conductivity reconstruction. Instead, values of potential differences calculated on the assumption of a homogeneous conductivity distribution are used.

Besides the useful potential differences caused by the current flow, there are also galvanic potential differences between electrodes. The component for measuring the potential difference **6** is only sensitive to the alternating current component and, consequently, is not disturbed by the presence of these constant galvanic potential differences. However, due to the differences in galvanic potentials of different electrodes, the input voltage varies by a jump when the input multiplexer **3** is switched. These jumps produce a transient that influences the results of the measurements. This influence increases when the time interval between the switch and the start of the potential difference measurement decreases. Therefore, to decrease the error while keeping the total duration of the measurements constant, the input multiplexer **3** should switch the device for measuring the potential difference **6** to the next electrode only after the output multiplexer **2** completes the total cycle of switches of the AC source to all other electrodes.

FIG. 2 shows the arrangement of the various components of the electric mammograph used to take measurements. With the help of the output multiplexer, the control unit connects the source of AC current to one of the electrodes of compact set **1** according to commands from the computer **11**. AC current of approximately 1 mA and a frequency of 10 kHz flows through the circuit, i.e., from the AC source to the multiplexer, to the electrode of set **1**, through the patient's body to the remote rest

electrode **5**. With the help of the input multiplexer, the microprocessor connects one of the rest electrodes from set **1** to the potential difference detector. It measures the amplitude of the alternating voltage between the electrode from set **1** and the remote activated electrode **7**. This measurement is sent in digital code to the microprocessor, which passes it to the computer **11**.

The measured data are used to reconstruct a 3-D conductivity distribution with the help of the algorithm shown in block diagram form in FIG. 3. In block **12** the measured potentials of the electrodes from the compact set, received through the connection line **10**, are used for synthesis of the reference set of potentials corresponding to a body with homogeneous conductivity. An approximation by the method of least squares described in Russian Patent N 96123647/14 is used. Only those potentials obtained from electrodes with good body contact are used. In blocks **13** and **14**, components of the electric intensity vector are calculated for the reference and measured data set by subtraction of the values of potentials on adjacent electrodes for each variant of connection of the current source. In the last case, corresponding potentials from the reference set are used instead of the potentials of those electrodes with insufficient contact.

In block **15** the distance is calculated between the activated electrode in the compact set and the point at which the conductivity is being reconstructed. This distance determines the radius of a circle that represents the line of intersection of the equipotential surface with the plane on which the electrodes are arranged and along which it is necessary to carry out weighted averaging. The electric intensity for the measured and the reference data set are calculated after the linear interpolation of the corresponding components of vectors, calculated in blocks **13** and

14. The relative difference of the electric intensities for the reference and measured data sets are multiplied by the weight function $1/R^4$, where R is the distance between the point where the conductivity is reconstructed and the current point on the line along which averaging is being carried out.

In block **16** the obtained value is numerically integrated along the circle. These operations are repeated for all points where the conductivity is to be reconstructed and for all variants of the activated electrodes. This process is controlled by block **17**. The result of these calculations, after adding a unit to obtained values, represents a 3-D distribution of the conductivity normalized on the average value. The result can be displayed on screen or printed out. Block **18** contains the software and hardware used to carry out these functions.

The external appearance of the electric mammograph without the computing unit is shown in FIG. 4. FIG. 5 shows an electric mammogram obtained by the invention. The mammogram represents a set of seven images of breast cross-sections parallel to the plane on which the electrodes are arranged. The depth of the cross-sections increases from left to right and from up to down with 8 mm steps. On the image one can clearly see the nipple 19, the ribs **20**, and the boundary **21** between areas with and without sufficient electrode contact with the body.

CLAIMS

1. A method of displaying a three-dimensional image of the conductivity distribution of biological tissue, said method comprising the steps of:

applying a source (4) of alternating current (AC) to a first activated electrode (1) of a compact set of electrodes arranged in a planar array, said compact set of electrodes being in contact with the surface of the biological tissues of interest, and to a first remotely located electrode (5, 7) in contact with the body but at some distance from the compact set of electrodes;

measuring the potential difference between a first at rest electrode (1) of said compact set and a second remotely located electrode (7,5), said second remote electrode being at rest;

switching the source (4) of AC current by multiplexer means (2, 3) to activate successively all of the electrodes (1) of said planar array of electrodes except said at rest electrode of step (b) and measuring the potential difference between said at rest electrodes in (b) for each activated electrode in turn to thereby obtain a first set of potential difference measurements for each activated electrode;

switching the electrode (1) to be measured in said planar array by multiplexer means (2, 3) to a second at rest electrode (1), activating successively every other electrode in said planar array, and measuring the potential difference between said second at rest electrode and said at rest remote electrode (7, 5) in turn to thereby obtain a second set of potential difference measurements for each activated electrode;

continue switching the at rest electrode (1), activating successively the remaining electrodes in said planar array, and measuring the potential difference between the selected at rest

electrode and said at rest remote electrode (7, 5) in turn until all planar electrodes combinations have been measured;

reconstructing a three-dimensional conductivity distribution using the method of back projection along equipotential surfaces of the electric field, the projected data being obtained by weighted averaging of the relative difference between the reference electric intensity corresponding to tissue with a homogeneous conductivity distribution and the measured electric intensity along the line of intersection of the equipotential surface containing the point where conductivity is reconstructed and with the surface on which the compact set of electrodes (1) is located.

2. The method of claim 1, whereby a threshold detector means (8) determines whether any particular electrode (1) of the planar array has sufficient contact with the tissue to give a meaningful measurement.

3. The method of claim 2, whereby the values of potential differences for those electrodes (1) having insufficient contact with the tissue are calculated based on the assumption of a homogeneous conductivity distribution rather than using the actual measured potential differences.

4. The method of claim 1, whereby the weighting coefficient of $1/R^4$ is used in the weighted averaging of step (f), where R is the distance between the point where the conductivity is being reconstructed and the current point on the line along which averaging is being carried out.

5. The method of claim 1, whereby said compact set of electrodes (1) is arranged on a rigid dielectric plane and the conducting portion of each electrode protrudes from said plane.

6. An apparatus for producing a three-dimensional image of the conductivity distribution of biological tissue comprising:

a plurality of individual electrodes (1) disposed in a rigid planar array and placed in contact with the biological tissue of interest;

an alternating current (AC) source (4) connected to one of the electrodes (active electrode) (1) in said planar array and to a single remote active electrode (5, 7) located at some distance from said planar array and in contact with the biological tissue;

an output multiplexing means (2) to successively switch the AC source to other electrodes (1) in said planar array making them active electrodes in turn;

an input multiplexing means (3) to connect a potential difference measuring means (6) to one of the non-active (at rest) electrodes (1) in said planar array and to an at rest single remote electrode (7, 5) located at some distance from said planar array and in contact with the biological tissue;

computing means coupled to said input and output multiplexing means (2, 3) for sequencing said AC source through said planar array electrodes (1) while taking potential difference measurements from other electrodes in said planar array and for reconstructing a three-dimensional conductivity distribution using a modified back projection method; and

display means for imaging the reconstructed three-dimensional conductivity distribution.

7. The apparatus of claim 6, wherein a threshold detector means (8) is provided to determine whether any particular electrode (1) of said planar array has sufficient contact with the tissue to give a meaningful measurement.

8. The apparatus of claim 7, wherein in reconstructing the conductivity distribution, the values of potential differences for those electrodes (1) having insufficient contact with

the tissue are calculated based on the assumption of a homogeneous conductivity distribution rather than using the actual measured potential differences.

9. The apparatus of claim 6, wherein the modified back projection reconstruction method used incorporates a weighting coefficient of $1/R^4$, where R is the distance between the point where the conductivity is being reconstructed and the current point on the line along which averaging is being carried out.

10. The apparatus of claim 6, wherein said planar array of electrodes (1) is arranged on a rigid dielectric plane and the conducting portion of each electrode protrudes from said plane.

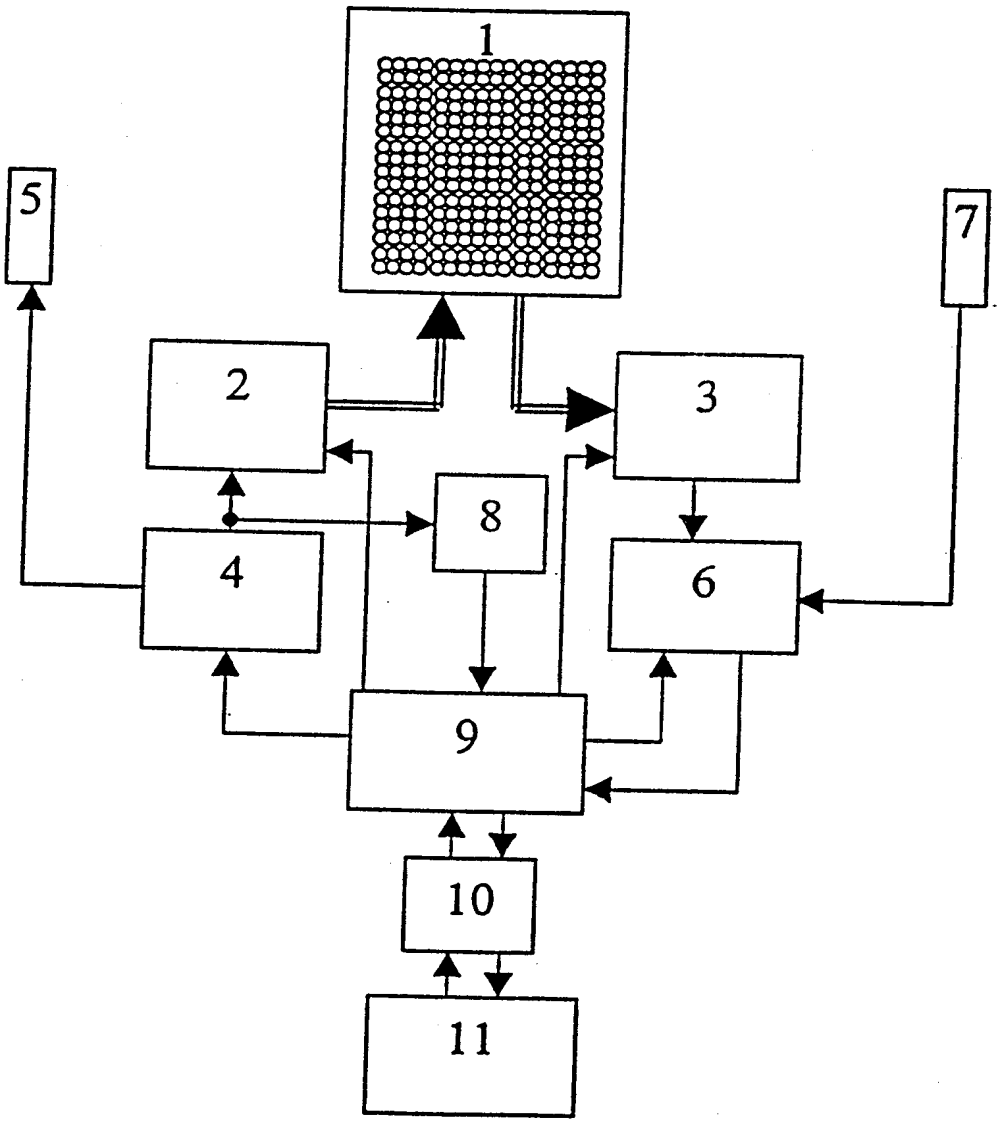


FIG. 1

Electric Mammograph

SHEET 2 of 5

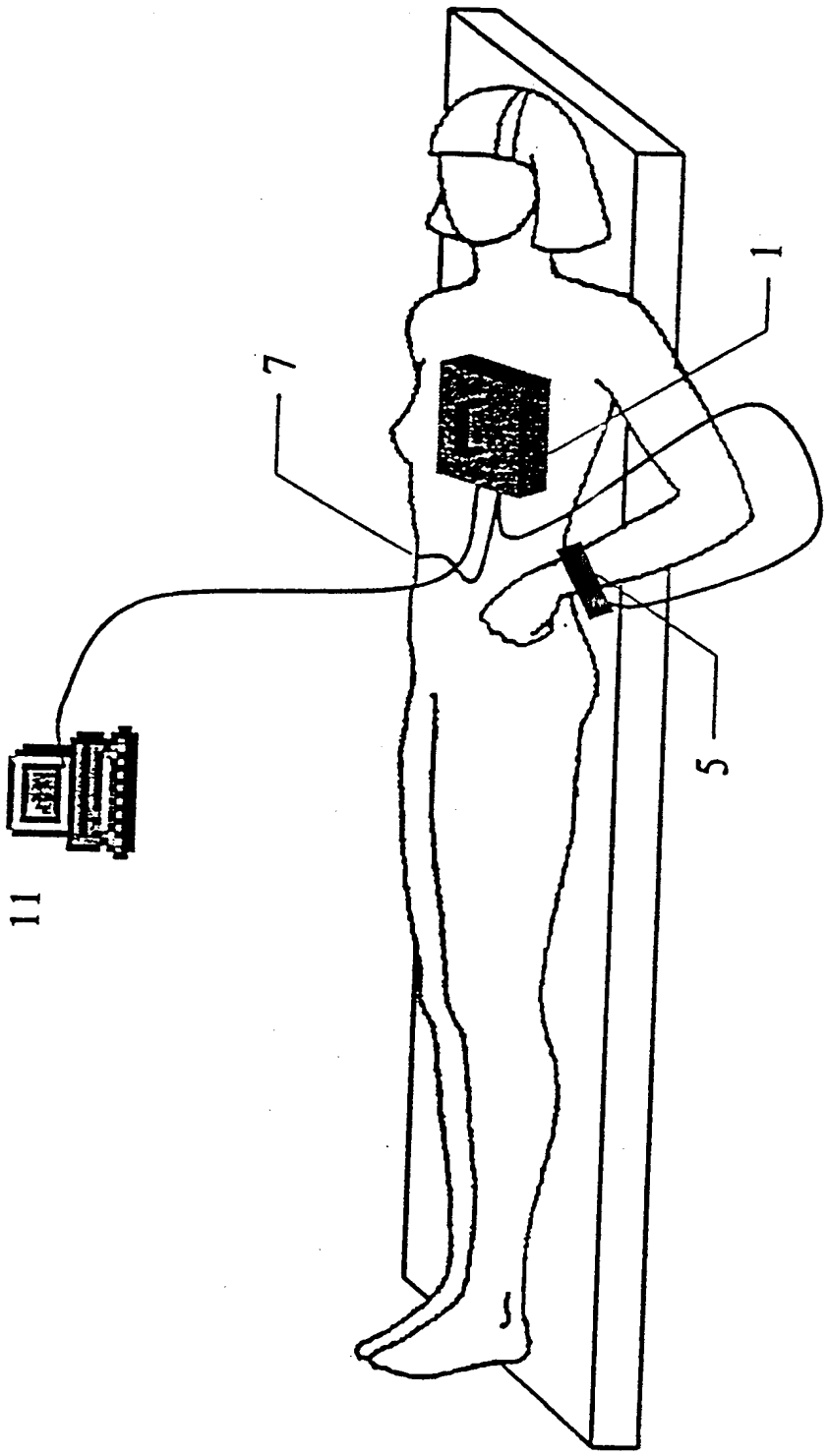


FIG. 2

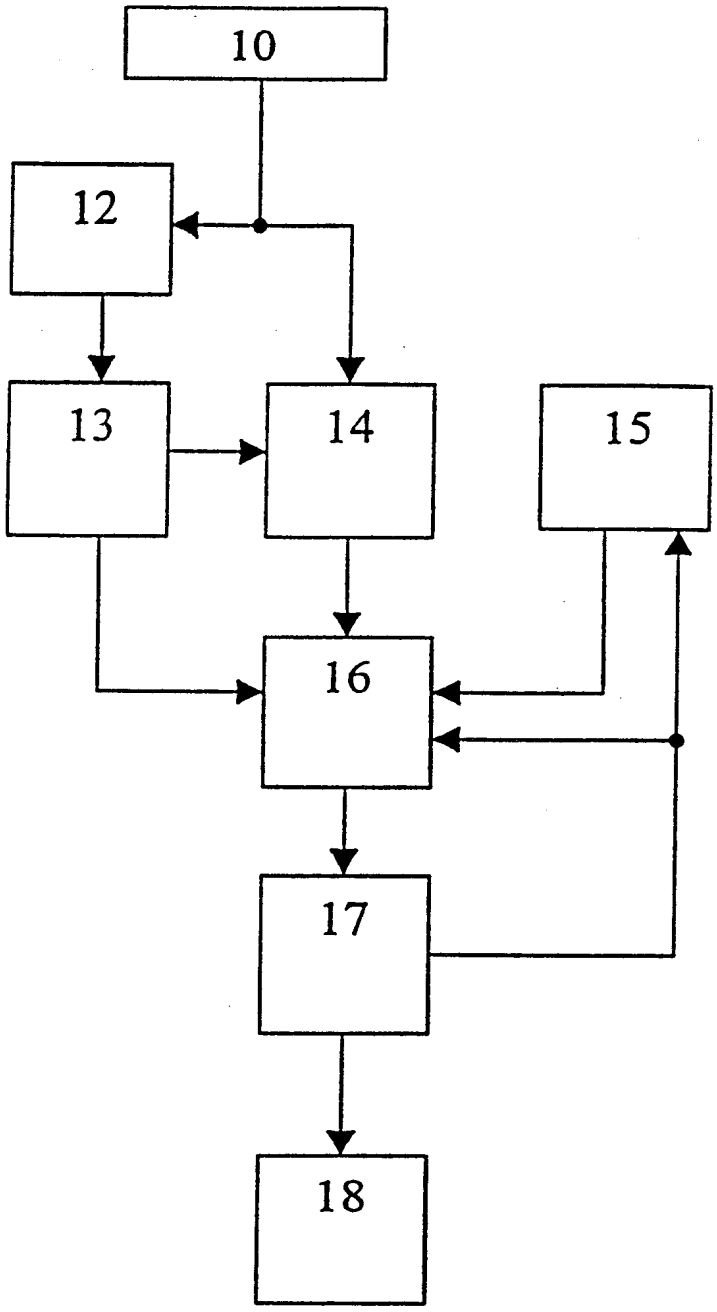


FIG. 3

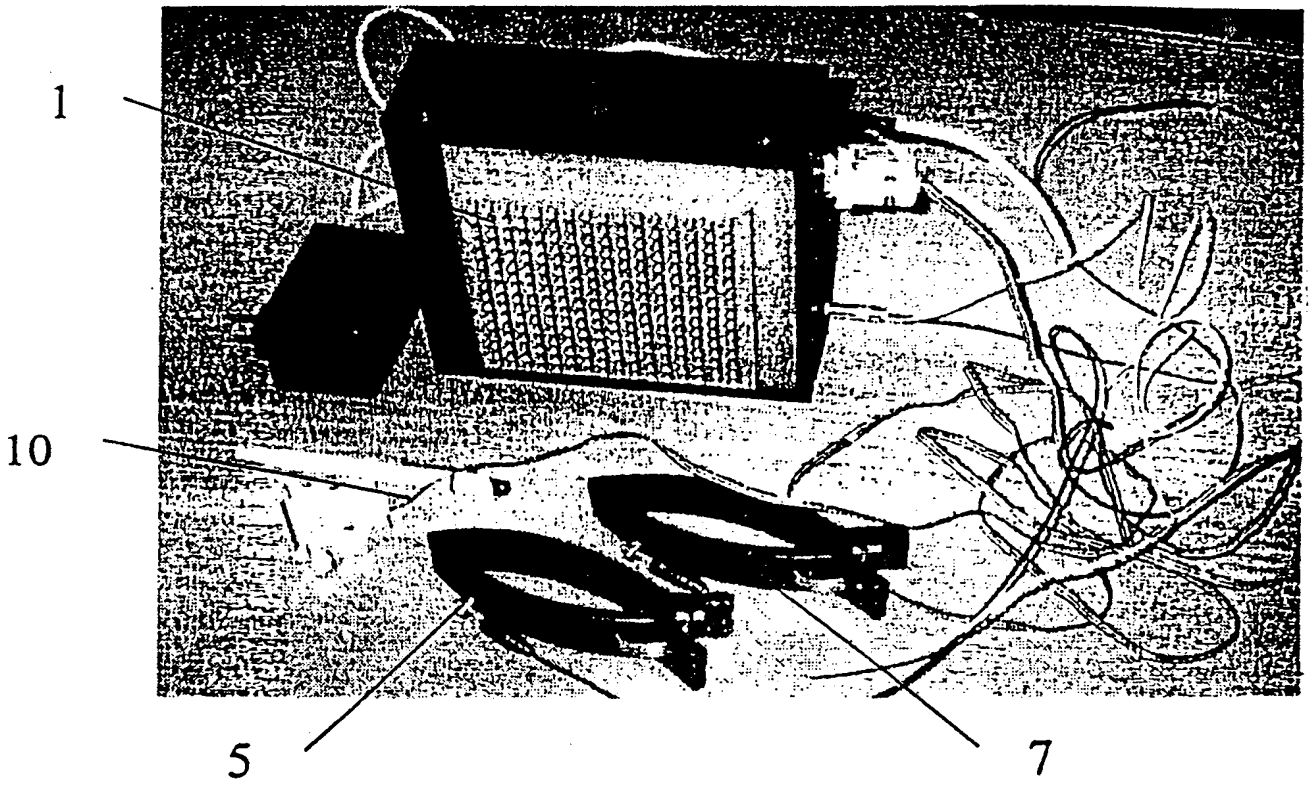


FIG. 4

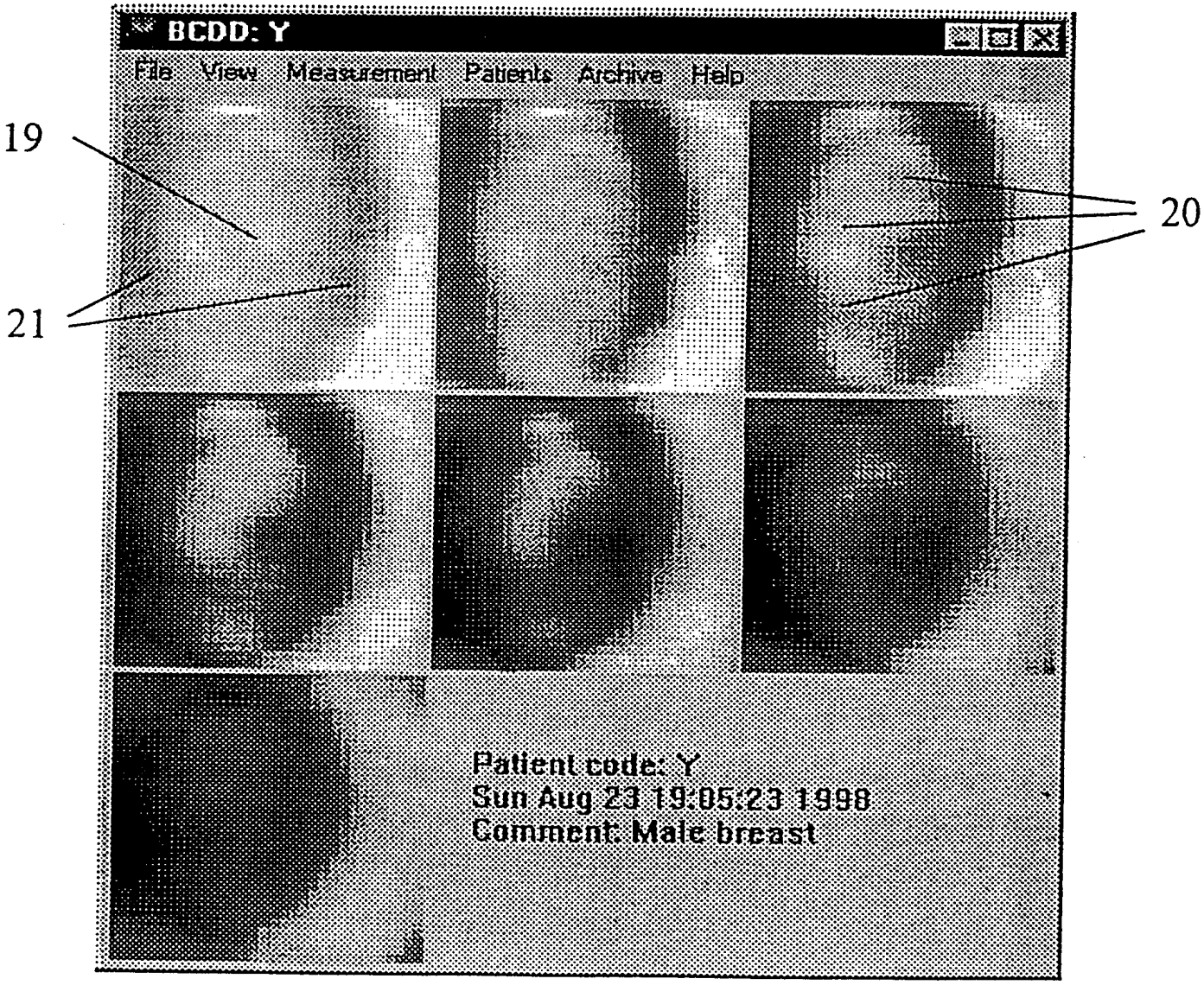

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Comment: Male breast

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :A61B 5/05
US CL :128/930; 324/717; 600/547

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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/930; 324/600, 713, 717; 600/547

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,351,697 A (CHENEY et al.) 04 October 1994, Abstract	1, 6

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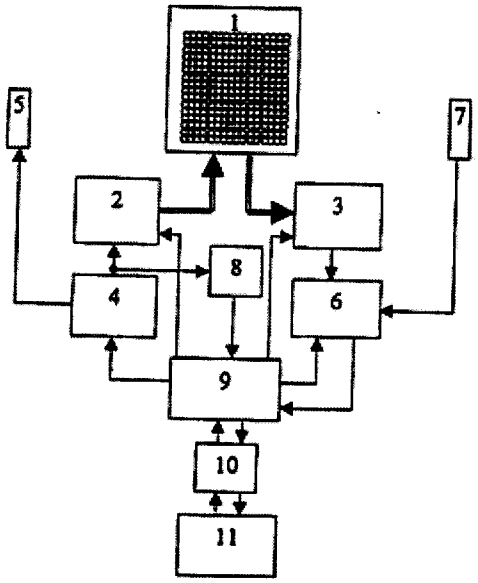
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(54) Title: ELECTRIC MAMMOGRAPH



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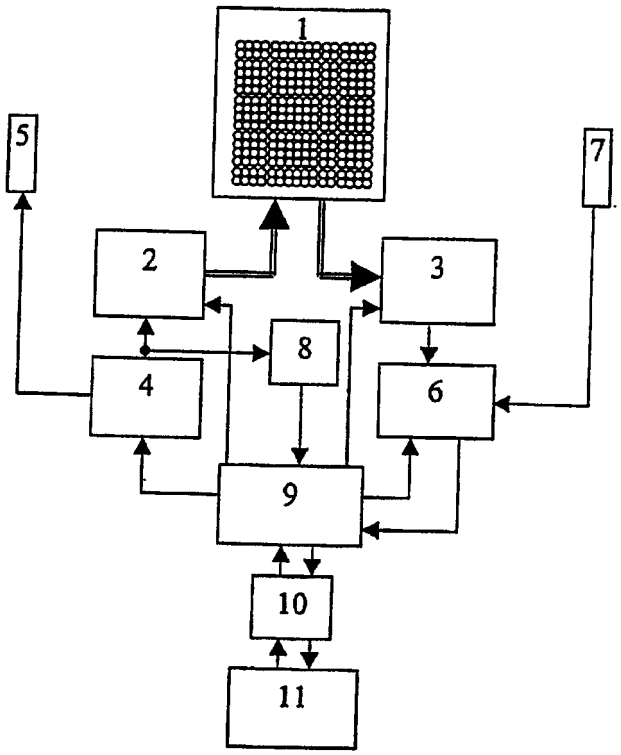
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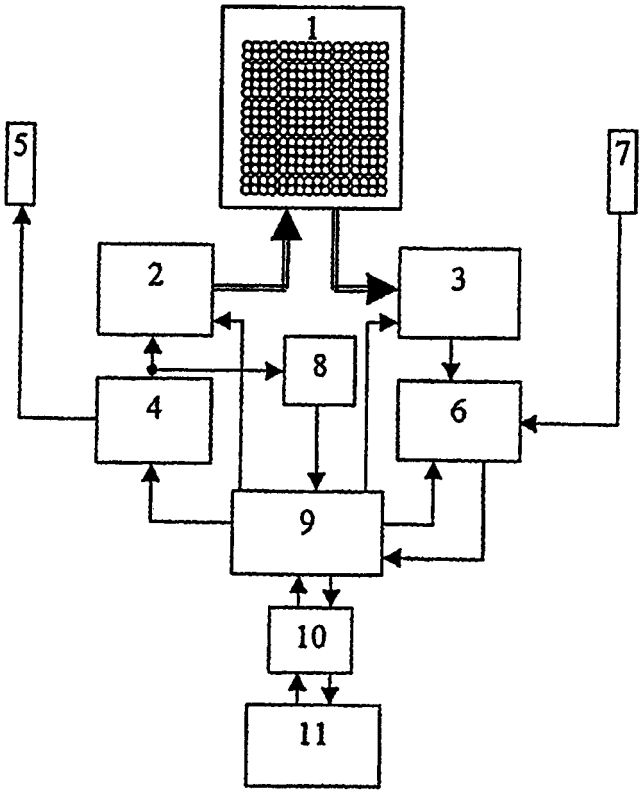
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CLAIMS

1. A method of displaying a three-dimensional image of the conductivity distribution of biological tissue, said method comprising the steps of:

applying a source (4) of alternating current (AC) to a first activated electrode (1) of a compact set of electrodes arranged in a planar array, said compact set of electrodes being in contact with the surface of the biological tissues of interest, and to a first remotely located electrode (5, 7) in contact with the body but at some distance from the compact set of electrodes;

measuring the potential difference between a first at rest electrode (1) of said compact set and a second remotely located electrode (7,5), said second remote electrode being at rest;

switching the source (4) of AC current by multiplexer means (2, 3) to activate successively all of the electrodes (1) of said planar array of electrodes except said at rest electrode of step (b) and measuring the potential difference between said at rest electrodes in (b) for each activated electrode in turn to thereby obtain a first set of potential difference measurements for each activated electrode;

switching the electrode (1) to be measured in said planar array by multiplexer means (2, 3) to a second at rest electrode (1), activating successively every other electrode in said planar array, and measuring the potential difference between said second at rest electrode and said at rest remote electrode (7, 5) in turn to thereby obtain a second set of potential difference measurements for each activated electrode;

continue switching the at rest electrode (1), activating successively the remaining electrodes in said planar array, and measuring the potential difference between the selected at rest

electrode and said at rest remote electrode (7, 5) in turn until all planar electrodes combinations have been measured;

reconstructing a three-dimensional conductivity distribution using the method of back projection along equipotential surfaces of the electric field, the projected data being obtained by weighted averaging of the relative difference between the reference electric intensity corresponding to tissue with a homogeneous conductivity distribution and the measured electric intensity along the line of intersection of the equipotential surface containing the point where conductivity is reconstructed and with the surface on which the compact set of electrodes (1) is located.

2. The method of claim 1, whereby a threshold detector means (8) determines whether any particular electrode (1) of the planar array has sufficient contact with the tissue to give a meaningful measurement.

3. The method of claim 2, whereby the values of potential differences for those electrodes (1) having insufficient contact with the tissue are calculated based on the assumption of a homogeneous conductivity distribution rather than using the actual measured potential differences.

4. The method of claim 1, whereby the weighting coefficient of $1/R^4$ is used in the weighted averaging of step (f), where R is the distance between the point where the conductivity is being reconstructed and the current point on the line along which averaging is being carried out.

5. The method of claim 1, whereby said compact set of electrodes (1) is arranged on a rigid dielectric plane and the conducting portion of each electrode protrudes from said plane.

6. An apparatus for producing a three-dimensional image of the conductivity distribution of biological tissue comprising:

a plurality of individual electrodes (1) disposed in a rigid planar array and placed in contact with the biological tissue of interest;

an alternating current (AC) source (4) connected to one of the electrodes (active electrode) (1) in said planar array and to a single remote active electrode (5, 7) located at some distance from said planar array and in contact with the biological tissue;

an output multiplexing means (2) to successively switch the AC source to other electrodes (1) in said planar array making them active electrodes in turn;

an input multiplexing means (3) to connect a potential difference measuring means (6) to one of the non-active (at rest) electrodes (1) in said planar array and to an at rest single remote electrode (7, 5) located at some distance from said planar array and in contact with the biological tissue;

computing means coupled to said input and output multiplexing means (2, 3) for sequencing said AC source through said planar array electrodes (1) while taking potential difference measurements from other electrodes in said planar array and for reconstructing a three-dimensional conductivity distribution using a modified back projection method; and

display means for imaging the reconstructed three-dimensional conductivity distribution.

7. The apparatus of claim 6, wherein a threshold detector means (8) is provided to determine whether any particular electrode (1) of said planar array has sufficient contact with the tissue to give a meaningful measurement.

8. The apparatus of claim 7, wherein in reconstructing the conductivity distribution, the values of potential differences for those electrodes (1) having insufficient contact with

the tissue are calculated based on the assumption of a homogeneous conductivity distribution rather than using the actual measured potential differences.

9. The apparatus of claim 6, wherein the modified back projection reconstruction method used incorporates a weighting coefficient of $1/R^4$, where R is the distance between the point where the conductivity is being reconstructed and the current point on the line along which averaging is being carried out.

10. The apparatus of claim 6, wherein said planar array of electrodes (1) is arranged on a rigid dielectric plane and the conducting portion of each electrode protrudes from said plane.

ELECTRIC MAMMOGRAPH

Technical Field

The invention is in the field of medical tomography, and in particular relates to a method and apparatus for the visualization and diagnosis of pathologic changes in breast tissues and other organs near the surface of the human body.

Background Art

It is known that electrical conductivity of many tumors, and in particular the malignant tumors of the mammary gland, significantly differs from the conductivity of surrounding sound tissues. This fact may be used for the detection and localization of such tumors.

Some devices are known for visualizing the spatial distribution of conductivity (impedance) in the human body, e.g., electrical impedance tomographs. (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph," International application PCT/RU97/00398.) In an electrical impedance tomograph, the source of alternating electric current is connected to pairs of electrodes placed along a line on the surface of a body and measurements of the potential differences are made on the other pairs of electrodes. The results of measurements obtained from various combinations of electrodes are used to reconstruct the conductivity distribution with the help of a computer. A three-dimensional distribution of conductivity, however, is not possible with this type of tomograph. Furthermore, its resolution falls significantly from the periphery to the center of contour of the electrodes. Consequently, it is not an adequate device for the diagnosis of mammary gland tumors.

An electroimpedance mammograph device, purporting

to yield a three-dimensional impedance distribution has also been described. (A. Nowakovsky, J. Wortek, and J. Stelter, "A Technical University of Gdansk Electroimpedance Mammograph," Proc. IX Int. Conf. Electrical Bio-Impedance, Heidelberg, 1995, p. 434-437; J. Wortek, J. Stelter, A. Nowakovsky, "Impedance mammograph 3D phantom studies," Proc. X Int. Conf. Electrical Bio-Impedance, Barcelona, 1998, p. 521-524.) This device contains a compact set of electrodes that are placed on the inner surface of a rigid hemisphere, multiplexers that are connected to the source of alternating electric current, and a device for measuring the potential difference between various pairs of electrodes. The measured potential differences are sent to a computer to reconstruct and display the three-dimensional impedance distribution inside the hemisphere. The serviceability of this device based on actual measurements on the human body have not yet been published.

A number of limitations for this device are apparent. The arrangement of electrodes on the hemisphere surface limits the application of the device because the contact with all the electrodes can be provided only for a breast of a definite size. The device also has no means to measure the quality of each contact, nor any means to correct the reconstruction calculations if any of the electrodes have insufficient contact with the body. This decreases the validity of the data. The electric current source and the measuring device are connected to pairs of electrodes placed on the hemisphere, requiring four multiplexers. When the number of electrodes is large, these multiplexers become the most complicated and expensive parts of the device. These multiplexers are also the largest source of spurious signals due to channel-to-channel crosstalk. Only 64 electrodes were used in the prototype. This is obviously insufficient for obtaining satisfactory resolution.

However, further increasing this number is problematical because of the difficulty of commutation by the chosen measuring circuit.

When a safe level of electrical current is used, the measured potential differences are small because of the small distances between electrodes. This decreases the signal-to-noise ratio and the display quality. This effect only gets worse with an increasing number of electrodes. The algorithm for image reconstruction is based on the perturbation method. It requires a calculation time of ten minutes on a workstation for a system of 64 electrodes (Nowakovsky). For 180 electrodes, the minimum necessary for practical applications, about ten hours are required for the calculations based on the estimations of the authors. This amount of time is not feasible for clinical practice.

Other attempts at obtaining three-dimensional electrical impedance images of a body have involved multi-dimensional electrode arrays that surround or partially surround the object being imaged. The reconstruction algorithms used and the methodology of making measurements were also different than those of the present invention. These efforts include U. S. Patents 5,284,142, 5,351,697, 4,263,920, 4,486,835, and 4,539,640.

A goal of the present invention is to provide a new method and apparatus for electric mammography with greater reliability and accuracy of measurements, higher resolution, and increased computational speed. This invention is particularly applicable to the clinical diagnosis of breast tumors and other subsurface areas.

Disclosure of the Invention

The electric mammograph is a device for the measurement and three-dimensional (3-D) reconstruction of the conductivity distribution in biological tissues for clinical diagnoses.

It consists of a compact array of electrodes positioned over the tissue being measured, two additional electrodes spaced apart from the array of electrodes, a source of alternating (AC) current, a means to measure potential difference, and computing means to reconstruct and visualize the resulting conductivity distribution.

Brief Description of the Drawings

The invention is illustrated in the following drawings.

FIG. 1 is a block diagram of the electric mammograph.

FIG. 2 shows the arrangement of the apparatus when conducting a mammograph examination.

FIG. 3 is a block diagram of the algorithm used for the three-dimensional conductivity distribution reconstruction.

FIG. 4 is a photograph of the apparatus

FIG. 5 is a sample electric mammogram.

Description of Preferred Embodiments

A block diagram of the components of the electric mammograph is shown in FIG. 1. A compact array of cylindrical protruding electrodes **1** is arranged in a rigid dielectric plane. The example shown has 256 electrodes. The output multiplexer **2** is connected to the electrode array **1** and is the means by which the alternating current (AC) source **4** is connected to one of the cylindrical electrodes in the array. The input multiplexer **3** serves to connect one of the non-activated or "rest" electrodes of the array to the potential difference measuring unit **6**. The microprocessor **9** and the computer **11,** connected via cables **10,** determine which electrode is activated and which of the rest electrodes is being measured at any given time.

Two single remote electrodes, **5** and **7**, are attached to the extremities of the patient. One remote electrode **5** is connected directly to the AC source. The other remote electrode **7**

is connected directly to the potential difference detector **6**. The AC source is connected to a voltage threshold detector **8**. The operation of the electric mammograph is controlled by a microprocessor/computer means. It gets inputs from the potential difference detector **6** and the threshold detector **8** and outputs to the two multiplexers **2**, **3**, the potential difference detector, and the AC source. The first remote electrode **5** connected to the AC source and the second remote electrode **7** are located on a patient's extremities, e.g., one on each wrist as shown in FIG. 2.

In the prior art methods of obtaining a tomographic image of a human body, a series of contact electrodes were placed on the surface of the patent's body. A source of electric current was connected sequentially to pairs of electrodes causing current to flow through the body. Measurements were then made of potential differences between pairs of other "non-activated" electrodes.

In the present invention, the output multiplexer **2** switches a single lead from the AC source to "activate" a single electrode in the electrode array **1** at a time, instead of activating pairs of electrodes in prior art devices. The second "activated" electrode is the remote electrode **5** that is always "on". Switching a single lead at a time reduces the spurious couplings arising from channel-to-channel penetration of signals in the multiplexer. It also simplifies the device and reduces its cost. The same is true for the input multiplexer **3**. The potential difference detector measures the difference between the selected array electrode and the remote rest electrode **7**. For a given rest electrode, the output multiplexer **2** sequences through all the other electrodes in the compact set while the potential difference detector makes its measurements. Then the rest electrode is switched and the output multiplexer sequence repeated.

Using the two singular electrodes **5**, **7** also increase the amplitude of the measured signals due to the increased distance between the points where the potentials are measured. This increases the signal-to-noise ratio and the accuracy of the measurements. The distance of these singular electrodes from the electrode array allows one to assume that the unperturbed equipotential surfaces of electric field are spherical in the examination area. It simplifies and speeds up the conductivity reconstruction calculations.

The method of back projection along equipotential surfaces of the electric field is used to reconstruct the 3-D conductivity distribution. It is assumed that in the case where the electric current is injected through one of the electrodes of the compact set of electrodes arranged in a planar array and the remote common electrode, equipotential surfaces near the two-dimensional set of electrodes are spherical. The procedure of back projection is reduced to the following. For some point with coordinates (X, Y, Z) inside the object under visualization, the distance is determined between this point and the injecting electrode of the compact array. This distance is equal to the radius r of the equipotential surface containing the point where the conductivity is reconstructed. Knowing this radius, it is possible to determine the line of intersection of the equipotential surface with the surface on which the electrodes are arranged. When the electrodes are arranged on the plane, given by equation $z=0$, this line is the circle lying in the (x, y) plane having its center at the point where the injecting electrode is located, and having radius r. Conductivity S (in arbitrary units) at the chosen point is calculated according to the equation:

$$S(x,y,z)=1+W_1(z)\sum_i \frac{1}{\int_{L(x,y,z,i)} W_2(l)dl} \int_{L(x,y,z,i)} W_2(l)(E_r(l)-E_m(l))/E_r(l)dl$$

where i – is the number of the injecting electrode, $L(x,y,z,i)$ - is the line of intersection of the equipotential surface with the surface on which the electrodes are arranged (circle with radius r). The components of the electric field vector $\vec{E}_m$ are first calculated at the nodes of the grid between the electrodes as the potential differences between adjacent electrodes in the x and y directions. Then these components are linearly interpolated to the current point of integration on the line L and the magnitude of this vector E_m is calculated.

The reference intensity of the electric field E_r corresponds to a homogeneous medium and is calculated numerically. Weighting coefficient $W_1(z)$ corrects the decrease of sensitivity with depth. In the present invention, the empirical equation $W_1=(z+\alpha)/(z+\beta), \alpha<<\beta$ is used for it. The weighting coefficient W_2 provides a relatively greater contribution to the calculated conductivity of those points on line L, which are located closer to the point at which the conductivity is reconstructed. In the present device, the equation: $W_2=1/R^4=1/\left((x-x_l)^2+(y-y_l)^2+z^2\right)^2$ is used, where R is the

distance between the point where the conductivity is reconstructed and the current point on the line along which integration is being carried out; the index *l* refers to the coordinates of this point.

The method of back projection is the fastest method used in electrical impedance tomography reconstruction. Its use, however, for reconstructing the static conductivity distribution for the 3-D case is only possible by a proper choice of the projected values.

In addition, the synthesized reference data set E_r must be used. This is obtained by approximating the real measured potentials according to the method of Korjenevsky. (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph," Russian Federation patent application N 96123647/14.)

In many cases it is difficult to obtain sufficient contact of all the electrodes with the patient's body. Consequently, the threshold detector **8** of the output voltage is used to determine whether the electrode being measured at any particular moment has sufficient contact with the body. The compact set of electrodes is arranged on a rigid dielectric plane and every electrode is a conducting protrusion from the plane. This arrangement permits an examination of a mammary gland regardless of its size. During an examination, this plane of electrodes is pressed against the breast, flattening it toward the chest. This increases the number of electrodes having contact with the body and decreases the thickness of the tissue layer to be measured. The protrusion of the electrodes improves their electrical contact with the body.

One or more of the electrodes on the periphery of the plane may not have contact with the body, depending on the size of the examined object. These electrodes are detected with the help

of the threshold detector of the output voltage mentioned above. The values of the potential differences measured from electrodes that have insufficient body contact cannot be used directly in the process of conductivity reconstruction. Instead, values of potential differences calculated on the assumption of a homogeneous conductivity distribution are used.

Besides the useful potential differences caused by the current flow, there are also galvanic potential differences between electrodes. The component for measuring the potential difference **6** is only sensitive to the alternating current component and, consequently, is not disturbed by the presence of these constant galvanic potential differences. However, due to the differences in galvanic potentials of different electrodes, the input voltage varies by a jump when the input multiplexer **3** is switched. These jumps produce a transient that influences the results of the measurements. This influence increases when the time interval between the switch and the start of the potential difference measurement decreases. Therefore, to decrease the error while keeping the total duration of the measurements constant, the input multiplexer **3** should switch the device for measuring the potential difference **6** to the next electrode only after the output multiplexer **2** completes the total cycle of switches of the AC source to all other electrodes.

FIG. 2 shows the arrangement of the various components of the electric mammograph used to take measurements. With the help of the output multiplexer, the control unit connects the source of AC current to one of the electrodes of compact set **1** according to commands from the computer **11**. AC current of approximately 1 mA and a frequency of 10 kHz flows through the circuit, i.e., from the AC source to the multiplexer, to the electrode of set **1**, through the patient's body to the remote rest

electrode **5**. With the help of the input multiplexer, the microprocessor connects one of the rest electrodes from set **1** to the potential difference detector. It measures the amplitude of the alternating voltage between the electrode from set **1** and the remote activated electrode **7**. This measurement is sent in digital code to the microprocessor, which passes it to the computer **11**.

The measured data are used to reconstruct a 3-D conductivity distribution with the help of the algorithm shown in block diagram form in FIG. 3. In block **12** the measured potentials of the electrodes from the compact set, received through the connection line **10**, are used for synthesis of the reference set of potentials corresponding to a body with homogeneous conductivity. An approximation by the method of least squares described in Russian Patent N 96123647/14 is used. Only those potentials obtained from electrodes with good body contact are used. In blocks **13** and **14**, components of the electric intensity vector are calculated for the reference and measured data set by subtraction of the values of potentials on adjacent electrodes for each variant of connection of the current source. In the last case, corresponding potentials from the reference set are used instead of the potentials of those electrodes with insufficient contact.

In block **15** the distance is calculated between the activated electrode in the compact set and the point at which the conductivity is being reconstructed. This distance determines the radius of a circle that represents the line of intersection of the equipotential surface with the plane on which the electrodes are arranged and along which it is necessary to carry out weighted averaging. The electric intensity for the measured and the reference data set are calculated after the linear interpolation of the corresponding components of vectors, calculated in blocks **13** and

14. The relative difference of the electric intensities for the reference and measured data sets are multiplied by the weight function $1/R^4$, where R is the distance between the point where the conductivity is reconstructed and the current point on the line along which averaging is being carried out.

In block **16** the obtained value is numerically integrated along the circle. These operations are repeated for all points where the conductivity is to be reconstructed and for all variants of the activated electrodes. This process is controlled by block **17**. The result of these calculations, after adding a unit to obtained values, represents a 3-D distribution of the conductivity normalized on the average value. The result can be displayed on screen or printed out. Block **18** contains the software and hardware used to carry out these functions.

The external appearance of the electric mammograph without the computing unit is shown in FIG. 4. FIG. 5 shows an electric mammogram obtained by the invention. The mammogram represents a set of seven images of breast cross-sections parallel to the plane on which the electrodes are arranged. The depth of the cross-sections increases from left to right and from up to down with 8 mm steps. On the image one can clearly see the nipple 19, the ribs **20**, and the boundary **21** between areas with and without sufficient electrode contact with the body.

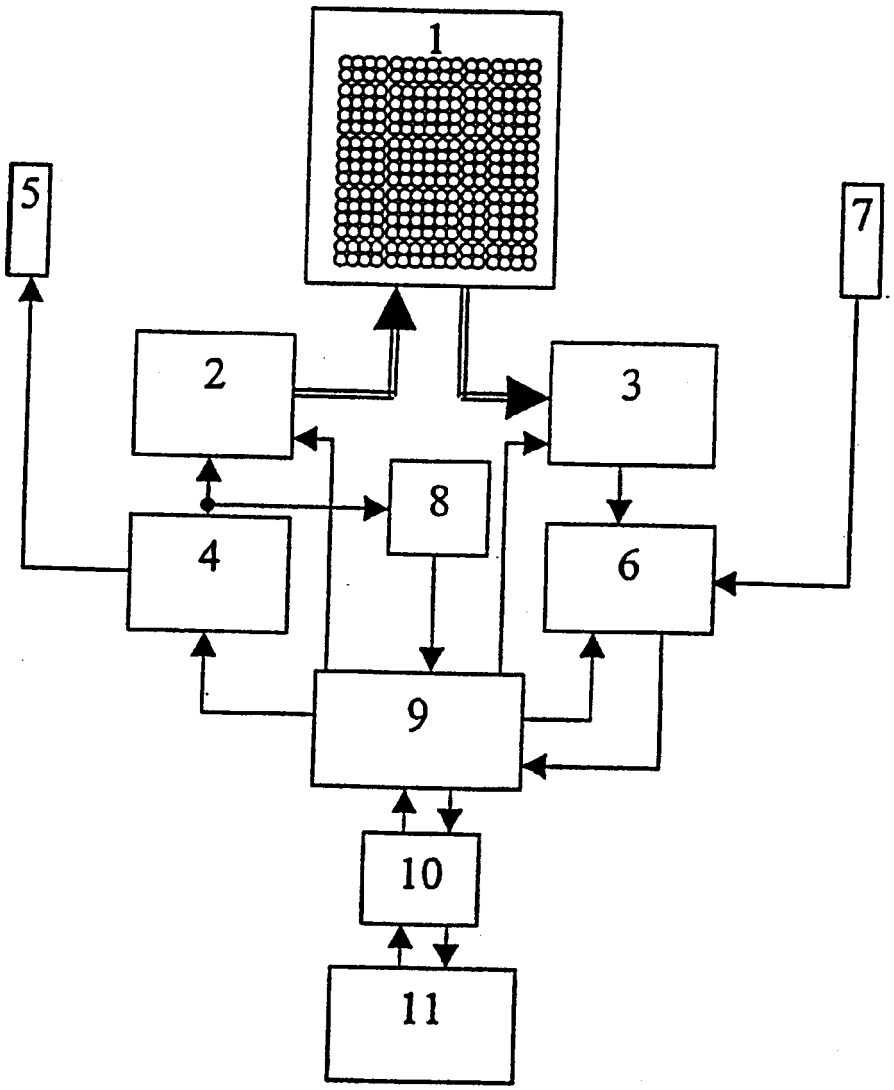


FIG. 1

Electric Mammograph

SHEET 2 of 5

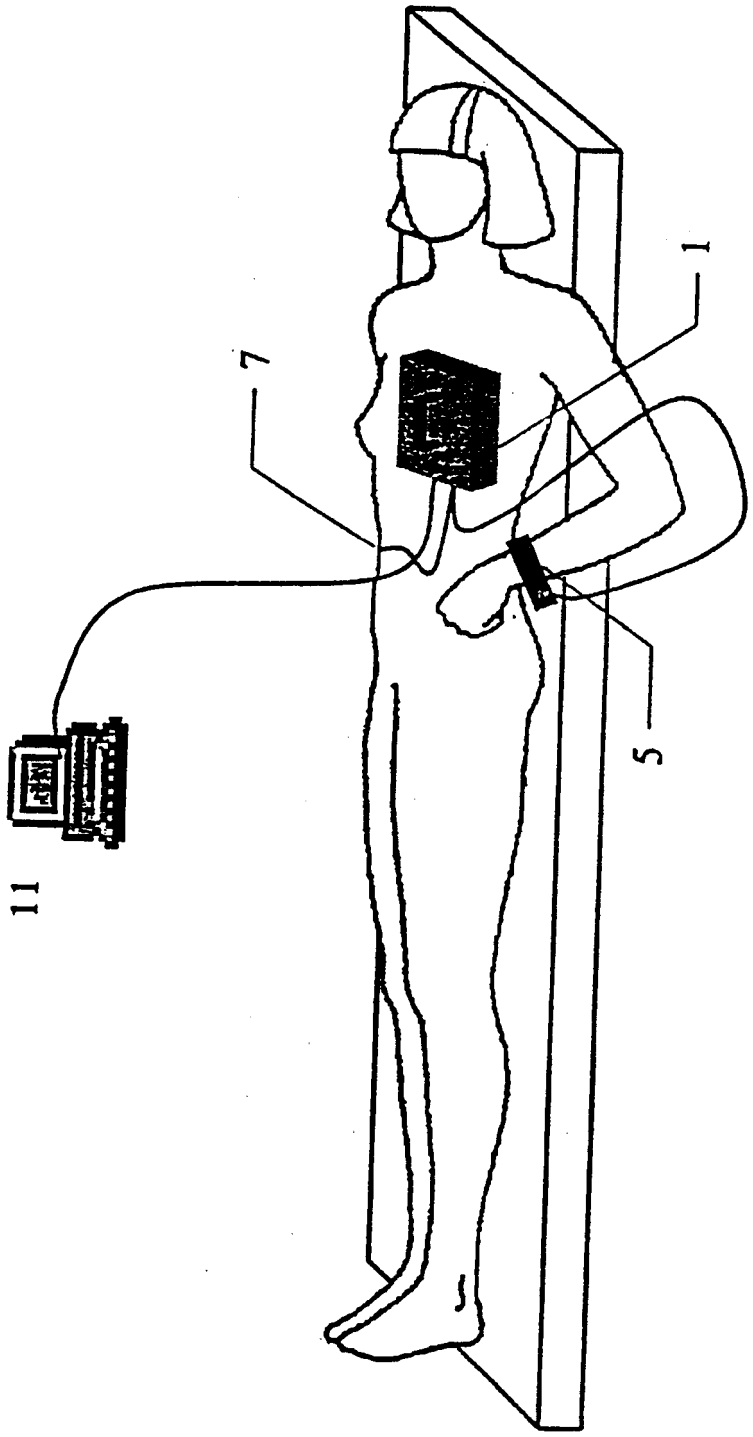


FIG. 2

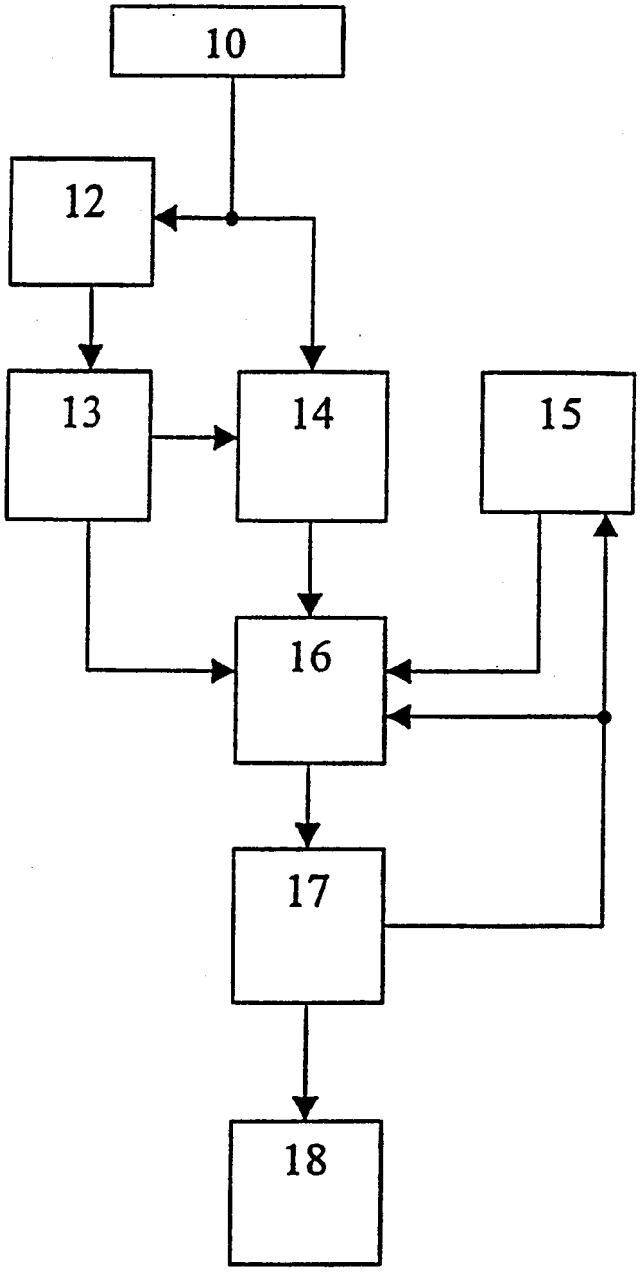


FIG. 3

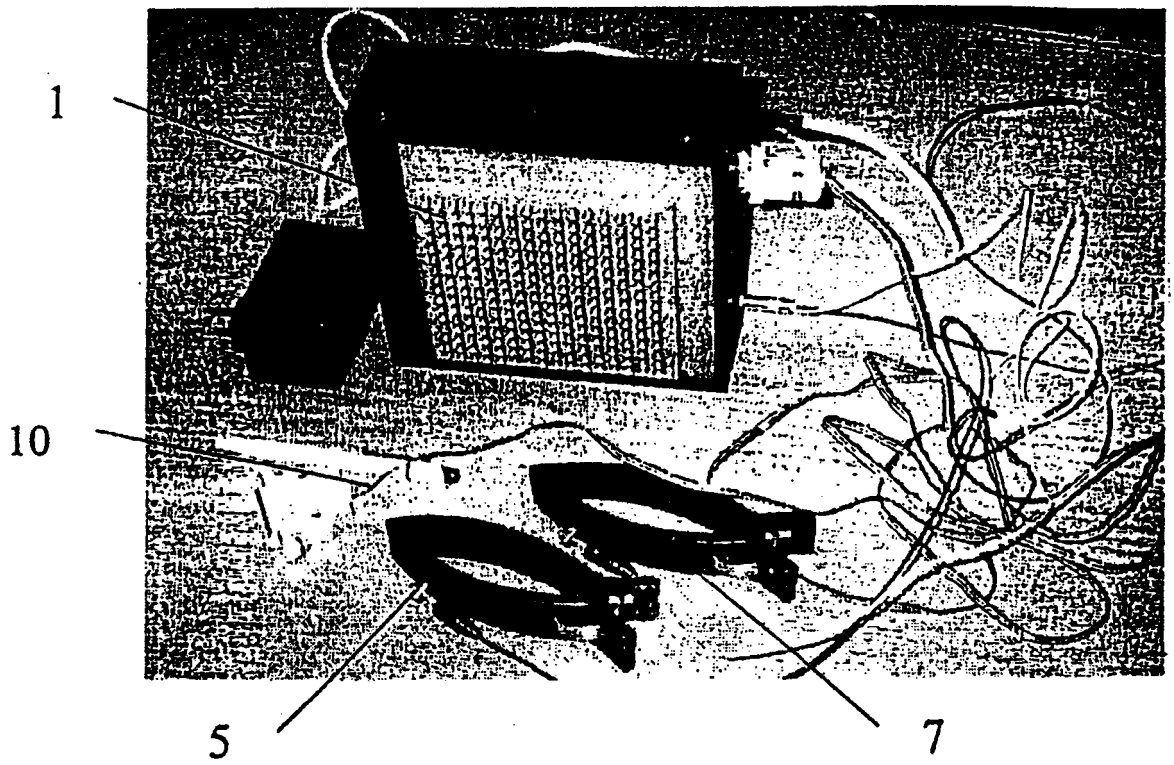


FIG. 4

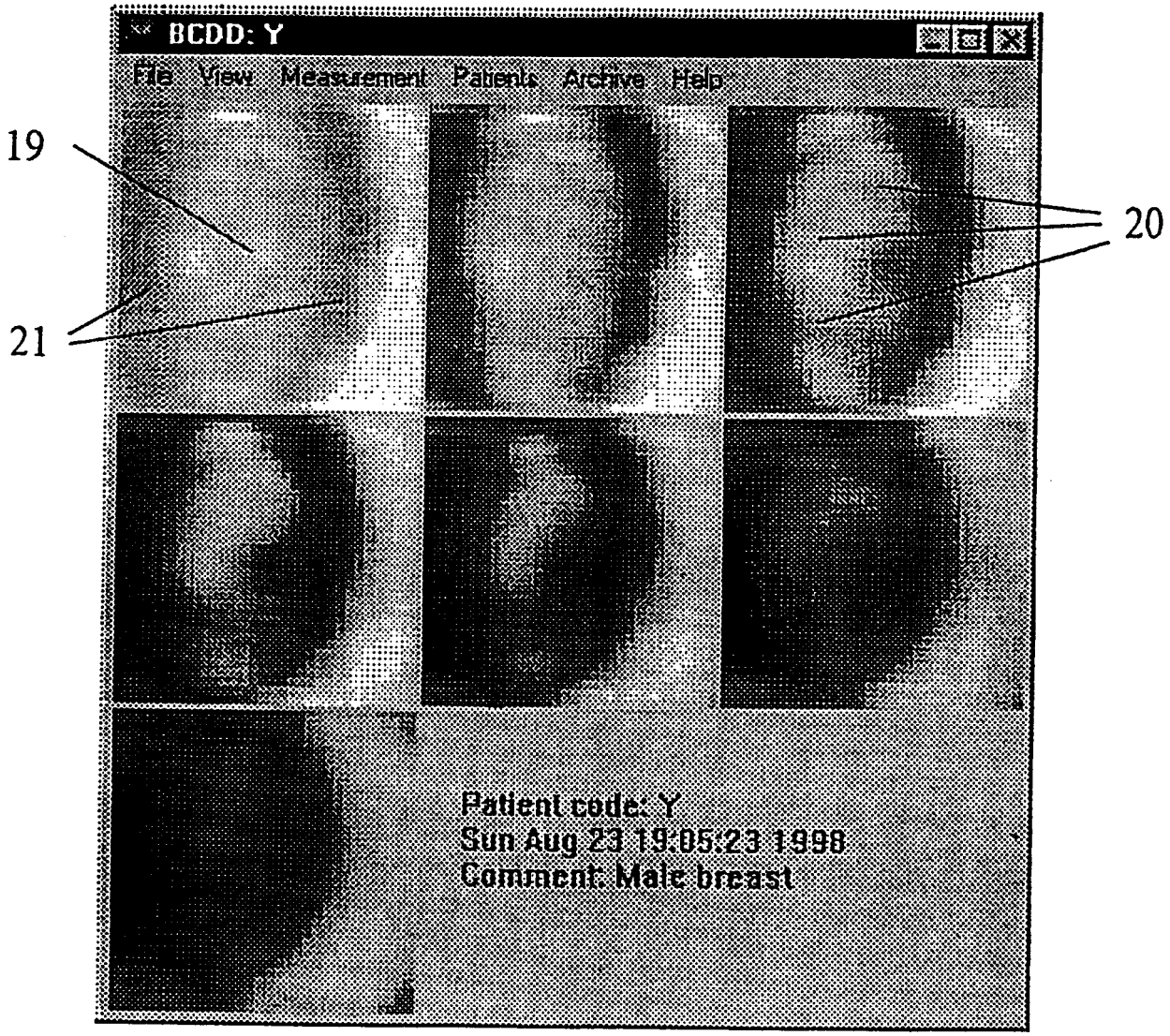
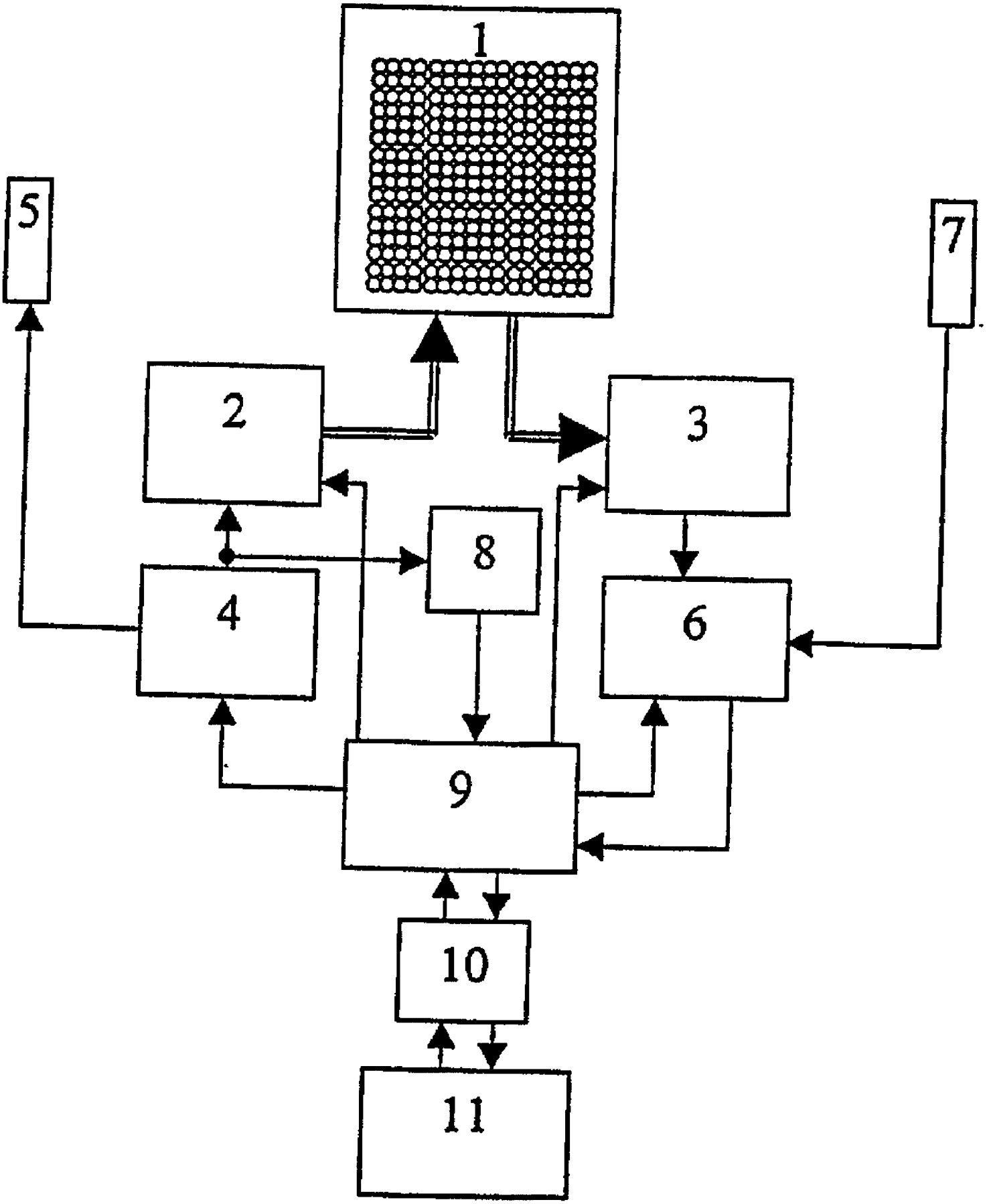

BCDD: Y
File View Measurement Patients Archive Help
19
20
21
Patient code: Y
Sun Aug 23 19:05:23 1998
Comment: Male breast

FIG. 5


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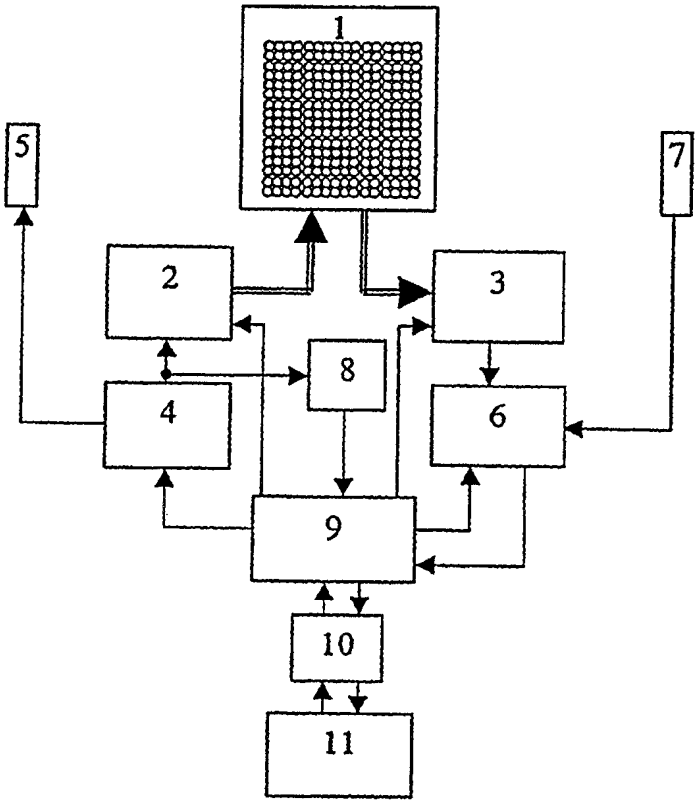
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(57) Abstract

The electric mammograph is an electrical impedance tomograph device for obtaining three–dimensional images of the conductivity distribution in biological tissues. A planar array of electrodes (1) is put in contact with the tissues of interest. An AC source (4) is connected to a single remotely attached electrode (5, 7) and to one of the planar array electrodes (1). Potential differences between the at rest electrodes in the planar array and a second remote at rest electrode (7, 5) are measured. The images are reconstructed using a modified back projection method.



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ELECTRIC MAMMOGRAPH

Technical Field

The invention is in the field of medical tomography, and in particular relates to a method and apparatus for the visualization and diagnosis of pathologic changes in breast tissues and other organs near the surface of the human body.

Background Art

It is known that electrical conductivity of many tumors, and in particular the malignant tumors of the mammary gland, significantly differs from the conductivity of surrounding sound tissues. This fact may be used for the detection and localization of such tumors.

Some devices are known for visualizing the spatial distribution of conductivity (impedance) in the human body, e.g., electrical impedance tomographs. (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph," International application PCT/RU97/00398.) In an electrical impedance tomograph, the source of alternating electric current is connected to pairs of electrodes placed along a line on the surface of a body and measurements of the potential differences are made on the other pairs of electrodes. The results of measurements obtained from various combinations of electrodes are used to reconstruct the conductivity distribution with the help of a computer. A three-dimensional distribution of conductivity, however, is not possible with this type of tomograph. Furthermore, its resolution falls significantly from the periphery to the center of contour of the electrodes. Consequently, it is not an adequate device for the diagnosis of mammary gland tumors.

An electroimpedance mammograph device, purporting

to yield a three-dimensional impedance distribution has also been described. (A. Nowakovsky, J. Wortek, and J. Stelter, "A Technical University of Gdansk Electroimpedance Mammograph," Proc. IX Int. Conf. Electrical Bio-Impedance, Heidelberg, 1995, p. 434-437; J. Wortek, J. Stelter, A. Nowakovsky, "Impedance mammograph 3D phantom studies," Proc. X Int. Conf. Electrical Bio-Impedance, Barcelona, 1998, p. 521-524.) This device contains a compact set of electrodes that are placed on the inner surface of a rigid hemisphere, multiplexers that are connected to the source of alternating electric current, and a device for measuring the potential difference between various pairs of electrodes. The measured potential differences are sent to a computer to reconstruct and display the three-dimensional impedance distribution inside the hemisphere. The serviceability of this device based on actual measurements on the human body have not yet been published.

A number of limitations for this device are apparent. The arrangement of electrodes on the hemisphere surface limits the application of the device because the contact with all the electrodes can be provided only for a breast of a definite size. The device also has no means to measure the quality of each contact, nor any means to correct the reconstruction calculations if any of the electrodes have insufficient contact with the body. This decreases the validity of the data. The electric current source and the measuring device are connected to pairs of electrodes placed on the hemisphere, requiring four multiplexers. When the number of electrodes is large, these multiplexers become the most complicated and expensive parts of the device. These multiplexers are also the largest source of spurious signals due to channel-to-channel crosstalk. Only 64 electrodes were used in the prototype. This is obviously insufficient for obtaining satisfactory resolution.

However, further increasing this number is problematical because of the difficulty of commutation by the chosen measuring circuit.

When a safe level of electrical current is used, the measured potential differences are small because of the small distances between electrodes. This decreases the signal-to-noise ratio and the display quality. This effect only gets worse with an increasing number of electrodes. The algorithm for image reconstruction is based on the perturbation method. It requires a calculation time of ten minutes on a workstation for a system of 64 electrodes (Nowakovsky). For 180 electrodes, the minimum necessary for practical applications, about ten hours are required for the calculations based on the estimations of the authors. This amount of time is not feasible for clinical practice.

Other attempts at obtaining three-dimensional electrical impedance images of a body have involved multi-dimensional electrode arrays that surround or partially surround the object being imaged. The reconstruction algorithms used and the methodology of making measurements were also different than those of the present invention. These efforts include U. S. Patents 5,284,142, 5,351,697, 4,263,920, 4,486,835, and 4,539,640.

A goal of the present invention is to provide a new method and apparatus for electric mammography with greater reliability and accuracy of measurements, higher resolution, and increased computational speed. This invention is particularly applicable to the clinical diagnosis of breast tumors and other subsurface areas.

Disclosure of the Invention

The electric mammograph is a device for the measurement and three-dimensional (3-D) reconstruction of the conductivity distribution in biological tissues for clinical diagnoses.

It consists of a compact array of electrodes positioned over the tissue being measured, two additional electrodes spaced apart from the array of electrodes, a source of alternating (AC) current, a means to measure potential difference, and computing means to reconstruct and visualize the resulting conductivity distribution.

Brief Description of the Drawings

The invention is illustrated in the following drawings.

FIG. 1 is a block diagram of the electric mammograph.

FIG. 2 shows the arrangement of the apparatus when conducting a mammograph examination.

FIG. 3 is a block diagram of the algorithm used for the three-dimensional conductivity distribution reconstruction.

FIG. 4 is a photograph of the apparatus

FIG. 5 is a sample electric mammogram.

Description of Preferred Embodiments

A block diagram of the components of the electric mammograph is shown in FIG. 1. A compact array of cylindrical protruding electrodes **1** is arranged in a rigid dielectric plane. The example shown has 256 electrodes. The output multiplexer **2** is connected to the electrode array **1** and is the means by which the alternating current (AC) source **4** is connected to one of the cylindrical electrodes in the array. The input multiplexer **3** serves to connect one of the non-activated or "rest" electrodes of the array to the potential difference measuring unit **6**. The microprocessor **9** and the computer **11,** connected via cables **10,** determine which electrode is activated and which of the rest electrodes is being measured at any given time.

Two single remote electrodes, **5** and **7**, are attached to the extremities of the patient. One remote electrode **5** is connected directly to the AC source. The other remote electrode **7**

is connected directly to the potential difference detector **6**. The AC source is connected to a voltage threshold detector **8**. The operation of the electric mammograph is controlled by a microprocessor/computer means. It gets inputs from the potential difference detector **6** and the threshold detector **8** and outputs to the two multiplexers **2**, **3**, the potential difference detector, and the AC source. The first remote electrode **5** connected to the AC source and the second remote electrode **7** are located on a patient's extremities, e.g., one on each wrist as shown in FIG. 2.

In the prior art methods of obtaining a tomographic image of a human body, a series of contact electrodes were placed on the surface of the patent's body. A source of electric current was connected sequentially to pairs of electrodes causing current to flow through the body. Measurements were then made of potential differences between pairs of other "non-activated" electrodes.

In the present invention, the output multiplexer **2** switches a single lead from the AC source to "activate" a single electrode in the electrode array **1** at a time, instead of activating pairs of electrodes in prior art devices. The second "activated" electrode is the remote electrode **5** that is always "on". Switching a single lead at a time reduces the spurious couplings arising from channel-to-channel penetration of signals in the multiplexer. It also simplifies the device and reduces its cost. The same is true for the input multiplexer **3**. The potential difference detector measures the difference between the selected array electrode and the remote rest electrode **7**. For a given rest electrode, the output multiplexer **2** sequences through all the other electrodes in the compact set while the potential difference detector makes its measurements. Then the rest electrode is switched and the output multiplexer sequence repeated.

Using the two singular electrodes **5**, **7** also increase the amplitude of the measured signals due to the increased distance between the points where the potentials are measured. This increases the signal-to-noise ratio and the accuracy of the measurements. The distance of these singular electrodes from the electrode array allows one to assume that the unperturbed equipotential surfaces of electric field are spherical in the examination area. It simplifies and speeds up the conductivity reconstruction calculations.

The method of back projection along equipotential surfaces of the electric field is used to reconstruct the 3-D conductivity distribution. It is assumed that in the case where the electric current is injected through one of the electrodes of the compact set of electrodes arranged in a planar array and the remote common electrode, equipotential surfaces near the two-dimensional set of electrodes are spherical. The procedure of back projection is reduced to the following. For some point with coordinates (X, Y, Z) inside the object under visualization, the distance is determined between this point and the injecting electrode of the compact array. This distance is equal to the radius r of the equipotential surface containing the point where the conductivity is reconstructed. Knowing this radius, it is possible to determine the line of intersection of the equipotential surface with the surface on which the electrodes are arranged. When the electrodes are arranged on the plane, given by equation $z=0$, this line is the circle lying in the (x, y) plane having its center at the point where the injecting electrode is located, and having radius r. Conductivity S (in arbitrary units) at the chosen point is calculated according to the equation:

$$S(x,y,z)=1+W_1(z)\sum_i \frac{1}{\int_{L(x,y,z,i)} W_2(l)dl} \int_{L(x,y,z,i)} W_2(l)(E_r(l)-E_m(l))/E_r(l)dl$$

where i – is the number of the injecting electrode, $L(x,y,z,i)$ - is the line of intersection of the equipotential surface with the surface on which the electrodes are arranged (circle with radius r). The components of the electric field vector $\vec{E}_m$ are first calculated at the nodes of the grid between the electrodes as the potential differences between adjacent electrodes in the x and y directions. Then these components are linearly interpolated to the current point of integration on the line L and the magnitude of this vector E_m is calculated.

The reference intensity of the electric field E_r corresponds to a homogeneous medium and is calculated numerically. Weighting coefficient $W_1(z)$ corrects the decrease of sensitivity with depth. In the present invention, the empirical equation $W_1=(z+\alpha)/(z+\beta), \alpha<<\beta$ is used for it. The weighting coefficient W_2 provides a relatively greater contribution to the calculated conductivity of those points on line L, which are located closer to the point at which the conductivity is reconstructed. In the present device, the equation: $W_2=1/R^4=1/\left((x-x_l)^2+(y-y_l)^2+z^2\right)^2$ is used, where R is the

distance between the point where the conductivity is reconstructed and the current point on the line along which integration is being carried out; the index *l* refers to the coordinates of this point.

The method of back projection is the fastest method used in electrical impedance tomography reconstruction. Its use, however, for reconstructing the static conductivity distribution for the 3-D case is only possible by a proper choice of the projected values.

In addition, the synthesized reference data set E_r must be used. This is obtained by approximating the real measured potentials according to the method of Korjenevsky. (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph," Russian Federation patent application N 96123647/14.)

In many cases it is difficult to obtain sufficient contact of all the electrodes with the patient's body. Consequently, the threshold detector **8** of the output voltage is used to determine whether the electrode being measured at any particular moment has sufficient contact with the body. The compact set of electrodes is arranged on a rigid dielectric plane and every electrode is a conducting protrusion from the plane. This arrangement permits an examination of a mammary gland regardless of its size. During an examination, this plane of electrodes is pressed against the breast, flattening it toward the chest. This increases the number of electrodes having contact with the body and decreases the thickness of the tissue layer to be measured. The protrusion of the electrodes improves their electrical contact with the body.

One or more of the electrodes on the periphery of the plane may not have contact with the body, depending on the size of the examined object. These electrodes are detected with the help

of the threshold detector of the output voltage mentioned above. The values of the potential differences measured from electrodes that have insufficient body contact cannot be used directly in the process of conductivity reconstruction. Instead, values of potential differences calculated on the assumption of a homogeneous conductivity distribution are used.

Besides the useful potential differences caused by the current flow, there are also galvanic potential differences between electrodes. The component for measuring the potential difference **6** is only sensitive to the alternating current component and, consequently, is not disturbed by the presence of these constant galvanic potential differences. However, due to the differences in galvanic potentials of different electrodes, the input voltage varies by a jump when the input multiplexer **3** is switched. These jumps produce a transient that influences the results of the measurements. This influence increases when the time interval between the switch and the start of the potential difference measurement decreases. Therefore, to decrease the error while keeping the total duration of the measurements constant, the input multiplexer **3** should switch the device for measuring the potential difference **6** to the next electrode only after the output multiplexer **2** completes the total cycle of switches of the AC source to all other electrodes.

FIG. 2 shows the arrangement of the various components of the electric mammograph used to take measurements. With the help of the output multiplexer, the control unit connects the source of AC current to one of the electrodes of compact set **1** according to commands from the computer **11**. AC current of approximately 1 mA and a frequency of 10 kHz flows through the circuit, i.e., from the AC source to the multiplexer, to the electrode of set **1**, through the patient's body to the remote rest

electrode **5**. With the help of the input multiplexer, the microprocessor connects one of the rest electrodes from set **1** to the potential difference detector. It measures the amplitude of the alternating voltage between the electrode from set **1** and the remote activated electrode **7**. This measurement is sent in digital code to the microprocessor, which passes it to the computer **11**.

The measured data are used to reconstruct a 3-D conductivity distribution with the help of the algorithm shown in block diagram form in FIG. 3. In block **12** the measured potentials of the electrodes from the compact set, received through the connection line **10**, are used for synthesis of the reference set of potentials corresponding to a body with homogeneous conductivity. An approximation by the method of least squares described in Russian Patent N 96123647/14 is used. Only those potentials obtained from electrodes with good body contact are used. In blocks **13** and **14**, components of the electric intensity vector are calculated for the reference and measured data set by subtraction of the values of potentials on adjacent electrodes for each variant of connection of the current source. In the last case, corresponding potentials from the reference set are used instead of the potentials of those electrodes with insufficient contact.

In block **15** the distance is calculated between the activated electrode in the compact set and the point at which the conductivity is being reconstructed. This distance determines the radius of a circle that represents the line of intersection of the equipotential surface with the plane on which the electrodes are arranged and along which it is necessary to carry out weighted averaging. The electric intensity for the measured and the reference data set are calculated after the linear interpolation of the corresponding components of vectors, calculated in blocks **13** and

14. The relative difference of the electric intensities for the reference and measured data sets are multiplied by the weight function $1/R^4$, where R is the distance between the point where the conductivity is reconstructed and the current point on the line along which averaging is being carried out.

In block **16** the obtained value is numerically integrated along the circle. These operations are repeated for all points where the conductivity is to be reconstructed and for all variants of the activated electrodes. This process is controlled by block **17**. The result of these calculations, after adding a unit to obtained values, represents a 3-D distribution of the conductivity normalized on the average value. The result can be displayed on screen or printed out. Block **18** contains the software and hardware used to carry out these functions.

The external appearance of the electric mammograph without the computing unit is shown in FIG. 4. FIG. 5 shows an electric mammogram obtained by the invention. The mammogram represents a set of seven images of breast cross-sections parallel to the plane on which the electrodes are arranged. The depth of the cross-sections increases from left to right and from up to down with 8 mm steps. On the image one can clearly see the nipple 19, the ribs **20**, and the boundary **21** between areas with and without sufficient electrode contact with the body.

CLAIMS

1. A method of displaying a three-dimensional image of the conductivity distribution of biological tissue, said method comprising the steps of:

applying a source (4) of alternating current (AC) to a first activated electrode (1) of a compact set of electrodes arranged in a planar array, said compact set of electrodes being in contact with the surface of the biological tissues of interest, and to a first remotely located electrode (5, 7) in contact with the body but at some distance from the compact set of electrodes;

measuring the potential difference between a first at rest electrode (1) of said compact set and a second remotely located electrode (7,5), said second remote electrode being at rest;

switching the source (4) of AC current by multiplexer means (2, 3) to activate successively all of the electrodes (1) of said planar array of electrodes except said at rest electrode of step (b) and measuring the potential difference between said at rest electrodes in (b) for each activated electrode in turn to thereby obtain a first set of potential difference measurements for each activated electrode;

switching the electrode (1) to be measured in said planar array by multiplexer means (2, 3) to a second at rest electrode (1), activating successively every other electrode in said planar array, and measuring the potential difference between said second at rest electrode and said at rest remote electrode (7, 5) in turn to thereby obtain a second set of potential difference measurements for each activated electrode;

continue switching the at rest electrode (1), activating successively the remaining electrodes in said planar array, and measuring the potential difference between the selected at rest

electrode and said at rest remote electrode (7, 5) in turn until all planar electrodes combinations have been measured;

reconstructing a three-dimensional conductivity distribution using the method of back projection along equipotential surfaces of the electric field, the projected data being obtained by weighted averaging of the relative difference between the reference electric intensity corresponding to tissue with a homogeneous conductivity distribution and the measured electric intensity along the line of intersection of the equipotential surface containing the point where conductivity is reconstructed and with the surface on which the compact set of electrodes (1) is located.

2. The method of claim 1, whereby a threshold detector means (8) determines whether any particular electrode (1) of the planar array has sufficient contact with the tissue to give a meaningful measurement.

3. The method of claim 2, whereby the values of potential differences for those electrodes (1) having insufficient contact with the tissue are calculated based on the assumption of a homogeneous conductivity distribution rather than using the actual measured potential differences.

4. The method of claim 1, whereby the weighting coefficient of $1/R^4$ is used in the weighted averaging of step (f), where R is the distance between the point where the conductivity is being reconstructed and the current point on the line along which averaging is being carried out.

5. The method of claim 1, whereby said compact set of electrodes (1) is arranged on a rigid dielectric plane and the conducting portion of each electrode protrudes from said plane.

6. An apparatus for producing a three-dimensional image of the conductivity distribution of biological tissue comprising:

a plurality of individual electrodes (1) disposed in a rigid planar array and placed in contact with the biological tissue of interest;

an alternating current (AC) source (4) connected to one of the electrodes (active electrode) (1) in said planar array and to a single remote active electrode (5, 7) located at some distance from said planar array and in contact with the biological tissue;

an output multiplexing means (2) to successively switch the AC source to other electrodes (1) in said planar array making them active electrodes in turn;

an input multiplexing means (3) to connect a potential difference measuring means (6) to one of the non-active (at rest) electrodes (1) in said planar array and to an at rest single remote electrode (7, 5) located at some distance from said planar array and in contact with the biological tissue;

computing means coupled to said input and output multiplexing means (2, 3) for sequencing said AC source through said planar array electrodes (1) while taking potential difference measurements from other electrodes in said planar array and for reconstructing a three-dimensional conductivity distribution using a modified back projection method; and

display means for imaging the reconstructed three-dimensional conductivity distribution.

7. The apparatus of claim 6, wherein a threshold detector means (8) is provided to determine whether any particular electrode (1) of said planar array has sufficient contact with the tissue to give a meaningful measurement.

8. The apparatus of claim 7, wherein in reconstructing the conductivity distribution, the values of potential differences for those electrodes (1) having insufficient contact with

the tissue are calculated based on the assumption of a homogeneous conductivity distribution rather than using the actual measured potential differences.

9. The apparatus of claim 6, wherein the modified back projection reconstruction method used incorporates a weighting coefficient of $1/R^4$, where R is the distance between the point where the conductivity is being reconstructed and the current point on the line along which averaging is being carried out.

10. The apparatus of claim 6, wherein said planar array of electrodes (1) is arranged on a rigid dielectric plane and the conducting portion of each electrode protrudes from said plane.

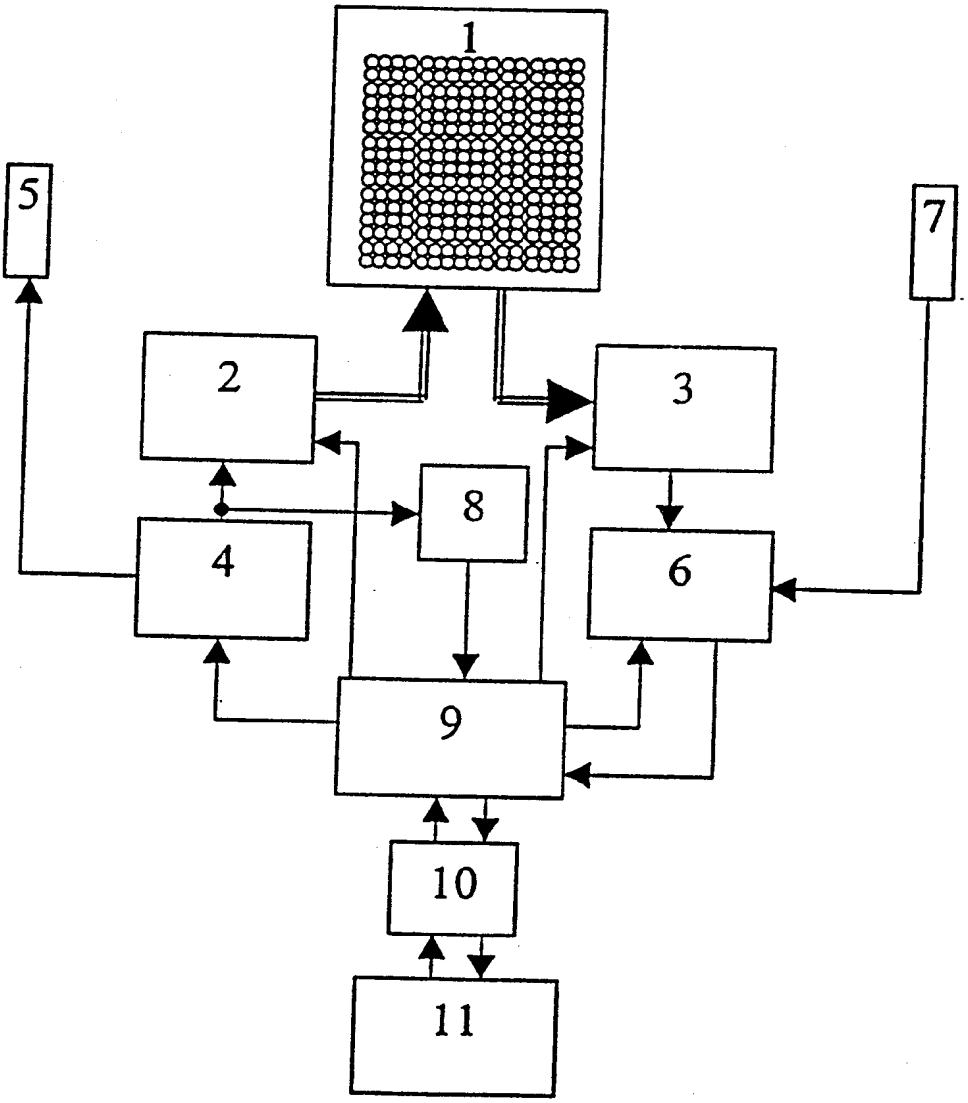


FIG. 1

Electric Mammograph

SHEET 2 of 5

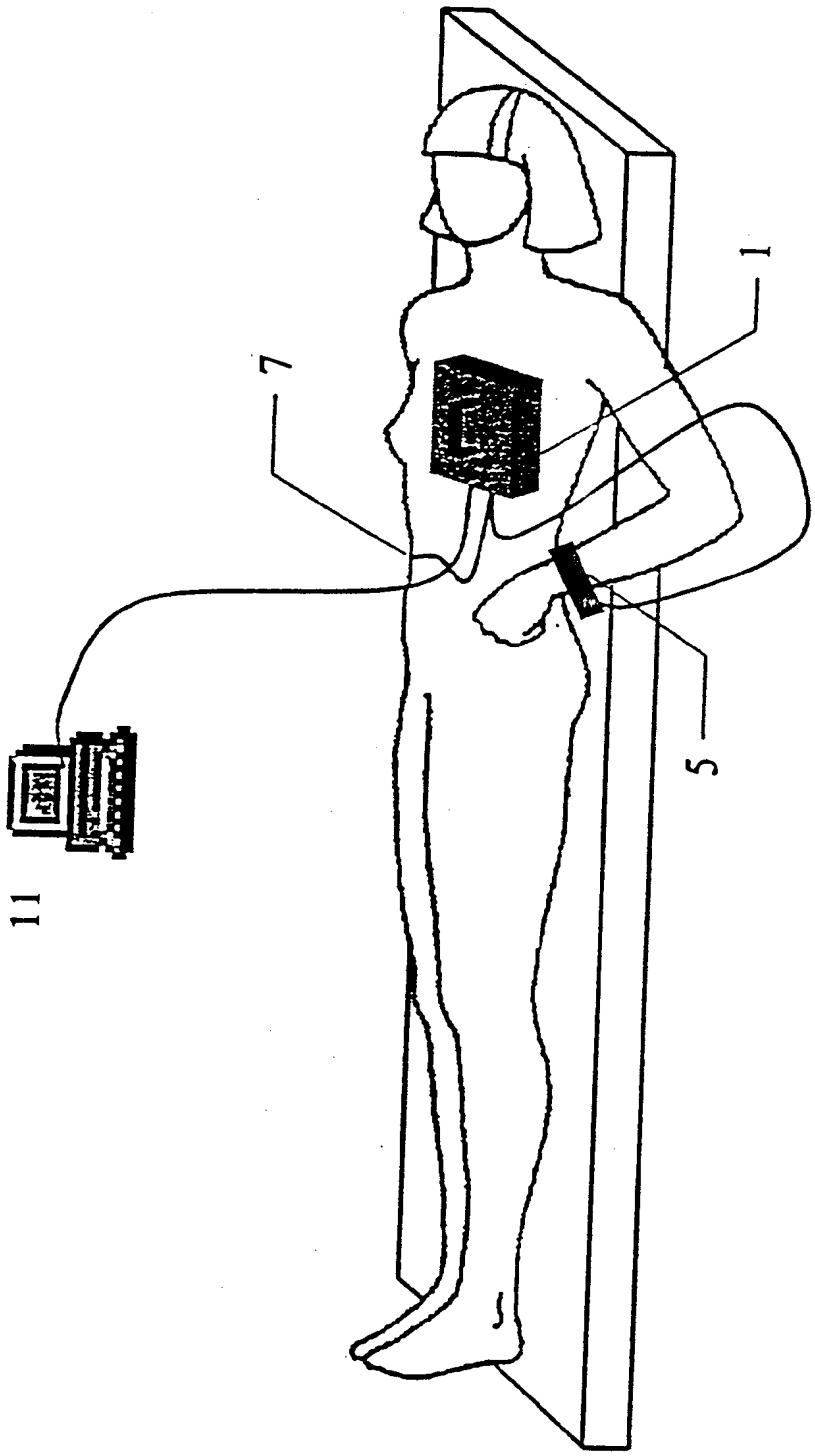


FIG. 2

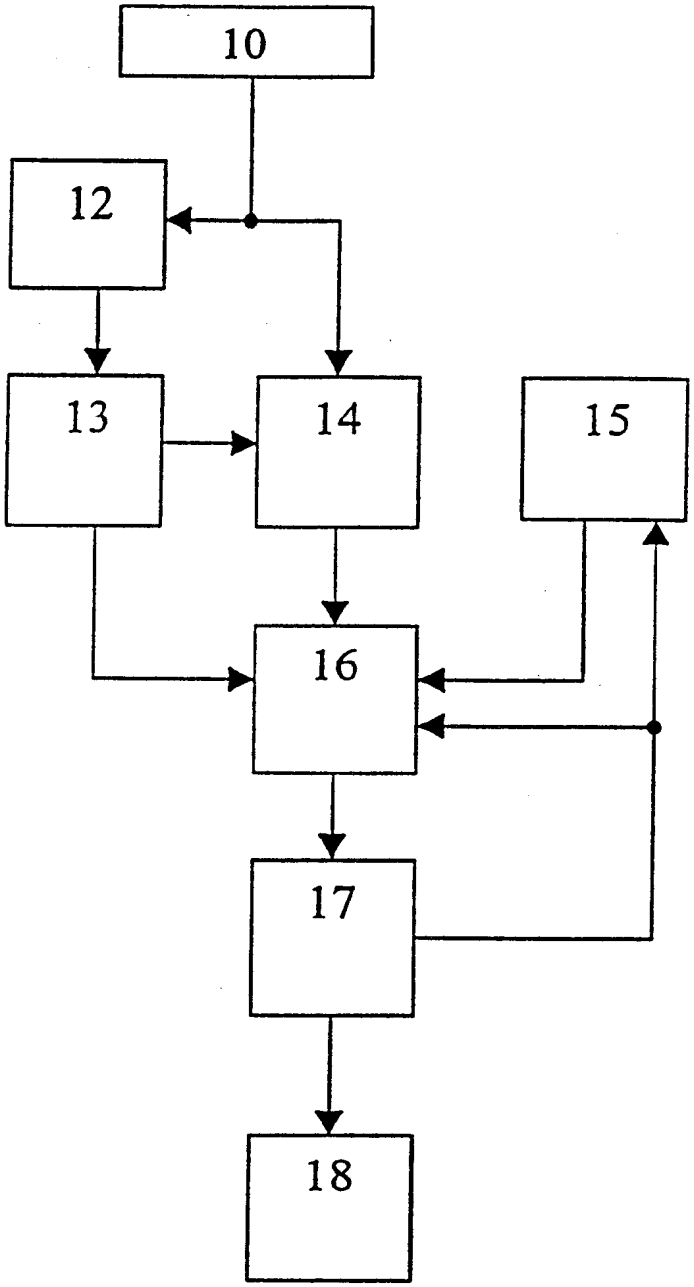


FIG. 3

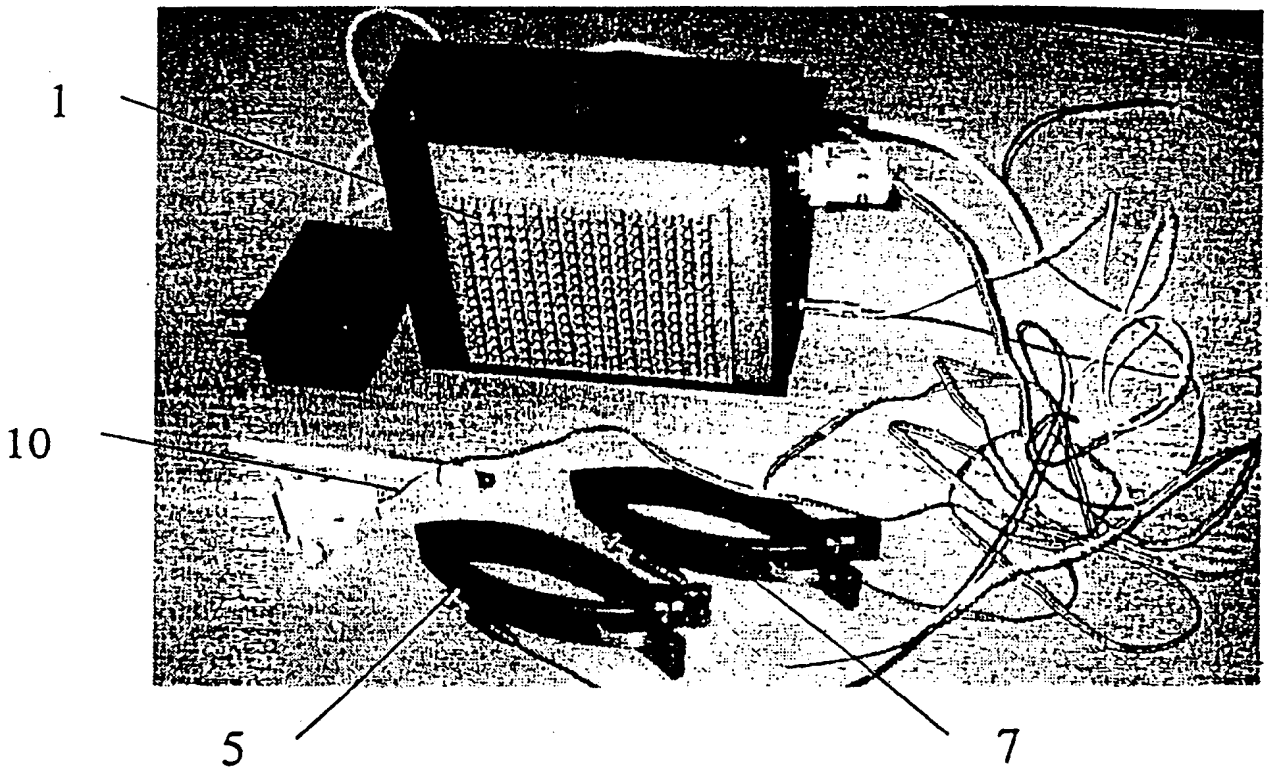


FIG. 4

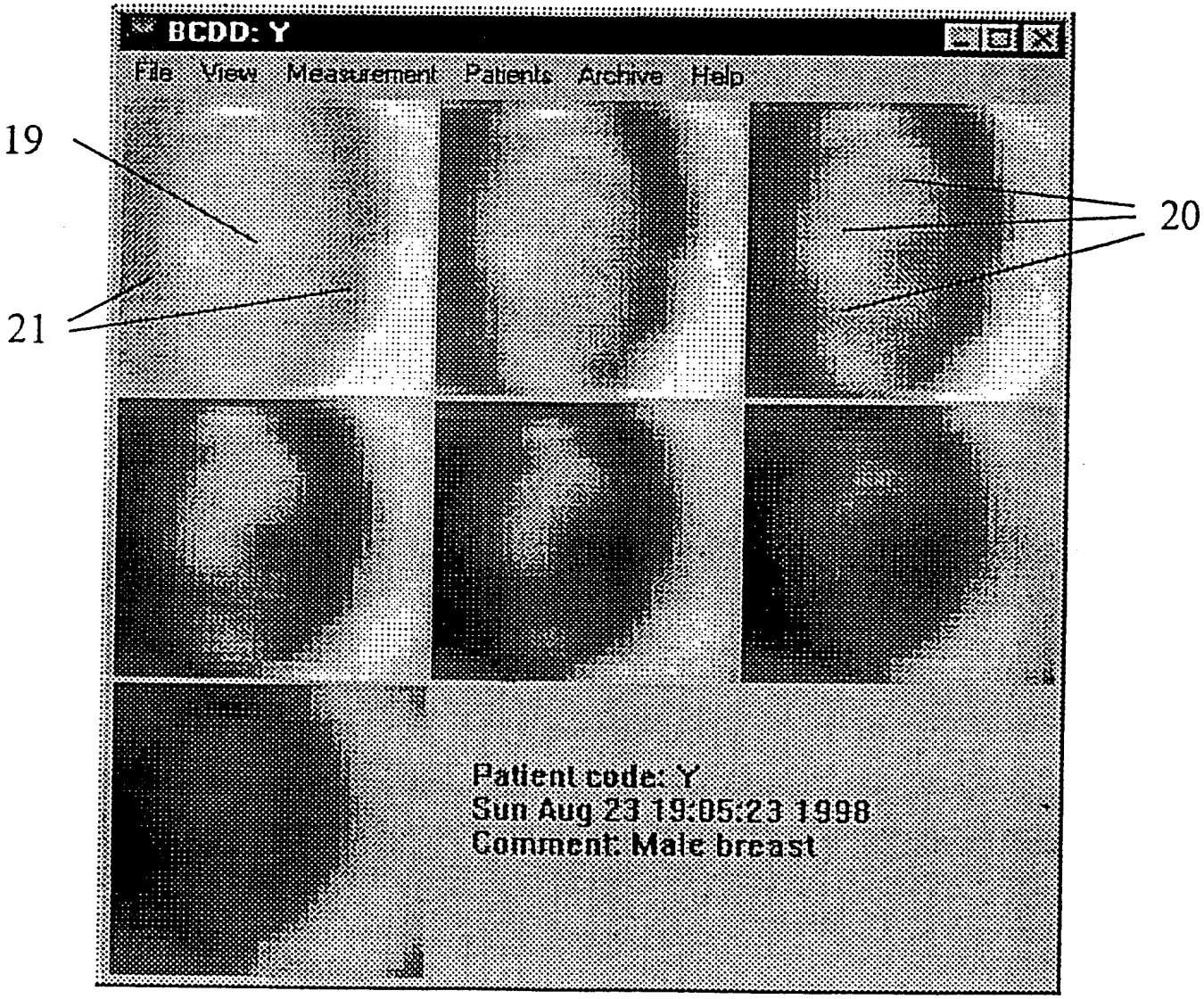

BCDD: Y
File View Measurement Patients Archive Help
19
21
20
Patient code: Y
Sun Aug 23 19:05:23 1998
Comment: Male breast

FIG. 5

INTERNATIONAL SEARCH REPORT

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PCT/US00/06283

A. CLASSIFICATION OF SUBJECT MATTER

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US CL :128/930; 324/717; 600/547

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Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/930; 324/600, 713, 717; 600/547

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,351,697 A (CHENEY et al.) 04 October 1994, Abstract	1, 6

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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(54) Bezeichnung: **ELEKTRISCHER MAMMOGRAPH**

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Beschreibung

Gebiet der Technik

[0001] Die Erfindung liegt im Bereich der medizinischen Tomographie, und betrifft insbesondere ein Verfahren und eine Vorrichtung für die Visualisierung und Diagnose pathologischer Veränderungen in Brustgeweben und anderen Organen in der Nähe der Oberfläche des menschlichen Körpers.

Stand der Technik

[0002] Es ist bekannt, dass sich die elektrische Leitfähigkeit vieler Tumore, und insbesondere bösartiger Tumore der Brustdüse, erheblich von der Leitfähigkeit des umgebenden gesunden Gewebes unterscheidet. Diese Tatsache kann für die Erfassung und Lokalisierung derartiger Tumore eingesetzt werden.

[0003] Einige Vorrichtungen sind für die Visualisierung der räumlichen Verteilung der Leitfähigkeit (Impedanz) im menschlichen Körper bekannt, wie z.B. elektrische Impedanz-Tomographen. (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph; Verfahren zum Erhalt eines tomographischen Bildes eines Körpers und elektrischer Impedanz-Tomograph"; Internationale Anmeldung PCT/RU97/00398.) In einem elektrischen Impedanz-Tomographen wird die Wechselstromquelle an Elektrodenpaare angeschlossen, die entlang einer Linie auf der Oberfläche eines Körpers angeordnet werden, und Messungen der Potentialdifferenzen werden an den anderen Elektrodenpaaren durchgeführt. Die aus den unterschiedlichen Elektrodenkombinationen erhaltenen Ergebnisse der Messungen werden für die Rekonstruktion der Verteilung der spezifischen elektrischen Leitfähigkeit mit Hilfe eines Computers verwendet. Eine dreidimensionale Verteilung der spezifischen elektrischen Leitfähigkeit ist jedoch mit diesem Typ von Tomographen nicht möglich. Weiter fällt seine Auflösung vom Umfang bis zur Mitte des Elektrodenumrisses erheblich ab. Folglich ist dieser Tomograph keine geeignete Vorrichtung für die Diagnose von Brustdüsen-Tumoren.

[0004] Eine Elektroimpedanz-Mammographvorrichtung, welche eine dreidimensionale Impedanzverteilung erreichen soll, wurde ebenfalls beschrieben. (A. Nowakovsky, J. Wortek, und J. Stelter, "A Technical University of Gdansk Electroimpedance Mammograph; Ein Elektroimpedanz-Mammograph der Technischen Universität von Gdansk," Proc. IX Int. Conf. Elektrische Bio-Impedanz, Heidelberg, 1995, Seiten 434–437; J. Wortek, J. Stelter, A. Nowakovsky, "Impedance mammograph 3D phantom studies; Impedanz-Mammograph 3D-Phantomstudien," Proc. X Int. Conf. Elektrische Bio-Impedannz, Barcelona, 1998, Seiten 521–524.) Diese Vorrichtung enthält einen kompakten Elektrodensatz, der auf der Innenfläche einer starren Halbkugel angeordnet ist, Multiplexer, die an die Wechelstromquelle angeschlossen sind, und eine Vorrichtung zum Messen der Potentialdifferenz zwischen verschiedenen Elektrodenpaaren. Die gemessenen Potentialdifferenzen werden an einen Computer zur Rekonstruktion und Anzeige der dreidimensionalen Impedanzverteilung im Inneren der Halbkugel gesendet. Die Tauglichkeit dieser Vorrichtung basierend auf tatsächlichen Messungen am menschlichen Körper ist noch nicht veröffentlicht worden.

[0005] Eine Reihe von Einschränkungen dieser Vorrichtung sind offensichtlich. Die Anordnung der Elektroden auf der Oberfläche der Halbkugel schränkt die Anwendung der Vorrichtung ein, da der Kontakt mit allen Elektroden nur für eine Brust mit einer bestimmten Größe geschaffen werden kann. Die Vorrichtung hat zudem weder eine Vorrichtung zur Messung der Qualität eines jeden Kontakts, noch jegliche Vorrichtung zur Korrektur der Rekonstruktionsberechnungen, falls eine der Elektroden einen unzureichenden Kontakt mit dem Körper aufweist. Dies vermindert die Gültigkeit der Daten. Die elektrische Stromquelle und die Messvorrichtung sind mit Elektrodenpaaren verbunden, die auf der Halbkugel angeordnet sind, und erfordern vier Multiplexer. Wenn die Anzahl der Elektroden groß ist, werden diese Multiplexer zu den kompliziertesten und teuersten Bauteilen der Vorrichtung. Diese Multiplexer sind zudem die größte Quelle innerer Störsignale aufgrund von Nebensprechen von Kanal zu Kanal. Nur 64 Elektroden wurden in dem Prototypen verwendet. Dies ist für den Erhalt einer zufriedenstellenden Auflösung offensichtlich nicht ausreichend. Eine weitere Erhöhung der Anzahl der Elektroden ist jedoch aufgrund der Schwierigkeit bei der Kommutierung durch den gewählten Messschaltkreis problematisch.

[0006] Wenn ein sicherer elektrischer Strompegel eingesetzt wird, sind die gemessenen Potentialdifferenzen gering, da zwischen den Elektroden nur kleine Entfernungen vorliegen. Dadurch werden der Rauschabstand und die Anzeigequalität verringert. Dieser Effekt verschlimmert sich mit zunehmender Anzahl an Elektroden nur. Der Algorithmus für die Rekonstruktion eines Bildes beruht auf der Störungsmethode. Er benötigt eine Berechnungszeit von zehn Minuten und einen Arbeitsplatz für ein System mit 64 Elektroden (Nowakovsky). Für

180 Elektroden, die notwendige Mindestanzahl für praktische Anwendungen, sind basierend auf den Schätzungen der Autoren ungefähr zehn Stunden für die Berechnungen erforderlich. Diese Zeitdauer ist in der klinischen Praxis nicht durchführbar.

[0007] Andere Versuche zum Erhalt dreidimensionaler elektrischer Impedanzbilder eines Körpers machten mehrdimensionale Elektrodengruppierungen notwendig, die das betrachtete Objekt umgeben oder teilweise umgeben. Die verwendeten Rekonstruktionsalgorithmen und die Methodenlehre zur Durchführung von Messungen unterschieden sich ebenfalls von denen der vorliegenden Erfindung. Diese Bemühungen schließen die US-Patente 5,284,142, 5,351,697, 4,263,920, 4,486,835, 4,539,640 und 5,810,742 ein.

[0008] Es ist ein Ziel der vorliegenden Erfindung, ein neues Verfahren und eine neue Vorrichtung zur elektrischen Mammogaphie zu schaffen, die eine größere Zuverlässigkeit und Genauigkeit der Messungen, eine höhere Auflösung und eine verbesserte Rechengeschwindigkeit aufweist. Diese Erfindung ist besonders bei der klinischen Diagnose von Brusttumoren und anderen Bereichen unter der Haut anwendbar.

Offenbarung der Erfindung

[0009] Der elektrische Mammograph ist eine Vorrichtung für die Messung und die dreidimensionale (3-D) Rekonstruktion der Verteilung der spezifischen elektrischen Leitfähigkeit in biologischen Geweben für klinische Diagnosen. Er weist einen kompakten Elektrodensatz, der über dem zu messenden Gewebe angeordnet ist, zwei zusätzliche Elektroden, die beabstandet von dem Elektrodensatz angeordnet sind, eine Vorrichtung zum Messen der Potentialdifferenz, und eine Berechnungsvorrichtung zur Rekonstruktion und Visualisierung der resultierenden Verteilung der spezifischen elektrischen Leitfähigkeit auf.

[0010] Weitere Einzelheiten, Vorteile und Merkmale ergeben sich aus der nachfolgenen Kurzbeschreibung der Erfindung anhand der Zeichnungen.

KURZBESCHREIBUNG DER ZEICHNUNGEN

[0011] Es zeigen:

[0012] Fig. 1 ein Blockdiagramm des elektrischen Mammographen;

[0013] Fig. 2 die Anordnung der Vorrichtung, wenn eine mammographische Untersuchung durchgeführt wird;

[0014] Fig. 3 ein Blockdiagramm des Algorithmus, der für die dreidimensionale Rekonstruktion der Verteilung der spezifischen elektrischen Leitfähigkeit verwendet wird;

[0015] Fig. 4 eine Fotografie der Vorrichtung; und

[0016] Fig. 5 ein Muster eines elektrischen Mammogramms.

BESCHREIBUNG DER BEVORZUGTEN AUSFÜHRUNGSFORMEN

[0017] Ein Blockdiagramm der Bauteile des elektrischen Mammographen ist in Fig. 1 gezeigt. Ein kompakter Satz zylindrischer vorstehender Elektroden **1** ist in einer starren dielektrischen Ebene angeordnet. Das gezeigte Beispiel weist 256 Elektroden auf. Der Ausgabe-Multiplexer **2** ist mit dem Elektrodensatz **1** verbunden und ist die Vorrichtung, über die die Wechselstromquelle (AC) **4** mit einer der zylindrischen Elektroden in dem Satz verbunden ist. Der Eingabe-Multiplexer **3** dient dazu, eine der nicht aktivierten oder "Ruhe"-Elektroden des Satzes mit der Potentialdifferenz-Messeinheit **6** zu verbinden. Der Mikroprozessor **9** und der Computer **11**, die über Kabel **10** verbunden sind, bestimmen, welche Elektrode aktiviert wird und welche der Ruheelektroden zu jedem beliebigen Zeitpunkt gemessen wird.

[0018] Zwei einzelne entfernt angeordnete Elektroden **5** und **7** sind an den Gliedmaßen des Patienten angebracht. Eine entfernt angeordnete Elektrode **5** ist direkt mit der Wechselstromquelle verbunden. Die andere entfernt angeordnete Elektrode **7** ist direkt mit dem Potentialdifferenz-Detektor **6** verbunden. Die Wechselstromquelle ist mit einem Spannungsschwellen-Detektor **8** verbunden. Der Betrieb des elektrischen Mammographen wird von einer Mikroprozessor-/Computervorrichtung gesteuert. Diese erhält Eingangssignale vom Potentialdifferenz-Detektor **6** und dem Schwellenwert-Detektor **8**, und gibt Ausgangssignale an die beiden Multiplexer **2**, **3**, den Potentialdifferenz-Detektor und die Wechselstromquelle aus. Die erste mit der Wechselstrom-

quelle verbundene entfernt angeordnete Elektrode **5** und die zweite entfernt angeordnete Elektrode **7** sind auf Gliedmaßen des Patienten angeordnet, wie z.B. in Fig. 2 gezeigt eine auf jedem Handgelenk.

[0019] Bei den Verfahren des Standes der Technik zum Erhalt eines tomographischen Bildes eines menschlichen Körpers wurde eine Reihe von Kontaktelektroden auf der Oberfläche des Körper des Patienten angeordnet. Eine elektrische Stromquelle wurde nacheinander an Elektrodenpaare angeschlossen, wodurch ein Stromfluss durch den Körper verursacht wurde. Dann wurden Messungen der Potentialdifferenzen zwischen Paaren anderer "nicht aktivierter" Elektroden durchgeführt.

[0020] Bei der vorliegenden Erfindung schaltet der Ausgabe-Multiplexer **2** im Unterschied zu Vorrichtungen des Standes der Technik, bei denen Ekeltrodenpaare aktiviert wurden, eine einzelne Leitung von der Wechselstromquelle, um eine einzelne Elektrode in dem Elektrodensatz **1** zu einem Zeitpunkt zu "aktivieren". Die zweite "aktivierte" Elektrode ist die entfernt angeordnete Elektrode **5**, die immer "eingeschaltet" ist. Das Schalten einer einzelnen Leitung zu einem Zeitpunkt verringert die Störkupplungen, die durch die Durchdringung von Signalen in dem Multiplexer von Kanal zu Kanal entstehen. Es vereinfacht zudem die Vorrichtung und verringert ihre Kosten. Das Selbe gilbt für den Eingabe-Multiplexer **3**. Der Potentialdifferenz-Detektor misst die Differenz zwischen der aus dem Satz ausgewählten Elektrode und der entfernt angeordneten Ruhe-Elektrode **7**. Bei einer vorgegebenen Ruheelektrode ordnet der Ausgabe-Multiplexer **2** alle anderen Elektroden in der kompakten Anordnung sequentiell, während der Potentialdifferenz-Detektor seine Messungen durchführt. Dann wird die Ruheelektrode geschaltet und die Ausgabe-Mutiplexer-Reihenfolge wiederholt.

[0021] Die Verwendung der beiden einzelnen Elektroden **5**, **7** erhöht zudem die Amplitude der gemessenen Signale aufgrund der größeren Entfernung zwischen den Punkten, an denen die Potentiale gemessen werden. Dadurch werden der Rauschabstand und die Genauigkeit der Messungen erhöht. Die Entfernung der einzelnen Elektroden von dem Elektrodensatz erlaubt die Annahme, dass die ungestörten Äquipotentialflächen des elektrischen Feldes im Untersuchungsbereich kugelförmig ausgebildet sind. Dies vereinfacht und beschleunigt die Berechnungen der Rekonstruktion der spezifischen elektrischen Leitfähigkeit.

[0022] Das Verfahren der Rückwärtsprojektion entlang von Äquipotentialflächen des elektrischen Feldes wird zur Rekonstruktion der 3-D Verteilung der spezifischen elektrischen Leitfähigkeit eingesetzt. Es wird davon ausgegangen, dass in dem Fall, dass der elektrische Strom durch eine der Elektroden des in einem ebenen Feld angeordneten kompakten Elektrodensatzes und der entfernt angeordneten herkömmlichen Elektrode injiziert wird, Äquipotentialflächen in der Nähe des zweidimensionalen Elektrodensatzes kugelförmig ausgebildet sind. Die Vorgehensweise der Rückwärtsprojektion wird auf das Folgende reduziert: für einen gewissen Punkt mit den Koordinaten (X, Y, Z) in dem Objekt unter Betrachtung wird die Entfernung zwischen diesem Punkt und der den Strom injizierenden Elektrode des kompakten Satzes bestimmt. Diese Entfernung entspricht dem Radius r der Äquipotentialfläche, die den Punkt aufweist, an dem die spezifische elektrische Leitfähigkeit rekonstruiert wird. Sobald dieser Radius bekannt ist, ist es möglich, die Schnittlinie der Äuipotentialfläche mit der Oberfläche, auf der die Elektroden angeordnet sind, zu bestimmen. Wenn die Elektroden auf der Ebene, welche durch die Gleichung z = 0 wiedergegeben wird, angeordnet sind, ist diese Linie der Kreis, der in der (x,y) Ebene liegt, deren Mittelpunkt an dem Punkt liegt, wo die strominjizierende Elektrode angeordnet ist, und der den Radius r aufweist. Die spezifische elektrische Leitfähigkeit S (in willkürlichen Einheiten) an dem gewählten Punkt wird gemäß folgender Gleichung berechnet:

$$S(x,y,z) = 1 + W_1(z) \sum_i \frac{1}{\int_{L(x,y,z,i)} W_2(l)\,dl} \int_{L(x,y,z,i)} W_2(l)\left(E_r(l) - E_m(l)\right)/E_r(l)\,dl$$

wobei i – die Anzahl der injizierenden Elektrode ist, und L(x,y,z,i) – die Schnittlinie der Äquipotentialfläche mit der Oberfläche, auf der die Elektroden angeordnet sind (Kreis mit dem Radius r) ist. Die Komponenten des elektrischen Feldvektors E_m, werden zuerst an den Knoten des Gitters zwischen den Elektroden als die Potentialdifferenzen zwischen benachbarten Elektroden in die x- und y-Richtungen berechnet. Dann werden diese Komponenten linear zu dem augenblicklichen Integrationspunkt auf der Linie L interpoliert und die Größe des Vektors Ein wird berechnet.

[0023] Die Referenzintensität des elektrischen Feldes E_r entspricht einem homogenen Medium und wird numerisch berechnet. Der Gewichtungskoeffizient $W_1(z)$ korrigiert die mit der Tiefe abnehmende Empfindlichkeit. In der vorliegenden Erfindung wird dazu die empirische Gleichung $W_1 = (z + \alpha)/(z + \beta)$, $\alpha << \beta$ verwendet. Der Gewichtungskoeffizient W_2 liefert einen relativen größeren Beitrag zu der berechneten spezifischen elektrischen Leitfähigkeit dieser Punkte auf der Linie L, die näher an dem Punkt angeordnet sind, an dem die spezi-

fische elektrische Leitfähigkeit rekonstruiert wird. Bei der vorliegenden Vorrichtung wird die Gleichung

$$W_2 = 1/R^4 = 1/((x - x_1)^2 + (Y - Y_1)^2 + z^2)^2$$

verwendet, wobei R die Entfernung zwischen dem Punkt, an dem die spezifische elektrische Leitfähigkeit rekonstruiert wird, und dem augenblicklichen Punkt auf der Linie ist, entlang welcher die Integration durchgeführt wird; der Index 1 bezieht sich auf die Koordinaten dieses Punktes.

[0024] Das Verfahren der Rückprojektion ist das schnellste bei der elektrischen Impedanztomographie-Rekonstruktion verwendete Verfahren. Sein Einsatz ist jedoch für die Rekonstruktion der Verteilung der statischen Leitfähigkeit für den 3-D Fall nur dann möglich, wenn die projizierten Werte richtig ausgewählt werden. Darüber hinaus muss die synthetisierte Referenzdatengruppe E_r verwendet werden. Diese wird durch Approximieren der wirklich gemessenen Potentiale gemäß dem Verfahren nach Korjenevsky (A. V. Korjenevsky, Yu. S. Kultiasov, V. A. Cherepenin, "Method of obtaining of tomographic image of a body and electrical impedance tomograph; Verfahren für den Erhalt eines tomographischen Bildes eines Körpers und elektrischer Impedanz-Tomograph in der Patentameldung N 96123647/14 der Russischen Föderation) erhalten.

[0025] In vielen Fällen ist es schwierig, einen ausreichenden Kontakt aller Elektroden mit dem Körper des Patienten zu erzielen. Folglich wird der Schwellenwert-Detektor **8** der Ausgangsspannung verwendet, um zu bestimmen, ob die zu messende Elektrode zu jedem bestimmten Zeitpunkt einen ausreichenden Kontakt mit dem Körper hat. Der kompakte Elektrodensatz ist auf einer steifen dielektrischen Fläche angeordnet und jede Elektrode ist ein leitender Vorsprung von dieser Fläche. Diese Anordnung erlaubt die Untersuchung einer Brustdüse unabhängig deren Größe. Während der Untersuchung wird die Elektrodenfläche gegen die Brust gedrückt, wodurch diese in Richtung des Brustkorbs flach gedrückt wird. Dadurch wird die Anzahl der Elektroden erhöht, die in Kontakt mit dem Körper ist, und die Dicke der zu messenden Gewebeschicht wird verringert. Die vorspringende Eigenschaft der Elektroden verbessert deren elektrischen Kontakt mit dem Körper.

[0026] Eine oder mehrere Elektroden auf dem Umfang der Fläche können keinen Kontakt mit dem Körper aufweisen, abhängig von der Größe des untersuchten Objekts. Diese Elektroden werden mit Hilfe des Schwellenwert-Detektors der Ausgangsspannung, welcher vorstehend erwähnt wurde, erfasst. Die Werte der aus den Elektroden mit unzureichendem Körperkontakt gemessenen Potentialdifferenzen können nicht direkt in dem Verfahren zur Rekonstruktion der Leitfähigkeit verwendet werden. Anstatt dessen werden werte von Potentialdifferenzen verwendet, die unter der Annahme einer homogenen Verteilung der spezifischen elektrischen Leitfähigkeit berechnet wurden.

[0027] Zudem gibt es neben den durch den Stromfluss verursachten nützlichen Potentialdifferenzen noch galvanische Potentialdifferenzen zwischen Elektroden. Das Bauteil zur Messung der Potentialdifferenz **6** spricht nur auf das Wechselstrom-Bauteil an, und wird folglich durch die Anwesenheit dieser konstanten galvanischen Potentialdifferenzen nicht gestört. Aufgrund der Unterschiede bei den galvanischen Potentialen der unterschiedlichen Elektroden variiert die Eingangsspannung jedoch sprunghaft, wenn der Eingabe-Multiplexer **3** geschaltet wird. Diese Sprünge oder plötzlichen Anstiege verursachen eine vorübergehende Spannungsspitze, die die Ergebnisse der Messungen beeinflusst. Dieser Einfluss nimmt zu, wenn das Zeitintervall zwischen dem Einschalten und dem Beginn der Messung der Potentialdifferenz abnimmt. Daher sollte der Eingabe-Multiplexer **3** zur Verringerung des Fehlers, während die Gesamtdauer der Messungen konstant bleibt, die Vorrichtung zur Messung der Potentialdifferenz **6** zur nächsten Elektrode erst dann schalten, nachdem der Ausgabe-Multiplexer **2** den Gesamtzyklus an Umschaltungen der Wechselstromquelle an alle anderen Elektroden beendet hat.

[0028] Fig. 2 zeigt die Anordnung der verschiedenen Bauteile des für die Durchführung von Messungen verwendeten elektrischen Mammographen. Mit Hilfe der Ausgabe-Multiplexer verbindet die Steuereinheit entsprechend den Befehlen vom Computer **11** die Wechselstromquelle mit einer der Elektroden der Kompaktgruppe **1**. Wechselstrom mit einer Stärke von ungefähr 1 mA und einer Frequenz von 10 kHz fließt durch den Schaltkreis, d.h. von der Wechselstromquelle zum Multiplexer, zur Elektrode des Satzes **1**, durch den Körper des Patienten zu der entfernt angeordneten Ruheelektrode **5**. Mit Hilfe des Eingabe-Multiplexers verbindet der Mikroprozessor eine der Ruheelektroden aus der Gruppe **1** mit dem Potentialdifferenz-Detektor. Dieser misst die Amplitude der Wechselspannung zwischen der Elektrode aus der Gruppe **1** und der entfernt angeordneten aktivierten Elektrode **7**. Diese Messung wird in digitalem Code an den Mikroprozessor gesendet, der sie an den Computer **11** weiterleitet.

[0029] Die gemessenen Daten werden zur Rekonstruktion einer 3-D Verteilung der spezifischen elektrischen

Leitfähigkeit mit Hilfe des im Blockdiagramm von Fig. 3 gezeigten Algorithmus verwendet. In Block **12** werden die gemessenen Potentiale der Elektroden aus dem kompakten Satz, welche durch die Verbindungsleitung **10** empfangen werden, für die Synthese der Bezugsgruppe von Potentialen, die einem Körper mit einer homogenen spezifischen elektrischen Leitfähigkeit entsprechen, verwendet. Es wird eine Approximation durch die Methode der kleinsten Quadrate, die in dem Russischen Patent Nr. 96123647/14 beschrieben wird, verwendet. Nur die von Elektroden mit einem guten Körperkontakt erhaltenen Potentiale werden verwendet. In den Blöcken **13** und **14** werden Komponenten des elektrischen Intensitätsvektors für die Referenz-Datengruppe und die gemessene Datengruppe durch Subtraktion der Werte der Potentiale auf benachbarten Elektroden für jede Verbindungsvariante der Stromquelle berechnet. Im letzten Fall werden entsprechende Potentiale aus der Referenzgruppe anstelle der Potentiale derjenigen Elektroden verwendet, die einen unzureichenden Kontakt aufweisen.

[0030] In Block **15** wird der Abstand zwischen der aktivierten Elektrode in der Kompaktgruppe und dem Punkt, an dem die Leitfähigkeit rekonstruiert wird, berechnet. Diese Entfernung bestimmt den Radius eines Kreises, der die Schnittlinie der Äquipotentialfläche mit der Ebene darstellt, auf der die Elektroden angeordnet sind und entlang welcher es nötig ist, eine gewichtete Durchschnittsbildung durchzuführen. Die elektrische Intensität für die gemessene Datengruppe und die Referenz-Datengruppe wird nach der linearen Interpolation der entsprechenden Vektorenkomponenten, die in den Blöcken **13** und **14** berechnet werden, berechnet. Die relative Differenz der elektrischen Intensitäten für die Bezugs- und Messdatengruppe wird mit der Gewichtungsfunktion $1/R^4$ multipliziert, wobei R die Entfernung zwischen dem Punkt, an dem die spezifische elektrische Leitfähigkeit rekonstruiert wird, und dem augenblicklichen Punkt auf der Leitung ist, entlang dem eine Durchschnittsbildung durchgeführt wird.

[0031] In Block **16** wird der erhaltene Wert numerisch entlang dem Kreis integriert. Die Vorgänge werden für alle Punkte wiederholt, an denen die Leitfähigkeit rekonstruiert werden soll, und für alle Varianten der aktivierten Elektroden. Dieser Vorgang wird durch Block **17** gesteuert. Das Ergebnis dieser Berechnungen stellt nach der Addition einer Einheit zu erhaltenen Werten eine 3-D Verteilung der spezifischen elektrischen Leitfähgikeit dar, die auf den Durchschnittswert genormt wurde. Das Ergebnis kann auf einem Bildschirm angezeigt oder ausgedruckt werden. Der Block **18** enthält die Software und Hardware, die zur Ausführung dieser Funktionen verwendet wird.

[0032] Das äußere Erscheinungsbild des ekektrischen Mammographen ohne die Recheneinheit ist in Fig. 4 gezeigt. Fig. 5 zeigt einen durch die Erfindung erhaltenen elektrischen Mammographen. Der Mammograph stellt eine Anordnung von 7 Bildern von Brustquerschnitten dar, die parallel zur Fläche liegen, auf der die Elektroden angeordnet sind. Die Tiefe der Querschnitte nimmt von links nach rechts und von oben nach unten in 8mm-Schritten zu. Auf dem Bild sind die Brustwarze **19**, die Rippen **20** und die Grenze **21** zwischen Bereichen mit und ohne ausreichenden Elektrodenkontakt mit dem Körper deutlich zu sehen.

Patentansprüche

1. Verfahren zum Anzeigen eines dreidimensionalen Bildes der Verteilung der spezifischen elektrischen Leitfähigkeit von biologischem Gewebe, wobei das Verfahren die folgenden Schritte aufweist:
Anlegen einer Wechselstrom (AC)-Quelle (**4**) an eine erste aktivierte Elektrode (**1**) eines in einer ebenen Gruppe angeordneten kompakten Elektrodensatzes, wobei der kompakte Elektrodensatz in Kontakt mit der Oberfläche des betreffenden biologischen Gewebes ist, und an eine erste, entfernt positionierte Elektrode (**5**, **7**), welche in Kontakt mit dem Körper, jedoch in einigem Abstand vom kompakten Elektrodensatz positioniert ist;
Messen der Potentialdifferenz zwischen einer ersten Ruheelektrode (**1**) des kompakten Elektrodensatzes und einer zweiten, entfernt positionierten Elektrode (**7**, **5**), wobei die zweite, entfernt positionierte Elektrode in Ruhestellung ist;
Schalten der Wechselstromquelle (**4**) mit Hilfe von Multiplexvorrichtungen (**2**, **3**) zur sukzessiven Aktivierung aller Elektroden (**1**) der ebenen Elektrodengruppe mit Ausnahme der Ruheelektrode von Schritt (b), und Messen wiederum der Potentialdifferenz zwischen den Ruheelektroden in (b) für jede aktivierte Elektrode, um auf diese Weise einen ersten Satz von Potentialdifferenzmessungen für jede aktivierte Elektrode zu erhalten;
Schalten der in dieser ebenen Gruppe zu messenden Elektrode (**1**) mit Hilfe der Multiplexvorrichtungen (**2**, **3**) zu einer zweiten Ruheelektrode (**1**), sukzessives Aktivieren jeder anderen Elektrode in dieser ebenen Gruppe, und Messen wiederum der Potentialdifferenz zwischen der zweiten Ruheelektrode und der entfernt positionierten Ruheelektrode (**7**, **5**), um auf diese Weise einen zweiten Satz von Potentialdifferenzmessungen für jede aktivierte Elektrode zu erhalten;
Fortführen des Schaltens der Ruheelektrode (**1**), des sukzessiven Aktivierens der verbleibenden Elektroden in der ebenen Gruppe, und des Messens wiederum der Potentialdifferenz zwischen der ausgewählten Ruheelek-

trode und der entfernt positionierten Ruheelektrode (**7**, **5**), bis alle planaren Elektrodenkombinationen gemessen worden sind;
Rekonstruieren einer dreidimensionalen Verteilung der spezifischen elektrischen Leitfähigkeit unter Verwendung des Rückwärtsprojektionsverfahrens entlang Äquipotentialflächen des elektrischen Feldes, wobei die projizierten Daten durch gewichtete Durchschnittsbildung der relativen Differenz zwischen der elektrischen Referenzintensität, welche Gewebe mit einer homogenen Verteilung der spezifischen elektrischen Leitfähigkeit entspricht, und der gemessenen elektrischen Intensität entlang der Schnittlinie der Äquipotentialfläche, welche den Punkt aufweist, an dem die spezifische elektrische Leitfähigkeit rekonstruiert wird, und mit der Oberfläche, auf der der kompakte Elektrodensatz (**1**) positioniert ist, erhalten wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, dass eine Schwellenwert-Erfassungsvorrichtung (**8**) bestimmt, ob irgendeine spezifische Elektrode (**1**) der ebenen Gruppe in ausreichendem Kontakt mit dem Gewebe ist, um eine aussagekräftige Messung zu erzielen.

3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, dass die Werte der Potentialdifferenzen für diejenigen Elektroden (**1**), welche einen unzureichenden Kontakt mit dem Gewebe aufweisen, vielmehr basierend auf der Annahme einer homogenen Verteilung der spezifischen elektrischen Leitfähigkeit berechnet werden, und nicht indem die tatsächlichen gemessenen Potentialdifferenzen herangezogen werden.

4. Verfahren nach Anspruch 1, dadurch gekennzeichnet, dass der Gewichtungskoeffizient von $1/R^4$ in der gewichteten Durchschnittsbildung von Schritt (f) verwendet wird, wobei R die Entfernung zwischen dem Punkt, an dem die spezifische elektrische Leitfähigkeit rekonstruiert wird, und dem augenblicklichen Punkt auf der Linie, entlang welcher die Durchschnittsbildung ausgeführt wird, ist.

5. Verfahren nach Anspruch 1, dadurch gekennzeichnet, dass der kompakte Elektrodensatz (**1**) auf einer starren dielektrischen Ebene angeordnet ist, und der leitende Abschnitt einer jeden Elektrode über die Ebene hinausragt.

6. Vorrichtung zur Erzeugung eines dreidimensionalen Bildes der Verteilung der spezifischen elektrischen Leitfähigkeit von biologischem Gewebe, welche Folgendes aufweist:
eine Vielzahl von individuellen Elektroden (**1**), die in einer starren ebenen Gruppe angeordnet sind und in Kontakt mit dem betreffenden biologischen Gewebe angeordnet sind;
eine Wechselstrom (AC)-Quelle (**4**), die an eine der Elektroden (aktive Elektrode) (**1**) in dieser ebenen Gruppe und an eine einzelne, in einigem Abstand von der ebenen Gruppe positionierte entfernt angeordnete und mit dem biologischen Gewebe in Kontakt stehende aktive Elektrode (**5**, **7**) angeschlossen ist;
eine Ausgabe-Multiplexvorrichtung (**2**) zum sukzessiven Schalten der Wechselstromquelle zu anderen Elektroden (**1**) in der ebenen Gruppe, wodurch diese wiederum zu aktiven Elektroden werden;
eine Eingabe-Multiplexvorrichtung (**3**) zum Verbinden einer Potentialdifferenz-Messvorrichtung (**6**) mit einer der nicht aktiven Elektroden (Ruheelektroden) (**1**) in der ebenen Gruppe und mit einer einzelnen, entfernt positionierten Ruheelektrode (**7**, **5**), die in einigem Abstand von der ebenen Gruppe und in Kontakt mit dem biologischen Gewebe angeordnet ist;
an die Eingabe- und Ausgabe-Multiplexvorrichtungen (**2**, **3**) angeschlossene Berechnungsvorrichtungen zum sequentiellen Anlegen der Wechselstromquelle an die Elektroden (**1**) der ebenen Gruppe, während Potentialdifferenzmessungen von anderen Elektroden in der ebenen Gruppe durchgeführt werden, und zum Rekonstruieren einer dreidimensionalen Verteilung der spezifischen elektrischen Leitfähigkeit, indem ein modifiziertes Rückwärtsprojektionsverfahren eingesetzt wird; und
eine Anzeigevorrichtung zum Abbilden der rekonstruierten dreidimensionalen Verteilung der spezifischen elektrischen Leitfähigkeit.

7. Vorrichtung nach Anspruch 6, dadurch gekennzeichnet, dass eine Schwellenwert-Erfassungsvorrichtung (**8**) vorgesehen ist, um zu bestimmen, ob eine spezifische Elektrode (**1**) der ebenen Gruppe in ausreichendem Kontakt mit dem Gewebe ist, um eine aussagekräftige Messung zu erzielen.

8. Vorrichtung nach Anspruch 7, dadurch gekennzeichnet, dass bei der Rekonstruktion der Verteilung der spezifischen elektrischen Leitfähigkeit die Werte der Potentialdifferenzen für diejenigen Elektroden (**1**), welche nicht in ausreichendem Kontakt mit dem Gewebe sind, vielmehr basierend auf der Annahme einer homogenen Verteilung der spezifischen elektrischen Leitfähigkeit berechnet werden, und nicht dadurch, dass die tatsächlichen gemessenen Potentialdifferenzen herangezogen werden.

9. Vorrichtung nach Anspruch 6, dadurch gekennzeichnet, dass das verwendete modifizierte Rückwärt-

sprojektions-Rekonstruktionsverfahren einen Gewichtungskoeffizienten von $1/R^4$ einschließt, wobei R die Entfernung zwischen dem Punkt, an dem die spezifische elektrische Leitfähigkeit rekonstruiert wird, und dem augenblicklichen Punkt auf der Linie, entlang welcher die Durchschnittsbildung durchgeführt wird, ist.

10. Vorrichtung nach Anspruch 6, dadurch gekennzeichnet, dass die ebene Gruppe von Elektroden (**1**) auf einer starren dielektrischen Ebene angeordnet ist, und der leitende Abschnitt einer jeden Elektrode über diese Ebene hinausragt.

Es folgen 5 Blatt Zeichnungen

Anhängende Zeichnungen

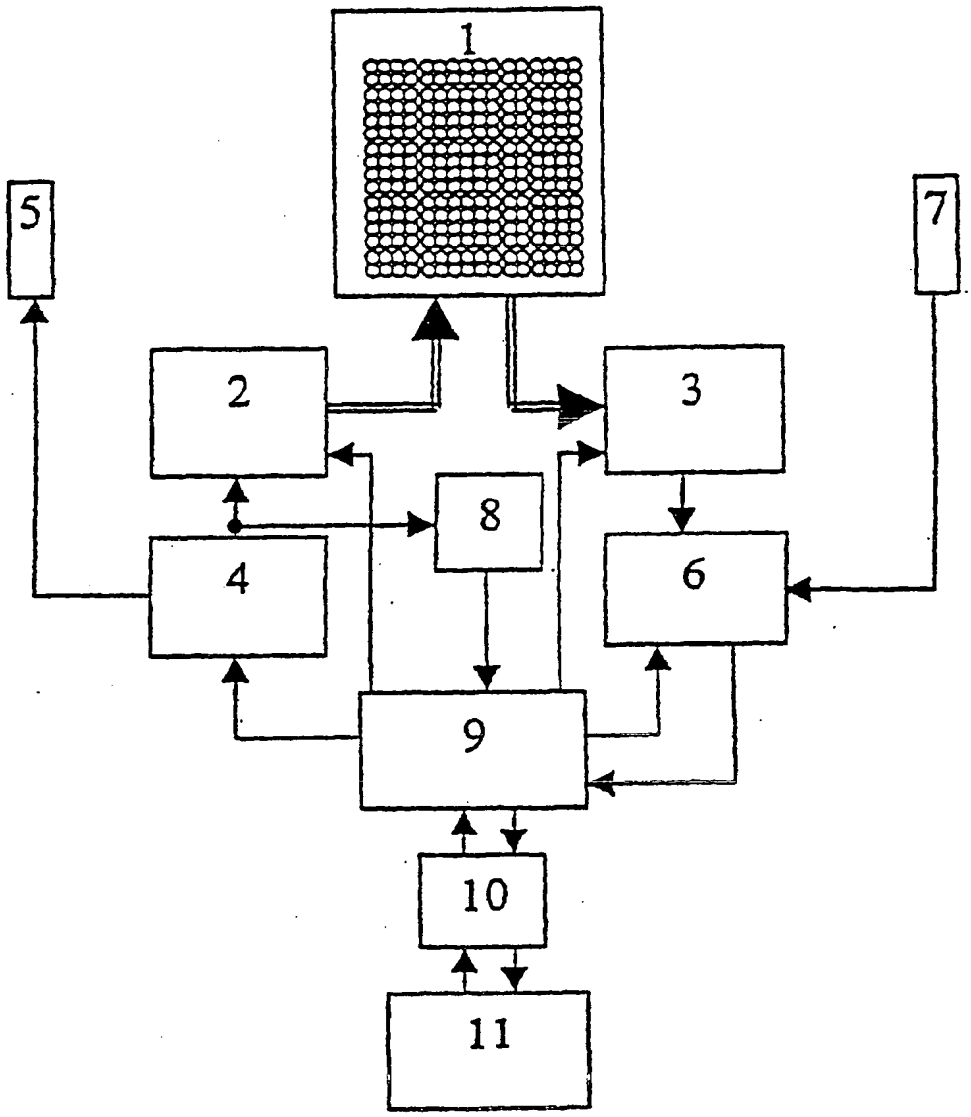


FIG. 1

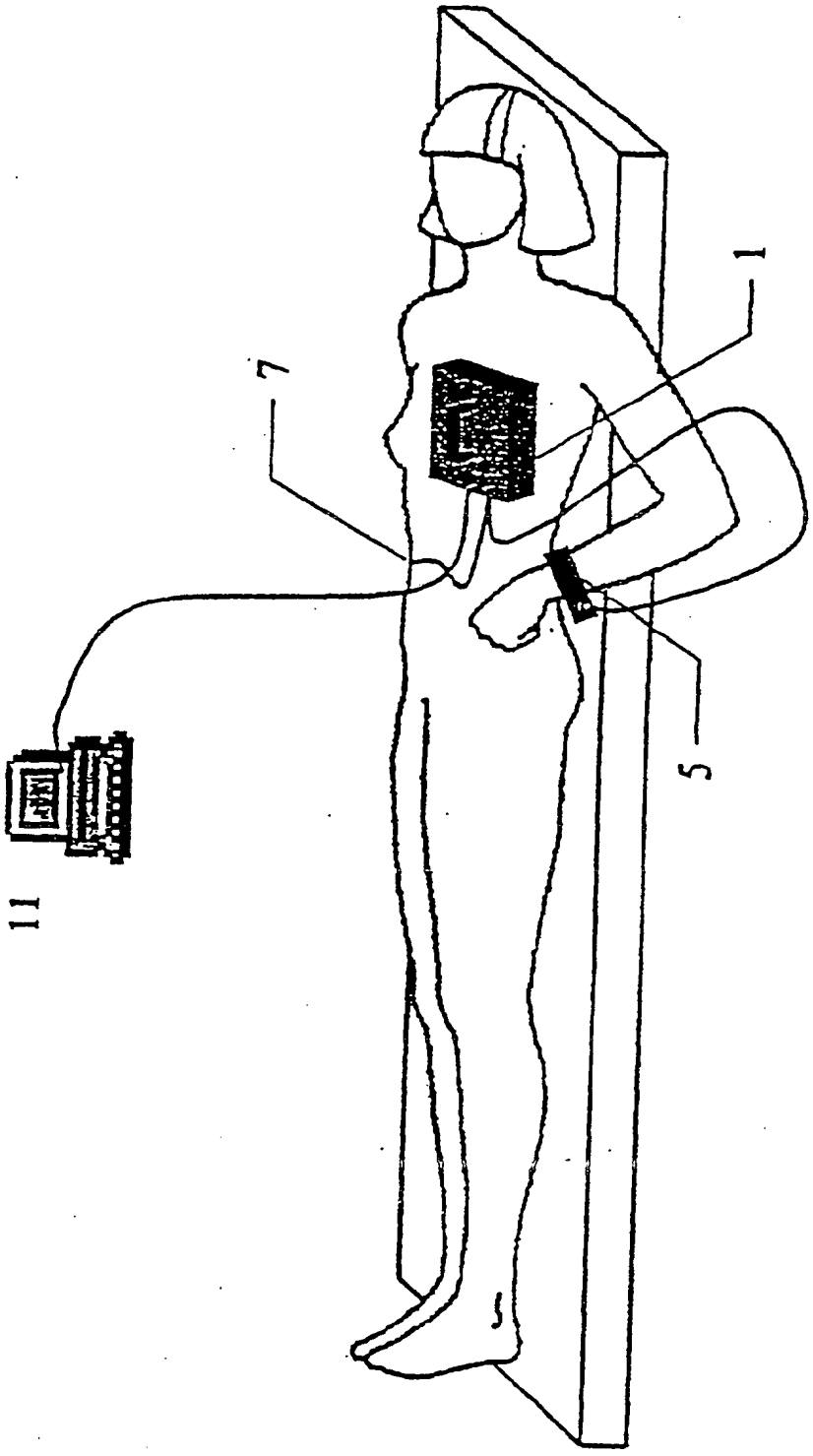


FIG. 2

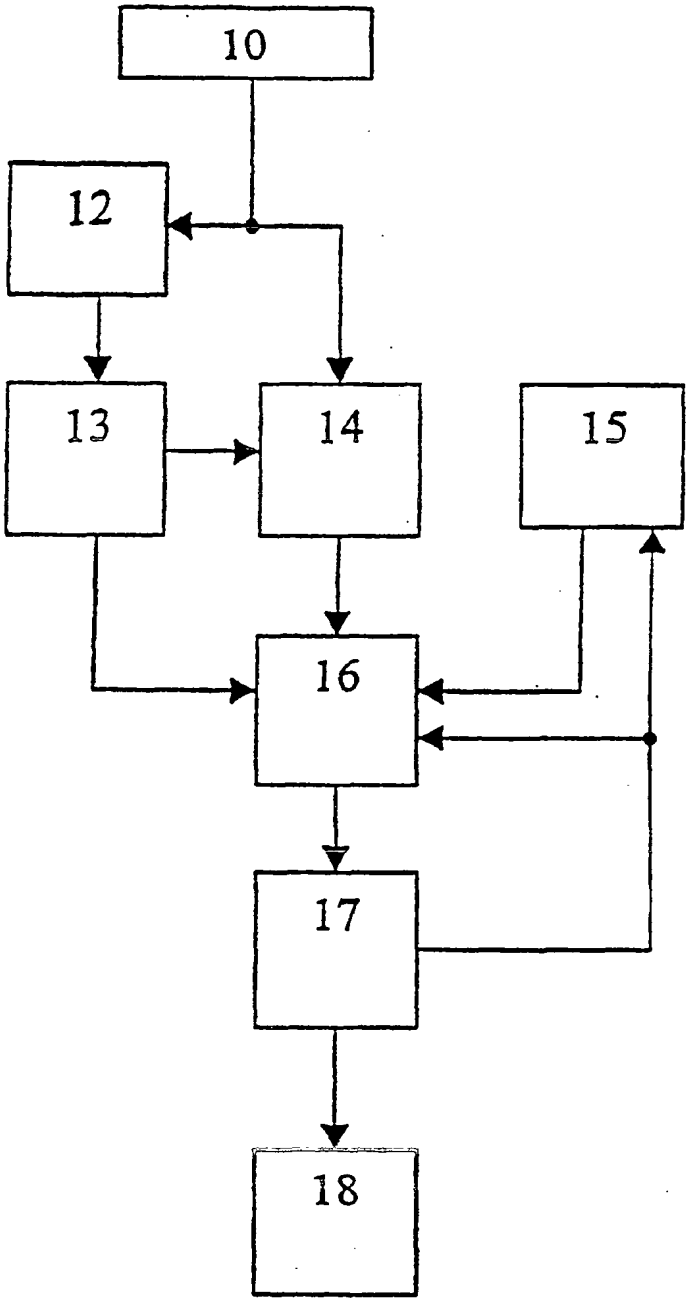


FIG. 3

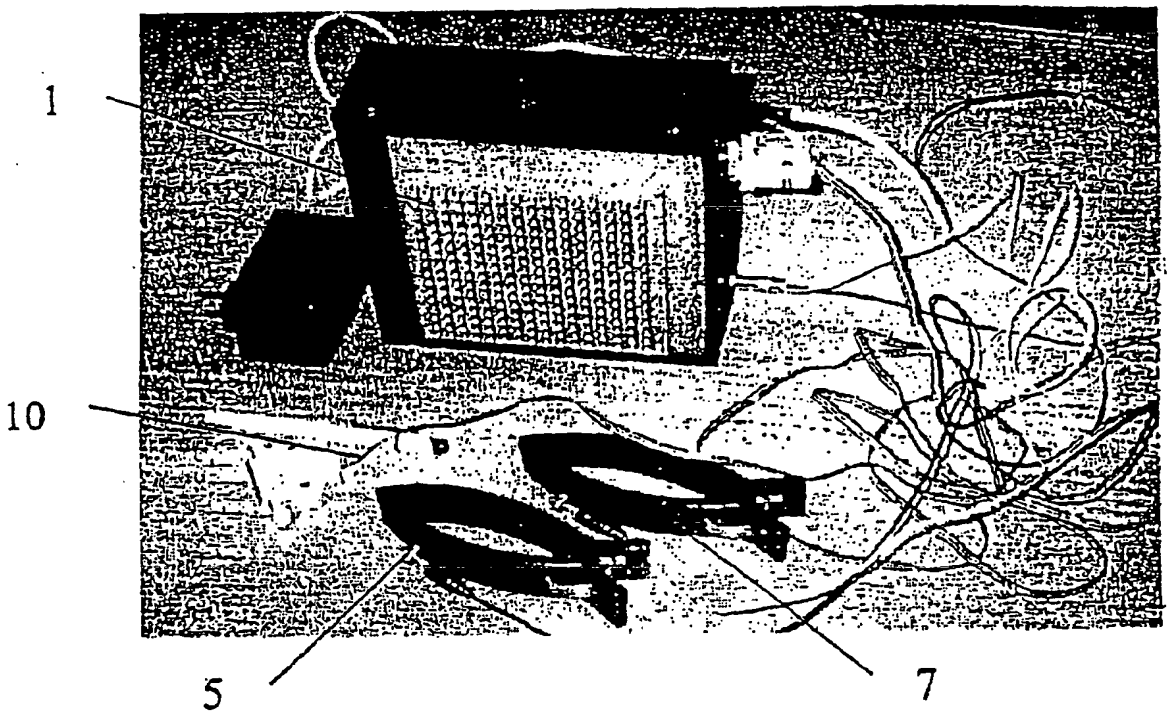


FIG. 4

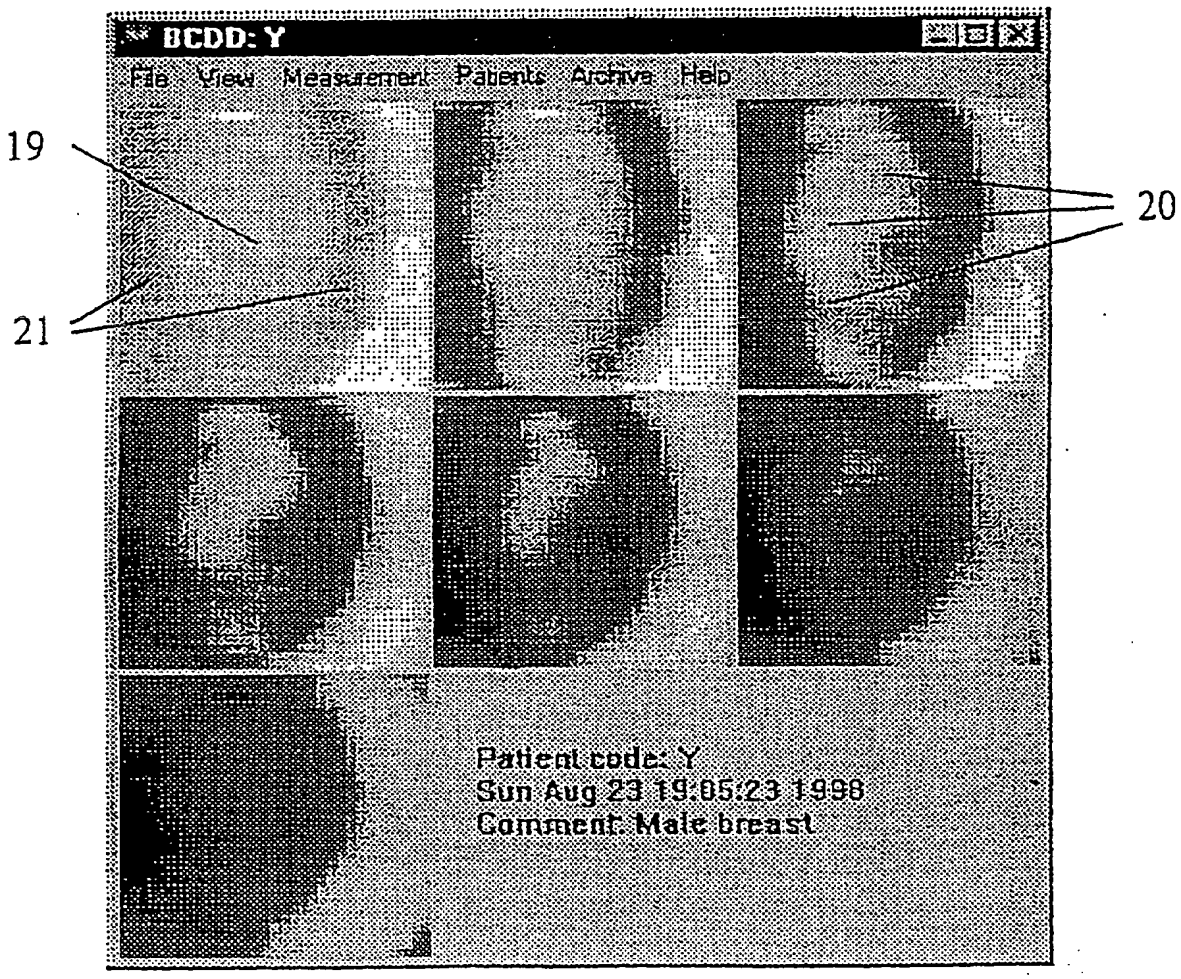

BCDD: Y
File View Measurement Patients Archive Help
19
20
21
Patient code: Y
Sun Aug 23 19:05:23 1998
Comment: Male breast

FIG. 5

PATENT ABSTRACTS OF JAPAN

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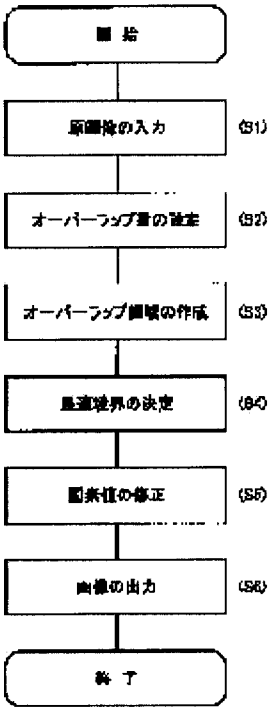
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(71)Applicant : DAINIPPON PRINTING CO LTD
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(54) METHOD AND SYSTEM FOR IMAGE CORRECTION

(57)Abstract:
PROBLEM TO BE SOLVED: To provide a method and a system for image correction with high processing efficiency and superior reproducibility which can generate an image with an inconspicuous seam when images are joined and eliminate the need for operator's skillfulness and manual operation.
SOLUTION: A source image as an object of endless processing is inputted (S1). After an overlap quantity is set (S2), an overlap area is generated nearby an end of the source image (S3) and in this overlap area, an optimum border as a minimum error border is determined according to pixel values at the end of the source image and other ends (S4). According to the optimum border, the pixel values are corrected (S5) to output a corrected image after the endless processing (S6).



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Ｈ04Ｎ	1/387		Ｈ04Ｎ	1/387		

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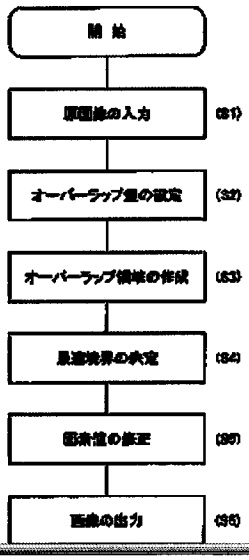
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ＣＥ10 ＣＥ11 ＣＥ17 ＣＦ03 ＣＨ08
ＤＡ07 ＤＡ08 ＤＡ16 ＤＢ02 ＤＢ06
ＤＢ09 ＤＣ23 ＤＣ25 ＤＣ32
5Ｃ076 ＡＡ12 ＡＡ31 ＢＡ06 ＣＡ01

(54)【発明の名称】　画像修正方法およびシステム

(57)【要約】
【課題】　画像を繋ぎ合わせた際に、その繋ぎ目が目立たない画像を作成することが可能であると共に、作業者の熟練、手作業が不要で処理効率が高く、かつ再現性に優れた画像修正方法およびシステムを提供する。
【解決手段】　エンドレス処理の対象とする原画像を入力する（Ｓ１）。オーバーラップ量を設定した後（Ｓ２）、原画像の端部付近にオーバーラップ領域を作成し（Ｓ３）、このオーバーラップ領域において、原画像の端部と他の端部の画素値に基づいて最小誤差境界となる最適境界を決定する（Ｓ４）。この最適境界に基づいて画素値を修正（Ｓ５）することによりエンドレス処理された修正画像を出力する（Ｓ６）。



JP,2003-317089,A　◉ STANDARD ○ ZOOM-UP ROTATION No Rotation ☐ REVERSAL NEXT PAGE
PREVIOUS PAGE　NEXT PAGE　DETAIL

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1

【特許請求の範囲】
【請求項１】同一の画像の端部と対向する端部を繋ぎ合わせた際に、その繋ぎ目が目立たないように画像を修正する方法であって、
修正対象となる原画像を入力する画像入力段階と、
原画像の繋ぎ目部分におけるオーバーラップ量を設定する段階と、
前記設定されたオーバーラップ量に基づいてオーバーラップ領域を作成する段階と、
前記入力された原画像の端部と対向する端部の境界を、前記オーバーラップ領域における前記端部の画素値と前記対向する端部の画素値の差が最小となる画素の累積に基づいて決定する段階と、
前記決定された境界に基づいて、前記原画像の端部および対向する端部の画素値を修正することにより修正画像を作成する段階と、
を有することを特徴とする画像修正方法。
【請求項２】修正対象となる原画像を入力する原画像入力手段と、
原画像の繋ぎ目部分におけるオーバーラップ量を設定するオーバーラップ量設定手段と、
前記設定されたオーバーラップ量に基づいてオーバーラップ領域を作成するオーバーラップ領域作成手段と、
前記入力された原画像の端部と対向する端部の境界を、前記オーバーラップ領域における前記端部の画素値と前記対向する端部の画素値の差が最小となる画素の累積に基づいて決定する最適境界決定手段と、
前記決定された境界に基づいて、前記原画像の端部および対向する端部の画素値を修正することにより修正画像を作成する画素値修正手段と、
得られた修正画像を出力する画像出力手段と、
を有することを特徴とする画像修正システム。
【請求項３】コンピュータに、
修正対象となる原画像を入力する画像入力段階と、
原画像の繋ぎ目部分におけるオーバーラップ量を設定する段階と、
前記設定されたオーバーラップ量に基づいてオーバーラップ領域を作成する段階と、
前記入力された原画像の端部と対向する端部の境界を、前記オーバーラップ領域における前記端部の画素値と前記対向する端部の画素値の差が最小となる画素の累積に基づいて決定する段階と、
前記決定された境界に基づいて、前記原画像の端部および対向する端部の画素値を修正することにより修正画像を作成する段階と、
を実行させるためのプログラム。
【発明の詳細な説明】

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印刷物に利用される画像の作成に関し、特に繋ぎ目が目立たないようにシームレスなエンドレス画像を作成するための技術に関する。
【０００２】
【従来の技術】建材印刷物は、出版印刷物、商業用印刷物等の汎用印刷物に比べて、長さが非常に長い（長尺）。例えば、壁面に加飾する印刷物を考えると、建物の床から天井までの長さは、通常２．５m程度はあり、また部屋の端から端までの水平方向長さも、６畳間の場合で、長辺が３．５m程度はある。したがって、建材印刷物用の画像も、最低限その程度の長さは繋ぎ目なく連続し、一続きとなったエンドレスな画像、すなわちエンドレス画像が必要となる。
【０００３】上記のような長尺の画像を印刷用版胴の１円周以内に収めることは不可能である。そのため、１円周分の画像の印刷方向の始端部の辺と終端部の辺とを版胴上で接続して（繋いで）製版する。そして、印刷時に版胴が１回転するごとに１円周分の画像が途切れることなく繰返し印刷されることによって、任意の長さの長尺印刷物を得ている。
【０００４】ただし、単に１円周分の画像の印刷方向の始端部の辺と終端部の辺とを突合わせて接続したのみでは、接続部（繋ぎ目）で画像が不連続となり、エンドレス画像は得られない。版胴画像のエンドレス化のためには、画像の繋ぎ目において、繋ぎ目を境界として両側画像の不連続部分を連続化して、繋ぎ目を目視で認識不能とする作業、すなわち、シームレス化が必要となる。
【０００５】そこで、特に木目模様の場合は有効な、画像繋ぎ目のシームレス化による版胴画像のエンドレス化の手法として、特公昭４３－２０６５号公報等記載のごとく、円周上の繋ぎ目を波形、あるいはジグザグの折れ線として、繋ぎ目自体を目立ち難い形状とし、かつ繋ぎ目近傍領域を熱線工が手作業で加筆、脱色、染色、削除等を行うことにより、画像の不連続を修正してシームレス化することが広く行われてきた（従来技術①）。
【０００６】又近年は、電子計算機を応用したデジタル画像処理技術の進歩によって、原稿画像をスキャナーで読込んでデジタルデータ化し、ＣＲＴ等の表示装置上でマウス、タブレット、カーソル等により修正箇所を指定し、画面内の他の部分等から適当な画像をコピーして移植する等の手法により、より作業性を向上させることが試みられている（従来技術②）。さらに、繋ぎ目のシームレス化の作業を両側画像の平均化演算処理によって、自動的に所定の式で計算することによって効率化する方法も提案されている（従来技術③）。
【０００７】
【発明が解決しようとする課題】しかしながら、上記従

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く同一のシームレス処理の版を再現することも困難である。

【０００８】上記従来技術②においては、シームレス化の作業にデジタル化、機械化した処理を採用することにより、上記従来技術①に比べれば、画像の繋ぎ目等の工程については、作業の効率化は図れた。しかし、特にシームレス化の作業自体は、依然として熟練工の勘と手作業に依存する点においては、ほとんど改善にはなっていない。

【０００９】上記従来技術③では、シームレス化の作業をもデジタル処理により自動化することによって効率化は図られた。しかし、シームレス化が、単に両側の画像を繋ぎ目において加算（平均化）しているため、繋ぎ目近傍において、空間周波数の高周波成分が欠落し、画像の微細構造ないしは先鋭度が低下する。そのため、遠くから見ると依然として繋ぎ目が認識されてしまうという問題点が残ることになる。

【００１０】上記のような点に鑑み、本発明は、その精度が高く繋ぎ目が目立たない画像を作成することが可能であると共に、作業者の熟練、手作業が不要で処理効率が高く、かつ再現性に優れた画像修正方法およびシステムを提供することを課題とする。

【００１１】

【課題を解決するための手段】上記課題を解決するため、本発明では、同一の画像の端部と対向する端部を繋ぎ合わせた際に、その繋ぎ目が目立たないように画像を修正する方法として、修正対象となる原画像を入力する画像入力段階、原画像の繋ぎ目部分におけるオーバーラップ量を設定する段階、前記設定されたオーバーラップ量に基づいてオーバーラップ領域を作成する段階、前記入力された原画像の端部と対向する端部の境界を、前記オーバーラップ領域における前記端部の画素値と前記対向する端部の画素値の差が最小となる画素の累積に基づいて決定する段階、前記決定された境界に基づいて、前記原画像の端部および対向する端部の画素値を修正することにより修正画像を作成する段階を実行するようにしたことを特徴とする。

【００１２】本発明によれば、原画像の繋ぎ目部分におけるオーバーラップ量に基づいて作成されるオーバーラップ領域において、原画像の端部と対向する端部の境界をその画素値の差が最小となる画素の累積に基づいて決定するようにしたので、画像を複数配列した際にも、繋ぎ目が目立たない画像を作成することが可能となる。

【００１３】

【発明の実施の形態】以下、図面を参照して本発明の一実施形態について詳細に説明する。

（1.システム構成）まず、本発明に係る画像修正システ

量設定手段、３は演算制御装置、３ａはオーバーラップ領域作成手段、３ｂは最適境界決定手段、３ｃは画素値修正手段、４は画像出力手段である。

【００１４】原画像入力手段１は、シームレス処理、エンドレス処理の対象となる原画像を入力するためのものであり、デジタルデータの読取装置で原画像データを読取らせることにより実現される。また、原画像が紙媒体等に絵画されている場合は、スキャナ、デジタルカメラ等を利用してデジタル化した後入力する。オーバーラップ量設定手段２は、原画像の端部と対向する端部をどの程度オーバーラップ、すなわち重複させるかを設定するためのものであり、マウス、キーボード等の入力機器で実現される。

【００１５】演算制御装置３は、本発明の中心的な役割を有するものであり、入力された原画像、設定されたオーバーラップ量に基づいて、原画像の両端部を修正することによりエンドレス化された修正画像を作成する機能を有している。実際には、コンピュータのＣＰＵ、メモリで構成され、メモリに専用のプログラムを読込み、ＣＰＵが順次実行することにより実現される。演算制御装置３は、さらにオーバーラップ領域作成手段３ａ、最適境界決定手段３ｂ、画素値修正手段３ｃを有している。オーバーラップ領域作成手段３ａは、入力された原画像のサイズおよび設定されたオーバーラップ量に基づいて、オーバーラップ領域のサイズを計算し、算出された大きさのメモリ空間を確保する機能を有している。最適境界決定手段３ｂは、オーバーラップ領域内の原画像の端部の画素値と対向する他の端部の画素値に基づいて原画像の端部と対向する他の端部の最適な境界を決定する機能を有している。画素値修正手段３ｃは、決定された最適境界に基づいて原画像上の画素値を変更する機能を有している。オーバーラップ領域作成手段３ａ、最適境界決定手段３ｂ、画素値修正手段３ｃはそれぞれ専用のプログラムをＣＰＵで実行することにより実現される。画像出力手段４は、作成された修正画像を出力する機能を有しており、画像を表示するためのディスプレイ装置、印刷するためのプリンター、データとして出力するためのハードディスク等の外部記憶装置、携帯可能な電子記録媒体への記録装置、さらにネットワークを介して遠隔地へ送信するための通信装置等が適用可能である。

【００１６】（2.処理の流れ）次に、本発明に係る画像修正方法について、図１に示した画像修正システムの処理動作と共に説明する。図２は本発明に係る画像修正方法の概要を示すフローチャートである。まず、原画像入力手段１より、エンドレス処理を行う対象となる原画像を入力する（ステップＳ１）。次に、オーバーラップ量設定手段２を用いて、オーバーラップ量の設定を行う

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域が決定される。オーバーラップ領域とは、原画像の端部と対向する端部の境界付近において、最適な境界を決定するための領域である。この最適境界決定処理を行わないと、原画像を複数並べた際に、互いの境界部で段差が目立つことになる。本実施形態では、オーバーラップ量の設定は、１方向で原画像の端部と対向する端部が互いに重なり合う画素数で設定される。

【００１７】続いて、入力された原画像のサイズ、および設定されたオーバーラップ量に基づいてオーバーラップ領域の作成を行う（ステップＳ３）。具体的には、オーバーラップ領域作成手段３ａが、コンピュータの主記憶装置内にオーバーラップ領域として必要なメモリ空間の確保を行う。例えば、原画像G_{org}のサイズ（画素数）が横ｘｐ×縦ｙｐであったとする。このとき、図３（ｂ）に示すように原画像G_{org}をｘ軸方向（図中左右方向）に複数並べた際に、隣接する原画像G_{org}と接する辺の長さ（画素数）はｙｐであるので、オーバーラップ量がαであるとすると、ｙｐ×αの大きさのオーバーラップ領域Ｏが作成される。本発明で処理する原画像G_{org}は１つだけであり、図３（ｂ）に示したように複数並べた場合の左右の画像は同じ原画像G_{org}であるが、ここでは説明の便宜上、一方を原画像G_L、他方を原画像G_Rとする。図３（ｂ）に示すように原画像G_Lと原画像G_Rにまたがってｙｐ×αの大きさのオーバーラップ領域が作成されることになる。

【００１８】オーバーラップ領域が作成されたら、次に、このオーバーラップ領域における原画像G_Lと原画像G_Rの最適な境界を決定する（ステップＳ４）。具体的には、オーバーラップ領域において、原画像G_Lと原画像G_Rの画素値の差の累計が最小となる最小誤差境界を求め、元の原画像の左辺、原画像の右辺の代わりに、求めた最小誤差境界を原画像G_Lと原画像G_Rの境界とする処理を行う。求められた最小誤差境界が最適境界となる。

【００１９】このような最小誤差境界の決定の手法としては、種々のものが提案されているため、FloydやDijkstraのアルゴリズム等の周知のものを適用すれば良いが、本実施形態における手法を具体的に説明する。図４にオーバーラップ量$\alpha=6$とした場合の原画像G_Lと原画像G_Rのオーバーラップ領域Ｏ付近を示す。図４の例では、$\alpha=6$であるため、オーバーラップ領域にはｘ軸方向（図の左右方向）に６画素分用意されることになる。このようなオーバーラップ領域の場合、まず、第１行目の６個の画素について、原画像G_Lの画素値と原画像G_Rの画素値との比較を行う。この両者の差を最小とする位置の算出には、一般にＬ²距離として知られる値を用いる。例えば、ある画素Ｑにおいて、原画像G_Lの

【００２０】〔数式１〕

$$L^2=(Q_L-Q_R)^2$$

【００２１】オーバーラップ領域全域に渡って、この値を計算すると、この配列はちょうどそこを境界とした誤差のマップになる。したがって、この（６×ｙｐ）画素の領域で上端（第１行目）から下端（第ｙｐ行目）に至る全ての経路について、途中の各要素のＬ²を累積していき、この累積したコスト（値）が最も小さな経路を、最も好ましい境界とするのである。なお、対象としている画像がカラーの場合は、各色に対応したチャンネルのＬ²の値の総和をとるものとする。このようにして、累積したコスト（値）が最も小さな経路を決定していくことにより、最小誤差境界が得られる。

【００２２】最適境界が決定されたら、決定された最適境界に基づいて、画素値修正手段３ｃが、原画像の画素値の修正を行う（ステップＳ５）。例えば、オーバーラップ領域において、図５に示すような最小誤差境界が得られた場合を考えてみる。図５において、網掛けで示す画素が最小誤差境界である。この場合、最小誤差境界よりも左側にある画素は、原画像G_Lの画素値を採用し、最小誤差境界よりも右側にある画素は、原画像G_Rの画素値を採用する。また、本実施形態では、最小誤差境界上に存在する画素については、原画像G_Lと原画像G_Rの画素値の平均を採るものとしている。図５において、「Ｌ」で示された画素は原画像G_Lの画素値が、「Ｒ」で示された画素は原画像G_Rの画素値がそれぞれ与えられることを示している。原画像の画素値を修正することにより修正画像が得られたら、画像出力手段４より出力する（ステップＳ６）。

【００２３】ここで、最小誤差境界の求め方の概要を整理しておく。最小誤差境界の求め方の概要を図６のフローチャートに示す。最小誤差境界を求めるためには、まず、第１行目の全画素（図の例では６画素）について各画素におけるL^2値を累積コストとして記憶する（ステップＳ１１）。続いて、第２行目の各画素について、自身の左上、真上、右上の画素について、最小の累積コストを持つものを、この画素に至る最短経路として記憶すると共に、その上側の画素の累積コストに自身のL^2値を加算したものを、自身の累積コストとして記憶する（ステップＳ１２）。このステップＳ１２の処理を最終行、図４、図５の例では第ｙｐ行目まで繰り返す。最終行の全画素のうち、最小の累積コストを持つ画素とそこに至る経路を最小誤差境界とする（ステップＳ１３）。

【００２４】この結果、図３（ｂ）に示したオーバーラップ領域Ｏには、図７（ａ）に示すような最適境界Ｂが得られることになる。図７（ａ）において、最適境界Ｂの右側は原画像G_Rの画素値、最適境界Ｂの左側は原画

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区切られた画像を並べるイメージとなる。しかし、図７（ｂ）に示すように画像の形状が、最適境界で示したような曲線であるのは現実的ではない。実際には、原画像の片側（例えば右側）のオーバーラップ領域を削除し、その領域の最適境界より右側の画素値を、対応する左側のオーバーラップ領域にコピーする。具体的には、図７（ｃ）に示すように、原画像G_{org}のP_Rで示した領域の画素に、P_R'で示した領域の画素がコピーされ、原画像G_{org}のP_Rで示した領域およびP_R'で示した領域が削除されることになる。すなわち、上記説明においては、説明の便宜上、図３（ｂ）に示したように２つの画像を並べた状態で説明したが、実際には、１つの原画像の両端部（図３（ａ）および図７（ｃ）の例では左右の両端部）の画素値に対して修正と削除が行われる。このようにして得られた修正画像をｘ軸方向に複数並べていくことにより、繋ぎ目が目立たなくなる。

【００２５】上記の例では、原画像をｘ軸方向に複数配列する場合にエンドレス画像となるように画像の修正を行ったが、ｙ軸方向に複数配列する場合であってもｘ軸とｙ軸が入れ替わるだけであり、本質的には同様の処理が行われる。また、ｘ軸方向、ｙ軸方向の双方に画像を配列する場合には、ｘ軸方向、ｙ軸方向の双方に上記画像修正処理を行うことにより、縦横の２次元に画像を配列した場合でも全ての繋ぎ目が目立たないような修正画像を得ることが可能となる。

【００２６】また、上記の例では、同一の画像を複数並べる場合について説明したが、接続する辺の長さ（画素数）が等しい複数の画像を順に繋ぎ目を目立たないように接続し、左端の画像の左端部と右端の画像の右端部を同様にオーバーラップ領域で最適境界で接続することで、シームレスな画像を作成することもできる。例えば、図３（ｂ）、図７（ａ）の原画像G_R、原画像G_Lとして別の画像を利用して修正処理を行うことになる。

【００２７】

【発明の効果】以上、説明したように本発明によれば、

エンドレス画像となるように修正すべき原画像を入力し、隣接する原画像とのオーバーラップ量を設定し、設定されたオーバーラップ量に基づいてオーバーラップ領域を作成し、入力された原画像の端部と対向する端部の境界を、オーバーラップ領域における前記端部の画素値と対向する端部の画素値の差が最小となる画素の累積に基づいて決定し、決定された境界に基づいて、原画像の端部の画素値を修正することによりエンドレス画像を作成するようにしたので、複数配列した際にも、繋ぎ目が目立たない画像を作成することが可能となるという効果を奏する。

【図面の簡単な説明】

【図１】本発明に係る画像修正システムの構成図である。

【図２】本発明に係る画像修正方法のフローチャートである。

【図３】原画像G_{org}、および原画像G_{OR}を複数並べる場合のオーバーラップ領域Ｏの関係を示す図である。

【図４】オーバーラップ領域Ｏ付近を示す図である。

【図５】最適境界決定後のオーバーラップ領域Ｏ付近を示す図である。

【図６】最小誤差境界の求め方の概要を示すフローチャートである。

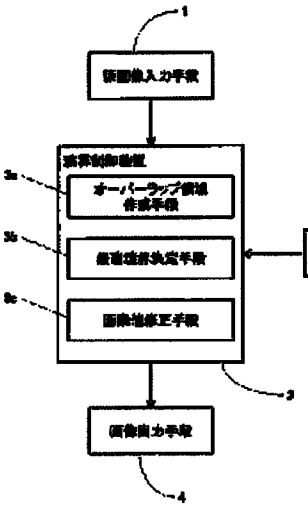
【図７】最適境界決定により得られる修正画像の状態を示す図である。

【符号の説明】

１・・・原画像入力手段
２・・・オーバーラップ量設定手段
３・・・演算制御装置
３ａ・・・オーバーラップ領域作成手段
３ｂ・・・最適境界決定手段
３ｃ・・・画素値修正手段
４・・・画像出力手段

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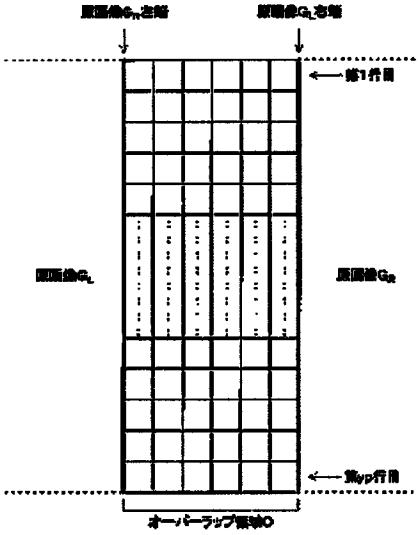
【図１】



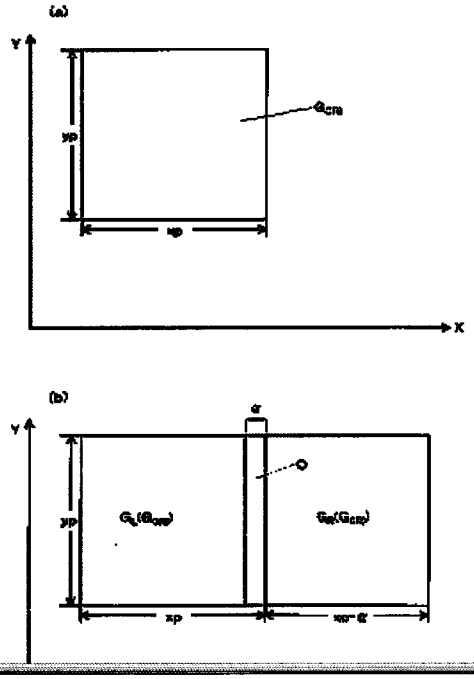
【図２】



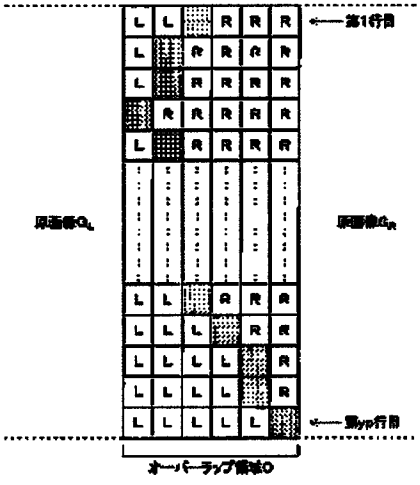
【図４】



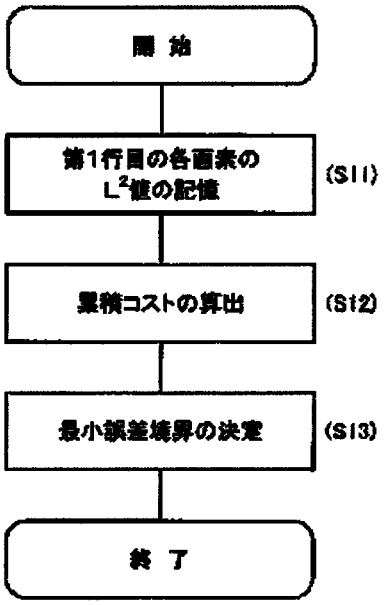
【図３】



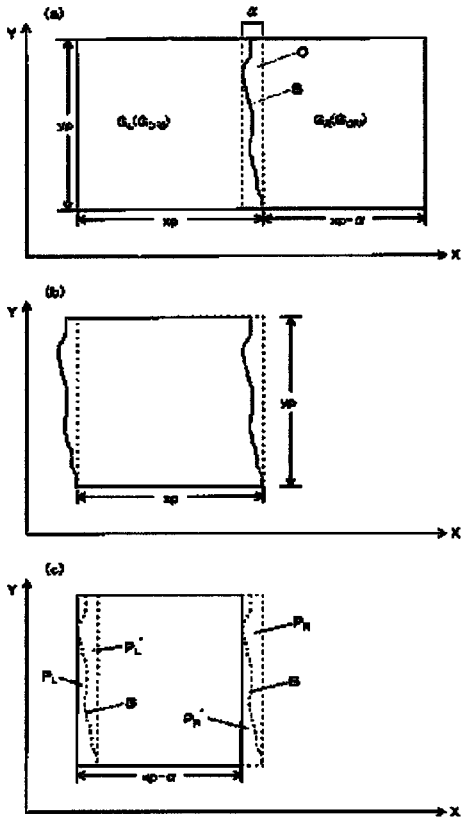
【図５】



【図６】


開 始
第1行目の各画素の
L^2値の記憶
(S11)
累積コストの算出
(S12)
最小誤差境界の決定
(S13)
終 了

【図７】


(a)
(b)
(c)
Y
X
O
B

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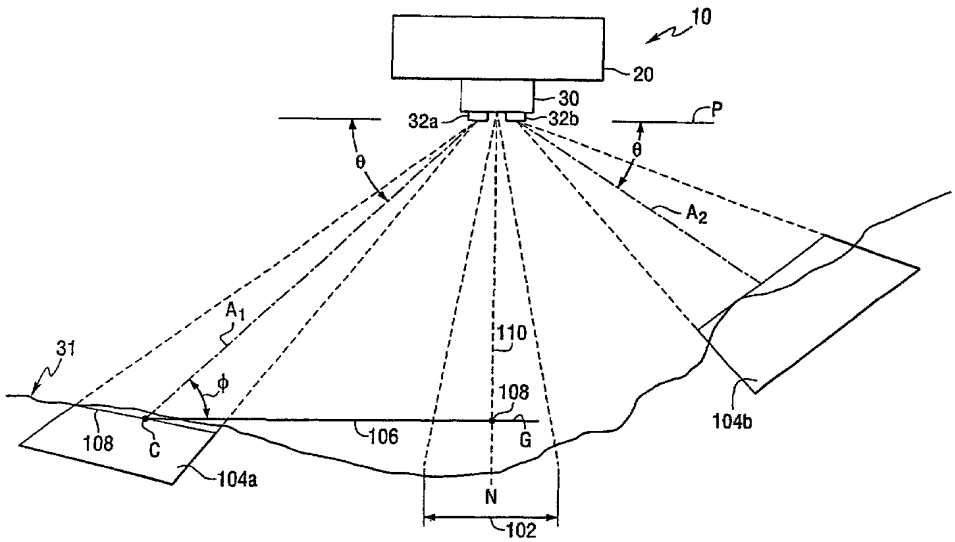
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(54) Title: OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM



(57) Abstract: A computerized system for displaying, geolocating, and taking measurements from captured oblique images includes a data file accessible by the computer system. The data file includes a plurality of image files corresponding to a plurality of captured oblique images, and positional data corresponding to the images. Image display and analysis software is executed by the system for reading the data file and displaying at least a portion of the captured oblique images. The software retrieves the positional data for one or more user-selected points on the displayed image, and calculates a separation distance between any two or more selected points. The separation distance calculation is user-selectable to determine various parameters including linear distance between, area encompassed within, relative elevation of, and height difference between selected points.

WO 2004/044692 A2

OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/425,275, filed November 8, 2002.

TECHNICAL FIELD

The present invention relates to photogrammetry. More particularly, the present invention relates to a method and apparatus for capturing oblique images and for measuring the objects and distances between the objects depicted therein.

BACKGROUND

Photogrammetry is the science of making measurements of and between objects depicted within photographs, especially aerial photographs. Generally, photogrammetry involves taking images of terrestrial features and deriving data therefrom, such as, for example, data indicating relative distances between and sizes of objects within the images. Photogrammetry may also involve coupling the photographs with other data, such as data representative of latitude and longitude. In effect, the image is overlaid and conformed to a particular spatial coordinate system.

Conventional photogrammetry involves the capture and/or acquisition of orthogonal images. The image-capturing device, such as a camera or sensor, is

orthogonal images. The image-capturing device, such as a camera or sensor, is carried by a vehicle or platform, such as an airplane or satellite, and is aimed at a nadir point that is directly below and/or vertically downward from that platform. The point or pixel in the image that corresponds to the nadir point is the only point/pixel that is truly orthogonal to the image-capturing device. All other points or pixels in the image are actually oblique relative to the image-capturing device. As the points or pixels become increasingly distant from the nadir point they become increasingly oblique relative to the image-capturing device and the ground sample distance (i.e., the surface area corresponding to or covered by each pixel) also increases. Such obliqueness in an orthogonal image causes features in the image to be distorted, especially images relatively distant from the nadir point.

Such distortion is removed, or compensated for, by the process of ortho-rectification which, in essence, removes the obliqueness from the orthogonal image by fitting or warping each pixel of an orthogonal image onto an orthometric grid or coordinate system. The process of ortho-rectification creates an image wherein all pixels have the same ground sample distance and are oriented to the north. Thus, any point on an ortho-rectified image can be located using an X, Y coordinate system and, so long as the image scale is known, the length and width of terrestrial features as well as the relative distance between those features can be calculated.

Although the process of ortho-rectification compensates to a degree for oblique distortions in an orthogonal image, it introduces other undesirable distortions and/or

inaccuracies in the ortho-rectified orthogonal image. Objects depicted in ortho-rectified orthogonal images may be difficult to recognize and/or identify since most observers are not accustomed to viewing objects, particularly terrestrial features, from above. To an untrained observer an ortho-rectified image has a number of distortions. Roads that are actually straight appear curved and buildings may appear to tilt. Further, ortho-rectified images contain substantially no information as to the height of terrestrial features. The interpretation and analysis of orthogonal and/or ortho-rectfified orthogonal images is typically performed by highly-trained analysts whom have undergone years of specialized training and experience in order to identify objects and terrestrial features in such images.

Thus, although orthogonal and ortho-rectified images are useful in photogrammetry, they lack information as to the height of features depicted therein and require highly-trained analysts to interpret detail from what the images depict.

Oblique images are images that are captured with the image-capturing device aimed or pointed generally to the side of and downward from the platform that carries the image-capturing device. Oblique images, unlike orthogonal images, display the sides of terrestrial features, such as houses, buildings and/or mountains, as well as the tops thereof. Thus, viewing an oblique image is more natural and intuitive than viewing an orthogonal or ortho-rectified image, and even casual observers are able to recognize and interpret terrestrial features and other objects depicted in oblique images. Each pixel in the foreground of an oblique image corresponds to a relatively small area of the

surface or object depicted (i.e., each foreground pixel has a relatively small ground sample distance) whereas each pixel in the background corresponds to a relatively large area of the surface or object depicted (i.e., each background pixel has a relatively large ground sample distance). Oblique images capture a generally trapezoidal area or view of the subject surface or object, with the foreground of the trapezoid having a substantially smaller ground sample distance (i.e., a higher resolution) than the background of the trapezoid.

Oblique images are considered to be of little or no use in photogrammetry. The conventional approach of forcing the variously-sized foreground and background pixels of an oblique image into a uniform size to thereby warp the image onto a coordinate system dramatically distorts the oblique image and thereby renders identification of objects and the taking of measurements of objects depicted therein a laborious and inaccurate task. Correcting for terrain displacement within an oblique image by using an elevation model further distorts the images thereby increasing the difficulty with which measurements can be made and reducing the accuracy of any such measurements.

Thus, although oblique images are considered as being of little or no use in photogrammetry, they are easily interpreted and contain information as to the height of features depicted therein.

Therefore, what is needed in the art is a method and apparatus for photogrammetry that enable geo-location and accurate measurements within oblique

images.

Moreover, what is needed in the art is a method and apparatus for photogrammetry that enable the measurement of heights and relative heights of objects within an image.

Furthermore, what is needed in the art is a method and apparatus for photogrammetry that utilizes more intuitive and natural images.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus for capturing, displaying, and making measurements of objects and distances between objects depicted within oblique images.

The present invention comprises, in one form thereof, a computerized system for displaying, geolocating, and taking measurements from captured oblique images. The system includes a data file accessible by the computer system. The data file includes a plurality of image files corresponding to a plurality of captured oblique images, and positional data corresponding to the images. Image display and analysis software is executed by the system for reading the data file and displaying at least a portion of the captured oblique images. The software retrieves the positional data for one or more user-selected points on the displayed image, and calculates a separation distance between any two or more selected points. The separation distance calculation is user-selectable to determine various parameters including linear distance between, area

encompassed within, relative elevation of, and height difference between selected points.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become apparent and be more completely understood by reference to the following description of one embodiment of the invention when read in conjunction with the accompanying drawings, wherein:

FIG. 1 illustrates one embodiment of a platform or vehicle carrying an image-capturing system of the present invention, and shows exemplary orthogonal and oblique images taken thereby;

FIG. 2 is a diagrammatic view of the image-capturing system of FIG. 1;

FIG. 3 is a block diagram of the image-capturing computer system of Fig. 2;

FIG. 4 is a representation of an exemplary output data file of the image-capturing system of Fig. 1;

FIG. 5 is a block diagram of one embodiment of an image display and measurement computer system of the present invention for displaying and taking measurements of and between objects depicted in the images captured by the image-capturing system of Fig. 1;

FIG. 6 depicts an exemplary image displayed on the system of Fig. 5, and illustrates one embodiment of the method of the present invention for the measurement

of and between objects depicted in such an image;

FIGS. 7 and 8 illustrate one embodiment of a method for capturing oblique images of the present invention;

FIGS. 9 and 10 illustrate a second embodiment of a method for capturing oblique images of the present invention.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate one preferred embodiment of the invention, in one form, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and particularly to Fig. 1, one embodiment of an apparatus for capturing and geolocating oblique images of the present invention is shown. Apparatus 10 includes a platform or vehicle 20 that carries image-capturing and geolocating system 30.

Platform 20, such as, for example, an airplane, space shuttle, rocket, satellite, or any other suitable vehicle, carries image-capturing system 30 over a predefined area of and at one or more predetermined altitudes above surface 31, such as, for example, the earth's surface or any other surface of interest. As such, platform 20 is capable of controlled movement or flight, either manned or unmanned, along a predefined flight path or course through, for example, the earth's atmosphere or outer space. Image-

capturing platform 20 includes a system for generating and regulating power (not shown) that includes, for example, one or more generators, fuel cells, solar panels, and/or batteries, for powering image-capturing system 30.

Image-capturing and geo-locating system 30, as best shown in Fig. 2, includes image capturing devices 32a and 32b, a global positioning system (GPS) receiver 34, an inertial navigation unit (INU) 36, clock 38, gyroscope 40, compass 42 and altimeter 44, each of which are interconnected with image-capturing computer system 46.

Image-capturing devices 32a and 32b, such as, for example, conventional cameras, digital cameras, digital sensors, charge-coupled devices, or other suitable image-capturing devices, are capable of capturing images photographically or electronically. Image-capturing devices 32a and 32b have known or determinable characteristics including focal length, sensor size and aspect ratio, radial and other distortion terms, principal point offset, pixel pitch, and alignment. Image-capturing devices 32a and 32b acquire images and issue image data signals (IDS) 48a and48b, respectively, corresponding to the particular images or photographs taken and which are stored in image-capturing computer system 46, as will be more particularly described hereinafter.

As best shown in Fig. 1, image-capturing devices 32a and 32b have respective central axes A_1 and A_2, and are mounted to platform 20 such that axes A_1 and A_2 are each at an angle of declination ? relative to a horizontal plane *P*. Declination angle ? is virtually any oblique angle, but is preferably from approximately 20° (twenty degrees) to

approximately 60° (sixty degrees) and is most preferably from approximately 40° (forty degrees) to approximately 50° (fifty degrees).

GPS receiver 34 receives global positioning system signals 52 that are transmitted by one or more global positioning system satellites 54. The GPS signals 52, in known fashion, enable the precise location of platform 20 relative to surface 31 to be determined. GPS receiver 34 decodes GPS signals 52 and issues location signals/data 56, that are dependent at least in part upon GPS signals 52 and which are indicative of the precise location of platform 20 relative to surface 31. Location signals/data 56 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

INU 36 is a conventional inertial navigation unit that is coupled to and detects changes in the velocity, including translational and rotational velocity, of image-capturing devices 32a and 32b and/or platform 20. INU 36 issues velocity signals/data 58 indicative of such velocities and/or changes therein to image-capturing computer system 46, which stores velocity signals/data 58 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

Clock 38 keeps a precise time measurement (time of validity) that is used to synchronize events within image-capturing and geo-locating system 30. Clock 38 provides time data/clock signal 62 that is indicative of the precise time that an image is taken by image-capturing devices 32a and 32b. Time data 62 is also provided to and

stored by image-capturing computer system 46. Alternatively, clock 38 is integral with image-capturing computer system 46, such as, for example, a clock software program.

Gyroscope 40 is a conventional gyroscope as commonly found on airplanes and/or within commercial navigation systems for airplanes. Gyroscope 40 provides signals including pitch signal 64, roll signal 66 and yaw signal 68, which are respectively indicative of pitch, roll and yaw of platform 20. Pitch signal 64, roll signal 66 and yaw signal 68 corresponding to each image captured by mage-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

Compass 42, such as, for example, a conventional electronic compass, indicates the heading of platform 20. Compass 42 issues heading signal/data 72 that is indicative of the heading of platform 20. Image-capturing computer system 46 receives and stores the heading signals/data 72 that correspond to each image captured by image-capturing devices 32a and 32b.

Altimeter 44 indicates the altitude of platform 20. Altimeter 44 issues altitude signal/data 74, and image-capturing computer system 46 receives and stores the altitude signal/data 74 that correspond to each image captured by image-capturing devices 32a and 32b.

As best shown in Fig. 3, image-capturing computer system 46, such as, for example, a conventional laptop personal computer, includes memory 82, input devices 84a and 84b, display device 86, and input and output (I/O) ports 88. Image-capturing computer system 46 executes image and data acquiring software 90, which is stored in

memory 82. Memory 82 also stores data used and/or calculated by image-capturing computer system 46 during the operation thereof, and 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 84a and 84b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and interaction of a user with software being executed by image-capturing computer system 46. Display device 86, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image-capturing computer system 46. I/O ports 88, such as, for example, serial and parallel data input and output ports, enable the input and/or output of data to and from image-capturing computer system 46.

Each of the above-described data signals is connected to image-capturing computer system 46. More particularly, image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74 are received via I/O ports 88 by and stored within memory 82 of image-capturing computer system 46.

In use, image-capturing computer system 46 executes image and data acquiring software 90, which, in general, controls the reading, manipulation, and storing of the above-described data signals. More particularly, image and data acquiring software 90 reads image data signals 48a and 48b and stores them within memory 82. Each of the location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals

64, 66 and 68, respectively, heading signal 72 and altitude signal 74 that represent the conditions existing at the instant an image is acquired or captured by image-capturing devices 32a and 32b and which correspond to the particular image data signals 48a and 48b representing the captured images are received by image-capturing computer system 46 via I/O ports 88. Image-capturing computer system 46 executing image and data acquiring software 90 issues image-capture signal 92 to image-capturing devices 32a and 32b to thereby cause those devices to acquire or capture an image at predetermined locations and/or at predetermined intervals which are dependent at least in part upon the velocity of platform 20.

Image and data acquiring software 90 decodes as necessary and stores the aforementioned signals within memory 82, and associates the data signals with the corresponding image signals 48a and 48b. Thus, the altitude, orientation in terms of roll, pitch, and yaw, and the location of image-capturing devices 32a and 32b relative to surface 31, i.e., longitude and latitude, for every image captured by image-capturing devices 32a and 32b is known.

Platform 20 is piloted or otherwise guided through an image-capturing path that passes over a particular area of surface 31, such as, for example, a predefined area of the surface of the earth or of another planet. Preferably, the image-capturing path of platform 20 is at right angles to at least one of the boundaries of the area of interest. The number of times platform 20 and/or image-capturing devices 32a, 32b pass over the area of interest is dependent at least in part upon the size of the area and the

amount of detail desired in the captured images. The particular details of the image-capturing path of platform 20 are described more particularly hereinafter.

As platform 20 passes over the area of interest a number of oblique images are captured by image-capturing devices 32a and 32b. As will be understood by those of ordinary skill in the art, images are captured or acquired by image-capturing devices 32a and 32b at predetermined image capture intervals which are dependent at least in part upon the velocity of platform 20.

Image data signals 48a and 48b corresponding to each image acquired are received by and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Similarly, the data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) corresponding to each captured image are received and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Thus, the location of image-capturing device 32a and 32b relative to surface 32 at the precise moment each image is captured is recorded within memory 82 and associated with the corresponding captured image.

As best shown in Fig. 1, the location of image-capturing devices 32a and 32b relative to the earth corresponds to the nadir point *N* of orthogonal image 102. Thus, the exact geo-location of the nadir point *N* of orthogonal image 102 is indicated by location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74. Once the nadir

point *N* of orthogonal image 102 is known, the geo-location of any other pixel or point within image 102 is determinable in known manner.

When image-capturing devices 32a and 32b are capturing oblique images, such as oblique images 104a and 104b (Fig. 1), the location of image-capturing devices 32a and 32b relative to surface 31 is similarly indicated by location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72, altitude signal 74 and the known angle of declination ? of the primary axes A_1 *and* A_2 of image-capturing devices 32a and 32b, respectively.

It should be particularly noted that a calibration process enables image and data acquiring software 90 to incorporate correction factors and/or correct for any error inherent in or due to image-capturing device 32, such as, for example, error due to calibrated focal length, sensor size, radial distortion, principal point offset, and alignment.

Image and data acquiring software 90 creates and stores in memory 82 one or more output image and data files 120. More particularly, image and data acquiring software 90 converts image data signals 48a, 48b and the orientation data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) into computer-readable output image and data files 120. As best shown in Fig. 4, output image and data file 120 contains a plurality of captured image files I_1, I_2, . . . , I_n corresponding to captured oblique images, and the positional data C_{PD1}, C_{PD2}, . . .

, C_{PDn} corresponding thereto.

Image files I_1, I_2, . . . , I_n of the image and data file 120 are stored in virtually any computer-readable image or graphics file format, such as, for example, JPEG, TIFF, GIF, BMP, or PDF file formats, and are cross-referenced with the positional data C_{PD1}, C_{PD2}, . . . , C_{PDn} which is also stored as computer-readable data. Alternatively, positional data C_{PD1}, C_{PD2}, . . . , C_{PDn} is embedded within the corresponding image files I_1, I_2, . . . , I_n in known manner. Image data files 120 are then processed, either by image and data acquiring software 90 or by post-processing, to correct for errors, such as, for example, errors due to flight path deviations and other errors known to one of ordinary skill in the art. Thereafter, image data files 120 are ready for use to display and make measurements of and between the objects depicted within the captured images, including measurements of the heights of such objects.

Referring now to Fig. 5, image display and measurement computer system 130, such as, for example, a conventional desktop personal computer or a mobile computer terminal in a police car, includes memory 132, input devices 134a and 134b, display device 136, and network connection 138. Image-capturing computer system 130 executes image display and analysis software 140, which is stored in memory 132. Memory 132 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 134a and 134b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and

interaction of a user with image display and analysis software 140 being executed by image display and measurement computer system 130. Display device 136, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image display and measurement computer system 130. Network connection 138 connects image display and measurement computer system 130 to a network (not shown), such as, for example, a local-area network, wide-area network, the Internet and/or the World Wide Web.

In use, and referring now to Fig. 6, image display and measurement computer system 130 executing image display and analysis software 140 accesses one or more output image and data files 120 that have been read into memory 132, such as, for example, via network connection 138, a floppy disk drive, removable memory card or other suitable means. One or more of the captured images I_1, I_2, . . . , I_n of output image and data files 120 is thereafter displayed as displayed oblique image 142 under the control of image display and analysis software 140. At approximately the same time, one or more data portions C_{PD1}, C_{PD2}, . . . , C_{PDn} corresponding to displayed oblique image 142 are read into a readily-accessible portion of memory 132.

It should be particularly noted that displayed oblique image 142 is displayed substantially as captured, i.e., displayed image 142 is not warped or fitted to any coordinate system nor is displayed image 142 ortho-rectified. Rather than warping displayed image 142 to a coordinate system in order to enable measurement of objects depicted therein, image display and analysis software 140, in general, determines the

geo-locations of selected pixels only as needed, or "on the fly", by referencing data portions C_{PD1}, C_{PD2}, . . . , C_{PDn} of output image and data files 120 and calculating the position and/or geo-location of those selected pixels using one or more projection equations as is more particularly described hereinafter.

Generally, a user of display and measurement computer system 130 takes measurements of and between objects depicted in displayed oblique image 142 by selecting one of several available measuring modes provided within image display and analysis software 140. The user selects the desired measurement mode by accessing, for example, a series of pull-down menus or toolbars *M*, or via keyboard commands. The measuring modes provided by image display and analysis software 140 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 of image display and analysis software 140 selects with one of input devices 134a, 134b a starting point or starting pixel 152 and an ending point or pixel 154 on displayed image 142, and image display and analysis software 140 automatically calculates and displays the quantity sought, such as, for example, the distance between starting pixel 152 and ending pixel

154.

When the user selects starting point/pixel 152, the geo-location of the point corresponding thereto on surface 31 is calculated by image display and analysis software 140 which executes one or more projection equations using the data portions C_{PD1}, C_{PD2}, . . . , C_{PDn} of output image and data files 120 that correspond to the particular image being displayed. The longitude and latitude of the point on surface 31 corresponding to pixel 152 are then displayed by image display and analysis software 140 on display 136, such as, for example, by superimposing the longitude and latitude on displayed image 142 adjacent the selected point/pixel or in pop-up display box elsewhere on display 136. The same process is repeated by the user for the selection of the end pixel/point 154, and by image display and analysis software 140 for the retrieval and display of the longitude and latitude information.

The calculation of the distance between starting and ending points/pixels 152, 154, respectively, is accomplished by determining the geo-location of each selected pixel 152, 154 "on the fly". The data portions C_{PD1}, C_{PD2}, . . . , C_{PDn} of output image and data file 120 corresponding to the displayed image are retrieved, and the geo-location of the point on surface 31 corresponding to each selected pixel are then determined. The difference between the geo-locations corresponding to the selected pixels determines the distance between the pixels.

As an example of how the geo-location of a given point or pixel within displayed oblique image 142 is determined, we will assume that displayed image 142

corresponds to orthogonal image 104a (Fig. 1). The user of image display and analysis software 140 selects pixel 154 which, for simplicity, corresponds to center *C* (Fig. 1) of oblique image 104a. As shown in Fig. 1, line 106 extends along horizontal plane *G* from a point 108 thereon that is directly below image-capturing device 32a to the center *C* of the near border or edge 108 of oblique image 104a. An extension of primary axis A_1 intersects with center *C*. Angle Ø is the angle formed between line 106 the extension of primary axis A_1. Thus, a triangle (not referenced) is formed having vertices at image-capturing device 32a, point 108 and center *C*, and having sides 106, the extension of primary axis A_1 and vertical (dashed) line 110 between point 108 and image-capturing device 32a.

Ground plane *G* is a substantially horizontal, flat or non-sloping ground plane (and which typically will have an elevation that reflects the average elevation of the terrain), and therefore the above-described triangle includes a right angle between side/line 110 and side/line 106. Since angle Ø and the altitude of image-capturing device 32 (i.e., the length of side 110) are known, the hypotenuse (i.e., the length of the extension of primary axis A_1) and remaining other side of the right triangle are calculated by simple geometry. Further, since the exact position of image-capturing device 32a is known at the time the image corresponding to displayed image 142 was captured, the latitude and longitude of point 108 are also known. Knowing the length of side 106, calculated as described above, enables the exact geo-location of pixel 154 corresponding to center *C* of oblique image 104a to be determined by image display

and analysis software 140. Once the geo-location of the point corresponding to pixel 154 is known, the geo-location of any other pixel in displayed oblique image 142 is determinable using the known camera characteristics, such as, for example, focal length, sensor size and aspect ratio, radial and other distortion terms, etc.

The distance between the two or more points corresponding to two or more selected pixels within displayed image 142 is calculated by image display and analysis software 140 by determining the difference between the geo-locations of the selected pixels using known algorithms, such as, for example, the Gauss formula and/or the vanishing point formula, dependent upon the selected measuring mode. The measurement of objects depicted or appearing in displayed image 142 is conducted by a substantially similar procedure to the procedure described above for measuring distances between selected pixels. For example, the lengths, widths and heights of objects, such as, for example, buildings, rivers, roads, and virtually any other geographic or man-made structure, appearing within displayed image 142 are measured by selecting the appropriate/desired measurement mode and selecting starting and ending pixels.

It should be particularly noted that in the distance measuring mode of image display and analysis software 140 the distance between the starting and ending points/pixels 152, 154, respectively, is determinable along virtually any path, such as, for example, a "straight-line" path *P1* or a path *P2* that involves the selection of intermediate points/pixels and one or more "straight-line" segments interconnected

therewith.

It should also be particularly noted that the distance measuring mode of image display and analysis software 140 determines the distance between selected pixels according to a "walk the earth" method. The "walk the earth method" creates a series of interconnected line segments, represented collectively by paths *P1* and *P2*, that extend between the selected pixels/points and which lie upon or conform to the planar faces of a series of interconnected facets that define a tessellated ground plane. The tessellated ground plane, as will be more particularly described hereinafter, closely follows or recreates the terrain of surface 31, and therefore paths *P1* and *P2* also closely follow the terrain of surface 31. By measuring the distance along the terrain simulated by the tessellated ground plane, the "walk the earth" method provides for a more accurate and useful measurement of the distance between selected points than the conventional approach, which warps the image onto a flat earth or average elevation plane system and measures the distance between selected points along the flat earth or plane and substantially ignores variations in terrain between the points.

For example, a contractor preparing to bid on a contract for paving a roadway over uneven or hilly terrain can determine the approximate amount or area of roadway involved using image display and analysis software 140 and the "walk the earth" measurement method provided thereby. The contractor can obtain the approximate amount or area of roadway from his or her own office without having to send a surveying crew to the site to obtain the measurements necessary.

In contrast to the "walk the earth" method provided by the present invention, the "flat earth" or average elevation distance calculating approaches include inherent inaccuracies when measuring distances between points and/or objects disposed on uneven terrain and when measuring the sizes and/or heights of objects similarly disposed. Even a modest slope or grade in the surface being captured results in a difference in the elevation of the nadir point relative to virtually any other point of interest thereon. Thus, referring again to Fig. 1, the triangle formed by line 106, the extension of primary axis A_1 and the vertical (dashed) line 110 between point 108 and image-capturing device 32a may not be a right triangle. If such is the case, any geometric calculations assuming that triangle to be a right triangle would contain errors, and such calculations would be reduced to approximations due to even a relatively slight gradient or slope between the points of interest.

For example, if surface 31 slopes upward between nadir point *N* and center *C* at the near or bottom edge 108 of oblique image 104 then second line 110 intersects surface 31 before the point at which such intersection would occur on a level or non-sloping surface 31. If center *C* is fifteen feet higher than nadir point *N* and with a declination angle ? equal to 40° (forty degrees), the calculated location of center *C* would be off by approximately 17.8 feet without correction for the change in elevation between the points.

As generally discussed above, in order to compensate at least in part for changes in elevation and the resultant inaccuracies in the measurement of and

between objects within image 142, image display and analysis software 140 references, as necessary, points within displayed image 142 and on surface 31 to a pre-calculated tessellated or faceted ground plane generally designated 160 in Fig. 6. Tessellated ground plane 160 includes a plurality of individual facets 162a, 162b, 162c, etc., each of which are interconnected to each other and are defined by four vertices (not referenced, but shown as points) having respective elevations. Adjacent pairs of facets 162a, 162b, 162c, etc., share two vertices. Each facet 162a, 162b, 162c, etc., has a respective pitch and slope. Tessellated ground plane 160 is created based upon various data and resources, such as, for example, topographical maps, and/or digital raster graphics, survey data, and various other sources.

Generally, the geo-location of a point of interest on displayed image 142 is calculated by determining which of facets 162a, 162b, 162c, etc., correspond to that point of interest. Thus, the location of the point of interest is calculated based on the characteristics, i.e., elevation, pitch and slope, of facets 162a, 162b, 162c, etc., rather than based upon a flat or average-elevation ground plane. Error is introduced only in so far as the topography of surface 31 and the location of the point of interest thereon deviate from the planar surface of the facet 162a, 162b, 162c, etc, within which the point of interest lies. That error is reducible through a bilinear interpolation of the elevation of the point of interest within a particular one of facets 162a, 162b, 162c, etc., and using that interpolated elevation in the location calculation performed by image display and analysis software 140.

To use tessellated ground plane 160, image display and analysis software 140 employs a modified ray-tracing algorithm to find the intersection of the ray projected from the image-capturing device 32a or 32b towards surface 31 and tessellated ground plane 160. The algorithm determines not only which of facets 162a, 162b, 162c, etc., is intersected by the ray, but also where within the facet the intersection occurs. By use of bi-linear interpolation, a fairly precise ground location can be determined. For the reverse projection, tessellated ground plane 160 is used to find the ground elevation value for the input ground location also using bi-linear interpolation. The elevation and location are then used to project backwards through a model of the image-capturing device 32a or 32b to determine which of the pixels within displayed image 142 corresponds to the given location.

More particularly, and as an example, image display and analysis software 140 performs and/or calculates the geo-location of point 164 by superimposing and/or fitting tessellated ground plane 160 to at least a portion 166, such as, for example, a hill, of surface 31. It should be noted that only a small portion of tessellated ground plane 160 and facets 162a, 162b, 162c, etc., thereof is shown along the profile of portion 166 of surface 31. As discussed above, each of facets 162a, 162b, 162c, etc., are defined by four vertices, each of which have respective elevations, and each of the facets have respective pitches and slopes. The specific position of point 164 upon the plane/surface of the facet 162a, 162b, 162c, etc., within which point 164 (or its projection) lies is determined as described above.

Tessellated ground plane 160 is preferably created outside the operation of image display and measurement computer system 130 and image display and analysis software 140. Rather, tessellated ground plane 160 takes the form of a relatively simple data table or look-up table 168 stored within memory 132 of and/or accessible to image display and measurement computer system 130. The computing resources required to calculate the locations of all the vertices of the many facets of a typical ground plane do not necessarily have to reside within image display and measurement computer system 130. Thus, image display and measurement computer system 130 is compatible for use with and executable by a conventional personal computer without requiring additional computing resources.

Calculating tessellated ground plane 160 outside of image display and measurement computer system 130 enables virtually any level of detail to be incorporated into tessellated ground plane 160, i.e., the size and/or area covered by or corresponding to each of facets 162a, 162b, 162c, etc., can be as large or as small as desired, without significantly increasing the calculation time, slowing the operation of, nor significantly increasing the resources required by image display and measurement computer system 130 and/or image display and analysis software 140. Display and measurement computer system 130 can therefore be a relatively basic and uncomplicated computer system.

The size of facets 162a, 162b, 162c, etc., are uniform in size throughout a particular displayed image 142. For example, if displayed image 142 corresponds to an

area that is approximately 750 feet wide in the foreground by approximately 900 feet deep, the image can be broken into facets that are approximately 50 square feet, thus yielding about 15 facets in width and 18 facets in depth. Alternatively, the size of facets 162a, 162b, 162c, etc., are uniform in terms of the number of pixels contained therein, i.e., each facet is the same number of pixels wide and the same number of pixels deep. Facets in the foreground of displayed image 142, where the pixel density is greatest, would therefore be dimensionally smaller than facets in the background of displayed image 142 where pixel density is lowest. Since it is desirable to take most measurements in the foreground of a displayed image where pixel density is greatest, creating facets that are uniform in terms of the number of pixels they contain has the advantage of providing more accurate measurements in the foreground of displayed image 142 relative to facets that are dimensionally uniform.

Another advantage of using pixels as a basis for defining the dimensions of facets 162a, 162b, 162c, etc., is that the location calculation (pixel location to ground location) is relatively simple. A user operates image display and measurement computer system 130 to select a pixel within a given facet, image display and analysis software 140 looks up the data for the facet corresponding to the selected pixel, the elevation of the selected pixel is calculated as discussed above, and that elevation is used within the location calculation.

Generally, the method of capturing oblique images of the present invention divides an area of interest, such as, for example, a county, into sectors of generally

uniform size, such as, for example, sectors that are approximately one square mile in area. This is done to facilitate the creation of a flight plan to capture oblique images covering every inch of the area of interest, and to organize and name the sectors and/or images thereof for easy reference, storage and retrieval (a process known in the art as "sectorization"). Because the edges of any geographic area of interest, such as a county, rarely falls on even square mile boundaries, the method of capturing oblique images of the present invention provides more sectors than there are square miles in the area of interest – how many more depends largely on the length of the county borders as well as how straight or jagged they are. Typically, you can expect one extra sector for every two to three miles of border. So if a county or other area of interest is roughly 20 miles by 35 miles, or 700 square miles, the area will be divided into approximately from 740 to 780 sectors.

The method of capturing oblique images of the present invention, in general, captures the oblique images from at least two compass directions, and provides full coverage of the area of interest from at least those two compass directions. Referring now to Figs. 7 and 8, a first embodiment of a method for capturing oblique images of the present invention is shown. For sake of clarity, Fig. 7 and 8 is based on a system having only one image-capturing device. However, it is to be understood that two or more image-capturing devices can be used.

The image-capturing device captures one or more oblique images during each pass over area 200. The image-capturing device, as discussed above, is aimed at an

angle over area 200 to capture oblique images thereof. Area 200 is traversed in a back-and-forth pattern, similar to the way a lawn is mowed, by the image-carrying device and/or the platform to ensure double coverage of area 200.

More particularly, area 200 is traversed by image-carrying device 32 and/or platform 20 following a first path 202 to thereby capture oblique images of portions 202a, 202b, and 202c of area 200. Area 200 is then traversed by image-carrying device 32 and/or platform 20 following a second path 204 that is parallel and spaced apart from, and in an opposite direction to, i.e., 180° (one-hundred and eighty degrees) from, first path 202, to thereby capture oblique images of portions 204a, 204b, 204c of area 200. By comparing Figs. 7 and 8, it is seen that a portion 207 (Fig. 8) of area 200 is covered by images 202a-c captured from a first direction or perspective, and by images 204a-c captured from a second direction or perspective. As such, the middle portion of area 200 is 100% (one-hundred percent) double covered. The above-described pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 202 and 204 is repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from each other as dictated by the size of area 200, and in the same direction as paths 202 and 204 to thereby one-hundred percent double cover area 200 from those perspectives/directions.

If desired, and for enhanced detail, area 200 is covered by two additional opposing and parallel third and fourth paths 206 and 208, respectively, that are

perpendicular to paths 202 and 204 as shown in Figs. 9 and 10. Area 200 is therefore traversed by image-carrying device 32 and/or platform 20 following third path 206 to capture oblique images of portions 206a, 206b and 206c of area 200, and is then traversed along fourth path 208 that is parallel, spaced apart from, and opposite to third path 206 to capture oblique images of portions 208a, 208b and 208c of area 200. This pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 206 and 208 is similarly repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from as dictated by the size of area 200, and in the same direction as paths 206 and 208 to thereby one-hundred percent double cover area 200 from those directions/perspectives.

As described above, image-carrying device 32 and/or platform 20, traverses or passes over area 200 along a predetermined path. However, it is to be understood that image-carrying device and/or platform 20 do not necessarily pass or traverse directly over area 200 but rather may pass or traverse an area adjacent, proximate to, or even somewhat removed from, area 200 in order to ensure that the portion of area 200 that is being imaged falls within the image-capture field of the image-capturing device. Path 202, as shown in Fig. 7, is such a path that does not pass directly over area 200 but yet captures oblique images thereof.

The present invention is capable of capturing images at various levels of resolution or ground sample distances. A first level of detail, hereinafter referred to as a

community level, has a ground sample distance of, for example, approximately two-feet per pixel. For orthogonal community-level images, the ground sample distance remains substantially constant throughout the image. Orthogonal community-level images are captured with sufficient overlap to provide stereo pair coverage. For oblique community-level images, the ground sample distance varies from, for example, approximately one-foot per pixel in the foreground of the image to approximately two-feet per pixel in the mid-ground of the image, and to approximately four-feet per pixel in the background of the image. Oblique community-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction captured. Approximately ten oblique community-level images are captured per sector.

A second level of detail, hereinafter referred to as a neighborhood level, is significantly more detailed than the community-level images. Neighborhood-level images have a ground sample distance of, for example, approximately six-inches per pixel. For orthogonal neighborhood-level images, the ground sample distance remains substantially constant. Oblique neighborhood-level images have a ground sample distance of, for example, from approximately four-inches per pixel in the foreground of the image to approximately six-inches per pixel in the mid-ground of the image, and to approximately ten-inches per pixel in the background of the image. Oblique neighborhood-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction

captured, and such that opposing compass directions provide 100% overlap with each other. Approximately one hundred (100) oblique area images are captured per sector.

It should be particularly noted that capturing oblique community and/or neighborhood-level images from all four compass directions ensures that every point in the image will appear in the foreground or lower portion of at least one of the captured oblique images, where ground sample distance is lowest and image detail is greatest.

In the embodiment shown, image-capturing and geo-locating system 30 includes a gyroscope, compass and altimeter. However, it is to be understood that the image-capturing and geo-locating system of the present invention can be alternately configured, such as, for example, to derive and/or calculate altitude, pitch, roll and yaw, and compass heading from the GPS and INU signals/data, thereby rendering one or more of the gyroscope, compass and altimeter unnecessary. In fact,

In the embodiment shown, image-capturing devices are at an equal angle of declination relative to a horizontal plane. However, it is to be understood that the declination angles of the image-capturing devices do not have to be equal.

In the embodiment shown, image-capturing computer system executes image and data acquiring software that issues a common or single image-capture signal to the image-capturing devices to thereby cause those devices to acquire or capture an image. However, it is to be understood that the present invention can be alternately configured to separately cause the image-capturing devices to capture images at different instants and/or at different intervals.

In the embodiment shown, the method of the present invention captures oblique images to provide double coverage of an area of interest from paths/perspectives that are substantially opposite to each other, i.e., 180° (one-hundred and eighty degrees) relative to each other. However, it is to be understood that the method of the present invention can be alternately configured to provide double coverage from paths/perspectives that are generally and/or substantially perpendicular relative to each other.

While the present invention has been described as having a preferred design, the invention can be further modified within the spirit and scope of this disclosure. This disclosure is therefore intended to encompass any equivalents to the structures and elements disclosed herein. Further, this disclosure is intended to encompass any variations, uses, or adaptations of the present invention that use the general principles disclosed herein. Moreover, this disclosure is intended to encompass any departures from the subject matter disclosed that come within the known or customary practice in the pertinent art and which fall within the limits of the appended claims.

WHAT IS CLAIMED IS:

1. A system for capturing images and geo-location data corresponding thereto, comprising:

an image-capturing device, said image-capturing device capturing oblique images at image-capturing events, said image capturing device issuing image-data signals corresponding to captured images;

at least one geo-locating device, each said at least one geo-locating device issuing a corresponding at least one geo-locating signal, each said at least one geo-locating signal being indicative at least in part of a geo-location of said image-capturing device during each image capturing event; and

a computer system receiving and storing said image-data signals and said at least one geo-locating signal; and

image and data acquiring software reading said image-data signals and said at least one geo-locating signal, said software associating each said image-data signal with a corresponding said at least one geo-locating signal for each image-capturing event.

2. The system of claim 1, wherein said at least one geo-locating device and said at least one geo-locating signal respectively comprise at least one of:

a clock issuing to said image-capturing computer system time data signals

indicative of a time of each said image-capturing event;

a global-positioning system (GPS) receiver receiving GPS signals and issuing to said image-capturing computer system location data signals indicative of a longitude and latitude of said image-capturing device at each said image-capturing event;

an inertial navigation unit (INU) issuing to said image-capturing computer system velocity data signals indicative of a velocity of said image-capturing device at each said image-capturing event;

a gyroscope issuing to said image-capturing computer system a pitch signal, a roll signal, and a yaw signal respectively indicative of a pitch, roll and yaw of said image capturing device at each said image-capturing event;

a compass issuing to said image-capturing computer system heading data signals indicative of a heading of said image-capturing device at each said image-capturing event; and

an altimeter issuing to said image-capturing computer system altitude data signals indicative of an altitude of said image-capturing device at each said image-capturing event.

3. The system of claim 1, wherein said at least one geo-locating device and said at least one geo-locating signal respectively comprise:

a clock issuing to said image-capturing computer system time data signals indicative of a time of each said image-capturing event;

a global-positioning system (GPS) receiver receiving GPS signals and issuing to said image-capturing computer system location data signals indicative of a longitude and latitude of said image-capturing device at each said image-capturing event;

an inertial navigation unit (INU) issuing to said image-capturing computer system velocity data signals indicative of a velocity of said image-capturing device at each said image-capturing event;

a gyroscope issuing to said image-capturing computer system a pitch signal, a roll signal, and a yaw signal respectively indicative of a pitch, roll and yaw of said image capturing device at each said image-capturing event;

a compass issuing to said image-capturing computer system heading data signals indicative of a heading of said image-capturing device at each said image-capturing event; and

an altimeter issuing to said image-capturing computer system altitude data signals indicative of an altitude of said image-capturing device at each said image-capturing event.

4. The system of claim 1, further comprising correction data indicative of characteristics of said image-capturing device including focal length, sensor size, radial distortion, principal point offset and alignment, said image and data acquiring software utilizing said correction data to correct captured images.

5. The system of claim 1, further comprising an output data file created by said image and data acquiring software, said output data file including a plurality of image files and positional data corresponding to each of said plurality of image files.

6. The system of claim 1, further comprising a platform carrying said image-capturing device a predetermined distance above a surface of interest.

7. A computerized system for displaying, geolocating, and making measurements based upon captured oblique images, comprising:

a computer system having a memory;

an image and data file accessible by said system and including a plurality of image files corresponding to a plurality of captured oblique images, said image and data file further including positional data corresponding to said plurality of image files;

image display and analysis software executed by said system for reading said image and data file and displaying at least a portion of the captured oblique images as a displayed image, said software retrieving said positional data of one or more selected points within said displayed image, said software calculating a separation distance between any two or more selected points within said displayed image.

8. The system of claim 7, further comprising a ground plane data file representing a tessellated ground plane, said ground plane data file accessible by said

computer system, said ground plane data file representing a tessellated ground plane that closely approximates at least a portion of the terrain depicted within said captured oblique images.

9. The system of claim 8, wherein said tessellated ground plane further comprises a plurality of interconnected facets, each of said plurality of facets having a respective pitch and slope.

10. The system of claim 9, wherein said ground plane data file comprises a plurality of vertices, each of said plurality of vertices having respective elevations and defining corners of said plurality of interconnected facets, two of said plurality of vertices shared by each of said interconnected facets.

11. The system of claim 10, wherein said image display and analysis software identifies which of said plurality of facets corresponds to a selected point on said displayed image, and calculates an elevation of said selected point dependent at least in part upon the elevation of the vertices of the facet corresponding to the selected point, said image display and analysis software using said calculated elevation for calculating said separation distance between said selected point and one or more further selected points.

12. The system of claim 11, wherein said image display and analysis software calculates a height of an object within said displayed image by calculating the separation distance between two or more selected points.

13. The system of claim 8, wherein said tessellated ground plane is one of superimposed upon and fit to said displayed image.

14. The system of claim 7, wherein said image display and analysis software includes user-selectable measuring modes accessible through at least one of pull-down menus, toolbars and keyboard commands.

15. The system of claim 7, wherein each of said images were captured by an image-capturing device and at respective image capturing events, said positional data of said image and data file including:

time data representing the time of each image-capturing event;

location data representing the location of the image-capturing device at each image-capturing event;

orientation data representing the orientation of the image-capturing device at each image-capturing event;

correction data representing correction factors for the image-capturing device; and

elevation data representing an average elevation of the surface captured by the image-capturing device.

16. The system of claim 15, wherein said location data includes latitude, longitude, and altitude of the image-capturing apparatus at each image-capturing event.

17. The system of claim 15, wherein said orientation data includes roll, pitch, yaw and heading of said image-capturing device at each image-capturing event.

18. The data set of claim 15, wherein said image-capturing device is a camera and said correction data includes at least one of focal length, sensor size, aspect ratio, principle point offset, distortion, and pixel pitch.

19. A computerized method for taking measurements within a displayed oblique image, comprising:

selecting with an input device a starting point and an end point on the displayed image;

retrieving from a data file positional data corresponding to said starting point and said end point;

referencing a ground plane data file corresponding to a tessellated ground plane having a plurality of facets, each of said facets having a respective pitch and slope, said

tessellated ground plane closely matching a terrain of said displayed oblique image;

connecting said starting and end points with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and

calculating the linear distance along said line segments between said starting and end points thereby taking into account said pitch and slope of said facets.

20. The method of claim 19, wherein said tessellated ground plane is superimposed upon said displayed oblique image.

21. The method of claim 19, comprising the further steps of:

selecting with an input device one or more intermediate points on the displayed image;

retrieving from said data file positional data corresponding to said one or more intermediate points; and

connecting adjacent intermediate points to each other, and connecting said starting and end points to adjacent intermediate points, with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and

calculating the distance along said line segments between said starting and end points.

22. The method of claim 19, wherein said plurality of facets each correspond to equal areas of said displayed oblique image.

23. The method of claim 19, wherein said plurality of facets each includes an equal number of pixels of said displayed oblique image.

24. A computerized method for taking measurements from an oblique image displayed on a computer system, at least one input device connected to said computer system, an image data file accessible by said computer system, said image data file including captured images and positional data corresponding thereto, said computerized method comprising:

placing the computer system into a desired one of a plurality of measurement modes, the desired measurement mode configured for calculating a desired measurement;

selecting a starting point on the displayed image;

retrieving the positional data corresponding to said starting point;

selecting an end point on the displayed image;

retrieving the positional data corresponding to said end point; and

calculating the desired measurement dependent at least in part upon said positional data of said starting and end points.

25. The method of claim 24, comprising the further steps of:

selecting one or more intermediate points on said displayed image; and

retrieving the positional data corresponding to said intermediate points.

26. The method of claim 24, wherein said plurality of measurement modes comprise a distance measuring mode calculating a distance between two or more selected points, a height measuring mode calculating a height difference between two or more selected points, a relative elevation measurement mode calculating the difference in elevation of two or more selected points, and an area measurement mode calculating the area encompassed by at least three points.

27. A method of capturing oblique images of an area of interest with an image-capturing device carried by a platform, each oblique image captured at a respective image-capturing event, said method comprising:

subdividing the area of interest into a plurality of sectors;

guiding the platform along a first path to thereby target one or more target sectors with the image-capturing device;

capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a first perspective;

guiding the platform along a second path to thereby target said target sectors;

capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a second perspective;

repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said first and second paths and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from each of said first and second perspectives; and

recording positional data indicative of a geo-location of said image-capturing device at each image-capturing event.

28. The method of claim 27, wherein said second path is substantially parallel relative to and 180° (one-hundred and eighty degrees) from said first path;

29. The method of claim 28, wherein said second path is also spaced apart from said first path.

30. The method of claim 27, comprising the further steps of:

guiding the platform along a third path to thereby target one or more target sectors with the image-capturing device, said third path being substantially perpendicular to said first and second paths;

capturing with the image-capturing device one or more oblique images to thereby

capture an entirety of each said target sector in oblique images captured from a third perspective; and

repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said third path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said third perspective.

31. The method of claim 30, comprising the further steps of:

guiding the platform along a fourth path to thereby target one or more target sectors with the image-capturing device, said fourth path being substantially parallel with said third path and 180° (one-hundred and eighty degrees) from said third path;

capturing with the image-capturing device one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a fourth perspective; and

repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said fourth path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said fourth perspective.

32. The method of claim 31, wherein said fourth path is also spaced apart from said third path.

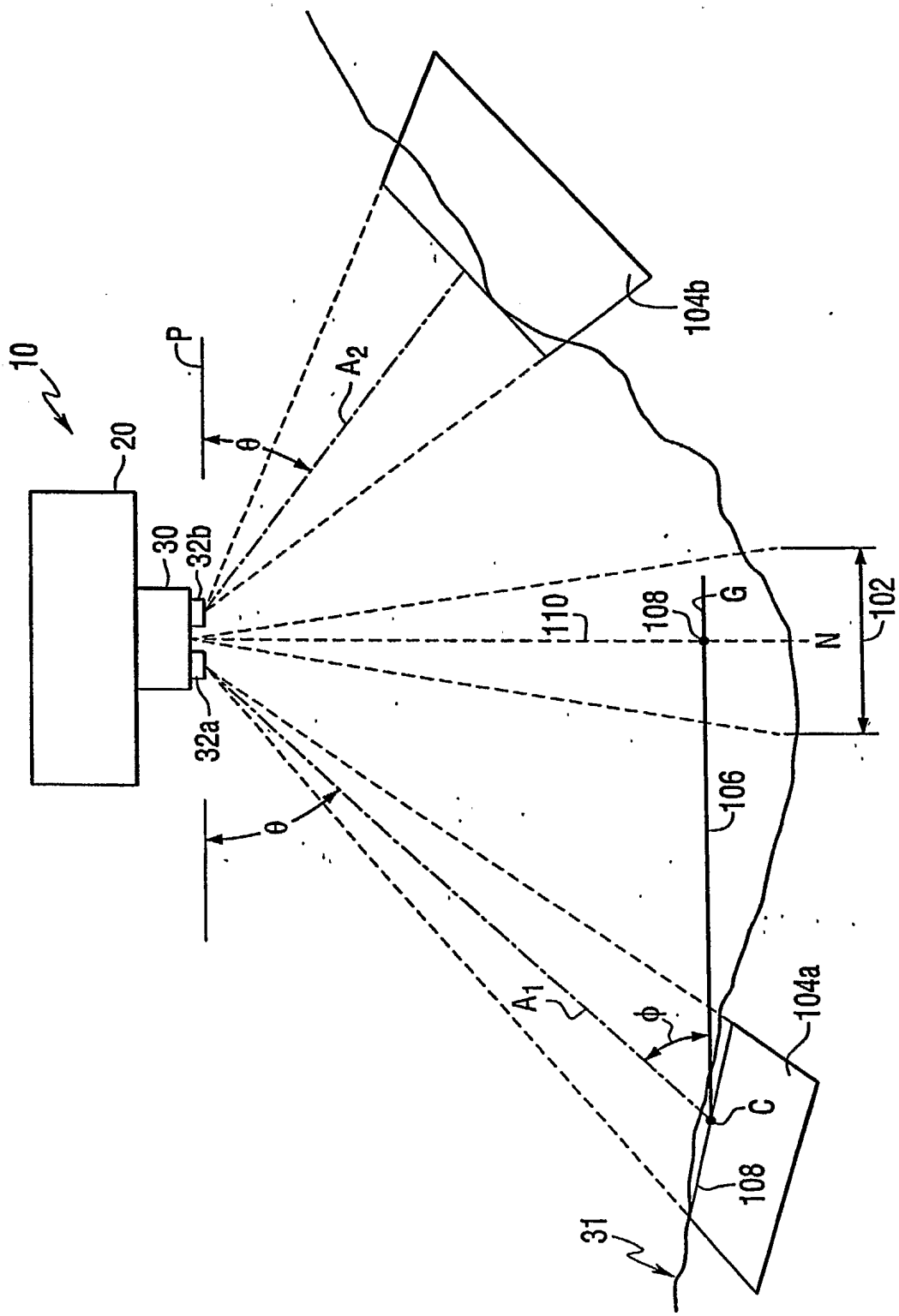


FIG. 1

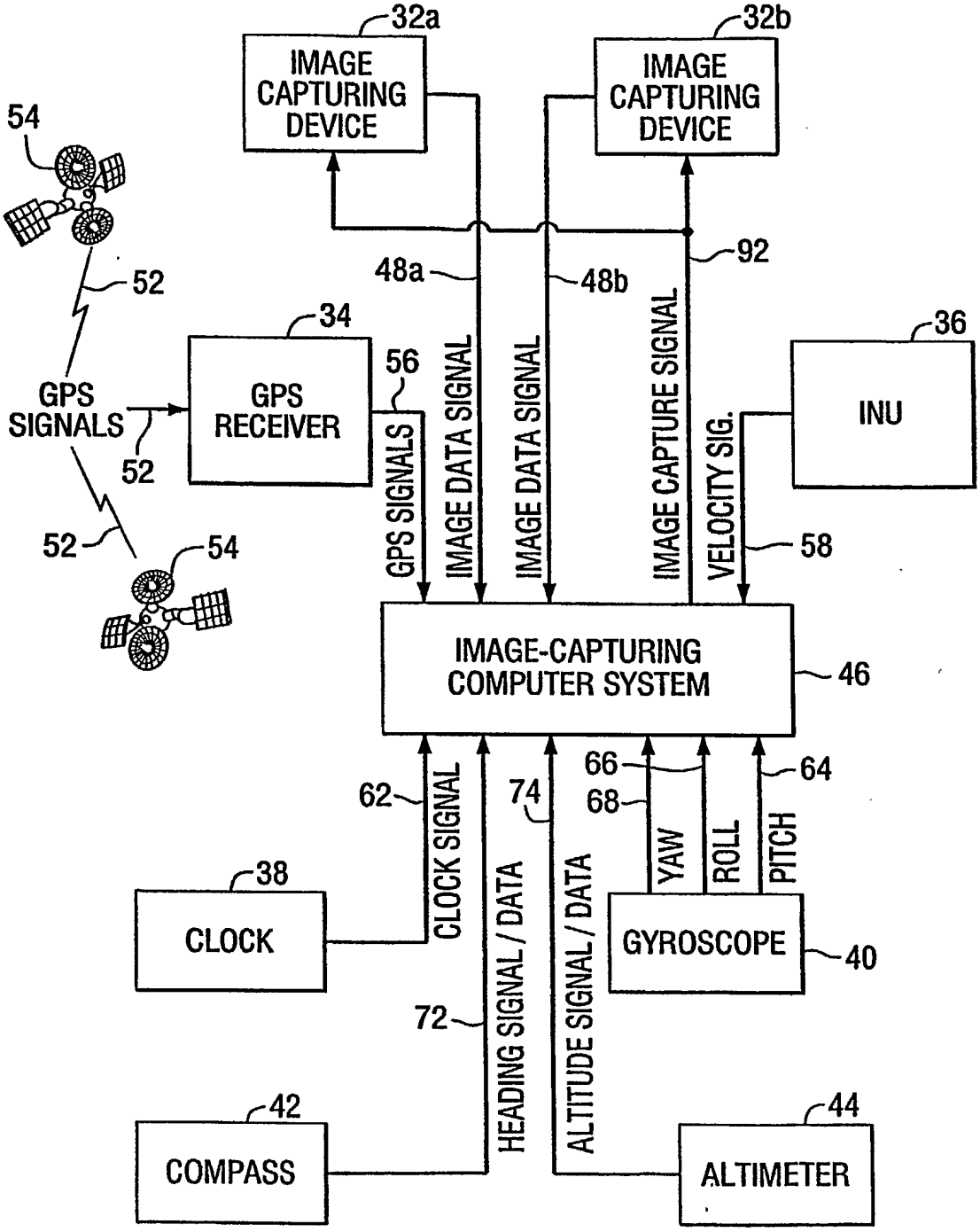

32a
IMAGE CAPTURING DEVICE
32b
IMAGE CAPTURING DEVICE
54
52
48a
48b
92
34
GPS SIGNALS
52
GPS RECEIVER
56
GPS SIGNALS
IMAGE DATA SIGNAL
IMAGE DATA SIGNAL
IMAGE CAPTURE SIGNAL
VELOCITY SIG.
36
INU
58
52
54
IMAGE-CAPTURING COMPUTER SYSTEM
46
62
CLOCK SIGNAL
74
HEADING SIGNAL / DATA
ALTITUDE SIGNAL / DATA
66
68
64
YAW
ROLL
PITCH
38
CLOCK
GYROSCOPE
40
72
42
COMPASS
44
ALTIMETER

FIG. 2

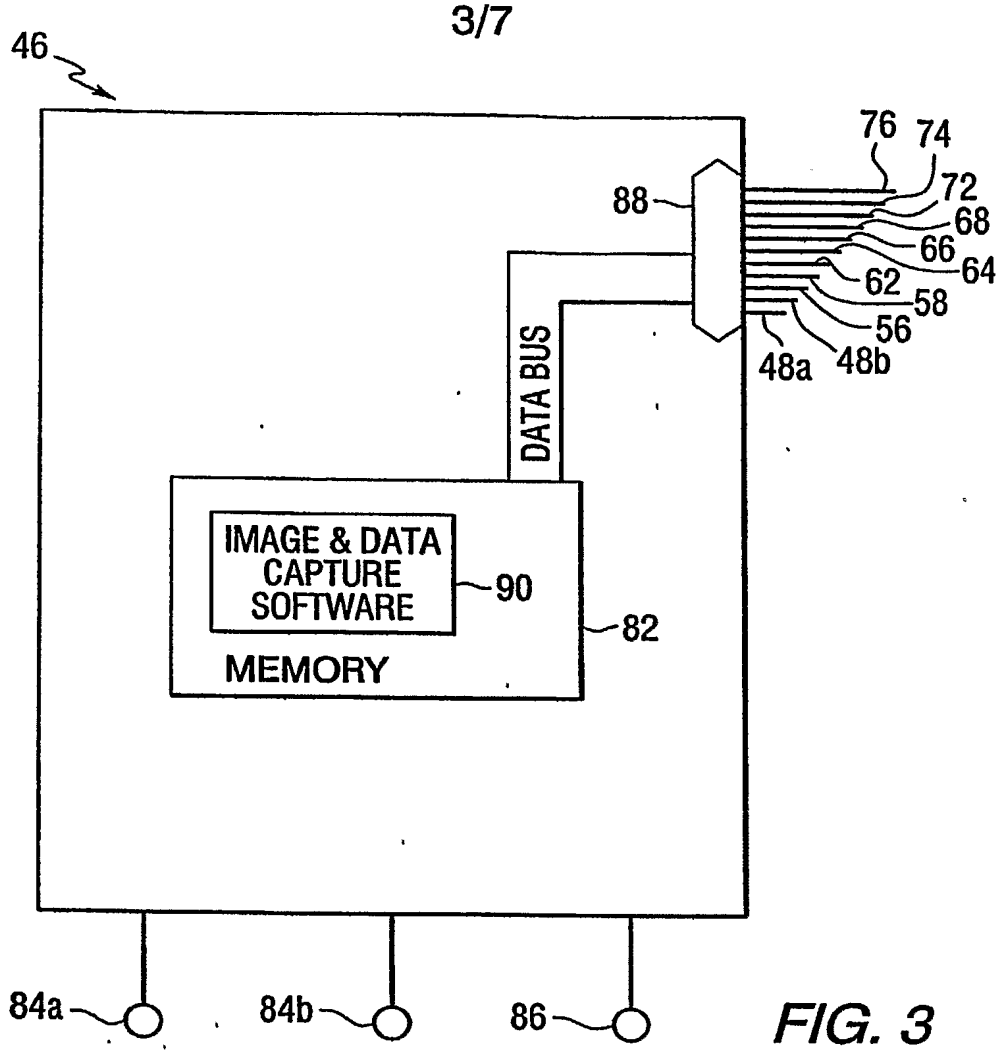

46
76
74
72
68
66
64
62
58
56
88
48a
48b
DATA BUS
IMAGE & DATA CAPTURE SOFTWARE
90
82
MEMORY
84a
84b
86

FIG. 3

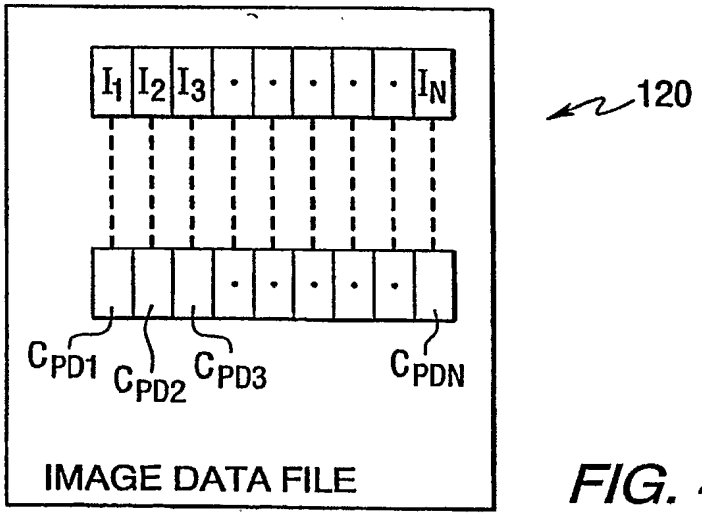

I_1 I_2 I_3 · · · · · I_N
120
C_{PD1} C_{PD2} C_{PD3} C_{PDN}
IMAGE DATA FILE

FIG. 4

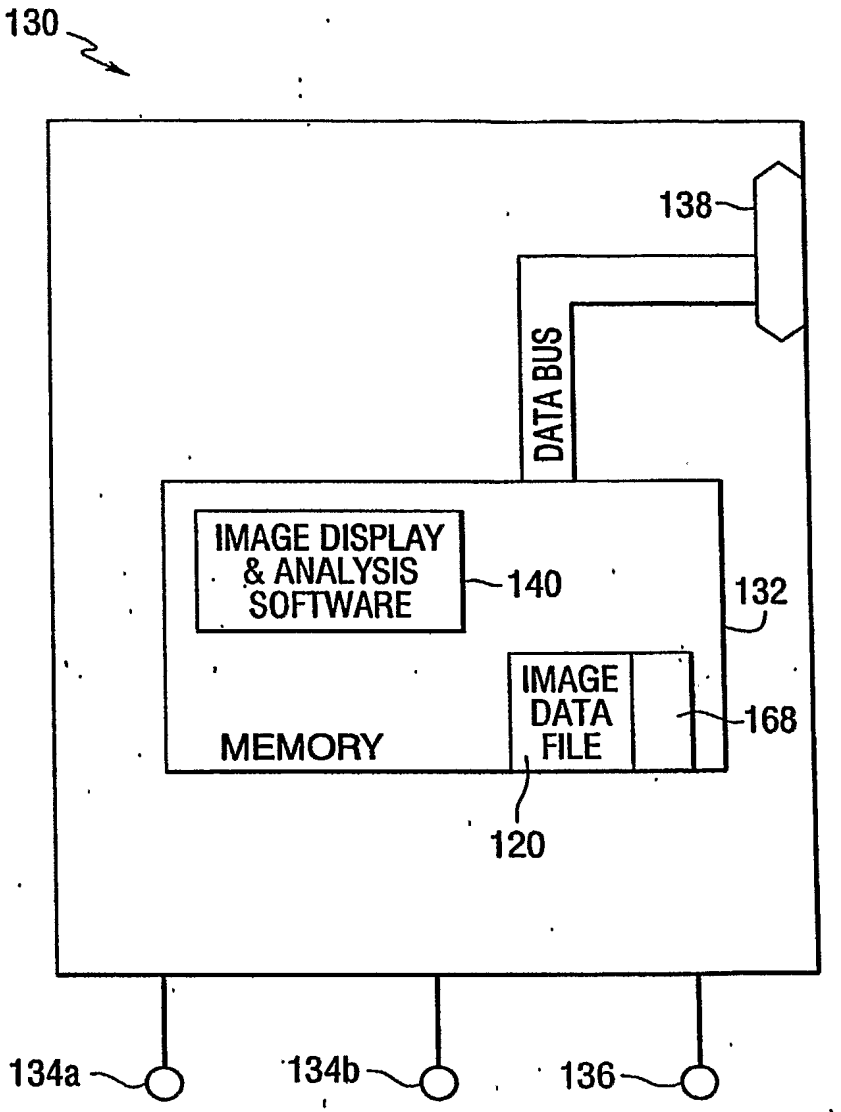

130
138
DATA BUS
IMAGE DISPLAY & ANALYSIS SOFTWARE
140
132
IMAGE DATA FILE
168
MEMORY
120
134a
134b
136

FIG. 5

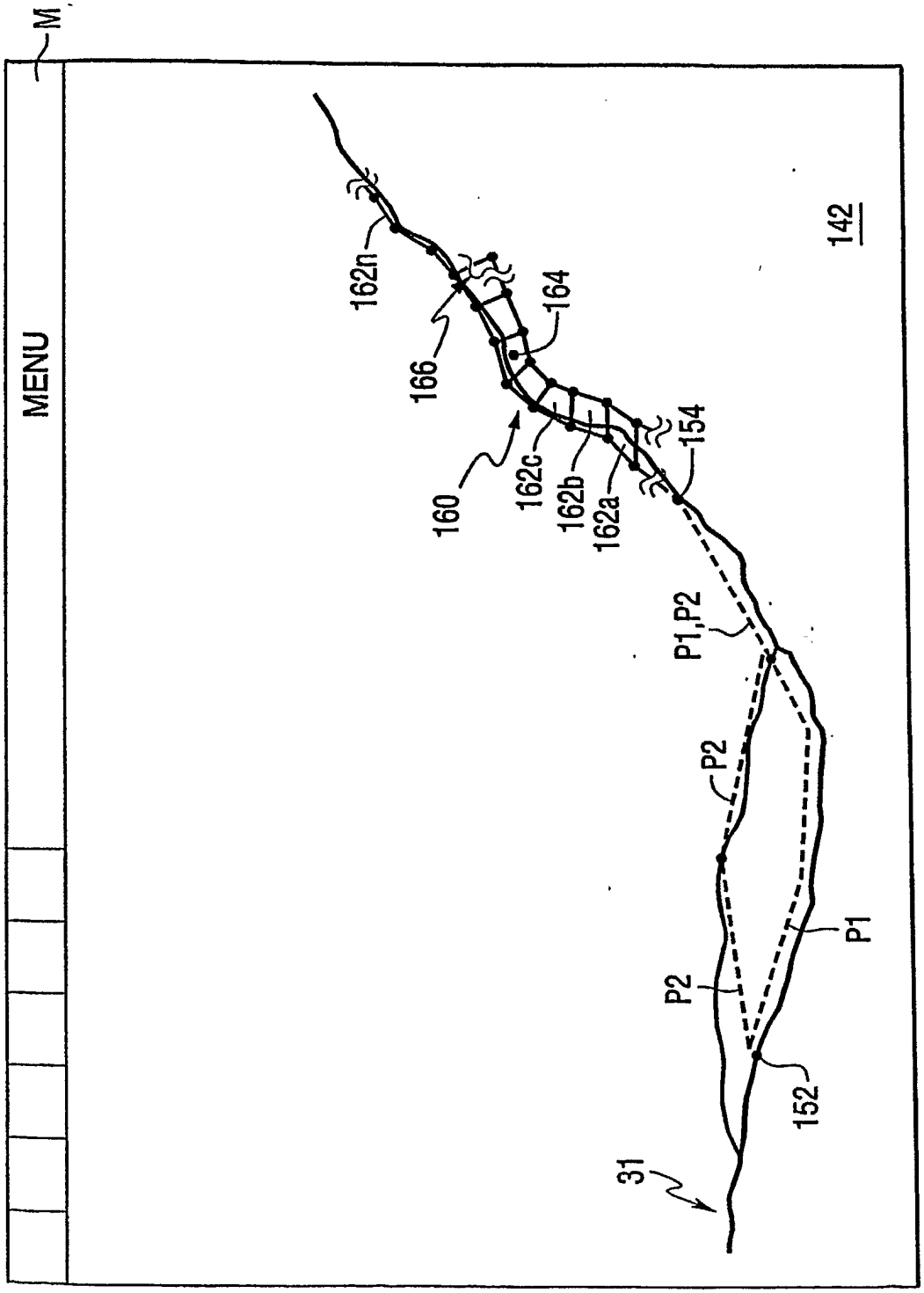

M
MENU
142
162n
166
164
160
162c
162b
162a
154
P1,P2
P2
P1
P2
152
31

FIG. 6

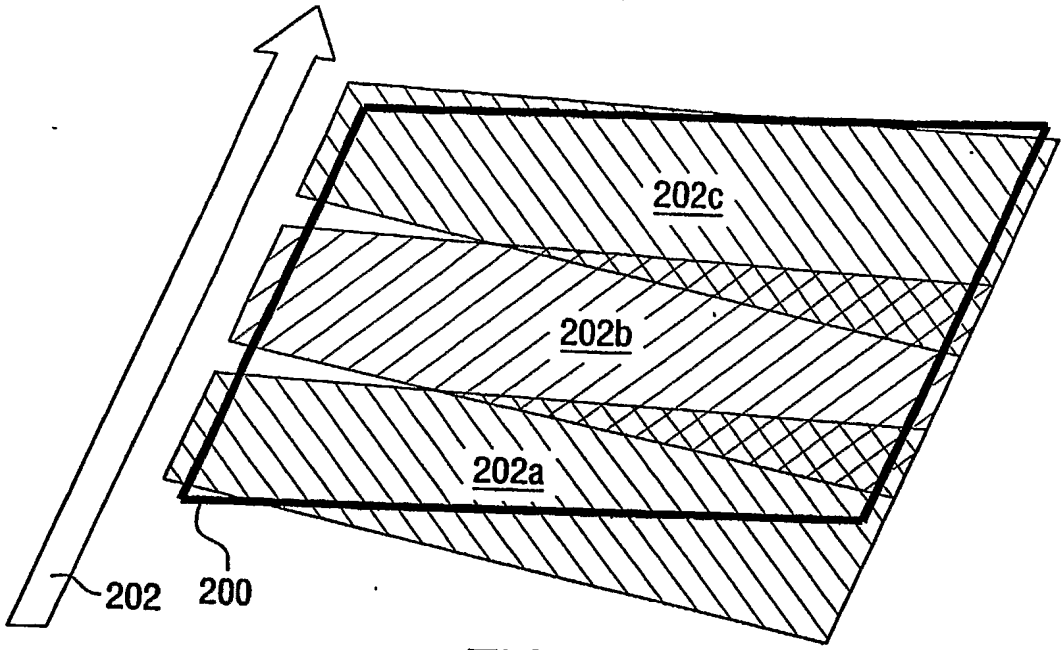


FIG. 7

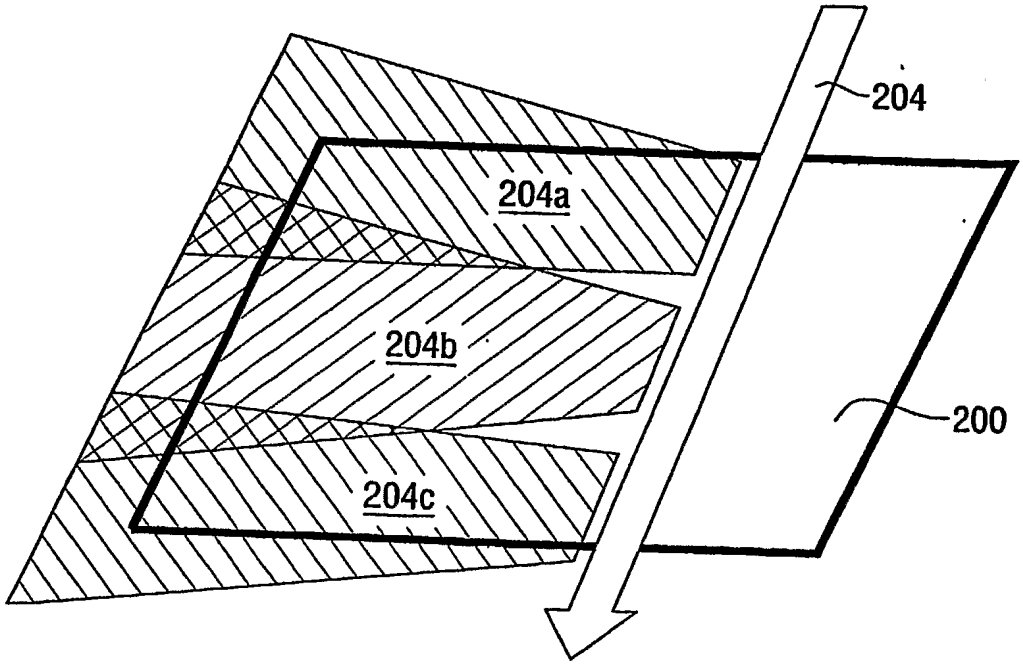


FIG. 8

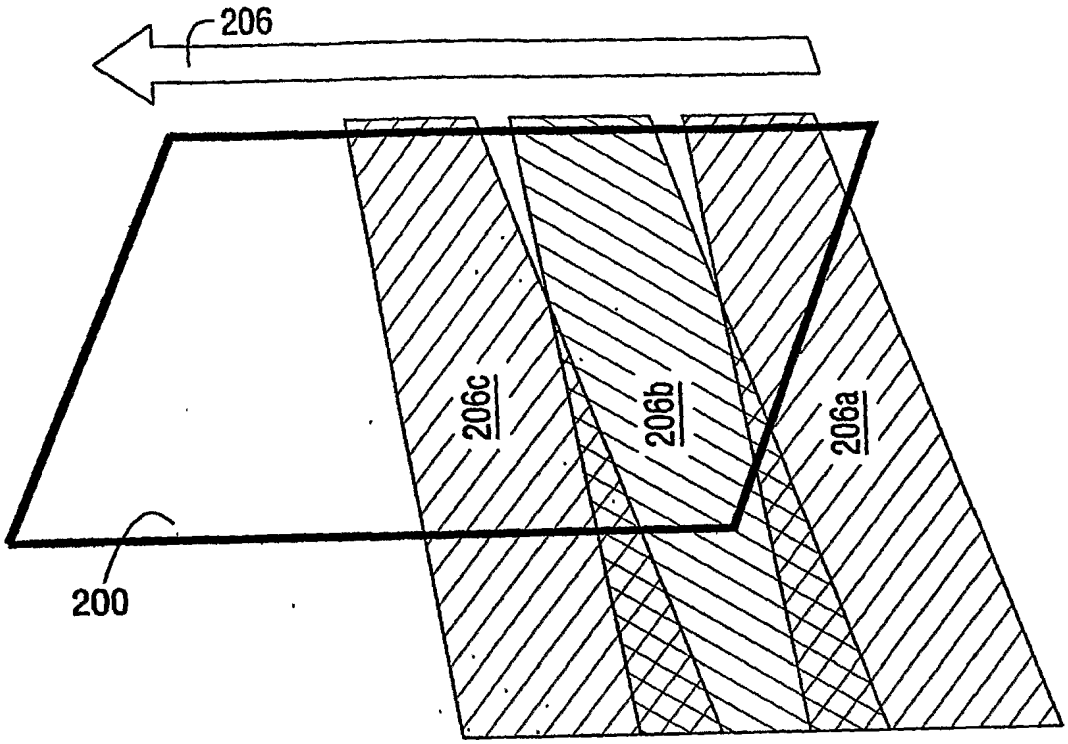


FIG. 9

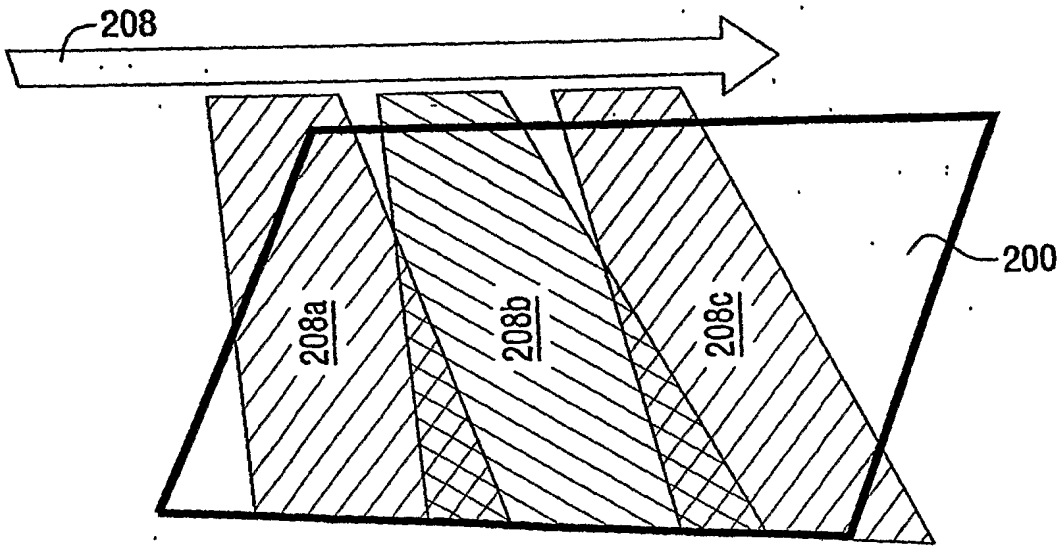


FIG. 10

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(54) Method and apparatus for capturing, geolocating and measuring oblique images

Verfahren und Gerät zur Erfassung, Geolokalisierung und Vermessung schräg aufgenommener Bilder

Procédé et appareil pour l'acquisition, géolocalisation et mesurage d'images obliques

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(56) References cited:
WO-A-99/18732 **US-A- 3 153 784**

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EP 1 418 402 B1

Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/425,275, filed November 8, 2002.

TECHNICAL FIELD

[0002] The present invention relates to photogrammetry. More particularly, the present invention relates to a method and apparatus for capturing oblique images and for measuring the objects and distances between the objects depicted therein.

BACKGROUND

[0003] Photogrammetry is the science of making measurements of and between objects depicted within photographs, especially aerial photographs. Generally, photogrammetry involves taking images of terrestrial features and deriving data therefrom, such as, for example, data indicating relative distances between and sizes of objects within the images. Photogrammetry may also involve coupling the photographs with other data, such as data representative of latitude and longitude. In effect, the image is overlaid and conformed to a particular spatial coordinate system.

[0004] Conventional photogrammetry involves the capture and/or acquisition of orthogonal images. The image-capturing device, such as a camera or sensor, is carried by a vehicle or platform, such as an airplane or satellite, and is aimed at a nadir point that is directly below and/or vertically downward from that platform. The point or pixel in the image that corresponds to the nadir point is the only point/pixel that is truly orthogonal to the image-capturing device. All other points or pixels in the image are actually oblique relative to the image-capturing device. As the points or pixels become increasingly distant from the nadir point they become increasingly oblique relative to the image-capturing device and the ground sample distance (i.e., the surface area corresponding to or covered by each pixel) also increases. Such obliqueness in an orthogonal image causes features in the image to be distorted, especially images relatively distant from the nadir point.

[0005] Such distortion is removed, or compensated for, by the process of ortho-rectification which, in essence, removes the obliqueness from the orthogonal image by fitting or warping each pixel of an orthogonal image onto an orthometric grid or coordinate system. The process of ortho-rectification creates an image wherein all pixels have the same ground sample distance and are oriented to the north. Thus, any point on an ortho-rectified image can be located using an X, Y coordinate system and, so long as the image scale is known, the length and width of terrestrial features as well as the relative distance between those features can be calculated.

[0006] Although the process of ortho-rectification compensates to a degree for oblique distortions in an orthogonal image, it introduces other undesirable distortions and/or inaccuracies in the ortho-rectified orthogonal image. Objects depicted in ortho-rectified orthogonal images may be difficult to recognize and/or identify since most observers are not accustomed to viewing objects, particularly terrestrial features, from above. To an untrained observer an ortho-rectified image has a number of distortions. Roads that are actually straight appear curved and buildings may appear to tilt. Further, ortho-rectified images contain substantially no information as to the height of terrestrial features. The interpretation and analysis of orthogonal and/or ortho-rectfified orthogonal images is typically performed by highly-trained analysts whom have undergone years of specialized training and experience in order to identify objects and terrestrial features in such images.

[0007] Thus, although orthogonal and ortho-rectified images are useful in photogrammetry, they lack information as to the height of features depicted therein and require highly-trained analysts to interpret detail from what the images depict.

[0008] Oblique images are images that are captured with the image-capturing device aimed or pointed generally to the side of and downward from the platform that carries the image-capturing device. Oblique images, unlike orthogonal images, display the sides of terrestrial features, such as houses, buildings and/or mountains, as well as the tops thereof. Thus, viewing an oblique image is more natural and intuitive than viewing an orthogonal or ortho-rectified image, and even casual observers are able to recognize and interpret terrestrial features and other objects depicted in oblique images. Each pixel in the foreground of an oblique image corresponds to a relatively small area of the surface or object depicted (i.e., each foreground pixel has a relatively small ground sample distance) whereas each pixel in the background corresponds to a relatively large area of the surface or object depicted (i.e., each background pixel has a relatively large ground sample distance). Oblique images capture a generally trapezoidal area or view of the subject surface or object, with the foreground of the trapezoid having a substantially smaller ground sample distance (i.e., a higher resolution) than the background of the trapezoid.

[0009] Oblique images are considered to be of little or no use in photogrammetry. The conventional approach of forcing the variously-sized foreground and background pixels of an oblique image into a uniform size to thereby warp the image onto a coordinate system dramatically distorts the oblique image and thereby renders identification of objects and the taking of measurements of objects depicted therein a laborious and inaccurate task. Correcting for terrain displacement within an oblique image by using an elevation model further distorts the images thereby increasing the difficulty with which meas-

urements can be made and reducing the accuracy of any such measurements.

[0010] Thus, although oblique images are considered as being of little or no use in photogrammetry, they are easily interpreted and contain information as to the height of features depicted therein. WO 99/18732 A1 discloses a system and method for capturing, geolocating and measuring oblique images comprising an image capturing device, a geolocating device, a computer system and image and data acquiring software, which associates the image data to the geolocating signal data.

Object of the invention

[0011] Therefore, what is needed in the art is a method and apparatus for photogrammetry that enable geo-location and accurate measurements within oblique images.

[0012] Moreover, what is needed in the art is a method and apparatus for photogrammetry that enable the measurement of heights and relative heights of objects within an image.

[0013] Furthermore, what is needed in the art is a method and apparatus for photogrammetry that utilizes more intuitive and natural images.

SUMMARY OF THE INVENTION

[0014] The present invention provides a system according to claim 1.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become apparent and be more completely understood by reference to the following description of one embodiment of the invention when read in conjunction with the accompanying drawings, wherein:

FIG. 1 illustrates one embodiment of a platform or vehicle carrying an image-capturing system of the present invention, and shows exemplary orthogonal and oblique images taken thereby;

FIG. 2 is a diagrammatic view of the image-capturing system of FIG. 1;

FIG. 3 is a block diagram of the image-capturing computer system of Fig. 2;

FIG. 4 is a representation of an exemplary output data file of the image-capturing system of Fig. 1;

FIG. 5 is a block diagram of one embodiment of an image display and measurement computer system of the present invention for displaying and taking measurements of and between objects depicted in the images captured by the image-capturing system of Fig. 1;

FIG. 6 depicts an exemplary image displayed on the system of Fig. 5, and illustrates one embodiment of the method of the present invention for the measurement of and between objects depicted in such an image;

FIGS. 7 and 8 illustrate one embodiment of a method for capturing oblique images of the present invention;

FIGS. 9 and 10 illustrate a second embodiment of a method for capturing oblique images of the present invention.

[0016] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate one preferred embodiment of the invention, in one form, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] Referring now to the drawings, and particularly to Fig. 1, one embodiment of an apparatus for capturing and geolocating oblique images of the present invention is shown. Apparatus 10 includes a platform or vehicle 20 that carries image-capturing and geolocating system 30.

[0018] Platform 20, such as, for example, an airplane, space shuttle, rocket, satellite, or any other suitable vehicle, carries image-capturing system 30 over a predefined area of and at one or more predetermined altitudes above surface 31, such as, for example, the earth's surface or any other surface of interest. As such, platform 20 is capable of controlled movement or flight, either manned or unmanned, along a predefined flight path or course through, for example, the earth's atmosphere or outer space. Image-capturing platform 20 includes a system for generating and regulating power (not shown) that includes, for example, one or more generators, fuel cells, solar panels, and/or batteries, for powering image-capturing system 30.

[0019] Image-capturing and geo-locating system 30, as best shown in Fig. 2, includes image capturing devices 32a and 32b, a global positioning system (GPS) receiver 34, an inertial navigation unit (INU) 36, clock 38, gyroscope 40, compass 42 and altimeter 44, each of which are interconnected with image-capturing computer system 46.

[0020] Image-capturing devices 32a and 32b, such as, for example, conventional cameras, digital cameras, digital sensors, charge-coupled devices, or other suitable image-capturing devices, are capable of capturing images photographically or electronically. Image-capturing devices 32a and 32b have known or determinable characteristics including focal length, sensor size and aspect ratio, radial and other distortion terms, principal point offset, pixel pitch, and alignment. Image-capturing devices 32a and 32b acquire images and issue image data signals (IDS) 48a and48b, respectively, corresponding to the particular images or photographs taken and which are stored in image-capturing computer system 46, as

will be more particularly described hereinafter.

[0021] As best shown in Fig. 1, image-capturing devices 32a and 32b have respective central axes A_1 and A_2, and are mounted to platform 20 such that axes A_1 and A_2 are each at an angle of declination θ relative to a horizontal plane *P*. Declination angle θ is virtually any oblique angle, but is preferably from approximately 20° (twenty degrees) to approximately 60° (sixty degrees) and is most preferably from approximately 40° (forty degrees) to approximately 50° (fifty degrees).

[0022] GPS receiver 34 receives global positioning system signals 52 that are transmitted by one or more global positioning system satellites 54. The GPS signals 52, in known fashion, enable the precise location of platform 20 relative to surface 31 to be determined. GPS receiver 34 decodes GPS signals 52 and issues location signals/data 56, that are dependent at least in part upon GPS signals 52 and which are indicative of the precise location of platform 20 relative to surface 31. Location signals/data 56 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0023] INU 36 is a conventional inertial navigation unit that is coupled to and detects changes in the velocity, including translational and rotational velocity, of image-capturing devices 32a and 32b and/or platform 20. INU 36 issues velocity signals/data 58 indicative of such velocities and/or changes therein to image-capturing computer system 46, which stores velocity signals/data 58 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0024] Clock 38 keeps a precise time measurement (time of validity) that is used to synchronize events within image-capturing and geo-locating system 30. Clock 38 provides time data/clock signal 62 that is indicative of the precise time that an image is taken by image-capturing devices 32a and 32b. Time data 62 is also provided to and stored by image-capturing computer system 46. Alternatively, clock 38 is integral with image-capturing computer system 46, such as, for example, a clock software program.

[0025] Gyroscope 40 is a conventional gyroscope as commonly found on airplanes and/or within commercial navigation systems for airplanes. Gyroscope 40 provides signals including pitch signal 64, roll signal 66 and yaw signal 68, which are respectively indicative of pitch, roll and yaw of platform 20. Pitch signal 64, roll signal 66 and yaw signal 68 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0026] Compass 42, such as, for example, a conventional electronic compass, indicates the heading of platform 20. Compass 42 issues heading signal/data 72 that is indicative of the heading of platform 20. Image-capturing computer system 46 receives and stores the heading signals/data 72 that correspond to each image captured by image-capturing devices 32a and 32b.

[0027] Altimeter 44 indicates the altitude of platform 20. Altimeter 44 issues altitude signal/data 74, and image-capturing computer system 46 receives and stores the altitude signal/data 74 that correspond to each image captured by image-capturing devices 32a and 32b.

[0028] As best shown in Fig. 3, image-capturing computer system 46, such as, for example, a conventional laptop personal computer, includes memory 82, input devices 84a and 84b, display device 86, and input and output (I/O) ports 88. Image-capturing computer system 46 executes image and data acquiring software 90, which is stored in memory 82. Memory 82 also stores data used and/or calculated by image-capturing computer system 46 during the operation thereof, and 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 84a and 84b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and interaction of a user with software being executed by image-capturing computer system 46. Display device 86, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image-capturing computer system 46. I/O ports 88, such as, for example, serial and parallel data input and output ports, enable the input and/or output of data to and from image-capturing computer system 46.

[0029] Each of the above-described data signals is connected to image-capturing computer system 46. More particularly, image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74 are received via I/O ports 88 by and stored within memory 82 of image-capturing computer system 46.

[0030] In use, image-capturing computer system 46 executes image and data acquiring software 90, which, in general, controls the reading, manipulation, and storing of the above-described data signals. More particularly, image and data acquiring software 90 reads image data signals 48a and 48b and stores them within memory 82. Each of the location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74 that represent the conditions existing at the instant an image is acquired or captured by image-capturing devices 32a and 32b and which correspond to the particular image data signals 48a and 48b representing the captured images are received by image-capturing computer system 46 via I/O ports 88. Image-capturing computer system 46 executing image and data acquiring software 90 issues image-capture signal 92 to image-capturing devices 32a and 32b to thereby cause those devices to acquire or capture an image at predetermined locations and/or at predetermined intervals which are dependent at least in part upon the velocity of platform 20.

[0031] Image and data acquiring software 90 decodes

as necessary and stores the aforementioned signals within memory 82, and associates the data signals with the corresponding image signals 48a and 48b. Thus, the altitude, orientation in terms of roll, pitch, and yaw, and the location of image-capturing devices 32a and 32b relative to surface 31, i.e., longitude and latitude, for every image captured by image-capturing devices 32a and 32b is known.

[0032] Platform 20 is piloted or otherwise guided through an image-capturing path that passes over a particular area of surface 31, such as, for example, a predefined area of the surface of the earth or of another planet. Preferably, the image-capturing path of platform 20 is at right angles to at least one of the boundaries of the area of interest. The number of times platform 20 and/or image-capturing devices 32a, 32b pass over the area of interest is dependent at least in part upon the size of the area and the amount of detail desired in the captured images. The particular details of the image-capturing path of platform 20 are described more particularly hereinafter.

[0033] As platform 20 passes over the area of interest a number of oblique images are captured by image-capturing devices 32a and 32b. As will be understood by those of ordinary skill in the art, images are captured or acquired by image-capturing devices 32a and 32b at predetermined image capture intervals which are dependent at least in part upon the velocity of platform 20.

[0034] Image data signals 48a and 48b corresponding to each image acquired are received by and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Similarly, the data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) corresponding to each captured image are received and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Thus, the location of image-capturing device 32a and 32b relative to surface 32 at the precise moment each image is captured is recorded within memory 82 and associated with the corresponding captured image.

[0035] As best shown in Fig. 1, the location of image-capturing devices 32a and 32b relative to the earth corresponds to the nadir point *N* of orthogonal image 102. Thus, the exact geo-location of the nadir point *N* of orthogonal image 102 is indicated by location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74. Once the nadir point *N* of orthogonal image 102 is known, the geo-location of any other pixel or point within image 102 is determinable in known manner.

[0036] When image-capturing devices 32a and 32b are capturing oblique images, such as oblique images 104a and 104b (Fig. 1), the location of image-capturing devices 32a and 32b relative to surface 31 is similarly indicated by location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72, altitude signal 74 and the known angle of declination θ of the primary axes A_1 *and* A_2 of image-capturing devices 32a and 32b, respectively.

[0037] It should be particularly noted that a calibration process enables image and data acquiring software 90 to incorporate correction factors and/or correct for any error inherent in or due to image-capturing device 32, such as, for example, error due to calibrated focal length, sensor size, radial distortion, principal point offset, and alignment.

[0038] Image and data acquiring software 90 creates and stores in memory 82 one or more output image and data files 120. More particularly, image and data acquiring software 90 converts image data signals 48a, 48b and the orientation data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) into computer-readable output image and data files 120. As best shown in Fig. 4, output image and data file 120 contains a plurality of captured image files I_1, I_2, ..., I_n corresponding to captured oblique images, and the positional data C_{PD1}, C_{PD2}, ... , C_{PDn} corresponding thereto.

[0039] Image files I_1, I_2, ..., I_n of the image and data file 120 are stored in virtually any computer-readable image or graphics file format, such as, for example, JPEG, TIFF, GIF, BMP, or PDF file formats, and are cross-referenced with the positional data C_{PD1}, C_{PD2}, ..., C_{PDn} which is also stored as computer-readable data. Alternatively, positional data C_{PD1}, C_{PD2}, ..., C_{PDn} is embedded within the corresponding image files I_1, I_2, ..., I_n in known manner. Image data files 120 are then processed, either by image and data acquiring software 90 or by post-processing, to correct for errors, such as, for example, errors due to flight path deviations and other errors known to one of ordinary skill in the art. Thereafter, image data files 120 are ready for use to display and make measurements of and between the objects depicted within the captured images, including measurements of the heights of such objects.

[0040] Referring now to Fig. 5, image display and measurement computer system 130, such as, for example, a conventional desktop personal computer or a mobile computer terminal in a police car, includes memory 132, input devices 134a and 134b, display device 136, and network connection 138. Image-capturing computer system 130 executes image display and analysis software 140, which is stored in memory 132. Memory 132 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 134a and 134b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and interaction of a user with image display and analysis software 140 being executed by image display and measurement

computer system 130. Display device 136, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image display and measurement computer system 130. Network connection 138 connects image display and measurement computer system 130 to a network (not shown), such as, for example, a local-area network, wide-area network, the Internet and/or the World Wide Web.

[0041] In use, and referring now to Fig. 6, image display and measurement computer system 130 executing image display and analysis software 140 accesses one or more output image and data files 120 that have been read into memory 132, such as, for example, via network connection 138, a floppy disk drive, removable memory card or other suitable means. One or more of the captured images I_1, I_2, ..., I_n of output image and data files 120 is thereafter displayed as displayed oblique image 142 under the control of image display and analysis software 140. At approximately the same time, one or more data portions C_{PD1}, C_{PD2}, ..., C_{PDn} corresponding to displayed oblique image 142 are read into a readily-accessible portion of memory 132.

[0042] It should be particularly noted that displayed oblique image 142 is displayed substantially as captured, i.e., displayed image 142 is not warped or fitted to any coordinate system nor is displayed image 142 ortho-rectified. Rather than warping displayed image 142 to a coordinate system in order to enable measurement of objects depicted therein, image display and analysis software 140, in general, determines the geo-locations of selected pixels only as needed, or "on the fly", by referencing data portions C_{PD1}, C_{PD2}, ..., C_{PDn} of output image and data files 120 and calculating the position and/or geo-location of those selected pixels using one or more projection equations as is more particularly described hereinafter.

[0043] Generally, a user of display and measurement computer system 130 takes measurements of and between objects depicted in displayed oblique image 142 by selecting one of several available measuring modes provided within image display and analysis software 140. The user selects the desired measurement mode by accessing, for example, a series of pull-down menus or toolbars *M*, or via keyboard commands. The measuring modes provided by image display and analysis software 140 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.

[0044] After selecting the desired measurement mode, the user of image display and analysis software 140 selects with one of input devices 134a, 134b a starting point or starting pixel 152 and an ending point or pixel 154 on displayed image 142, and image display and analysis software 140 automatically calculates and displays the quantity sought, such as, for example, the distance between starting pixel 152 and ending pixel 154.

[0045] When the user selects starting point/pixel 152, the geo-location of the point corresponding thereto on surface 31 is calculated by image display and analysis software 140 which executes one or more projection equations using the data portions C_{PD1}, C_{PD2}, ..., C_{PDn} of output image and data files 120 that correspond to the particular image being displayed. The longitude and latitude of the point on surface 31 corresponding to pixel 152 are then displayed by image display and analysis software 140 on display 136, such as, for example, by superimposing the longitude and latitude on displayed image 142 adjacent the selected point/pixel or in pop-up display box elsewhere on display 136. The same process is repeated by the user for the selection of the end pixel/point 154, and by image display and analysis software 140 for the retrieval and display of the longitude and latitude information.

[0046] The calculation of the distance between starting and ending points/pixels 152, 154, respectively, is accomplished by determining the geo-location of each selected pixel 152, 154 "on the fly". The data portions C_{PD1}, C_{PD2}, ..., C_{PDn} of output image and data file 120 corresponding to the displayed image are retrieved, and the geo-location of the point on surface 31 corresponding to each selected pixel are then determined. The difference between the geo-locations corresponding to the selected pixels determines the distance between the pixels.

[0047] As an example of how the geo-location of a given point or pixel within displayed oblique image 142 is determined, we will assume that displayed image 142 corresponds to orthogonal image 104a (Fig. 1). The user of image display and analysis software 140 selects pixel 152 which, for simplicity, corresponds to center *C* (Fig. 1) of oblique image 104a. As shown in Fig. 1, line 106 extends along horizontal plane *G* from a point 108 thereon that is directly below image-capturing device 32a to the center *C* of the near border or edge 108 of oblique image 104a. An extension of primary axis A_1 intersects with center *C*. Angle ∅ is the angle formed between line 106 the extension of primary axis A_1. Thus, a triangle (not referenced) is formed having vertices at image-capturing device 32a, point 108 and center *C*, and having sides 106, the extension of primary axis A_1 and vertical (dashed) line 110 between point 108 and image-capturing device 32a.

[0048] Ground plane *G* is a substantially horizontal, flat or non-sloping ground plane (and which typically will have an elevation that reflects the average elevation of the terrain), and therefore the above-described triangle includes a right angle between side/line 110 and side/line 106. Since angle ∅ and the altitude of image-capturing device 32 (i.e., the length of side 110) are known, the hypotenuse (i.e., the length of the extension of primary axis A_1) and remaining other side of the right trian-

gle are calculated by simple geometry. Further, since the exact position of image-capturing device 32a is known at the time the image corresponding to displayed image 142 was captured, the latitude and longitude of point 108 are also known. Knowing the length of side 106, calculated as described above, enables the exact geo-location of pixel 154 corresponding to center *C* of oblique image 104a to be determined by image display and analysis software 140. Once the geo-location of the point corresponding to pixel 154 is known, the geo-location of any other pixel in displayed oblique image 142 is determinable using the known camera characteristics, such as, for example, focal length, sensor size and aspect ratio, radial and other distortion terms, etc.

[0049] The distance between the two or more points corresponding to two or more selected pixels within displayed image 142 is calculated by image display and analysis software 140 by determining the difference between the geo-locations of the selected pixels using known algorithms, such as, for example, the Gauss formula and/or the vanishing point formula, dependent upon the selected measuring mode. The measurement of objects depicted or appearing in displayed image 142 is conducted by a substantially similar procedure to the procedure described above for measuring distances between selected pixels. For example, the lengths, widths and heights of objects, such as, for example, buildings, rivers, roads, and virtually any other geographic or man-made structure, appearing within displayed image 142 are measured by selecting the appropriate/desired measurement mode and selecting starting and ending pixels.

[0050] It should be particularly noted that in the distance measuring mode of image display and analysis software 140 the distance between the starting and ending points/pixels 152, 154, respectively, is determinable along virtually any path, such as, for example, a "straight-line" path *P1* or a path *P2* that involves the selection of intermediate points/pixels and one or more "straight-line" segments interconnected therewith.

[0051] It should also be particularly noted that the distance measuring mode of image display and analysis software 140 determines the distance between selected pixels according to a "walk the earth" method. The "walk the earth method" creates a series of interconnected line segments, represented collectively by paths *P1* and *P2*, that extend between the selected pixels/points and which lie upon or conform to the planar faces of a series of interconnected facets that define a tessellated ground plane. The tessellated ground plane, as will be more particularly described hereinafter, closely follows or recreates the terrain of surface 31, and therefore paths *P1* and *P2* also closely follow the terrain of surface 31. By measuring the distance along the terrain simulated by the tessellated ground plane, the "walk the earth" method provides for a more accurate and useful measurement of the distance between selected points than the conventional approach, which warps the image onto a flat earth or average elevation plane system and measures the distance between selected points along the flat earth or plane and substantially ignores variations in terrain between the points.

[0052] For example, a contractor preparing to bid on a contract for paving a roadway over uneven or hilly terrain can determine the approximate amount or area of roadway involved using image display and analysis software 140 and the "walk the earth" measurement method provided thereby. The contractor can obtain the approximate amount or area of roadway from his or her own office without having to send a surveying crew to the site to obtain the measurements necessary.

[0053] In contrast to the "walk the earth" method provided by the present invention, the "flat earth" or average elevation distance calculating approaches include inherent inaccuracies when measuring distances between points and/or objects disposed on uneven terrain and when measuring the sizes and/or heights of objects similarly disposed. Even a modest slope or grade in the surface being captured results in a difference in the elevation of the nadir point relative to virtually any other point of interest thereon. Thus, referring again to Fig. 1, the triangle formed by line 106, the extension of primary axis A_1 and the vertical (dashed) line 110 between point 108 and image-capturing device 32a may not be a right triangle. If such is the case, any geometric calculations assuming that triangle to be a right triangle would contain errors, and such calculations would be reduced to approximations due to even a relatively slight gradient or slope between the points of interest.

[0054] For example, if surface 31 slopes upward between nadir point *N* and center *C* at the near or bottom edge 108 of oblique image 104 then second line 110 intersects surface 31 before the point at which such intersection would occur on a level or non-sloping surface 31. If center *C* is fifteen feet higher than nadir point *N* and with a declination angle θ equal to 40° (forty degrees), the calculated location of center *C* would be off by approximately 17.8 feet without correction for the change in elevation between the points.

[0055] As generally discussed above, in order to compensate at least in part for changes in elevation and the resultant inaccuracies in the measurement of and between objects within image 142, image display and analysis software 140 references, as necessary, points within displayed image 142 and on surface 31 to a pre-calculated tessellated or faceted ground plane generally designated 160 in Fig. 6. Tessellated ground plane 160 includes a plurality of individual facets 162a, 162b, 162c, etc., each of which are interconnected to each other and are defined by four vertices (not referenced, but shown as points) having respective elevations. Adjacent pairs of facets 162a, 162b, 162c, etc., share two vertices. Each facet 162a, 162b, 162c, etc., has a respective pitch and slope. Tessellated ground plane 160 is created based upon various data and resources, such as, for example, topographical maps, and/or digital raster graphics, sur-

vey data, and various other sources.

[0056] Generally, the geo-location of a point of interest on displayed image 142 is calculated by determining which of facets 162a, 162b, 162c, etc., correspond to that point of interest. Thus, the location of the point of interest is calculated based on the characteristics, i.e., elevation, pitch and slope, of facets 162a, 162b, 162c, etc., rather than based upon a flat or average-elevation ground plane. Error is introduced only in so far as the topography of surface 31 and the location of the point of interest thereon deviate from the planar surface of the facet 162a, 162b, 162c, etc, within which the point of interest lies. That error is reducible through a bilinear interpolation of the elevation of the point of interest within a particular one of facets 162a, 162b, 162c, etc., and using that interpolated elevation in the location calculation performed by image display and analysis software 140.

[0057] To use tessellated ground plane 160, image display and analysis software 140 employs a modified ray-tracing algorithm to find the intersection of the ray projected from the image-capturing device 32a or 32b towards surface 31 and tessellated ground plane 160. The algorithm determines not only which of facets 162a, 162b, 162c, etc., is intersected by the ray, but also where within the facet the intersection occurs. By use of bi-linear interpolation, a fairly precise ground location can be determined. For the reverse projection, tessellated ground plane 160 is used to find the ground elevation value for the input ground location also using bi-linear interpolation. The elevation and location are then used to project backwards through a model of the image-capturing device 32a or 32b to determine which of the pixels within displayed image 142 corresponds to the given location.

[0058] More particularly, and as an example, image display and analysis software 140 performs and/or calculates the geo-location of point 164 by superimposing and/or fitting tessellated ground plane 160 to at least a portion 166, such as, for example, a hill, of surface 31. It should be noted that only a small portion of tessellated ground plane 160 and facets 162a, 162b, 162c, etc., thereof is shown along the profile of portion 166 of surface 31. As discussed above, each of facets 162a, 162b, 162c, etc., are defined by four vertices, each of which have respective elevations, and each of the facets have respective pitches and slopes. The specific position of point 164 upon the plane/surface of the facet 162a, 162b, 162c, etc., within which point 164 (or its projection) lies is determined as described above.

[0059] Tessellated ground plane 160 is preferably created outside the operation of image display and measurement computer system 130 and image display and analysis software 140. Rather, tessellated ground plane 160 takes the form of a relatively simple data table or look-up table 168 stored within memory 132 of and/or accessible to image display and measurement computer system 130. The computing resources required to calculate the locations of all the vertices of the many facets of a typical ground plane do not necessarily have to reside within image display and measurement computer system 130. Thus, image display and measurement computer system 130 is compatible for use with and executable by a conventional personal computer without requiring additional computing resources.

[0060] Calculating tessellated ground plane 160 outside of image display and measurement computer system 130 enables virtually any level of detail to be incorporated into tessellated ground plane 160, i.e., the size and/or area covered by or corresponding to each of facets 162a, 162b, 162c, etc., can be as large or as small as desired, without significantly increasing the calculation time, slowing the operation of, nor significantly increasing the resources required by image display and measurement computer system 130 and/or image display and analysis software 140. Display and measurement computer system 130 can therefore be a relatively basic and uncomplicated computer system.

[0061] The size of facets 162a, 162b, 162c, etc., are uniform in size throughout a particular displayed image 142. For example, if displayed image 142 corresponds to an area that is approximately 750 feet wide in the foreground by approximately 900 feet deep, the image can be broken into facets that are approximately 50 square feet, thus yielding about 15 facets in width and 18 facets in depth. Alternatively, the size of facets 162a, 162b, 162c, etc., are uniform in terms of the number of pixels contained therein, i.e., each facet is the same number of pixels wide and the same number of pixels deep. Facets in the foreground of displayed image 142, where the pixel density is greatest, would therefore be dimensionally smaller than facets in the background of displayed image 142 where pixel density is lowest. Since it is desirable to take most measurements in the foreground of a displayed image where pixel density is greatest, creating facets that are uniform in terms of the number of pixels they contain has the advantage of providing more accurate measurements in the foreground of displayed image 142 relative to facets that are dimensionally uniform.

[0062] Another advantage of using pixels as a basis for defining the dimensions of facets 162a, 162b, 162c, etc., is that the location calculation (pixel location to ground location) is relatively simple. A user operates image display and measurement computer system 130 to select a pixel within a given facet, image display and analysis software 140 looks up the data for the facet corresponding to the selected pixel, the elevation of the selected pixel is calculated as discussed above, and that elevation is used within the location calculation.

[0063] Generally, the method of capturing oblique images of the present invention divides an area of interest, such as, for example, a county, into sectors of generally uniform size, such as, for example, sectors that are approximately one square mile in area. This is done to facilitate the creation of a flight plan to capture oblique images covering every inch of the area of interest, and to organize and name the sectors and/or images thereof for easy reference, storage and retrieval (a process

known in the art as "sectorization"). Because the edges of any geographic area of interest, such as a county, rarely falls on even square mile boundaries, the method of capturing oblique images of the present invention provides more sectors than there are square miles in the area of interest - how many more depends largely on the length of the county borders as well as how straight or jagged they are. Typically, you can expect one extra sector for every two to three miles of border. So if a county or other area of interest is roughly 20 miles by 35 miles, or 700 square miles, the area will be divided into approximately from 740 to 780 sectors.

[0064] The method of capturing oblique images of the present invention, in general, captures the oblique images from at least two compass directions, and provides full coverage of the area of interest from at least those two compass directions. Referring now to Figs. 7 and 8, a first embodiment of a method for capturing oblique images of the present invention is shown. For sake of clarity, Fig. 7 and 8 is based on a system having only one image-capturing device. However, it is to be understood that two or more image-capturing devices can be used.

[0065] The image-capturing device captures one or more oblique images during each pass over area 200. The image-capturing device, as discussed above, is aimed at an angle over area 200 to capture oblique images thereof. Area 200 is traversed in a back-and-forth pattern, similar to the way a lawn is mowed, by the image-carrying device and/or the platform to ensure double coverage of area 200.

[0066] More particularly, area 200 is traversed by image-carrying device 32 and/or platform 20 following a first path 202 to thereby capture oblique images of portions 202a, 202b, and 202c of area 200. Area 200 is then traversed by image-carrying device 32 and/or platform 20 following a second path 204 that is parallel and spaced apart from, and in an opposite direction to, i.e., 180° (one-hundred and eighty degrees) from, first path 202, to thereby capture oblique images of portions 204a, 204b, 204c of area 200. By comparing Figs. 7 and 8, it is seen that a portion 207 (Fig. 8) of area 200 is covered by images 202a-c captured from a first direction or perspective, and by images 204a-c captured from a second direction or perspective. As such, the middle portion of area 200 is 100% (one-hundred percent) double covered. The above-described pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 202 and 204 is repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from each other as dictated by the size of area 200, and in the same direction as paths 202 and 204 to thereby one-hundred percent double cover area 200 from those perspectives/directions.

[0067] If desired, and for enhanced detail, area 200 is covered by two additional opposing and parallel third and fourth paths 206 and 208, respectively, that are perpendicular to paths 202 and 204 as shown in Figs. 9 and 10. Area 200 is therefore traversed by image-carrying device 32 and/or platform 20 following third path 206 to capture oblique images of portions 206a, 206b and 206c of area 200, and is then traversed along fourth path 208 that is parallel, spaced apart from, and opposite to third path 206 to capture oblique images of portions 208a, 208b and 208c of area 200. This pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 206 and 208 is similarly repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from as dictated by the size of area 200, and in the same direction as paths 206 and 208 to thereby one-hundred percent double cover area 200 from those directions/perspectives.

[0068] As described above, image-carrying device 32 and/or platform 20, traverses or passes over area 200 along a predetermined path. However, it is to be understood that image-carrying device and/or platform 20 do not necessarily pass or traverse directly over area 200 but rather may pass or traverse an area adjacent, proximate to, or even somewhat removed from, area 200 in order to ensure that the portion of area 200 that is being imaged falls within the image-capture field of the image-capturing device. Path 202, as shown in Fig. 7, is such a path that does not pass directly over area 200 but yet captures oblique images thereof.

[0069] The present invention is capable of capturing images at various levels of resolution or ground sample distances. A first level of detail, hereinafter referred to as a community level, has a ground sample distance of, for example, approximately two-feet per pixel. For orthogonal community-level images, the ground sample distance remains substantially constant throughout the image. Orthogonal community-level images are captured with sufficient overlap to provide stereo pair coverage. For oblique community-level images, the ground sample distance varies from, for example, approximately one-foot per pixel in the foreground of the image to approximately two-feet per pixel in the mid-ground of the image, and to approximately four-feet per pixel in the background of the image. Oblique community-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction captured. Approximately ten oblique community-level images are captured per sector.

[0070] A second level of detail, hereinafter referred to as a neighborhood level, is significantly more detailed than the community-level images. Neighborhood-level images have a ground sample distance of, for example, approximately six-inches per pixel. For orthogonal neighborhood-level images, the ground sample distance remains substantially constant. Oblique neighborhood-level images have a ground sample distance of, for example, from approximately four-inches per pixel in the foreground of the image to approximately six-inches per pixel in the mid-ground of the image, and to approximately ten-

inches per pixel in the background of the image. Oblique neighborhood-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction captured, and such that opposing compass directions provide 100% overlap with each other. Approximately one hundred (100) oblique area images are captured per sector.

[0071] It should be particularly noted that capturing oblique community and/or neighborhood-level images from all four compass directions ensures that every point in the image will appear in the foreground or lower portion of at least one of the captured oblique images, where ground sample distance is lowest and image detail is greatest.

[0072] In the embodiment shown, image-capturing and geo-locating system 30 includes a gyroscope, compass and altimeter. However, it is to be understood that the image-capturing and geo-locating system of the present invention can be alternately configured, such as, for example, to derive and/or calculate altitude, pitch, roll and yaw, and compass heading from the GPS and INU signals/data, thereby rendering one or more of the gyroscope, compass and altimeter unnecessary.

[0073] In the embodiment shown, image-capturing devices are at an equal angle of declination relative to a horizontal plane. However, it is to be understood that the declination angles of the image-capturing devices do not have to be equal.

[0074] In the embodiment shown, image-capturing computer system executes image and data acquiring software that issues a common or single image-capture signal to the image-capturing devices to thereby cause those devices to acquire or capture an image. However, it is to be understood that the present invention can be alternately configured to separately cause the image-capturing devices to capture images at different instants and/or at different intervals.

[0075] In the embodiment shown, the method of the present invention captures oblique images to provide double coverage of an area of interest from paths/perspectives that are substantially opposite to each other, i.e., 180° (one-hundred and eighty degrees) relative to each other. However, it is to be understood that the method of the present invention can be alternately configured to provide double coverage from paths/perspectives that are generally and/or substantially perpendicular relative to each other.

[0076] While the present invention has been described as having a preferred design, the invention can be further modified within the scope of the claims. This disclosure is therefore intended to encompass any equivalents to the structures and elements disclosed herein. Further, this disclosure is intended to encompass any variations, uses, or adaptations of the present invention that use the general principles disclosed herein. Moreover, this disclosure is intended to encompass any departures from the subject matter disclosed that come within the known or customary practice in the pertinent art and which fall within the limits of the appended claims.

Claims

1. A computerized system for displaying, geolocating, and making measurements based upon captured oblique images, comprising:

   a computer system (130) having a memory (132);
   an image and data file (120) accessible by said system (130) and including a plurality of image files corresponding to a plurality of captured oblique images, said image and data file (120) further including positional data corresponding to said plurality of image files; and
   image display and analysis software (140) executed by said system (130) for reading said image and data file (120) and displaying at least a portion of the captured oblique images as a displayed oblique image, said image display and analysis software (140) calculating the geo-locations of two or more selected points within said displayed oblique image based at least in part upon said positional data, said image display and analysis software (140) calculating a separation distance between any two or more selected points within said displayed oblique image;
   characterized by
   a ground plane data file representing a tessellated ground plane (160), said ground plane data file providing data to said image display and analysis software (140), said ground plane data file representing a tessellated ground plane that closely approximates at least a portion of the terrain depicted within said captured oblique images, said tessellated ground plane further comprising a plurality of interconnected images, said tessellated ground plane further comprising a plurality of interconnected facets (162a, 162b, 162c, ...), each of said plurality of facets having a respective pitch and slope, said ground plane data file comprising a plurality of vertices, each of said plurality of vertices having respective elevations and defining corners of said plurality of interconnected facets (162a, 162b, 162c, ...), two of said plurality of vertices shared by each of said interconnected facets; and
   said image display and analysis software (140) identifying which of said plurality of facets corresponds to a selected point on said displayed oblique image, and calculating an elevation of said selected point dependent at least in part upon the elevation of the vertices of the facet corresponding to the selected point, said image display and analysis software (140) using said

calculated elevation for calculating said separation distance between said selected point and one or more further selected points.

2. The system of claim 1, wherein
said image display and analysis software (140) calculating said geo-locations only as needed.

3. The system of claim 1 or 2, wherein said image display and analysis software (140) calculates a height of an object within said displayed oblique image by calculating the separation distance between two or more selected points.

4. The system of one of the claims 1 to 3, wherein said tessellated ground plane (160) is superimposed upon and fit to said displayed oblique image.

5. The system of one of the claims 1 to 4, wherein said image display and analysis software (140) includes user-selectable measuring modes accessible through at least one of pull-down menus, toolbars and keyboard commands.

6. The system of one of the claims 1 to 5, wherein each of said images were captured by an image-capturing device (32a, 32b) and at respective image capturing events, said positional data of said image and data file including:

time data representing the time of each image-capturing event;
location data representing the location of the image-capturing device (32a, 32b) at each image-capturing event;
orientation data representing the orientation of the image-capturing device (32a, 32b) at each image-capturing event;
correction data representing correction factors for the image-capturing device (32a, 32b); and
elevation data representing an average elevation of the surface captured by the image-capturing device (32a, 32b).

7. The system of claim 6, wherein said location data includes latitude, longitude, and altitude of the image-capturing apparatus (32a, 32b) at each image-capturing event.

8. The system of claim 6 or 7, wherein said orientation data includes roll, pitch, yaw and heading of said image-capturing device (32a, 32b) at each image-capturing event.

9. The system of one of the claims 6 to 8, wherein said image-capturing device (32a, 32b) is a camera and said correction data includes at least one of focal length, sensor size, aspect ratio, principal point offset, distortion, and pixel pitch.

10. The system of one of the claims 6 to 9, comprising:

an input device (134a, 134b) for selecting a starting point and an end point on the displayed oblique image; and
said image display and analysis software (140) for retrieving from said data file positional data corresponding to said starting point and said end point; for referencing said ground plane data file corresponding to said tessellated ground plane having a plurality of facets, each of said facets having a respective pitch and slope, said tessellated ground plane closely matching a terrain of said displayed oblique image; for connecting said starting and end points with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and for calculating the linear distance along said line segments between said starting and end points thereby taking into account said pitch and slope of said facets.

11. The system of one of the claims 1 to 10, wherein said image display and analysis software (140) superimposes said tessellated ground plane upon said displayed oblique image.

12. The system of claim 10 or 11, comprising:

said input device (134a, 134b) for selecting one or more intermediate points on said displayed oblique image; and
said image display and analysis software (140) for retrieving from said data file positional data corresponding to said one or more intermediate points; for connecting adjacent intermediate points to each other, and connecting said starting and end points to adjacent intermediate points, with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and for calculating the distance along said line segments between said starting and end points.

13. The system of one of the claims 1 to 12, wherein said plurality of facets (162a, 162b, 162c, ...) each correspond to equal areas of said displayed oblique image.

14. The system of one of the claims 1 to 13, wherein said plurality of facets (162a, 162b, 162c, ...) each includes an equal number of pixels of said displayed oblique image.

15. The system of one of the claims 1 to 14, comprising an input device (134a, 134b) for selecting one or

more intermediate points on said displayed oblique image; and the said image display and analysis software (140) for retrieving the positional data corresponding to said intermediate points.

16. The system of one of the claims 1 to 15, wherein said separation distance comprises a distance between two or more selected points, a height difference between two or more selected points, a difference in elevation of two or more selected points, and an area encompassed by at least three points.

17. The system of one of the claims 1 to 16, comprising:

an image-capturing device (32a, 32b), said image-capturing device (32a, 32b) capturing oblique images at image-capturing events, said image capturing device (32a, 32b) issuing image-data signals corresponding to captured images;
at least one geo-locating device (34, ..., 44), each said at least one geo-locating device (34, ..., 44) issuing a corresponding at least one geo-locating signal, each said at least one geo-locating signal being indicative at least in part of a geo-location of said image-capturing device (32a, 32b) during each image capturing event; and
a computer system (46) receiving and storing said image-data signals and said at least one geo-locating signal; and
image and data acquiring software (90) reading said image-data signals and said at least one geo-locating signal, said software (90) associating each said image-data signal with a corresponding said at least one geo-locating signal for each image-capturing event.

18. The system of claim 17, wherein said at least one geo-locating device and said at least one geo-locating signal respectively comprise at least one of:

a clock (38) issuing to said image-capturing computer system (46) time data signals indicative of a time of each said image-capturing event;
a global-positioning system (GPS) receiver (34) receiving GPS signals and issuing to said image-capturing computer system (46) location data signals indicative of a longitude and latitude of said image-capturing device (32a, 32b) at each said image-capturing event;
an inertial navigation unit (36) issuing to said image-capturing computer system (46) velocity data signals indicative of a velocity of said image-capturing device (32a, 32b) at each said image-capturing event;
a gyroscope (40) issuing to said image-capturing computer system (46) a pitch signal, a roll signal, and a yaw signal respectively indicative of a pitch, roll and yaw of said image capturing device (32a, 32b) at each said image-capturing event;
a compass (42) issuing to said image-capturing computer system (46) heading data signals indicative of a heading of said image-capturing device (32a, 32b) at each said image-capturing event; and
an altimeter (44) issuing to said image-capturing computer system (46) altitude data signals indicative of an altitude of said image-capturing device (32a, 32b) at each said image-capturing event.

19. The system of claim 17 or 18, further comprising correction data indicative of characteristics of said image-capturing device (32a, 32b) including focal length, sensor size, radial distortion, principal point offset and alignment, said image and data acquiring software (90) utilizing said correction data to correct captured images.

20. The system of one of the claims 17 to 19, further comprising an output data file created by said image and data acquiring software (90), said output data file including a plurality of image files and positional data corresponding to each of said plurality of image files.

21. The system of one of the claims 17 to 20, further comprising a platform (20) carrying said image-capturing device (32a, 32b) a predetermined distance above a surface of interest.

22. The system of claim 21 wherein said image-capturing device (32a, 32b) captures oblique images of an area of interest as said oblique images by:

subdividing the area (200) of interest into a plurality of sectors (202a, 202b, 202c);
guiding said platform (20) along a first path (202) to thereby target one or more target sectors with said image-capturing device (32a, 32b);
capturing with said image-capturing device (32a, 32b) one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a first perspective;
guiding said platform (20) along a second path (204) to thereby target said target sectors;
capturing with said image-capturing device (32a, 32b) one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a second perspective;
repeating said guiding and capturing steps along paths substantially parallel to and spaced

apart from said first and second paths (202, 204) and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from each of said first and second perspectives; and
recording positional data indicative of a geo-location of said image-capturing device (32a, 32b) at each image-capturing event.

23. The system of claim 22, wherein said second path (204) is substantially parallel relative to and 180° (one-hundred and eighty degrees) from said first path (202).

24. The system of claim 23, wherein said second path (204) is also spaced apart from said first path (202).

25. The system of one of the claims 22 to 24, wherein
said platform (20) is guided along a third path (206) to thereby target one or more target sectors with said image-capturing device (32a, 32b), said third path (206) being substantially perpendicular to said first and second paths (202, 204);
said image-capturing device (32a, 32b) captures one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a third perspective; wherein
said platform (20) is guided and said image-capturing device (32a, 32b) captures said oblique images along paths substantially parallel to and spaced apart from said third path (306); and
said image-capturing device (32a, 32b) captures one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said third perspective.

26. The system of claim 25, wherein
said platform (20) is guided along a fourth path (208) to thereby target one or more target sectors with said image-capturing device (32a, 32b), said fourth path (208) being substantially parallel with said third path (206) and 180° (one-hundred and eighty degrees) from said third path (206);
said image-capturing device (32a, 32b) captures one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a fourth perspective; and
said guiding and capturing steps are repeated along paths substantially parallel to and spaced apart from said fourth path (208) and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said fourth perspective.

27. The system of claim 26, wherein said fourth path (208) is also spaced apart from said third path (206).

Patentansprüche

1. Computerisiertes System zum Darstellen, Erdpositionsbestimmen und Durchführen von Messungen auf der Grundlage aufgenommener schräger Bilder, umfassend:

ein Computersystem (130) mit einem Speicher (132);
eine Bild- und Datendatei (120), auf die durch das System (130) zugegriffen werden kann, und die eine Vielzahl von Bilddateien umfasst, die einer Vielzahl aufgenommener schräger Bilder entsprechen, wobei die Bild- und Datendatei (120) weiterhin Positionsdaten umfasst, die zu der Vielzahl von Bilddateien gehören; und
eine Bildanzeige- und -analyse-Software (140), die von dem System (130) zum Lesen der Bild- und Datendatei (120) und zum Anzeigen mindestens eines Teils der aufgenommenen schrägen Bilder als ein angezeigtes schräges Bild ausgeführt wird, wobei die Bildanzeige- und -analyse-Software (140) die Erdpositionen von zwei oder mehr ausgewählten Punkten zumindest teilweise auf der Grundlage der Positionsdaten berechnet, wobei die Bildanzeige- und -analyse-Software (140) einen Abstand zwischen allen zwei oder mehr ausgewählten Punkten innerhalb des angezeigten schrägen Bildes berechnet;
gekennzeichnet durch
eine Grundebenendatendatei eine mosaikartige Grundebene (160) darstellt, wobei die Grundebenendatendatei der Bildanzeige- und -analyse-Software (140) Daten bereitstellt, wobei die Grundebenendatendatei eine mosaikartige Grundebene darstellt, welche zumindest einen Teil des innerhalb des aufgenommenen schrägen Bildes dargestellten Geländes nah annähert, wobei die mosaikartige Grundebene weiterhin eine Vielzahl zusammenhängender Bilder umfasst, wobei die mosaikartige Grundebene weiterhin eine Vielzahl zusammenhängender Facetten (162a, 162b, 162c, ...) umfasst, wobei jede der Vielzahl von Facetten einen entsprechende Abstand und Steigung aufweist, wobei die Grundebenendatendatei eine Vielzahl von Eckpunkten umfasst, wobei jeder der Vielzahl von Eckpunkten entsprechende Höhelagen aufweist und Ecken der Vielzahl der zusammenhängenden Facetten (162a, 162b, 162c, ...) definiert, wobei jede der zusammenhängenden Facetten sich zwei aus der Vielzahl der Facetten teilt; und
die Bildanzeige- und -analyse-Software (140), die identifiziert, welche der Vielzahl der Facetten zu einem ausgewählten Punkt auf dem angezeigten schrägen Bild gehört, und die eine Höhe

des ausgewählten Punkts abhängig zumindest teilweise von der Höhenlage der Eckpunkte derjenigen Facette berechnet, die zu dem ausgewählten Punkt gehört, wobei die Bildanzeige- und -analyse-Software (140) die berechnete Höhenlage zum Berechnen des Abstandes zwischen dem ausgewählten Punkt und einem oder mehreren weiteren ausgewählten Punkten verwendet.

2. System nach Anspruch 1, wobei die Bildanzeige- und -analyse-Software (140) die Erdpositionen nur bei Bedarf berechnet.

3. System nach Anspruch 1 oder 2, wobei die Bildanzeige- und -analyse-Software (140) eine Höhe eines innerhalb des angezeigten schrägen Bildes vorhandenen Objekts berechnet, und zwar durch Berechnen des Abstandes zwischen zwei oder mehr ausgewählten Punkten.

4. System nach einem der Ansprüche 1 bis 3, wobei die mosaikartige Grundebene (160) dem angezeigten schrägen Bild überlagert und angepasst ist.

5. System nach einem der Ansprüche 1 bis 4, wobei die Bildanzeige- und -analyse-Software (140) nutzerauswählbare Messmodi umfasst, auf die durch Pulldown-Menüs, Symbolleisten und / oder Tastaturkommandos zugegriffen werden kann.

6. System nach einem der Ansprüche 1 bis 5, wobei jedes der Bilder von einer Bildaufnahmevorrichtung (32a, 32b) und zu entsprechenden Bildaufnahmeereignissen aufgenommen wurden, wobei die Positionsdaten der Bild- und Datendatei umfassen:

Zeitdaten, die der Zeit jedes Bildaufnahmeereignisses entsprechen;
Positionsdaten, die dem Ort der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis entsprechen;
Ausrichtungsdaten, die der Ausrichtung der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis entsprechen;
Korrekturdaten, die Korrekturfaktoren für die Bildaufnahmevorrichtung (32a, 32b) entsprechen; und
Höhenlagendaten, die einer durchschnittlichen Höhenlage der durch die Bildaufnahmevorrichtung (32a, 32b) aufgenommenen Oberfläche entsprechen.

7. System nach Anspruch 6, wobei die Positionsdaten einen Breitengrad, einen Längengrad und eine Höhenlage der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis umfassen.

8. System nach Anspruch 6 oder 7, wobei die Ausrichtungsdaten ein Rollen, Stampfen, Gieren und eine Ausrichtung der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis umfassen.

9. System nach einem der Ansprüche 6 bis 8, wobei die Bildaufnahmevorrichtung (32a, 32b) eine Kamera ist und die Korrekturdaten eine Brennweite, eine Sensorgröße, ein Bildseitenverhältnis, einen Hauptpunktversatz, eine Verzerrung und / oder einen Bildpunktabstand umfassen.

10. System nach einem der Ansprüche 6 bis 9, umfassend:

eine Eingabevorrichtung (134a, 134b) zum Auswählen eines Anfangspunkts und eines Endpunkts auf dem angezeigten schrägen Bild; und die Bildanzeige- und -analyse-Software (140) zum Auslesen von Positionsdaten aus der Datendatei, die zu dem Anfangspunkt und dem Endpunkt gehören; zum Referenzieren der Grundebenendatei, die zur mosaikartigen Grundebene gehört, die eine Vielzahl von Facetten aufweist, wobei jede der Facetten einen zugehörige Abstand und Steigung aufweist, wobei die mosaikartige Grundebene mit einem Gelände des angezeigten schrägen Bildes nahezu übereinstimmt; zum Verbinden der Anfangs- und Endpunkte mit Linienabschnitten, wobei die Linienabschnitte an den Abstand und die Steigung der Facetten angepasst sind, um dem Gelände zu folgen; und zum Berechnen des geraden Abstands entlang der Liniensegmente zwischen den Anfangs- und Endpunkten, wobei der Abstand und die Steigung der Facetten berücksichtige werden.

11. System nach einem der Ansprüche 1 bis 10, wobei die Bildanzeige- und - analyse-Software (140) die mosaikartige Grundebene auf das angezeigte schräge Bild überlagert.

12. System nach Anspruch 10 oder 11, umfassend:

die Eingabevorrichtung (134a, 134b) zum Auswählen eines oder mehrerer Zwischenpunkte auf dem angezeigten schrägen Bild; und
die Bildanzeige- und -analyse-Software (140) zum Auslesen von Positionsdaten aus der Datendatei, die zu dem einen oder den mehreren Zwischenpunkten gehören; zum Verbinden benachbarter Zwischenpunkte miteinander und zum Verbinden des Anfangs- und Endpunkts mit benachbarten Zwischenpunkten durch Linienabschnitte, wobei die Linienabschnitte an den Abstand und die Steigung der Facetten angepasst sind, um dem Gelände zu folgen; und zum

Berechnen des Abstands entlang der Liniensegmente zwischen dem Anfangs- und dem Endpunkt.

13. System nach einem der Ansprüche 1 bis 12, wobei die Vielzahl der Facetten (162a, 162b, 162c, ...) jeweils gleichen Flächen des angezeigten schrägen Bildes entsprechen.

14. System nach einem der Ansprüche 1 bis 13, wobei die Vielzahl der Facetten (162a, 162b, 162c, ...) jeweils eine gleiche Zahl von Bildpunkten des angezeigten schrägen Bildes umfasst.

15. System nach einem der Ansprüche 1 bis 14, umfassend eine Eingabevorrichtung (134a, 134b) zum Auswählen eines oder mehrerer Zwischenpunkte auf dem angezeigten schrägen Bild; und die Bildanzeige- und -analyse-Software (140) zum Auslesen der Positionsdaten, die zu den Zwischenpunkten gehören.

16. System nach einem der Ansprüche 1 bis 15, wobei der Abstand einen Abstand zwischen zwei oder mehr ausgewählten Punkten, einen Höhenunterschied zwischen zwei oder mehr ausgewählten Punkten, einen Höhenlagenunterschied zwischen zwei oder mehr ausgewählten Punkten und eine durch zumindest drei Punkte umfasste Fläche umfasst.

17. System nach einem der Ansprüche 1 bis 16, umfassend:

eine Bildaufnahmevorrichtung (32a, 32b), wobei die Bildaufnahmevorrichtung (32a, 32b) schräge Bilder zu Bildaufnahmeereignissen aufnimmt, wobei die Bildaufnahmevorrichtung (32a, 32b) Bilddatensignale ausgibt, die den aufgenommenen Bildern entsprechen;
mindestens eine Erdpositionsbestimmungsvorrichtung (34, ..., 44), wobei die mindestens eine Erdpositionsbestimmungsvorrichtung (34, ..., 44) zumindest ein zugehöriges Erdpositionsbestimmungssignal ausgibt, wobei jedes der mindestens einen Erdpositionsbestimmungssignale zumindest teilweise eine Erdposition der Bildaufnahmevorrichtung (32a, 32b) während jedes Bildaufnahmeereignisses anzeigt; und
ein Computersystem (46), das Bilddatensignale und das mindestens eine Erdpositionsbestimmungssignal empfängt und speichert;
Bild- und Datenaufnahme-Software (90), welche die Bilddatensignale und das mindestens eine Erdpositionsbestimmungssignal liest, wobei die Software (90) jedes Bilddatensignal mit einem zugehörigen mindestens einen Erdpositionsbestimmungssignal für jedes Bildaufnahmeereignis verknüpft.

18. System nach Anspruch 17, wobei die mindestens eine Erdpositionsbestimmungsvorrichtung und das mindestens ein Erdpositionsbestimmungssignal entsprechend umfassen:

eine Uhr (38), die Zeitdatensignale an das bildaufnehmende Computersystem (46) ausgibt, die einen Zeitpunkt jedes Bildaufnahmeereignisses angeben;
einen GPS-Empfänger (34), der GPS-Signale empfängt und Positionsdatensignale an das bildaufnehmende Computersystem (46) ausgibt, die einen Längengrad und einen Breitengrad der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis angeben;
eine Trägheitsnavigationseinheit (36), die Geschwindigkeitsdatensignale an das bildaufnehmende Computersystem (46) ausgibt, die eine Geschwindigkeit der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis angeben;
ein Gyroskop (40), das ein Stampfsignal, ein Rollsignal und ein Giersignal an das bildaufnehmende Computersystem (46) ausgibt, die ein entsprechendes Stampfen, Rollen und Gieren zu jedem Bildaufnahmeereignis angeben;
einen Kompass (42), der Ausrichtungsdatensignale an das bildaufnehmende Computersystem (46) ausgibt, die eine Ausrichtung der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis angeben; und / oder
einen Höhenmesser (44), der Höhenlagendatensignale an das bildaufnehmende Computersystem (46) ausgibt, die eine Höhenlage der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis angeben.

19. System nach Anspruch 17 oder 18, weiterhin umfassend Korrekturdaten, die Eigenschaften der Bildaufnahmevorrichtung (32a, 32b) angeben, einschließlich Brennweite, Sensorgröße, radiale Verzerrung, Hauptpunktversatz und Ausrichtung, wobei die Bild- und Datenaufnahme-Software (90) die Korrekturdaten verwendet, um aufgenommene Bilder zu korrigieren.

20. System nach einem der Ansprüche 17 bis 19, weiterhin umfassend eine Ausgabedatendatei, die durch die Bild- und Datenaufnahme-Software (90) erzeugt wird, wobei die Ausgabedatendatei eine Vielzahl von Bilddateien und zu der Vielzahl von Bilddateien gehörige Positionsdaten umfasst.

21. System nach einem der Ansprüche 17 bis 19, weiterhin umfassend eine Plattform (20) zum Tragen der Bildaufnahmevorrichtung (32a, 32b) um einen

vorbestimmten Anstand oberhalb der von Interesse seienden Oberfläche.

22. System nach Anspruch 21, wobei die Bildaufnahmevorrichtung (32a, 32b) schräge Bilder einer von Interesse seienden Fläche als die schrägen Bilder aufnimmt mittels:

Unterteilen der von Interesse seienden Fläche (200) in eine Vielzahl von Sektoren (202a, 202b, 202c);
Führen der Plattform (20) entlang eines ersten Pfads (202), um so mit der Bildaufnahmevorrichtung (32a, 32b) auf einen oder mehrere Zielsektoren zu zielen;
Aufnehmen eines oder mehrerer schräger Bilder mit der Bildaufnahmevorrichtung (32a, 32b), um damit eine Gesamtheit jedes der Zielsektoren mit schrägen Bildern, die aus einer ersten Perspektive aufgenommen werden, abzudekken;
Führen der Plattform (20) eines zweiten Pfads (204), um so auf die Zielsektoren zu zielen;
Aufnehmen eines oder mehrerer schräger Bilder mit der Bildaufnahmevorrichtung (32a, 32b), um damit eine Gesamtheit jedes der Zielsektoren mit schrägen Bildern, die aus einer zweiten Perspektive aufgenommen werden, abzudekken;
Wiederholen der Führungs- und Aufnahmeschritte entlang von Pfaden, die im wesentlichen parallel und beabstandet von dem ersten und zweiten Pfad (202, 204) liegen, und Aufnehmen eines oder mehrerer schräger Bilder, um damit eine Gesamtheit jedes der Vielzahl der Zielsektoren mit schrägen Bilder, die sowohl aus der ersten als auch aus der zweiten Perspektive aufgenommen werden, abzudecken; und
Aufnehmen von Positionsdaten, die eine Erdposition der Bildaufnahmevorrichtung (32a, 32b) zu jedem Bildaufnahmeereignis anzeigen.

23. System nach Anspruch 22, wobei der zweite Pfad (204) im wesentlichen parallel zum und um 180° (einhundertachtzig Grad) gedreht zum ersten Pfad (202) liegt.

24. System nach Anspruch 23, wobei der zweite Pfad (204) vom ersten Pfad (202) auch beabstandet ist.

25. System nach einem der Ansprüche 22 bis 24, wobei die Plattform (20) entlang eines dritten Pfads (206) geführt wird, um so mit der Bildaufnahmevorrichtung (32a, 32b) auf einen oder mehrere Zielsektoren zu zielen, wobei der dritte Pfad (206) im wesentlichen senkrecht zum dem ersten und dem zweiten Pfad (202, 204) liegt;
die Bildaufnahmevorrichtung (32a, 32b) ein oder mehrere schräge Bilder aufnimmt, um damit eine Gesamtheit jedes Zielsektors mit schrägen Bildern, die aus einer dritten Perspektive aufgenommen werden, abzudecken; wobei
die Plattform (20) geführt wird und die Bildaufnahmevorrichtung (32a, 32b) die schrägen Bilder entlang von Pfaden aufnimmt, der im wesentlichen parallel und beabstandet von dem dritten Pfad (306) liegen; und
wobei die Bildaufnahmevorrichtung (32a, 32b) ein oder mehrere schräge Bilder aufnimmt, um damit eine Gesamtheit jedes aus der Vielzahl der Zielsektoren mit schrägen Bildern, die aus der dritten Perspektive aufgenommen werden, abzudecken.

26. System nach Anspruch 25, wobei
die Plattform (20) entlang eines vierten Pfads (208) geführt wird, um so mit der Bildaufnahmevorrichtung (32a, 32b) auf einen oder mehrere Zielsektoren zu zielen, wobei der vierte Pfad (208) im wesentlichen parallel zum und um 180° (einhundertachtzig Grad) gedreht zum dritten Pfad (206) liegt;
die Bildaufnahmevorrichtung (32a, 32b) ein oder mehrere schräge Bilder aufnimmt, um damit eine Gesamtheit jedes Zielsektors mit schrägen Bildern, die aus einer vierten Perspektive aufgenommen werden, abzudecken; und
die Führungs- und Aufnahmeschritte entlang von Pfaden wiederholt werden, die im wesentlichen parallel zu und beabstandet von dem vierten Pfad (208) liegen, und Aufnehmen eines oder mehrerer schräger Bilder, um damit eine Gesamtheit jedes der Vielzahl der Zielsektoren mit schrägen Bilder, die aus der vierten Perspektive aufgenommen werden, abzudecken.

27. System nach Anspruch 26, wobei der vierte Pfad (208) von dem dritten Pfad (206) auch beabstandet ist.

Revendications

1. Système numérisé destiné à afficher, géolocaliser et faire des mesures basées sur des images obliques capturées, comprenant :

un système d'ordinateur (130) comportant une mémoire (132) ;
un fichier (120) d'images et de données accessible audit système (130) et comprenant une pluralité de fichiers d'images correspondant à une pluralité d'images obliques capturées, ledit fichier (120) d'images et de données comprenant en outre des données de position correspondant à ladite pluralité de fichiers d'images ; et
un logiciel (140) d'affichage et d'analyse d'ima-

ges exécuté par ledit système (130) pour lire ledit fichier (120) d'images et de données et afficher au moins une partie des images obliques capturées en tant qu'image oblique affichée, ledit logiciel (140) d'affichage et d'analyse d'images calculant les géolocalisations de deux ou de plus de deux points sélectionnés dans ladite image oblique affichée en se basant au moins en partie sur lesdites données de position, ledit logiciel (140) d'affichage et d'analyse d'images calculant une distance de séparation entre deux quelconques des deux ou plus de deux points sélectionnés dans ladite image oblique affichée ;

caractérisé par

un fichier de données de plan de sol représentant un plan de sol (160) en mosaïque, ledit fichier de données de plan de sol fournissant des données audit logiciel (140) d'affichage et d'analyse d'images, ledit fichier de données de plan de sol représentant un plan de sol en mosaïque qui approxime étroitement au moins une partie du terrain décrit dans lesdites images obliques capturées, ledit plan de sol en mosaïque comprenant en outre une pluralité d'images interconnectées, ledit plan de sol en mosaïque comprenant en outre une pluralité de facettes interconnectées (162a, 162b, 162c, ...), chacune des facettes de ladite pluralité ayant un pas et une pente respectifs, ledit fichier de données de plan de sol comprenant une pluralité de sommets, chacun des sommets de ladite pluralité ayant des élévations respectives et définissant des coins de ladite pluralité de facettes interconnectées (162a, 162b, 162c, ...), deux des sommets de ladite pluralité étant partagés par chacune des facettes interconnectée ; et

ledit logiciel (140) d'affichage et d'analyse d'images identifiant laquelle des facettes de ladite pluralité correspond à un point sélectionné sur ladite image oblique affichée, et calculant une élévation dudit point sélectionné dépendant au moins en partie de l'élévation des sommets de la facette correspondant au point sélectionné, ledit logiciel (140) d'affichage et d'analyse d'images utilisant ladite élévation calculée pour calculer ladite distance de séparation entre ledit point sélectionné et un ou plusieurs autres points sélectionnés.

2. Système selon la revendication 1, dans lequel ledit logiciel (140) d'affichage et d'analyse d'images ne calcule lesdites géolocalisations que si nécessaire.

3. Système selon la revendication 1 ou 2, dans lequel ledit logiciel (140) d'affichage et d'analyse d'images calcule une hauteur d'un objet dans ladite image oblique affichée en calculant la distance de séparation entre deux ou plus de deux points sélectionnés.

4. Système selon l'une des revendications 1 à 3, dans lequel ledit plan de sol en mosaïque (160) est superposé et s'adapte à ladite image oblique affichée.

5. Système selon l'une des revendications 1 à 4, dans lequel ledit logiciel (140) d'affichage et d'analyse d'images comprend des modes de mesure sélectionnables par l'utilisateur, accessibles par au moins soit des menus déroulants, soit des barres d'outils, soit des commandes de clavier.

6. Système selon l'une des revendications 1 à 5, dans lequel chacune desdites images a été capturée par un dispositif (32a, 32b) de capture d'image et lors d'événements respectifs de capture d'image, lesdites données de position dudit fichier d'images et de données comprenant :

des données de temps représentant l'instant de chaque événement de capture d'image ;
des données de localisation représentant la localisation du dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image ;
des données d'orientation représentant l'orientation du dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image ;
des données de correction représentant des facteurs de correction pour le dispositif (32a, 32b) de capture d'image ; et
des données d'élévation représentant une élévation moyenne de la surface capturée par le dispositif (32a, 32b) de capture d'image.

7. Système selon la revendication 6, dans lequel lesdites données de localisation comprennent la latitude, la longitude et l'altitude du dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image.

8. Système selon la revendication 6 ou 7, dans lequel lesdites données d'orientation comprennent le roulis, le tangage, le lacet et le cap dudit dispositif (32a, 32b) de capture d'image lors de chaque événement de capture d'image.

9. Système selon l'une des revendications 6 à 8, dans lequel ledit dispositif (32a, 32b) de capture d'image est une caméra et lesdites données de correction comprennent au moins soit la distance focale, soit la taille du capteur, soit le rapport d'allongement, soit le décalage du point principal, soit la distorsion, soit le pas des pixels.

10. Système selon l'une des revendications 6 à 9, comprenant :

un dispositif d'entrée (134a, 134b) destiné à sélectionner un point de départ et un point final sur l'image oblique affichée ; et
ledit logiciel (140) d'affichage et d'analyse d'images destiné à retrouver à partir dudit fichier de données les données de position correspondant audit point de départ et audit point final ; à référencer ledit fichier de données de plan de sol correspondant audit plan de sol en mosaïque comportant une pluralité de facettes, chacune desdites facettes ayant un pas et une pente respectifs, ledit plan de sol en mosaïque s'adaptant étroitement à un terrain de ladite image oblique affichée ; à connecter lesdits points de départ et final avec des segments de droite, lesdits segments de droite étant conformes auxdits pas et pente desdites facettes afin de suivre ainsi ledit terrain ; et à calculer la distance linéaire le long desdits segments de droite entre lesdits points de départ et final en tenant ainsi compte desdits pas et pente desdites facettes.

11. Système selon l'une des revendications 1 à 10, dans lequel ledit logiciel (140) d'affichage et d'analyse d'images superpose ledit plan de sol en mosaïque sur ladite image oblique affichée.

12. Système selon la revendication 10 ou 11, comprenant :

ledit dispositif d'entrée (134a, 134b) destiné à sélectionner un ou plusieurs points intermédiaires sur ladite image oblique affichée ; et
ledit logiciel (140) d'affichage et d'analyse d'images destiné à retrouver à partir dudit fichier de données les données de position correspondant au(x)dit(s) un ou plusieurs points intermédiaires ; à connecter les points intermédiaires adjacents l'un à l'autre, et à connecter lesdits points de départ et final aux points intermédiaires adjacents, au moyen de segments de droite, lesdits segments de droite étant conformes auxdits pas et pente desdites facettes, afin de suivre ainsi ledit terrain ; et à calculer la distance le long desdits segments de droite entre lesdits points de départ et final.

13. Système selon l'une des revendications 1 à 12, dans lequel chacune des facettes ladite pluralité (162a, 162b, 162c, ...) correspond à des surfaces égales de ladite image oblique affichée.

14. Système selon l'une des revendications 1 à 13, dans lequel chacune des facettes de ladite pluralité (162a, 162b, 162c, ...) comprend un nombre égal de pixels de ladite image oblique affichée.

15. Système selon l'une des revendications 1 à 14, comprenant un dispositif d'entrée (134a, 134b) destiné à sélectionner un ou plusieurs points intermédiaires sur ladite image oblique affichée ; et ledit logiciel (140) d'affichage et d'analyse d'images destiné à retrouver les données de position correspondant auxdits points intermédiaires.

16. Système selon l'une des revendications 1 à 15, dans lequel ladite distance de séparation comprend une distance entre deux ou plus de deux points sélectionnés, une différence de hauteur entre deux ou plus de deux points sélectionnés, une différence en élévation entre deux ou plus de deux points sélectionnés, et une surface comprenant au moins trois points.

17. Système selon l'une des revendications 1 à 16, comprenant :

un dispositif de capture d'image (32a, 32b), ledit dispositif de capture d'image (32a, 32b) capturant des images obliques lors d'événements de capture d'image, ledit dispositif de capture d'image (32a, 32b) délivrant des signaux de données d'image correspondant aux images capturées;
au moins un dispositif de géolocalisation (34, ..., 44) délivrant au moins un signal de géolocalisation correspondant, chacun desdits au moins un signal de géolocalisation étant indicatif au moins en partie d'une géolocalisation dudit dispositif de capture d'image (32a, 32b) pendant chaque événement de capture d'image ; et
un système d'ordinateur (46) recevant et mémorisant lesdits signaux de données d'image et ledit au moins un signal de géolocalisation ; et
un logiciel (90) d'acquisition d'images lisant lesdits signaux d'image et ledit au moins un signal de géolocalisation, ledit logiciel (90) associant chaque signal de données d'image avec ledit au moins un signal de géolocalisation correspondant pour chaque événement de capture d'image.

18. Système selon la revendication 17, dans lequel ledit au moins un dispositif de géolocalisation et ledit au moins un signal de géolocalisation comprennent au moins :

soit une horloge (38) délivrant audit système d'ordinateur (46) de capture d'image des signaux de données de temps indicatifs d'un instant de chacun desdits événements de capture d'image ;
soit un récepteur de système de positionnement global (GPS) recevant des signaux GPS et délivrant audit système d'ordinateur (46) de capture d'image des signaux de données de loca-

lisation indicatifs d'une longitude et d'une latitude dudit dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image ;
soit une unité (36) de navigation par inertie délivrant audit système d'ordinateur (46) de capture d'image des signaux de données de vitesse indicatifs d'une vitesse dudit dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image ;
soit un gyroscope (40) délivrant audit système d'ordinateur (46) de capture d'image un signal de tangage, un signal de roulis et un système de lacet respectivement indicatifs d'un tangage, d'un roulis et d'un lacet dudit dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image ;
soit un compas (42) délivrant audit système d'ordinateur (46) de capture d'image des signaux de données de cap indicatifs d'un cap dudit dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image ; et
soit un altimètre (44) délivrant audit système d'ordinateur (46) de capture d'image des signaux de données d'altitude indicatifs d'une altitude dudit dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image.

19. Dispositif selon la revendication 17 ou 18, comprenant en outre des données de correction indicatives des caractéristiques dudit dispositif (32a, 32b) de capture d'image comprenant la distance focale, la taille du capteur, la distorsion radiale, le décalage et l'alignement du point principal, ledit logiciel (90) d'acquisition d'images et de données utilisant lesdites données de correction pour corriger les images capturées.

20. Système selon l'une des revendications 17 à 19, comprenant en outre un fichier de données de sortie créé par logiciel (90) d'acquisition d'images et de données, ledit fichier de données de sortie comprenant une pluralité de fichiers d'images et de données de position correspondant à chacun des fichiers d'images de ladite pluralité.

21. Système selon l'une des revendications 17 à 20, comprenant en outre une plate-forme (20) portant ledit dispositif (32a, 32b) de capture d'image à une distance prédéterminée au-dessus d'une surface intéressante.

22. Système selon la revendication 21, dans lequel ledit dispositif (32a, 32b) de capture d'image capture des images obliques d'une zone intéressante en tant que dites images obliques en :

subdivisant la zone intéressante (200) en une pluralité de secteurs (202a, 202b, 202c) ;
guidant ladite plate-forme (20) selon un premier chemin (202) de manière à viser ainsi un ou plusieurs secteurs cibles avec ledit dispositif (32a, 32b) de capture d'image ;
capturant au moyen dudit dispositif (32a, 32b) de capture d'image une ou plusieurs images obliques de manière à couvrir ainsi une totalité de chacun desdits secteurs cibles dans les images obliques capturées à partir d'une première perspective ;
guidant ladite plate-forme (20) selon un deuxième chemin (204) de manière à viser ainsi lesdits secteurs cibles ;
capturant au moyen dudit dispositif (32a, 32b) de capture d'image une ou plusieurs images obliques de manière à couvrir ainsi une totalité de chacun desdits secteurs cibles dans les images obliques capturées à partir d'une deuxième perspective ;
répétant lesdites étapes de guidage et de capture selon des chemins sensiblement parallèles auxdits premier et deuxième chemins (202, 204) et espacés de ceux-ci, et capturant une ou plusieurs image(s) oblique(s) de manière à couvrir ainsi une totalité de chacun des secteurs cibles de ladite pluralité dans les images obliques capturées à partir de chacune desdites première et deuxième perspectives ; et
enregistrant les données de position indicatives d'une géolocalisation dudit dispositif (32a, 32b) de capture d'image à chaque événement de capture d'image.

23. Système selon la revendication 22, dans lequel ledit deuxième chemin (204) est sensiblement parallèle par rapport audit premier chemin (202) et à 180° (cent quatre-vingts degrés) de celui-ci.

24. Système selon la revendication 23, dans lequel ledit deuxième chemin (204) est également espacé dudit premier chemin (202).

25. Système selon l'une des revendications 22 à 24, dans lequel
ladite plate-forme (20) est guidée selon un troisième chemin (206) de manière à viser ainsi un ou plusieurs secteurs cibles au moyen dudit dispositif (32a, 32b) de capture d'image, ledit troisième chemin (206) étant sensiblement perpendiculaire auxdits premier et deuxième chemin (202, 204) ;
ledit dispositif (32a, 32b) de capture d'image capture une ou plusieurs image(s) oblique(s) de manière à couvrir ainsi une totalité de chacun desdits secteurs cibles dans les images obliques capturées à partir d'une troisième perspective ; dans lequel
ladite plate-forme (20) est guidée et ledit dispositif (32a, 32b) de capture d'image capture lesdites ima-

ges obliques selon des chemins sensiblement parallèles audit troisième chemin (206) et espacés de celui-ci ; et
ledit dispositif (32a, 32b) de capture d'image capture une ou plusieurs image(s) oblique(s) de manière à couvrir ainsi une totalité de chacun des secteurs de ladite pluralité dans les images obliques capturées à partir de ladite troisième perspective.

26. Système selon la revendication 25, dans lequel ladite plate-forme (20) est guidée selon un quatrième chemin (208) de manière à viser un ou plusieurs sedeur(s) cible(s) avec ledit dispositif (32a, 32b) de capture d'image, ledit quatrième chemin (208) étant sensiblement parallèle audit troisième chemin (206) et à 180° (cent quatre-vingts degrés) dudit troisième chemin ;
ledit dispositif (32a, 32b) de capture d'image capture une ou plusieurs image(s) oblique(s) de manière à couvrir ainsi une totalité de chacun desdits secteurs cibles dans les images obliques capturées à partir d'une quatrième perspective ; et
lesdites étapes de guidage et de capture sont répétées selon des chemins sensiblement parallèles audit quatrième chemin (208) et espacés de celui-ci et capturant une ou plusieurs image(s) oblique(s) de manière à couvrir ainsi une totalité de chacun des secteurs cibles de ladite pluralité dans les images obliques capturées à partir de ladite quatrième perspective.

27. Système selon la revendication 26, dans lequel ledit quatrième chemin (208) est également espacé dudit troisième chemin (206).

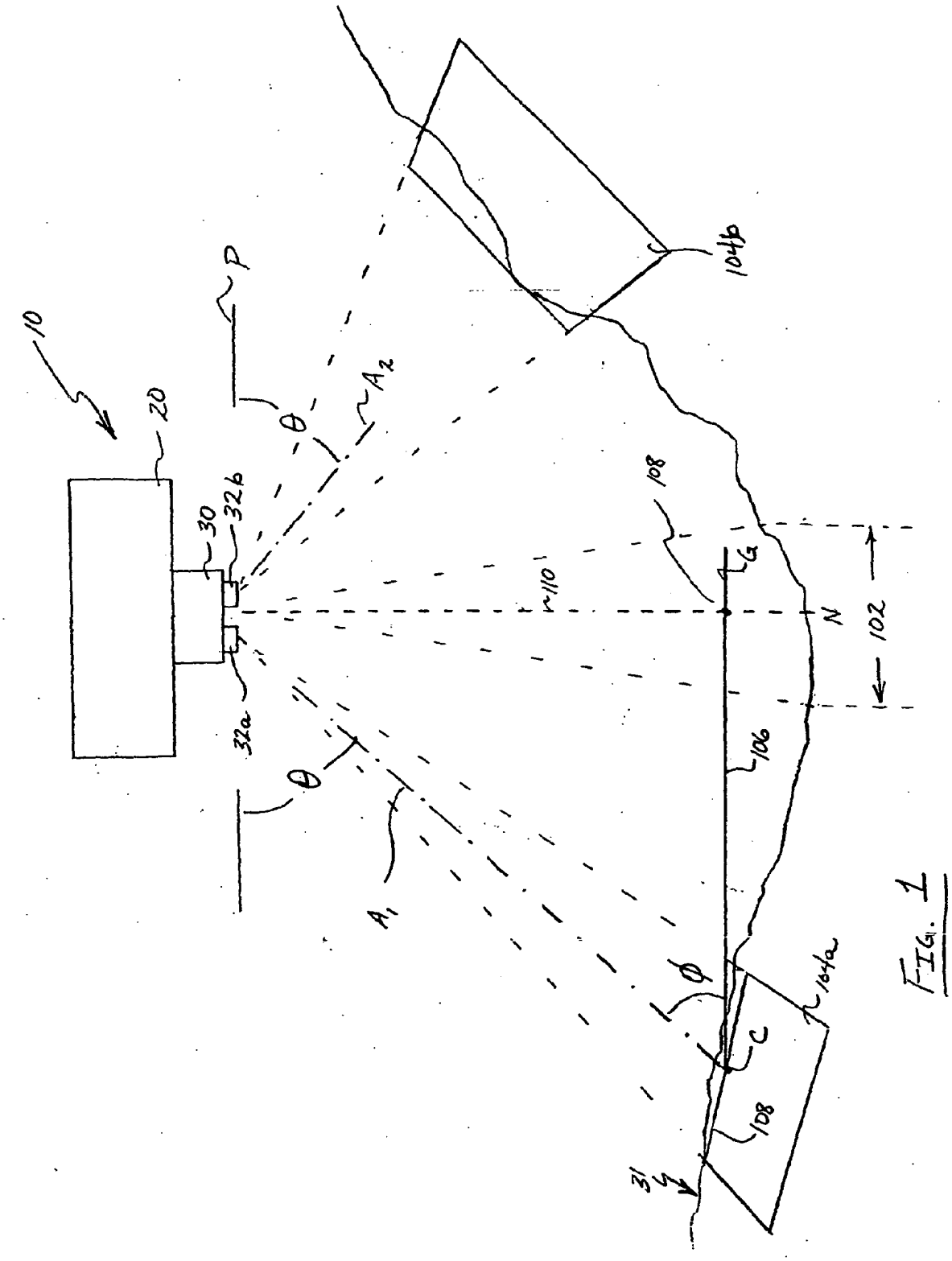


FIG. 1

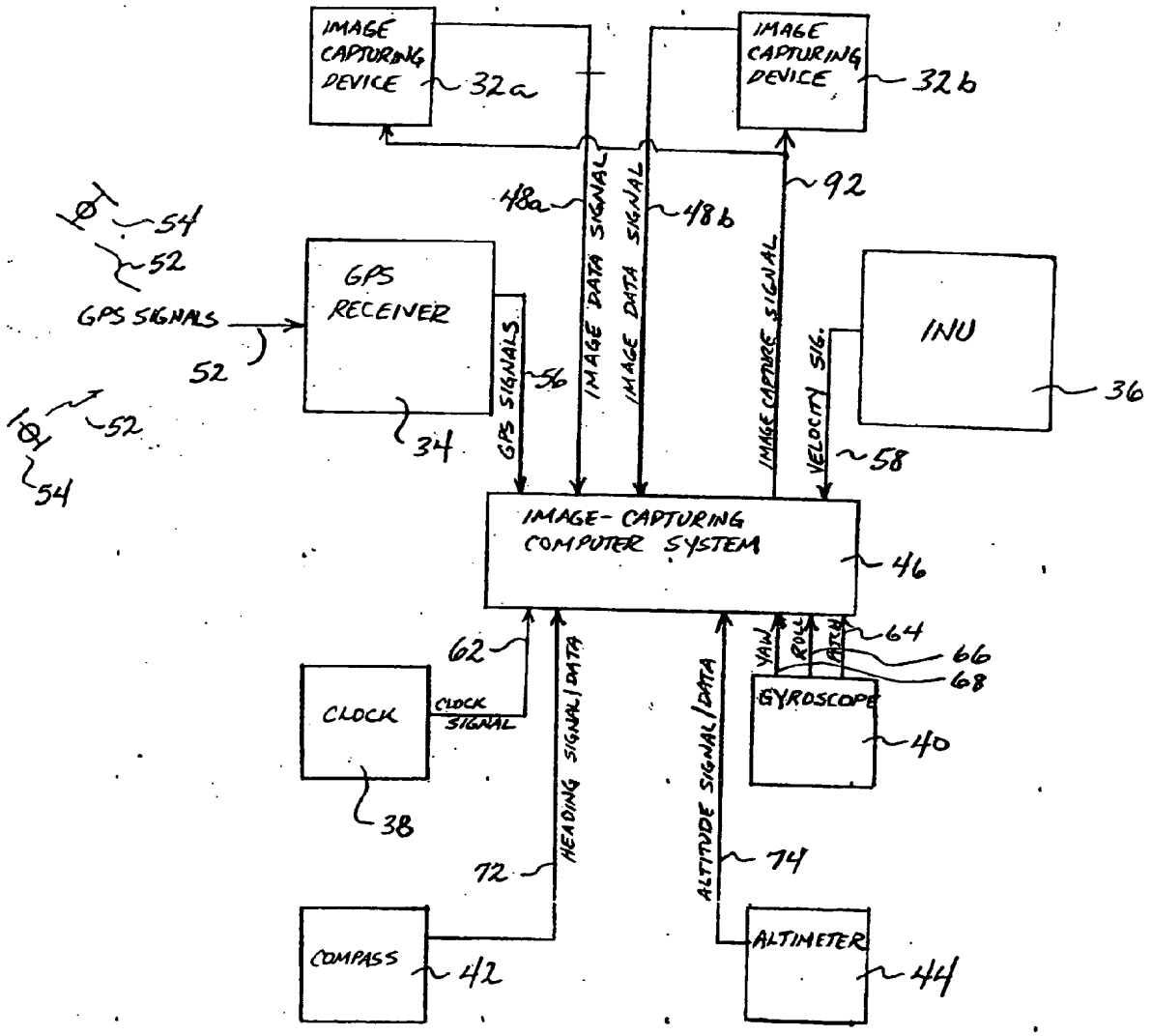

IMAGE CAPTURING DEVICE
32a
IMAGE CAPTURING DEVICE
32b
92
48a
48b
IMAGE DATA SIGNAL
IMAGE DATA SIGNAL
IMAGE CAPTURE SIGNAL
54
52
GPS SIGNALS
52
GPS RECEIVER
34
GPS SIGNALS
56
INU
36
VELOCITY SIG.
58
52
54
IMAGE-CAPTURING COMPUTER SYSTEM
46
62
64
66
68
YAW
ROLL
PITCH
CLOCK
CLOCK SIGNAL
38
GYROSCOPE
40
HEADING SIGNAL/DATA
72
ALTITUDE SIGNAL/DATA
74
COMPASS
42
ALTIMETER
44

FIG. 2

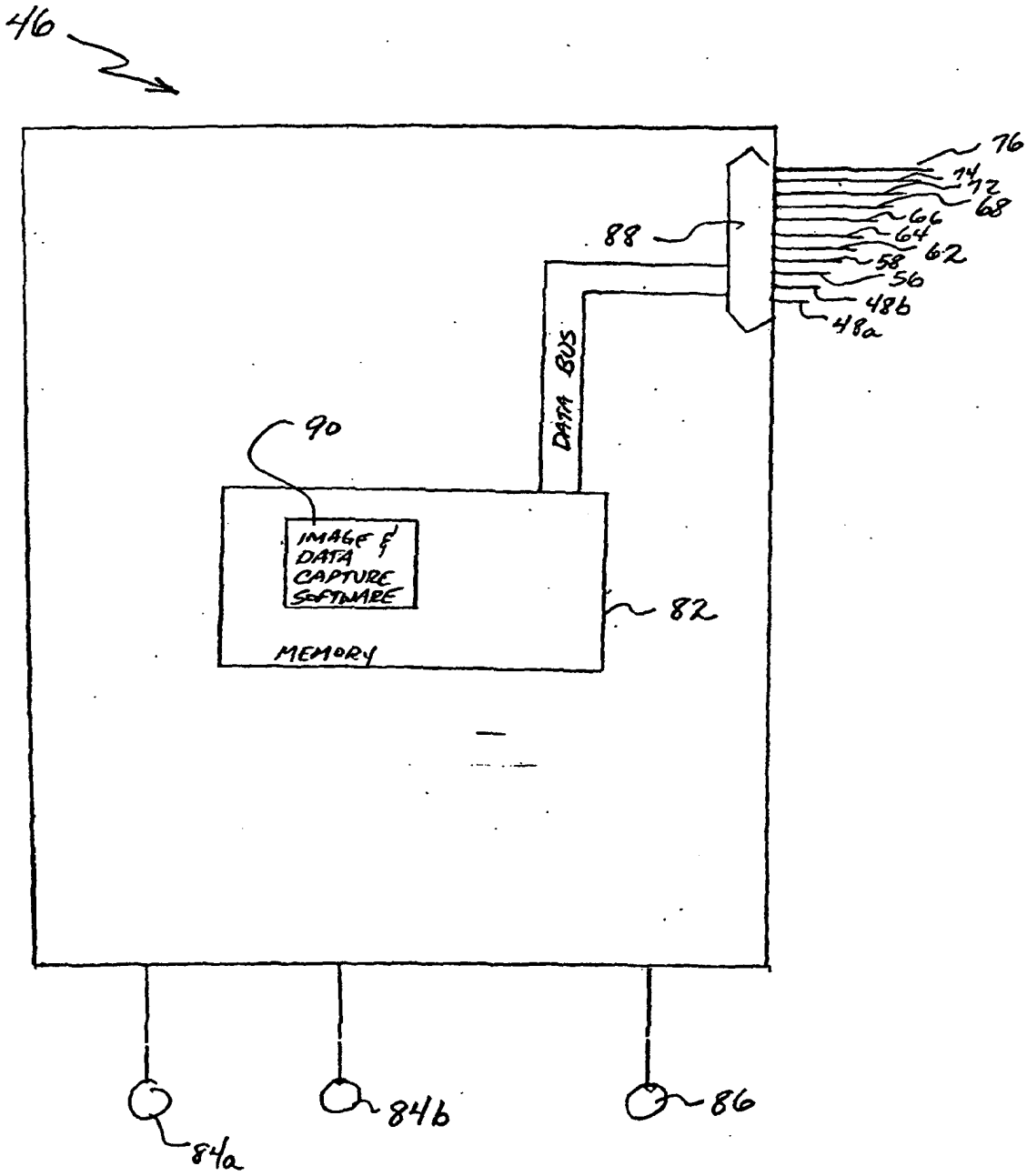

46
76
74
72
68
66
64
62
58
56
48b
48a
88
DATA BUS
90
IMAGE & DATA CAPTURE SOFTWARE
MEMORY
82
84a
84b
86

FIG. 3

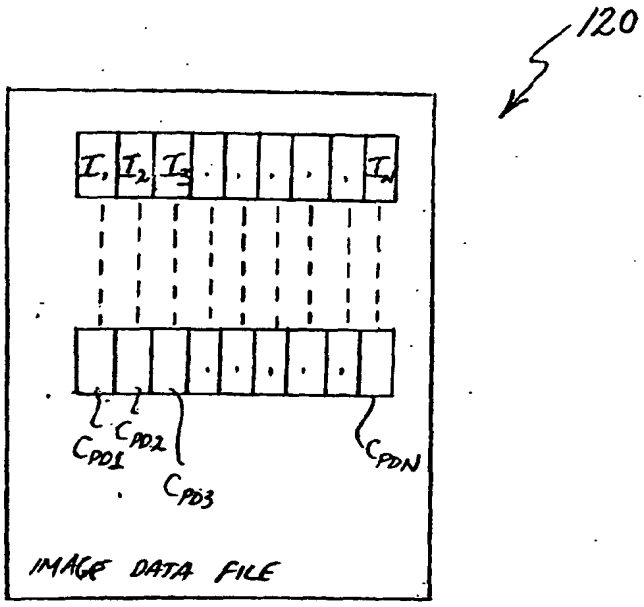


FIG. 4

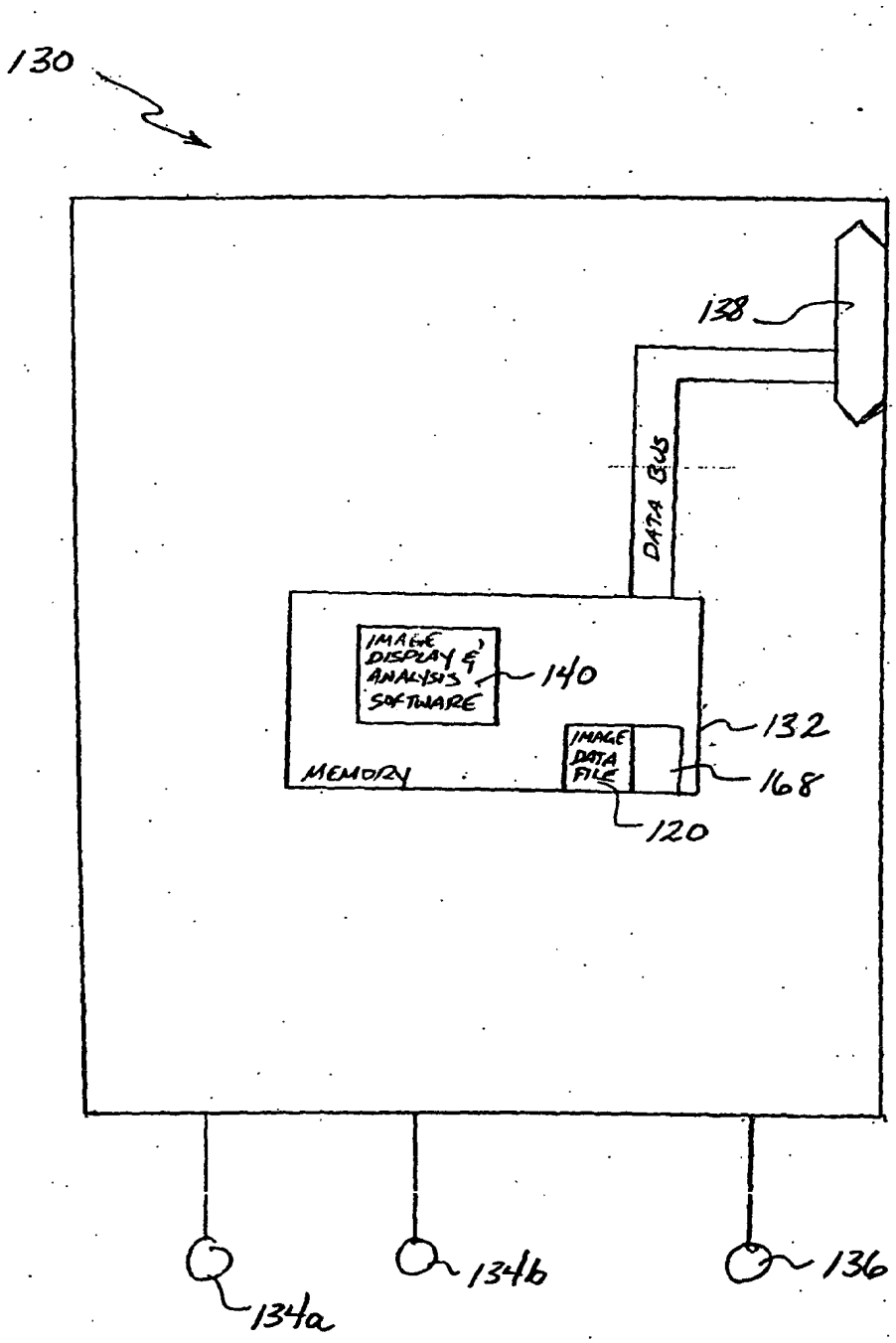

130
138
DATA BUS
IMAGE DISPLAY & ANALYSIS SOFTWARE
140
MEMORY
IMAGE DATA FILE
132
168
120
134a
134b
136

FIG. 5

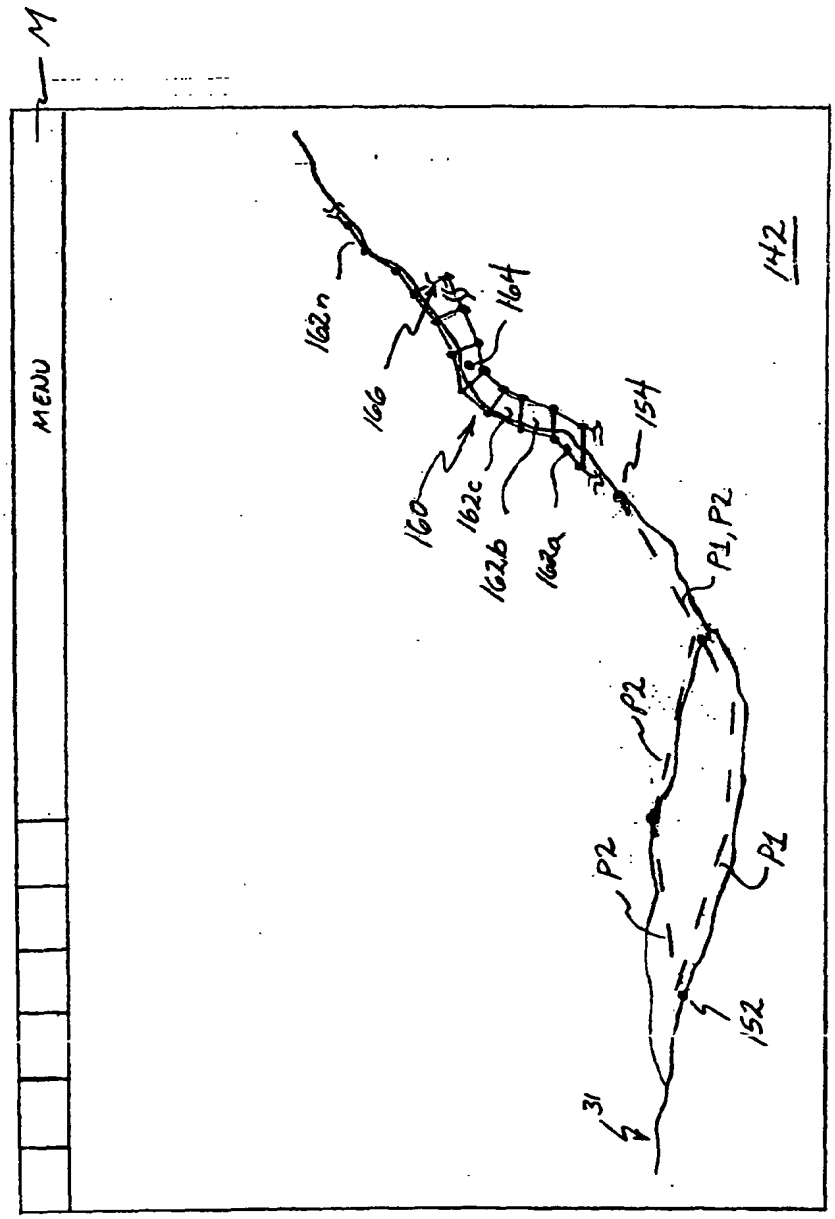

M
MENU
142
162n
164
166
160
162c
162b
162a
154
P1, P2
P2
P2
P1
152
31

FIG. 6

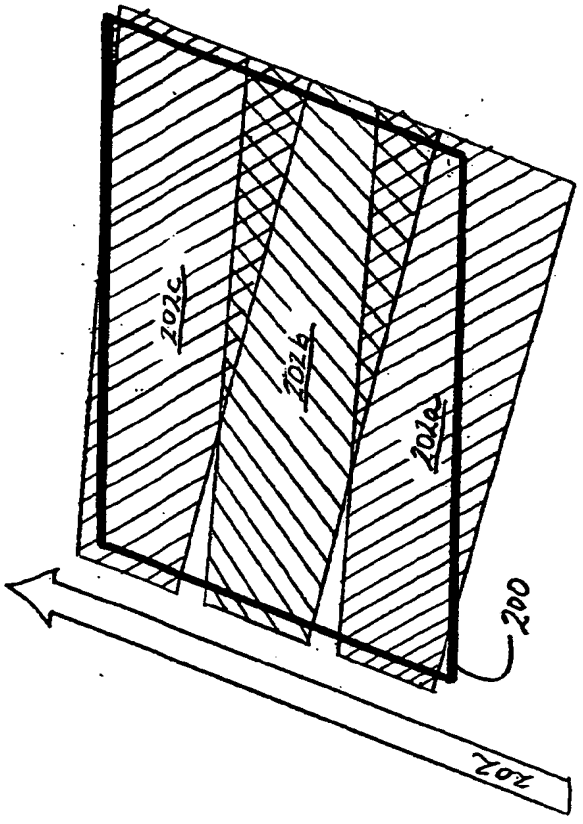


FIG. 1

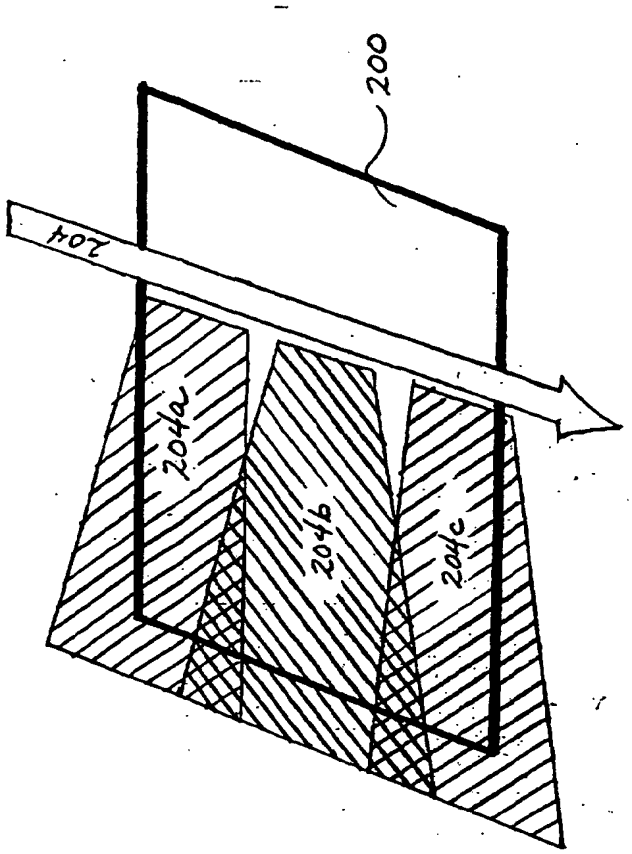


FIG. 8

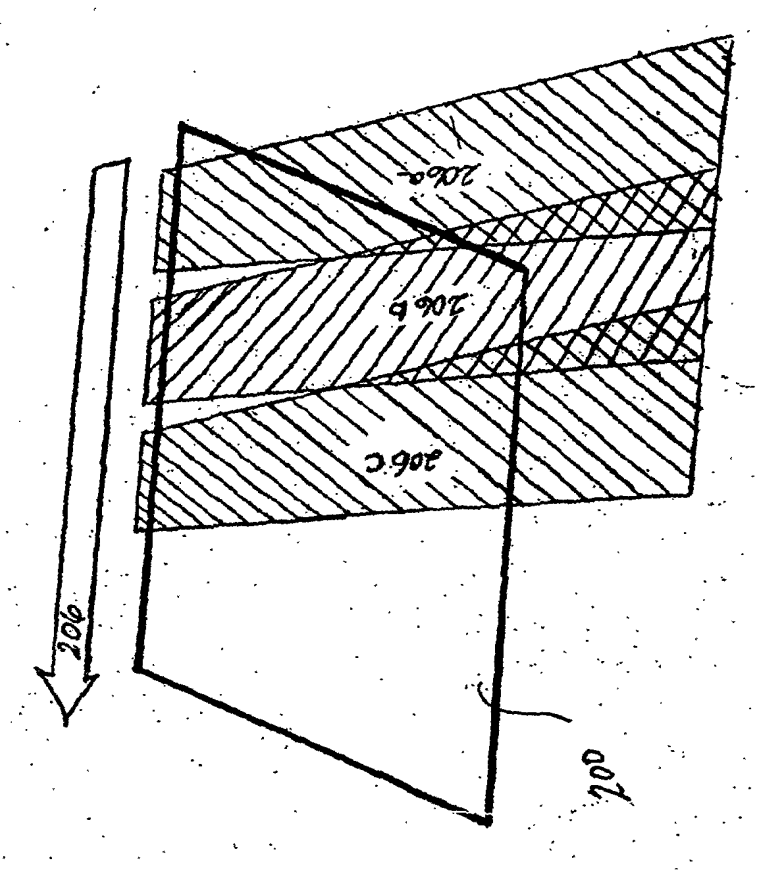


Fig. 9

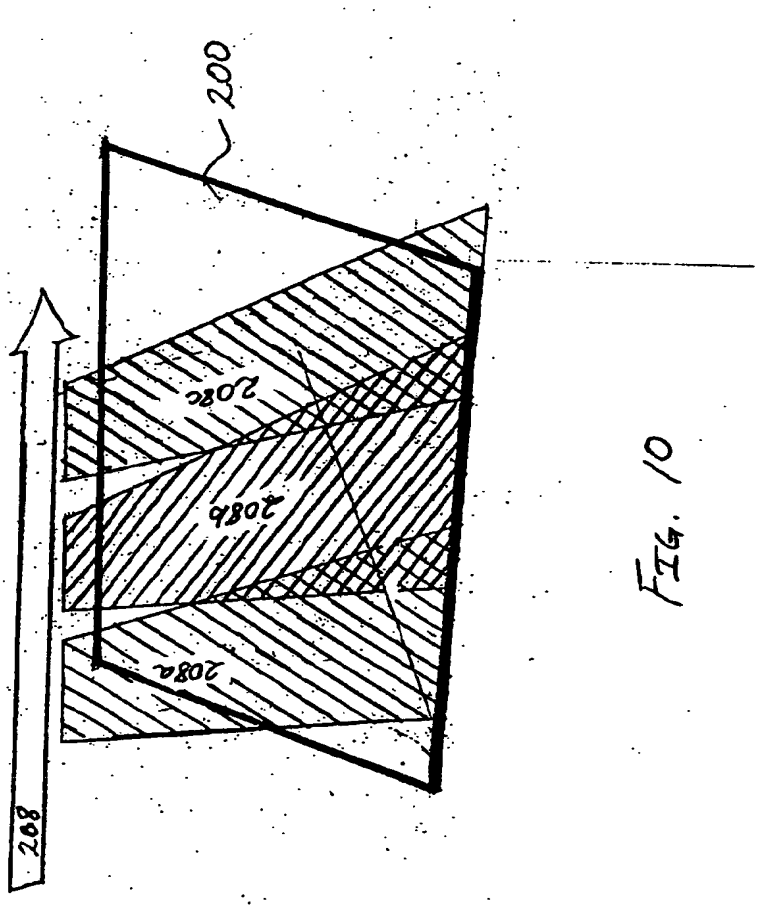


FIG. 10

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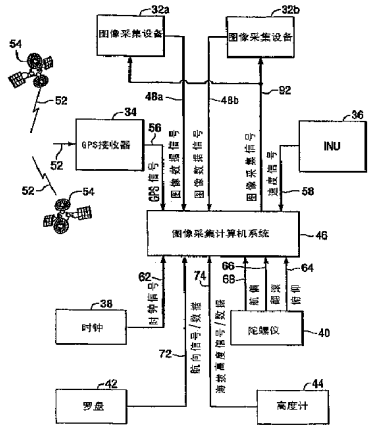
权利要求书 9 页 说明书 20 页 附图 7 页

[54] 发明名称

倾斜地理定位和测量系统

[57] 摘要

一种从采集的倾斜图像(32a 和 32b)进行显示，地理定位和测量的计算机化系统(46)包括可由计算机系统访问的数据文件。 数据文件包括与多个采集的倾斜图像(32a 和 32b)对应的多个图像文件，和与该图像对应的位置数据。 图像显示和分析软件由系统(46)执行，以读取数据文件以及显示采集的倾斜图像的至少一部分。 该软件检索用户在显示图像上选择的一个或多个点的位置数据，并且计算任何两个或多个选择点之间的分离距离。 该分离距离计算是用户可选择的，以确定各种参数，包括选择点之间的直线距离，由选择点包围的面积，选择点的相对标高，和选择点之间的高度差。



1．一种用于采集图像及相应的地理位置数据的系统，包括：

图像采集设备，所述图像采集设备在图像采集事件中采集倾斜图像，所述图像采集设备发出与所采集图像对应的图像数据信号；

至少一个地理定位设备，所述至少一个地理定位设备中的每一个发出相应的至少一个地理定位信号，所述至少一个地理定位信号的每一个在每个图像采集事件期间至少表示部分所述图像采集设备的地理位置；以及

计算机系统，其接收和存储所述图像数据信号和所述至少一个地理定位信号；以及

图像和数据获取软件，其读取所述图像数据信号和所述至少一个地理定位信号，对于每个图像采集事件，所述软件将每个所述图像数据信号与相应的所述至少一个地理定位信号相关联。

2．根据权利要求1所述的系统，其中所述至少一个地理定位设备和所述至少一个地理定位信号分别包括以下至少之一：

向所述图像采集计算机系统发出时间数据信号的时钟，所述时间数据信号表示每个所述图像采集事件的时间；

全球定位系统(GPS)接收器，其接收GPS信号，并在每个所述图像采集事件中，将表示所述图像采集设备经度和纬度的位置数据信号发送到所述图像采集计算机系统；

惯性导航设备(INU)，其在每个所述图像采集事件中，将表示所述图像采集设备速度的速度数据信号发送到所述图像采集计算机系统；

陀螺仪，其在每个所述图像采集事件中，将分别表示所述图像采集设备的俯仰、滚动和偏航的俯仰信号、滚动信号和偏航信号，发送到所述图像采集计算机系统；

罗盘，其在每个所述图像采集事件中，将表示所述图像采集设备

航向的航向数据信号发送到所述图像采集计算机系统；以及

高度计，其在每个所述图像采集事件中，将表示所述图像采集设备海拔高度的海拔高度数据信号发送到所述图像采集计算机系统。

3．根据权利要求 1 所述的系统，其中所述至少一个地理定位设备和所述至少一个地理定位信号分别包括：

向所述图像采集计算机系统发出时间数据信号的时钟，所述时间数据信号表示每个所述图像采集事件的时间；

全球定位系统(GPS)接收器，其接收 GPS 信号，并在每个所述图像采集事件中，将表示所述图像采集设备经度和纬度的位置数据信号发送到所述图像采集计算机系统；

惯性导航设备(INU)，其在每个所述图像采集事件中，将表示所述图像采集设备速度的速度数据信号发送到所述图像采集计算机系统；

陀螺仪，其在每个所述图像采集事件中，将分别表示所述图像采集设备的俯仰、滚动和偏航的俯仰信号、滚动信号和偏航信号发送到所述图像采集计算机系统；

罗盘，其在每个所述图像采集事件中，将表示所述图像采集设备航向的航向数据信号发送到所述图像采集计算机系统；以及

高度计，其在每个所述图像采集事件中，将表示所述图像采集设备海拔高度的海拔高度数据信号发送到所述图像采集计算机系统。

4．根据权利要求 1 所述的系统，进一步包括表示所述图像采集设备特性的校正数据，所述特性包括焦距、传感器尺寸、径向畸变、主点偏移和对准，所述图像和数据获取软件利用所述校正数据来校正采集的图像。

5．根据权利要求 1 所述的系统，进一步包括由所述图像和数据获

取软件产生的输出数据文件，所述输出数据文件包括多个图像文件和与所述多个图像文件中的每一个对应的位置数据。

6．根据权利要求 1 所述的系统，进一步包括一个平台，该平台将所述图像采集设备携带到距感兴趣表面上方预定的距离。

7．一种计算机化系统，基于采集的倾斜图像用于显示、地理定位和进行测量，包括：

具有存储器的计算机系统；

图像和数据文件，其可由所述系统进行访问，并且包括与多个采集的倾斜图像对应的多个图像文件，所述图像和数据文件进一步包括与所述多个图像文件对应的位置数据；

图像显示和分析软件，其由所述系统运行，以读取所述图像和数据文件，并将该采集的倾斜图像的至少一部分作为显示图像进行显示，所述软件检索所述显示图像中的一个或多个选择点的所述位置数据，所述软件计算所述显示图像中的任何两个或多个选择点之间的分离距离。

8．根据权利要求 7 所述的系统，进一步包括表示方块状地平面的地平面数据文件，所述地平面数据文件可由所述计算机系统访问，所述地平面数据文件表示与所述采集的倾斜图像中描述的地形的至少一部分十分近似的方块状地平面。

9．根据权利要求 8 所述的系统，其中所述方块状地平面进一步包括多个互连的小平面，所述多个小平面中的每一个具有各自的间距和坡度。

10．根据权利要求 9 所述的系统，其中所述地平面数据文件包括多个顶点，所述多个顶点中的每一个具有各自的标高，并且定义所述多个互连小平面的角，所述多个顶点中的两个由所述互连小平面中的每一个共有。

11．根据权利要求 10 所述的系统，其中所述图像显示和分析软件识别所述多个小平面中的哪一个对应于所述显示图像上的选择点，并且计算所述选择点的标高，所述标高至少部分取决于与该选择点对应的该小平面的顶点的标高，所述图像显示和分析软件使用所述计算的标高计算所述选择点和一个或多个其它选择点之间的所述分离距离。

12．根据权利要求 11 所述的系统，其中所述图像显示和分析软件通过计算两个或多个选择点之间的该分离距离，来计算所述显示图像中物体的高度。

13．根据权利要求 8 所述的系统，其中所述方块状地平面为叠加和拟合到所述显示图像上的一个。

14．根据权利要求 7 所述的系统，其中所述图像显示和分析软件包括用户可选择的测量模式，可以通过下拉菜单、工具栏和键盘命令中的至少一种访问该模式。

15．根据权利要求 7 所述的系统，其中所述图像中的每一个由图像采集设备在各个图像采集事件中采集，所述图像和数据文件的所述位置数据包括：

表示每个图像采集事件时间的时间数据；

在每个图像采集事件中表示该图像采集设备位置的位置数据；

在每个图像采集事件中表示该图像采集设备定向的定向数据；

表示该图像采集设备的校正系数的校正数据；以及

表示由该图像采集设备所采集的该表面的平均标高的标高数据。

16．根据权利要求 15 所述的系统，其中所述位置数据包括在每个图像采集事件中所述图像采集设备的纬度、经度和海拔高度。

17．根据权利要求 15 所述的系统，其中所述定向数据包括在每个图像采集事件中所述图像采集设备的滚动、俯仰、偏航和航向。

18．根据权利要求 15 所述的数据组，其中所述图像采集设备是照相机，且所述校正数据至少包括焦距、传感器尺寸、长宽比、主点偏移、畸变和像素间距中的一个。

19．用于在显示的倾斜图像中进行测量的计算机化方法，包括：

在该显示图像上用输入设备选择起始点和结束点；

从数据文件检索与所述起始点和所述结束点对应的位置数据；

参考与具有多个小平面的方块状地平面对应的地平面数据文件，所述小平面中的每一个具有各自的间距和坡度，所述方块状地平面与所述显示的倾斜图像的地形精密地匹配；

用线段将所述起始点和结束点连接，所述线段符合所述小平面的所述间距和坡度，由此遵循所述地形；以及

沿所述起始点和结束点之间的所述线段计算该线距离，因此，考虑到了所述小平面的所述间距和坡度。

20．根据权利要求 19 所述的方法，其中所述方块状地平面叠加在所述显示的倾斜图像上。

21．根据权利要求19所述的方法，进一步包括以下步骤：

在该显示图像上用输入设备选择一个或多个中间点；

从所述数据文件检索与所述一个或多个中间点对应的位置数据；以及

将相邻的中间点彼此连接，并且用线段将所述起始点和结束点连接到相邻的中间点，所述线段符合所述小平面的所述间距和坡度，由此遵循所述地形；以及

沿所述起始点和结束点之间的所述线段计算该距离。

22．根据权利要求19所述的方法，其中所述多个小平面中的每一个与所述显示的倾斜图像的相等面积相对应。

23．根据权利要求19所述的方法，其中所述多个小平面中的每一个包括所述显示的倾斜图像的相等数量的像素。

24．一种计算机化方法，用于从显示在计算机系统上的倾斜图像上进行测量，至少一个输入设备连接到所述计算机系统，图像数据文件可由所述计算机系统访问，所述图像数据文件包括与之对应的采集的图像和位置数据，所述计算机化方法包括：

将该计算机系统置于多个测量模式的所需一个之中，配置该所需的测量模式，以计算所需的测量；

在该显示图像上选择起始点；

检索与所述起始点对应的该位置数据；

在该显示图像上选择结束点；

检索与所述结束点对应的该位置数据；以及

计算该所需的测量，该测量至少部分地取决于所述起始点和结束

点的所述位置数据。

25．根据权利要求24所述的方法，进一步包括以下步骤：

在所述显示图像上选择一个或多个中间点；以及

检索与所述中间点对应的该位置数据。

26．根据权利要求24所述的方法，其中所述多个测量模式包括：距离测量模式，用于计算两个或多个选择点之间的距离；高度测量模式，用于计算两个或多个选择点之间的高度差；相对标高测量模式，用于计算两个或多个选择点标高的差值；和面积测量模式，用于计算由至少三个点包围的面积。

27．用平台携带的图像采集设备来采集感兴趣区域的倾斜图像的一种方法，在各个图像采集事件中采集每个倾斜图像，所述方法包括：

将该感兴趣区域分为多个区；

沿第一路线引导该平台，由此用该图像采集设备瞄准一个或多个目标区；

用该图像采集设备采集一个或多个倾斜图像，由此在从第一视角采集的倾斜图像中覆盖每个所述目标区的全部；

沿第二路线引导该平台，由此瞄准所述目标区；

用该图像采集设备采集一个或多个倾斜图像，由此在从第二视角采集的倾斜图像中覆盖每个所述目标区的全部；

沿着基本上与所述第一和第二路线平行且与所述第一和第二路线间隔一定距离的路线，重复所述引导和采集步骤，并且采集一个或多个倾斜图像，由此，在从所述第一和第二视角中的每一个采集的倾斜图像中，覆盖了所述多个区中每一个的全部；以及

在每个图像采集事件中，记录表示所述图像采集设备地理位置的

位置数据。

28．根据权利要求 27 所述的方法，其中所述第二路线基本上平行于所述第一路线，且关于所述第一路线成 180°(180 度)。

29．根据权利要求 28 所述的方法，其中所述第二路线也与所述第一路线间隔一定距离。

30．根据权利要求 27 所述的方法，进一步包括以下步骤：

沿第三路线引导该平台，由此用该图像采集设备瞄准一个或多个目标区，所述第三路线基本上与所述第一和第二路线垂直；

用该图像采集设备采集一个或多个倾斜图像，由此在从第三视角采集的倾斜图像中采集每个所述目标区的全部；以及

沿着基本上与所述第三路线平行而且与所述第三路线间隔一定距离的路线，重复所述引导和采集步骤，并且采集一个或多个倾斜图像，由此在从所述第三视角采集的倾斜图像中覆盖所述多个区中每一个的全部。

31．根据权利要求 30 所述的方法，进一步包括以下步骤：

沿第四路线引导该平台，由此用该图像采集设备瞄准一个或多个目标区，所述第四路线基本上平行于所述第三路线，并且与所述第三路线成 180°(180 度)角；

用该图像采集设备采集一个或多个倾斜图像，由此在从第四视角采集的倾斜图像中采集每个所述目标区的全部；以及

沿基本上与所述第四路线平行而且与所述第四路线间隔一定距离的路线重复所述引导和采集步骤，并且采集一个或多个倾斜图像，由此在从所述第四视角采集的倾斜图像中覆盖所述多个区中每一个的

全部。

32．根据权利要求31所述的方法，其中所述第四路线也与所述第三路线间隔一定距离。

倾斜地理定位和测量系统

相关申请的相互引用

本申请要求申请日为 2002 年 11 月 8 日、序列号为 60/425275 的美国临时专利申请的权益。

发明领域

本发明涉及摄影测量，尤其涉及用于采集倾斜图像和用于测量物体以及图像中所示物体之间的距离的方法和装置。

技术背景

摄影测量是对显示在照片中、尤其是航摄照片中的物体及物体之间进行测量的一门科学。通常，摄影测量包括拍摄地形特征的图像，并且从其推导数据，例如，该数据表示所述图像中物体之间的相对距离及物体的尺寸。摄影测量也可以包括将照片与其它数据联系起来，例如代表纬度和经度的数据。实际上，所述图像被叠加并且符合特定的空间坐标系。

传统的摄影测量包括采集和/或获取正交图像。诸如照相机或传感器这样的图像采集设备是正交图像。诸如照相机或传感器这样的图像采集设备由诸如飞机或卫星这样的运载体或平台携带，并且瞄准平台正下方的和/或从平台垂直向下的最底点(nadir point)。图像中对应于最底点的点或像素是精确地与图像采集设备正交的唯一的点/像素。图像中所有其它的点或像素实际上相对于图像采集设备倾斜。当点或像素逐渐远离最底点时，它们相对于图像采集设备愈加地倾斜，并且地面取样距离(即，对应于每个像素或由每个像素覆盖的表面积)也增加。正交图像中的倾斜导致图像中的特征畸变，尤其在离最底点较远

的图像中。

该畸变通过正交校正过程被消除或补偿，实质上，通过在正网格(orthometric grid)或坐标系上拟合或弯曲正交图像的每个像素，所述正交校正过程从正交图像中消除倾斜。所述正交校正过程产生了图像，其中所有的像素具有相同的地面取样距离并且都被朝北定向。因此，在正交校正图像上的任何点都可以使用 X，Y 坐标系来定位，并且只要知道图像比例，就能够计算出地形特征的长度和宽度，以及这些特征之间的相对距离。

尽管正交校正过程一定程度上补偿了正交图像中的倾斜畸变，但是它在正交校正的正交图像中引入了其它不期望的畸变和/或误差。由于多数观察者不习惯从上方观察物体，尤其是地形特征，因此显示在正交校正过的正交图像中的物体可能难以识别和/或鉴定。对于未受培训的观察者而言正交校正图像具有许多畸变。实际上直的道路看上去弯曲，建筑物可能看上去倾斜。而且，正交校正图像基本上不包含关于地形特征的高度信息。为了识别这种图像中的物体和地形特征，正交和/或正交校正正交图像的解释和分析通常由受过高等培训的分析员来进行，这些人员接受了多年的专门培训并且具有多年的经验。

因此，尽管正交和正交校正图像在摄影测量中有用，但是它们缺少关于其中所示特征的高度信息，并且要求受过高等培训的分析员来解释图像所显示的细节。

倾斜图像是用通常瞄准或指向携带图像采集设备的平台的侧向或下方的图像采集设备采集的图像。与正交图像不同，倾斜图像显示了诸如房屋、建筑和/或山脉这样的地形特征的侧部及其顶部。因此，观察倾斜图像比观察正交或正交校正图像更自然和直观，甚至临时的观察者也能够识别和解释显示在倾斜图像中的地形特征和其它物体。在倾斜图像的前景中的每个像素对应于所示的表面或物体的较小面

积(即，每个前景像素具有较小的地面取样距离)，而背景中的每个像素对应于所示的表面或物体的较大面积(即，每个背景像素具有较大的地面取样距离)。倾斜图像采集对象表面或物体的大致梯形面积或视图，并且梯形前景具有基本上比梯形背景小的地面取样距离(即，更高的分辨率)。

在摄影测量中倾斜图像被认为几乎或完全没有用处。将不同尺寸的倾斜图像的前景像素和背景像素变换为统一的尺寸，并由此在坐标系上弯曲该图像的传统方法极大地扭曲了倾斜图像，并且由此造成了物体的识别以及在图像中显示物体的测量任务变得费力而不精确。通过使用高程模型在倾斜图像中进行地形移位的校正进一步扭曲了图像，由此增加了进行测量的难度，而减小了任何这样的测量的精确度。

因此，尽管在摄影测量中倾斜图像被认为几乎或完全没有用处，但是它们容易被理解，并且包含关于其中所示特征的高度信息。

因此，在本领域中需要一种用于摄影测量的方法和装置，其能够实现倾斜图像中的地理定位和精确测量。

而且，在本领域中需要一种用于摄影测量的方法和装置，其能够实现图像中物体的标高和相对标高的测量。

进一步地，在本领域中需要一种用于摄影测量的方法和装置，其利用更多直观的和自然的图像。

发明内容

本发明提供了用于采集、显示和测量物体以及倾斜图像中所示的物体之间的距离的一种方法和装置。

本发明的一种形式包括从采集的倾斜图像进行显示、地理定位和测量的计算机化系统。该系统包括可由计算机系统访问的数据文件。数据文件包括对应于多个采集的倾斜图像的多个图像文件，和对应于该图像的位置数据。该系统运行图像显示和分析软件，以读取数据文件以及显示所述采集的倾斜图像的至少一部分。该软件为显示图像上

的一个或多个用户选择点检索位置数据，并且计算任何两个或多个选择点之间的分离距离。该分离距离计算是用户可选择的，其用于确定各种参数，包括选择点之间的直线距离，选择点内包围的面积，选择点的相对标高，选择点之间的高度差。

附图简述

当结合附图阅读时，参考本发明的实施例的以下描述，本发明的上述和其它特征和优点以及实现它们的方式将变得明显并被完全理解，其中：

图 1 示出了携带本发明的图像采集系统的平台或运载体的一个实施例，并且示出了由此拍摄的典型正交图像和倾斜图像；

图 2 是图 1 的图像采集系统的简图；

图 3 是图 2 的图像采集计算机系统的结构图；

图 4 是图 1 的图像采集系统的示例性输出数据文件的图示；

图 5 是本发明的图像显示和测量计算机系统的一个实施例的结构图，所述系统用于显示并对在由图 1 的图像采集系统采集的图像中所示的物体及物体之间进行测量；

图 6 示出了显示在图 5 的系统上的示例性图像，并且示出了对在该图像中所示物体及物体之间进行测量的本发明的方法的一个实施例；

图 7 和 8 示出了本发明用于采集倾斜图像的方法的一个实施例；

图 9 和 10 示出了本发明用于采集倾斜图像的方法的第二实施例；

在所有的这几幅图中相应的附图标记表示相应的部分。这里阐述的范例以一种形式说明了本发明的优选实施例，并且该范例不旨在以任何方式限制本发明的范围。

发明详述

现在参考附图，尤其参考图 1，示出了本发明用于对倾斜图像进

行采集和地理定位的装置的一个实施例。装置 10 包括携带图像采集和地理定位系统 30 的平台或运载体 20。

平台 20，例如飞机，航天飞机，火箭，卫星，或者任何合适的运载体，在表面 31 的预定区域上方和在表面 31 上的一个或多个预定海拔高度携带图像采集系统 30，所述表面 31 例如为地球表面或者任何感兴趣的其它表面。因而，平台 20 能够在有人驾驶或无人驾驶情况下，经由例如地球大气层或外层空间沿着预定的飞行路径或路线受控运动或者飞行。图像采集平台 20 包括用于产生和调节能量的系统(未示出)，该系统例如包括一个或多个发动机，燃料电池，太阳电池板，和/或电池，为图像采集系统 30 提供动力。

从图 2 中最清楚地看到，图像采集和地理定位系统 30 包括图像采集设备 32a 和 32b，全球定位系统(GPS)接收器 34，惯性导航单元(INU)36，时钟 38，陀螺仪 40，罗盘 42 和高度计 44，它们中的每一个都与图像采集计算机系统 46 互连。

图像采集设备 32a 和 32b，例如传统相机，数字相机，数字传感器，电荷耦合器件，或者其它合适的图像采集设备，能够用摄像或者电子仪器采集图像。图像采集设备 32a 和 32b 所具有的已知或确定的特性包括焦距，传感器尺寸和长宽比，径向畸变和其它畸变项，主点偏移，像素间距，和对准。图像采集设备 32a 和 32b 分别获取图像和发出图像数据信号(IDS)48a 和 48b，该图像信号对应于拍摄的特定图像或照片并且存储在图像采集计算机系统 46 中，以下更具体地描述。

如图 1 所示，图像采集设备 32a 和 32b 各自具有中心轴 A_1 和 A_2，并且安装到平台 20 上，使得每一个轴 A_1 和 A_2 相对于水平面 P 具有偏角 θ。偏角 θ 实质上是任何倾斜角度，但是优选地从大约 20°(20 度)到大约 60°(60 度)，并且最优选地从大约 40°(40 度)到大约 50°(50 度)。

GPS 接收器 34 接收全球定位系统信号 52，该信号由一个或多个全球定位系统卫星 54 发射。GPS 信号 52 以公知的形式能够确定平台

20 相对于表面 31 的精确位置。GPS 接收器 34 对 GPS 信号 52 进行译码并且发出位置信号/数据 56，该位置信号/数据 56 至少部分地取决于 GPS 信号 52，并指示了平台 20 相对于表面 31 的精确位置。对应于图像采集设备 32a 和 32b 采集的每个图像的位置信号/数据 56 被图像采集计算机系统 46 接收和存储。

INU 36 是传统的惯性导航单元，其连接到图像采集设备 32a 和 32b 和/或平台 20，并且检测图像采集设备 32a 和 32b 和/或平台 20 的速度的变化，包括平动速度和旋转速度。INU 36 将表示速度和/或速度变化的速度信号/数据 58 发送到存储速度信号/数据 58 的图像采集计算机系统 46，该速度信号/数据 58 对应于由图像采集设备 32a 和 32b 采集并且被图像采集计算机系统 46 接收和存储的每个图像。

时钟 38 保持准确的时间测量值(有效时间)，该时间测量值用于对图像采集和地理定位系统 30 中的事件进行同步。时钟 38 提供了时间数据/时钟信号 62，所述时间数据/时钟信号 62 表示图像采集设备 32a 和 32b 拍摄图像的准确时间。时间数据 62 也被提供给图像采集计算机系统 46 并由图像采集计算机系统 46 存储。可选地，时钟 38 与图像采集计算机系统 46 集成在一起，例如时钟软件程序。

陀螺仪 40 是在飞机上和/或用于飞机的商业导航系统中很常见的传统的陀螺仪。陀螺仪 40 提供的信号包括俯仰信号 64，滚动信号 66 和偏航信号 68，其分别表示平台 20 的俯仰，滚动和偏航。对应于图像采集设备 32a 和 32b 采集的每个图像的俯仰信号 64，滚动信号 66 和偏航信号 68 被图像采集计算机系统 46 接收和存储。

罗盘 42，例如传统的电子罗盘，指示平台 20 的航向。罗盘 42 发出表示平台 20 航向的航向信号/数据 72。图像采集计算机系统 46 接收和存储该航向信号/数据 72，该航向信号/数据 72 对应于图像采集设备 32a 和 32b 采集的每个图像。

高度计 44 指示平台 20 的海拔高度。高度计 44 发出海拔高度信号

/数据 74，图像采集计算机系统 46 接收和存储该海拔高度信号/数据 74，该海拔高度信号/数据 74 对应于图像采集设备 32a 和 32b 采集的每个图像。

如图 3 所示，图像采集计算机系统 46，例如传统的膝上型个人电脑，包括存储器 82，输入设备 84a 和 84b，显示设备 86，和输入和输出(I/O)端口 88。图像采集计算机系统 46 运行图像和数据获取软件 90，该软件存储在存储器 82 中。图像采集计算机系统 46 在其操作期间使用和/或计算的数据也存储在存储器 82 中，并且存储器 82 包括，例如非易失性只读存储器，随机存取存储器，硬盘存储器，移动存储卡和/或其它合适的记忆体存储设备和/或介质。输入设备 84a 和 84b，例如鼠标，键盘，控制杆等，使得能够进行数据的输入，以及用户和由图像采集计算机系统 46 运行的软件之间的交互作用。显示设备 86，例如液晶显示器或阴极射线管，向图像采集计算机系统 46 的用户显示信息。I/O 端口 88，例如串行和并行数据输入和输出端口，使得能够向图像采集计算机系统 46 输入和/或从其输出数据。

上述的每一个数据信号都连接到图像采集计算机系统 46。更具体地，图像数据信号 48，位置信号 56，速度信号 58，时间数据信号 62，俯仰、滚动和偏航信号 64，66 和 68，航向信号 72 和海拔高度信号 74 通过 I/O 端口 88 被接收并且存储在图像采集计算机系统 46 的存储器 82 中。

在使用时，图像采集计算机系统 46 运行图像和数据获取软件 90，该软件通常控制对上述数据信号的读取、操作和存储。更具体地，图像和数据获取软件 90 读取图像数据信号 48a 和 48b，并将它们存储在存储器 82 中。表示在获取图像瞬间的存在状态的位置信号 56，速度信号 58，时间数据信号 62，俯仰、滚动和偏航信号 64，66 和 68，航向信号 72 和海拔高度信号 74 中的每一个由图像采集设备 32a 和 32b 获取和采集，并且对应于表示所采集的图像的特定图像数据信号

48a 和 48b，这些信号通过 I/O 端口 88 由图像采集计算机系统 46 接收。运行图像和数据获取软件 90 的图像采集计算机系统 46 将图像采集信号 92 发送到图像采集设备 32a 和 32b，由此导致这些设备在至少部分取决于平台 20 速度的预定位置和/或以预定时间间隔获取或采集图像。

图像和数据获取软件 90 按照需要对前述信号进行解码并将其存储在存储器 82 中，并且使得该数据信号与相应的图像信号 48a 和 48b 相关联。因此，可以知道图像采集设备 32a 和 32b 采集的每个图像的海拔高度，就俯仰、滚动和偏航而言的定向，图像采集设备 32a 和 32b 相对于表面 31 的位置，即，经度和纬度。

经由图像采集路线驾驶或者以其它方式引导平台 20，所述图像采集路线经过表面 31 的特定区域上方，例如地球或另一行星表面的预定区域。优选地，平台 20 的图像采集路线与感兴趣区域的至少一个边界成直角。平台 20 和/或图像采集设备 32a，32b 经过感兴趣区域上方的次数至少部分取决于该区域的大小以及在采集的图像中所需的细节量。以下更具体地描述平台 20 的图像采集路线的特定细节。

当平台 20 经过感兴趣区域上方时，大量倾斜图像被图像采集设备 32a 和 32b 采集。本领域的普通技术人员将会理解，以预定的图像获取时间间隔，图像采集设备 32a 和 32b 采集或获取图像，所述时间间隔至少部分取决于平台 20 的速度。

图像采集计算机系统 46 的存储器 82 通过 I/O 端口 88 接收并存储对应于获取的每个图像的图像数据信号 48a 和 48b。类似地，图像采集计算机系统 46 的存储器 82 通过 I/O 端口 88 接收并存储对应于采集的每个图像的数据信号(即，图像数据信号 48，位置信号 56，速度信号 58，时间数据信号 62，俯仰、滚动和偏航信号 64，66，68，航向信号 72 和海拔高度信号 74)。因此，在采集每个图像的准确时刻，图像采集设备 32a 和 32b 相对于表面 32 的位置被记录在存储器 82 中，

并且与相应的采集图像相关联。

如图 1 所示，图像采集设备 32a 和 32b 相对于地球的位置对应于正交图像 102 的最底点 N。因此，正交图像 102 的最底点 N 的精确地理位置由位置信号 56，速度信号 58，时间数据信号 62，俯仰、滚动和偏航信号 64，66，68，航向信号 72 和海拔高度信号 74 表示。一旦正交图像 102 的最底点 N 已知，可以用公知的方式确定图像 102 内任何其它像素或点的地理位置。

当图像采集设备 32a 和 32b 采集诸如倾斜图像 104a 和 104b(图 1)的倾斜图像时，图像采集设备 32a 和 32b 相对于表面 31 的位置类似地分别由位置信号 56，速度信号 58，时间数据信号 62，俯仰、滚动和偏航信号 64，66，68，航向信号 72，海拔高度信号 74 和图像采集设备 32a 和 32b 的主轴线 A_1 和 A_2 的已知偏角 θ 表示。

特别应当注意的是，校准过程使图像和数据获取软件 90 能够结合校正系数和/或能够对图像采集设备 32 固有的或由其引起的任何误差进行校正，例如由于校准的焦距，传感器尺寸，径向畸变，主点偏移，和对准引起的误差。

图像和数据获取软件 90 产生并在存储器 82 中存储一个或多个输出图像和数据文件 120。更具体地，图像和数据获取软件 90 将图像数据信号 48a，48b 和定向数据信号(即，图像数据信号 48，位置信号 56，速度信号 58，时间数据信号 62，俯仰、滚动和偏航信号 64，66，68，航向信号 72 和海拔高度信号 74)转换为计算机可读的输出图像和数据文件 120。如图 4 所示，输出图像和数据文件 120 包含对应于采集的倾斜图像的多个采集图像文件 I_1，I_2，...，I_n，和与之对应的位置数据 C_{PD1}，C_{PD2}，...，C_{PDn}。

图像和数据文件 120 的图像文件 I_1，I_2，...，I_n 实际上以计算机可读的任何图像或图形文件格式被存储，例如 JPEG，TIFF，GIF，BMP，或者 PDF 文件格式，并且与同样作为计算机可读数据存储的位置数

据 C_{PD1}，C_{PD2}，...，C_{PDn} 相互参照。可选地，位置数据 C_{PD1}，C_{PD2}，...，C_{PDn} 以公知的方式嵌入到相应的图像文件 I_1，I_2，...，I_n 中。然后由图像和数据获取软件 90 或者由后处理过程对图像数据文件 120 进行处理，以校正误差，例如由于飞行路线偏移导致的误差和本领域普通技术人员公知的其它误差。之后，图像数据文件 120 准备好用于显示所采集图像中描述的物体，并对所采集图像中描述的物体及物体之间进行测量，包括该物体的高度测量。

现在参考图 5，图像显示和测量计算机系统 130，例如传统的台式个人电脑或者警车中的移动电脑终端，包括存储器 132，输入设备 134a 和 134b，显示设备 136，和网络连接器 138。图像采集计算机系统 130 运行图像显示和分析软件 140，该软件存储在存储器 132 中。存储器 132 包括，例如非易失性只读存储器，随机存取存储器，硬盘存储器，移动存储卡和/或其它合适的记忆体存储设备和/或介质。输入设备 134a 和 134b，例如鼠标，键盘，控制杆等，允许数据的输入，并使用户与图像显示和测量计算机系统 130 运行的图像显示和分析软件 140 之间能够进行交互作用。显示设备 136，例如液晶显示器或阴极射线管，向图像显示和测量计算机系统 130 的用户显示信息。网络连接器 138 将图像显示和测量计算机系统 130 连接到网络(未示出)，例如局域网，广域网，因特网和/或万维网。

现在参考图 6，在使用中，运行图像显示和分析软件 140 的图像显示和测量计算机系统 130 访问一个或多个例如通过网络连接器 138，软盘驱动器，移动存储卡或其它适当方式读入存储器 132 中的输出图像和数据文件 120。此后，在图像显示和分析软件 140 的控制下，输出图像和数据文件 120 的一个或多个采集图像 I_1，I_2，...，I_n 作为显示倾斜图像 142 被显示。在大约相同的时间，对应于显示倾斜图像 142 的一个或多个数据部分 C_{PD1}，C_{PD2}，...，C_{PDn} 被读入到存储器 132 的可访问部分。

特别应当注意的是，基本上当采集时对显示倾斜图像 142 进行显示，即显示的图像 142 没有针对任何坐标系弯曲或拟合，也没有被正交校正。图像显示和分析软件 140 并不为了能够测量图像中显示的物体而针对一个坐标系弯曲显示的图像 142，而是通常通过参考输出图像和数据文件 120 的数据部分 C_{PD1}，C_{PD2}，...，C_{PDn} 和使用一个或多个下文中将具体说明的投影方程计算那些所选像素的位置和/或地理位置，来确定仅根据需要而选择的或“在空中”选择的像素的地理位置。

通常，显示和测量计算机系统 130 的用户通过选择图像显示和分析软件 140 中提供的几个可用测量模式中的一个，对显示在显示倾斜图像 142 中的物体及其之间进行测量。用户例如通过访问一系列下拉菜单或工具栏 M，或者通过键盘命令选择所需的测量模式。图像显示和分析软件 140 提供的测量模式包括，例如，距离模式，其能够测量两个或多个选择点之间的距离；面积模式，其能够测量由若干选择的和互连的点包围的面积；高度模式，其能够测量两个或多个选择点之间的高度；和标高模式，其能够测量一个选择点相对于一个或多个其它选择点的标高变化。

当选择所需的测量模式之后，图像显示和分析软件 140 的用户用输入设备 134a，134b 中的一个在显示图像 142 上选择起始点或开始像素 152 和结束点或像素 154，并且图像显示和分析软件 140 自动计算和显示探索量(quantity sought)，例如开始像素 152 和结束像素 154 之间的距离。

当用户选择开始点/像素 152 时，由图像显示和分析软件 140 计算表面 31 上与之对应的点的地理位置，所述图像显示和分析软件 140 利用与被显示的特定图像对应的输出图像和数据文件 120 的数据部分 C_{PD1}，C_{PD2}，...，C_{PDn}，运行一个或多个投影方程。然后，图像显示和分析软件 140 将与像素 152 对应的表面 31 上的点的经度和纬度

显示在显示器 136 上，例如，在显示图像 142 上，靠近选择点/像素叠加经度和纬度，或在显示器 136 上其它位置的弹出显示框中叠加经度和纬度。用户重复同样的过程，以选择结束像素/点 154，并且图像显示和分析软件 140 重复同样的过程，以检索和显示经度和纬度信息。

通过确定每个“在空中”选择的像素 152，154 的地理位置，分别完成起始和结束点/像素 152，154 之间距离的计算。检索与显示图像对应的输出图像和数据文件 120 的数据部分 C_{PD1}，C_{PD2}，...，C_{PDn}，然后确定与每个所选像素对应的表面 31 上点的地理位置。与所选像素对应的地理位置之间的差异决定了像素之间的距离。

作为如何确定显示倾斜图像 142 内给定点或像素的地理位置的例子，我们将假设显示图像 142 对应于正交图像 104(图 1)。图像显示和分析软件 140 的用户选择像素 154，为了简便，该像素对应于倾斜图像 104a 的中心 C(图 1)。如图 1 所示，线 106 沿着水平面 G，从其上位于图像采集设备 32a 正下方的点 108 延伸到倾斜图像 104a 的近边界或边缘 108 的中心 C。主轴线 A_1 的延伸线与中心 C 相交。角 φ 是在线 106 与主轴线 A_1 的延伸线之间形成的角。因此，形成一个三角形(未标示)，该三角形的顶点分别是图像采集设备 32a，点 108 和中心 C，该三角形的边分别是边 106，主轴线 A_1 的延伸线，以及点 108 和图像采集设备 32a 之间的垂线(虚线)110。

地平面 G 基本上是水平的、平坦的或不倾斜的地平面(其一般具有反映地形平均标高的标高)，因此上述的三角形包括边/线 110 和边/线 106 之间的直角。由于角 φ 和图像采集设备 32 的海拔高度(即，边 110 的长度)是已知的，因此可以通过简单的几何学计算该直角三角形的斜边(即，主轴线 A_1 的延伸线的长度)和剩下的另一边。而且，由于在与显示图像 142 对应的图像被采集的时刻，图像采集设备 32a 的精确位置已知，因此点 108 的纬度和经度也已知。知道按照上述计算的

边 106 的长度，能够通过图像显示和分析软件 140 确定与倾斜图像 104a 的中心 C 对应的像素 154 的准确地理位置。一旦知道了与像素 154 对应的点的地理位置，就可以利用已知相机特性来确定显示倾斜图像 142 中的任何其它像素的地理位置，例如焦距，传感器尺寸和长宽比，径向畸变和其它畸变项等。

通过利用公知算法确定所选像素的地理位置之间的差异，图像显示和分析软件 140 计算与显示图像 142 中两个或多个所选像素对应的两个或多个点之间的距离，所述算法例如为高斯公式和/或灭点(vanishing point)公式，这取决于选择的测量模式。通过与上述测量所选像素之间的距离基本类似的过程，来对显示或出现在显示图像 142 中的物体进行测量。例如，通过选择合适的/所需的测量模式，以及选择开始和结束像素，来测量出现在显示图像 142 中的诸如建筑物，河流，道路，以及实质上任何其它地理或人造结构的物体的长度，宽度和高度。

特别应当注意的是，在图像显示和分析软件 140 的距离测量模式中，开始和结束点/像素 152，154 之间的距离实质上可以沿任何路线确定，例如“直线”路线 P1，或者包括选择中间点/像素和一个或多个与之互连的“直线”段的路线 P2。

也特别应当注意的是，图像显示和分析软件 140 的距离测量模式根据“漫步地球”法确定所选像素之间的距离。“漫步地球法”产生了一系列互连的直线段，这些线段共同由路线 P1 和 P2 表示，所述路线 P1 和 P2 在所选像素/点之间延伸，并且落在或依照定义了方格状地平面的一系列互连小平面中的平面上。如以下将具体描述的，方格状地平面很接近地遵照或再现表面 31 的地形，因此路线 P1 和 P2 也很接近地遵照表面 31 的地形。通过沿着由方格状地平面模拟的地形测量距离，“漫步地球”法提供了比传统方法更精确和有用的选择点之间的距离测量，所述传统方法在平地或平均标高平面系统上弯曲图像，并

且沿平地或平面测量选择点之间的距离，基本上忽略点之间的地形变化。

例如，准备对在不平地形或者丘陵地形上铺路的合同进行投标的承包商，可以使用图像显示和分析软件 140 和由此提供的“漫步地球”测量法，来确定所包含道路的近似数量或面积。承包商可以从他或她自己的办公室获得道路的近似数量或面积，而不必派遣测绘队到现场获得必要的测量值。

与本发明提供的“漫步地球”法相比，当测量位于不平地形上的点和/或物体之间的距离时，以及当测量类似物体的尺寸和/或高度时，“平地”或平均标高距离计算法包含固有的不精确性。即使采集表面中的适度倾斜或坡度，也导致最底点的标高实际上相对于其上任何其它兴趣点的差值。因此，再次参考图 1，由线 106，主轴线 A_1 的延伸线，以及点 108 和图像采集设备 32a 之间的垂线(虚线)110 形成的三角形可能不是直角三角形。如果发生这种情况，假设该三角形是直角三角形的任何几何计算会包含误差，甚至兴趣点之间的较小的梯度或斜坡也会导致该计算结果成为近似值。

例如，如果表面 31 在最底点 N 和倾斜图像 104 的靠近边缘或底部边缘 108 的中心 C 之间向上倾斜，那么第二线 110 在其与水平或非倾斜表面 31 的交点之前的一点与表面 31 相交。如果中心 C 比最底点 N 高 15 英尺，并且具有 40°(40 度)偏角 θ，如果不对点之间的标高变化进行校正，那么计算的中心 C 的位置将偏差大约 17.8 英尺。

大体如上所述，为了至少部分地补偿标高的变化，和图像 142 中的物体及物体之间的测量产生的不精确性，图像显示和分析软件 140 按照需要参考显示图像 142 中和表面 31 上的点，与预先计算的、图 6 中表示为 160 的方格状或分成小面的地平面进行参照。方格状地平面 160 包括多个独立的小平面 162a，162b，162c 等，每个小平面与每个其它小平面互相连接，并且由具有各自标高的四个顶点(未标示，

但是以点示出)定义。小平面 162a，162b，162c 等中的相邻两个共用两个顶点。每个小平面 162a，162b，162c 等具有各自的间距和坡度。方格状地平面 160 基于各种数据和资源而产生，例如地形图，和/或数字光栅图形，测绘数据，和各种其它的资源。

通常，通过确定小平面 162a，162b，162c 等中的哪一个对应于感兴趣点，来计算显示图像 142 上感兴趣点的地理位置。因此，感兴趣点的位置基于小平面 162a，162b，162c 等的标高、间距和坡度特征计算，而不是基于平坦的或平均标高地平面计算。感兴趣点位于小平面 162a，162b，162c 等的平面内，只有在表面 31 的地形和其上感兴趣点的位置偏离这些平面的情况下，才会引入误差。通过对小平面 162a，162b，162c 等中的特定一个小平面内感兴趣点的标高进行双线性插值，并且在图像显示和分析软件 140 执行的位置计算中利用该以插值的标高，可以减小误差。

为了使用方块状地平面 160，图像显示和分析软件 140 利用改进的光线跟踪算法，来找到从图像采集设备 32a 或 32b 朝表面 31 和方块状地平面 160 投射光线的交点。该算法不仅确定了小平面 162a，162b，162c 等中的哪一个与该光线相交，而且确定了在小平面内的什么位置发生该相交。通过使用双线性插值，可以确定相当精确的地面位置。对于反向投影，使用方块状地平面 160 也利用双线性插值，得到输入地面位置的地面标高值。然后通过图像采集设备 32a 或 32b 的模型，将该标高和位置用于反向投影，以确定显示图像 142 中哪一个像素对应于给定位置。

更具体地，作为一个例子，通过将方块状地平面 160 叠加和/或拟合到表面 31 的至少一个诸如小山这样的部分 166，图像显示和分析软件 140 执行和/或计算点 164 的地理位置。应当注意，只有方块状地平面 160 及其小平面 162a，162b，162c 等中的一小部分，沿着表面 31 的部分 166 的轮廓显示。如上所述，小平面 162a，162b，162c

等中的每一个由四个顶点定义，每个顶点具有各自的标高，每个小平面具有各自的间距和坡度。如上所述，确定在小平面 162a，162b，162c 等的平面/表面(点 164(或其投影)位于该平面/表面上)上点 164 的具体位置。

优选地，在图像显示和测量计算机系统 130 以及图像显示和分析软件 140 的操作之外产生方块状地平面 160。更好地，方块状地平面 160 采用存储在图像显示和测量计算机系统 130 的和/或可访问存储器中较简单的数据表或查询表 168 的形式。计算典型地平面的许多小平面的所有顶点位置所需的计算资源，不一定在图像显示和测量计算机系统 130 中。因此，在不需要附加计算资源的情况下，图像显示和测量计算机系统 130 与传统个人电脑的应用兼容，并可由传统的个人电脑执行。

在图像显示和测量计算机系统 130 之外计算方块状地平面 160，实际上能够使方块状地平面 160 中包含任何级别的细节，即，由小平面 162a，162b，162c 等中的每一个覆盖的或对应的尺寸和/或面积，可以按照需要变大或变小，而不会明显地增加计算时间，减慢操作，也不会显著增加图像显示和测量计算机系统 130 和/或图像显示和分析软件 140 所需的资源。显示和测量计算机系统 130 因此可以是较基本的和不复杂的计算机系统。

小平面 162a，162b，162c 等的尺寸在特定的显示图像 142 中是一致的。例如，如果显示图像 142 对应于在前景中大约 750 英尺宽和大约 900 英尺深的面积，那么该图像可以被分为大约 50 平方英尺的小平面，因此在宽度上产生了大约 15 个小平面，在深度上产生了 18 个小平面。可选择地，小平面 162a，162b，162c 等的尺寸就包含于其中的像素数量而言是一致的，即，每个小平面具有相同数量的像素宽度和相同数量的像素深度。因此，在像素密度最大的显示图像 142 的前景中的小平面，在尺寸上小于像素密度最低的显示图像 142 的背景

中的小平面。由于希望在像素密度最大的显示图像的前景中进行大多数的测量，与尺寸一致的小平面相比，产生包含的像素数量一致的小平面具有的优点是，在显示图像 142 的前景中提供了更精确的测量。

使用像素作为基础来定义小平面 162a，162b，162c 等的尺寸的另一优点是，位置计算(像素位置到地面位置)较简单。用户操作图像显示和测量计算机系统 130，以选择给定小平面中的像素，图像显示和分析软件 140 查询与选择像素对应的小平面的数据，如上所述计算所选像素的标高，该标高用于位置计算中。

通常，本发明采集倾斜图像的方法，将例如国家这样的感兴趣区域划分为尺寸基本一致的区，例如面积大约为一平方英里的区。这样做便于制定飞行计划，以采集覆盖每一英寸感兴趣区域的倾斜图像，并且组织和命名这些区和/或其图像，以容易地标识，存储和检索(在本领域中被称为“分区”法)。因为任何感兴趣的地理区域的边缘，例如国家，极少落在整齐划一的平分英里边界，所以本发明采集倾斜图像的方法提供了比感兴趣区域中的平方英里数要多的区——多出多少主要取决于该国家边界的长度，以及边界的平直或曲折程度如何。典型地，可以预期边界的每二到三英里具有一个额外的区。因此如果国家或其它感兴趣区域约为 20 英里乘 35 英里，或者为 700 平方英里，那么该面积将被分为大约 740－780 个区。

通常，本发明采集倾斜图像的方法从至少两个罗盘方向采集倾斜图像，并且从至少这两个罗盘方向提供感兴趣区域的完全覆盖。现在参考图 7 和 8，显示了本发明用于采集倾斜图像的方法的第一实施例。为了清楚，图 7 和 8 基于仅具有一个图像采集设备的系统。然而，应当理解可以使用两个或多个图像采集设备。

图像采集设备在每次穿越区域 200 期间采集一个或多个倾斜图像。如上所述，图像采集设备以一个角度瞄准区域 200，以采集倾斜图像。图像捕捉设备和/或平台以类似于修剪草坪的方式来回地穿越

区域 200，以保证区域 200 的双重覆盖。

更具体地，图像捕捉设备 32 和/或平台 20 沿着第一路线 202 穿越区域 200，由此采集区域 200 的区 202a，202b 和 202c 的倾斜图像。然后图像捕捉设备 32 和/或平台 20 沿着第二路线 204 穿越区域 200，由此采集区域 200 的区 204a，204b 和 204c 的倾斜图像，其中所述第二路线 204 与所述第一路线 202 平行且间隔一定距离，并且与其成 180°(180 度)的相反方向。通过比较图 7 和 8，可以看出区域 200 的区 207(图 8)被从第一方向或视角采集的图像 202a-c 覆盖，且被从第二方向或视角采集的图像 204a-c 覆盖。同样，区域 200 的中间区被 100%(百分之一百)双重覆盖。重复沿着平行于路线 202 和 204 的相反路线通过或穿越区域 200 的上述模式，直到整个区域 200 被至少一个从互相平行、由区域 200 的尺寸规定的距离互相间隔并且沿着与路线 202 和 204 相同方向的路径采集的倾斜图像完全覆盖为止，从而从那些视角/方向百分之一百双重覆盖区域 200。

如果需要，为了增强细节，两个附加的相反并平行的第三和第四路线 206 和 208 分别覆盖区域 200，如图 9 和 10 所示，路线 206 和 208 垂直于路线 202 和 204。因此图像捕捉设备 32 和/或平台 20 沿着第三路线 206 穿越区域 200，以采集区域 200 的区 206a，206b 和 206c 的倾斜图像，然后，沿着第四路线 208 穿越，以采集区域 200 的区 208a，208b 和 208c 的倾斜图像，所述第四路线 208 与第三路线 206 平行，间隔一定距离并且方向相反。类似地重复沿着平行于路线 206 和 208 的相反路线通过或穿越区域 200 的上述模式，直到整个区域 200 被至少一个从平行于、由区域 200 的尺寸规定的距离互相间隔、且与路线 206 和 208 相同方向的路径采集的倾斜图像完全覆盖为止，从而从那些视角/方向百分之一百双重覆盖区域 200。

如上所述，图像捕捉设备 32 和/或平台 20 沿着预定路线通过或穿越区域 200。然而，应当理解，图像捕捉设备和/或平台 20 并不一定

直接通过或穿越区域200，而是可以通过或穿越与区域200邻近、接壤，甚至一定程度上脱离区域200的区域，以确保正在被成像的区域200的区落在图像采集设备的图像采集范围内。如图7所示，路线202是这样的路线，其不直接经过区域200上方，但是仍采集其倾斜图像。

本发明能够以各种级别的分辨率和地面取样距离采集图像。第一级别的细节，之后称为社区级，具有例如约为每个像素2英尺的地面取样距离。对于正交社区级图像，地面取样距离在整个图像中基本保持恒定。正交社区级图像用足够的交叠进行采集，以提供立体双层覆盖。对于倾斜社区级图像，地面取样距离变化，例如，从图像前景中的大约每个像素1英尺，到图像中景中的大约每个像素2英尺，以及到图像背景中的大约每个像素4英尺。倾斜社区级图像用足够的交叠进行采集，从而典型地，由至少两个从每个罗盘方向采集的倾斜图像覆盖每个感兴趣的区域。每个区大约采集10个倾斜社区级图像。

第二级别的细节，之后称为邻居级，其明显地比社区级图像更详细。邻居级图像具有例如约为每个像素6英寸的地面取样距离。对于正交邻居级图像，地面取样距离基本保持恒定。倾斜邻居级图像具有的地面取样距离，例如，从图像前景中的大约每个像素4英寸，到图像中景中的大约每个像素6英寸，以及到图像背景中的大约每个像素10 英寸。倾斜邻居级图像用足够的交叠进行采集，从而典型地，由至少两个从每个罗盘方向采集的倾斜图像覆盖每个感兴趣的区域，从而相对的罗盘方向提供了互相之间的100%交叠。每个区大约采集一百(100)个倾斜区域图像。

特别应当注意的是，从所有四个罗盘方向采集倾斜社区级和/或邻居级图像，保证了图像中的每个点将会出现在至少一个采集的倾斜图像的前景或者下部中，在图像的前景或下部中地面采样距离最小且图像细节最大。

在所示实施例中，图像采集和地理定位系统30包括陀螺仪，罗盘

和高度计。然而，应当理解，本发明的图像采集和地理定位系统可替代地可以构造成：例如，从 GPS 和 INU 信号/数据推导和/或计算海拔高度，俯仰，滚动和偏航，和罗盘导航，实际上，由此导致不再必需一个或多个陀螺仪，罗盘和高度计。

在所示的实施例中，图像采集设备相对于水平面具有相等偏角。然而，应当理解，图像采集设备的偏角不必相等。

在所示的实施例中，图像采集计算机系统运行图像和数据获取软件，该图像和数据获取软件将通用的或单独的图像采集信号发送到图像采集设备，由此促使那些设备获取或采集图像。然而，应当理解，本发明可替代地可以构造成，在不同的时刻和/或以不同的时间间隔，分别促使图像采集设备采集图像。

在所示的实施例中，本发明的方法采集倾斜图像，以从基本上彼此相对、即互相成 180°(180 度)的路线/视角提供对感兴趣区域的双重覆盖。然而，应当理解，本发明的方法可替代地可以构造成，从大致和/或基本互相垂直的路线/视角提供双重覆盖。

尽管以具有的优选设计描述了本发明，但是在该公开的精神和范围内，本发明可以被进一步修改。因此，该公开意味着包含其中公开的结构和元素的任何等价物。另外，该公开意味着包含使用其中公开的一般原理的本发明的任何变化，使用或修改。而且，该公开意味着包含在相关领域中的已知或惯用实施范围内，并且落入附加权利要求的限制内的本公开主旨的引申。

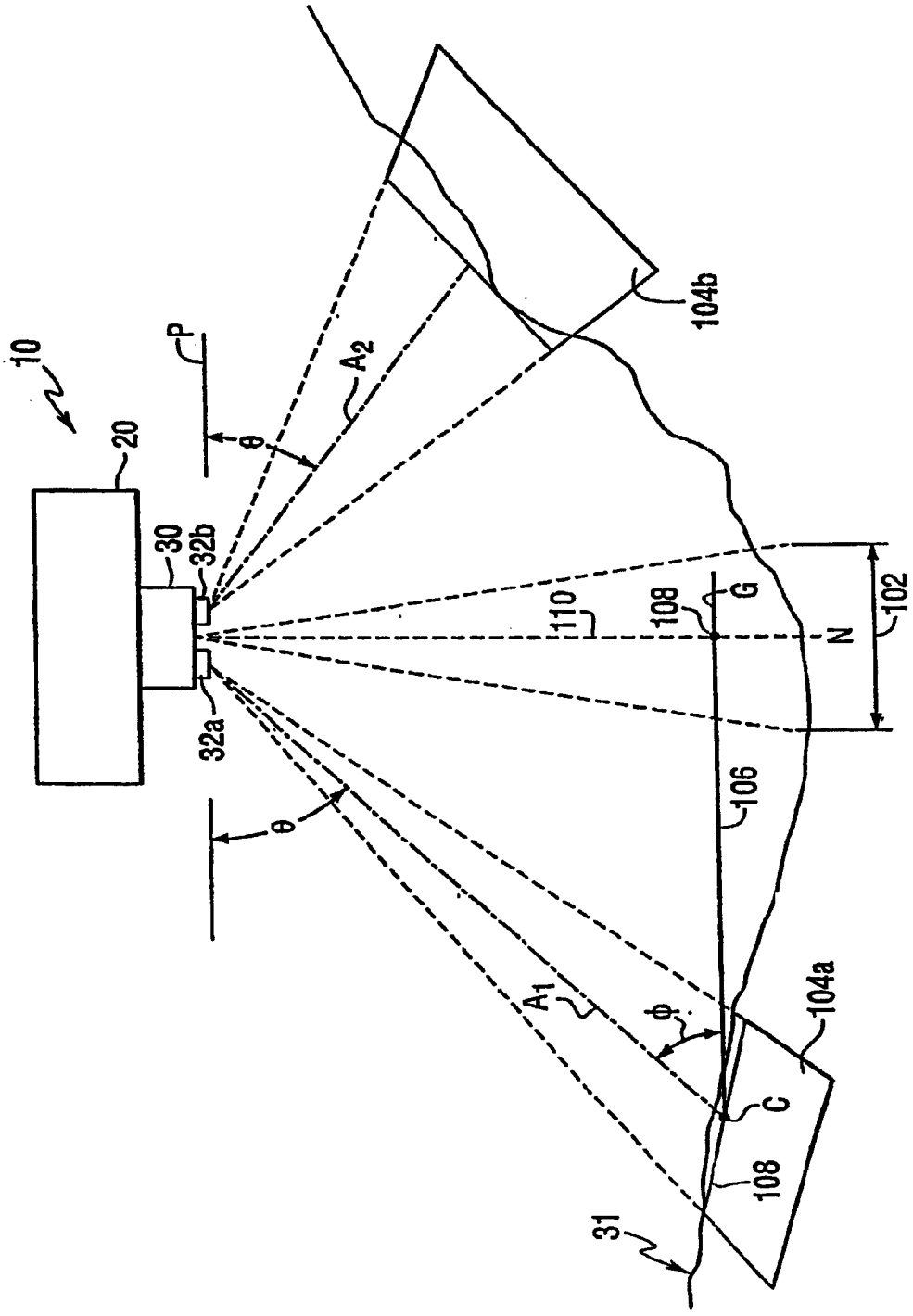


图1

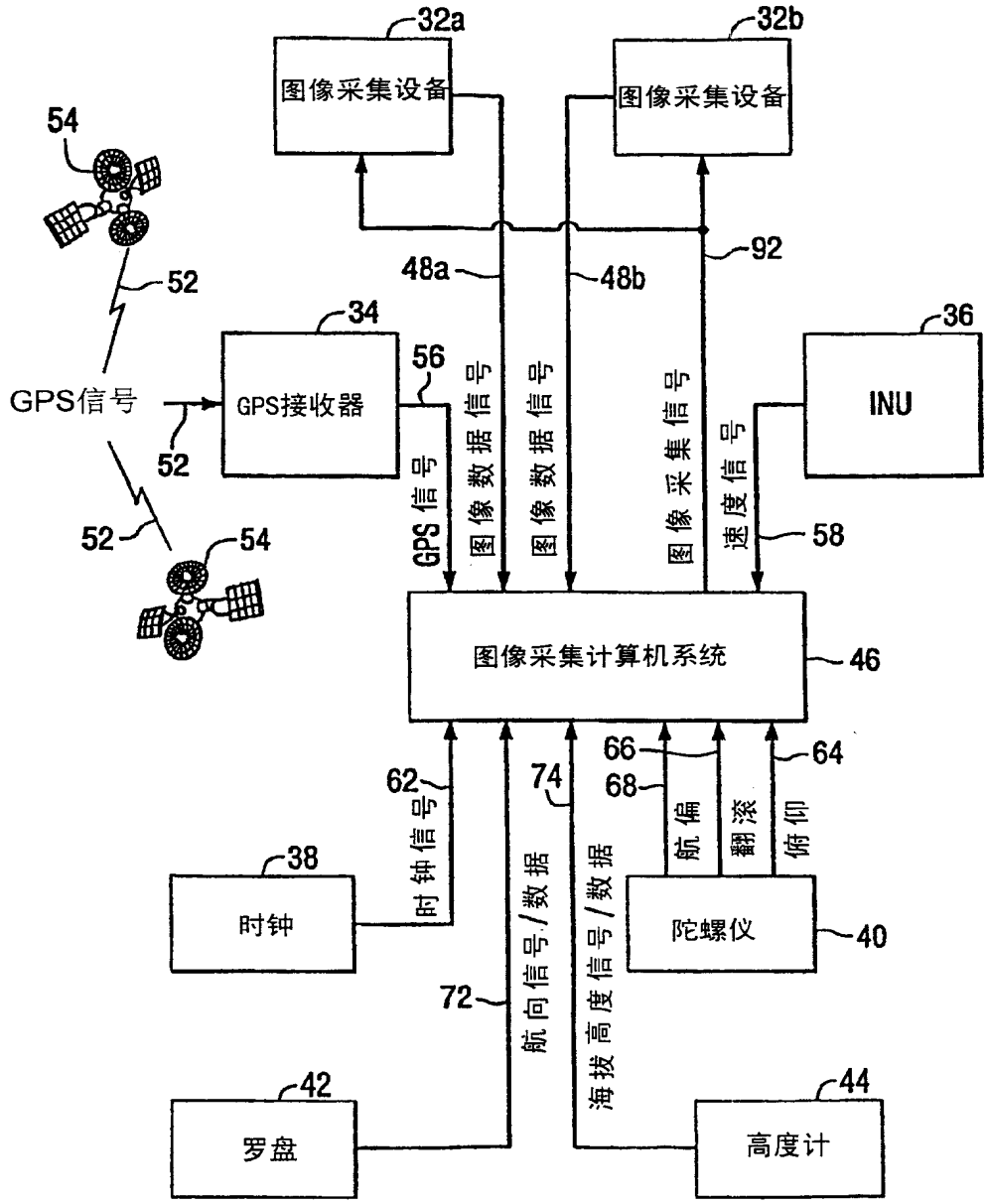

32a
图像采集设备
32b
图像采集设备
54
52
GPS信号
52
34
GPS接收器
56
52
54
48a
48b
92
36
INU
GPS信号
图像数据信号
图像数据信号
图像采集信号
速度信号
58
图像采集计算机系统
46
62
时钟信号
38
时钟
66
68
74
64
航偏
翻滚
俯仰
陀螺仪
40
72
航向信号/数据
海拔高度信号/数据
42
罗盘
44
高度计

图2

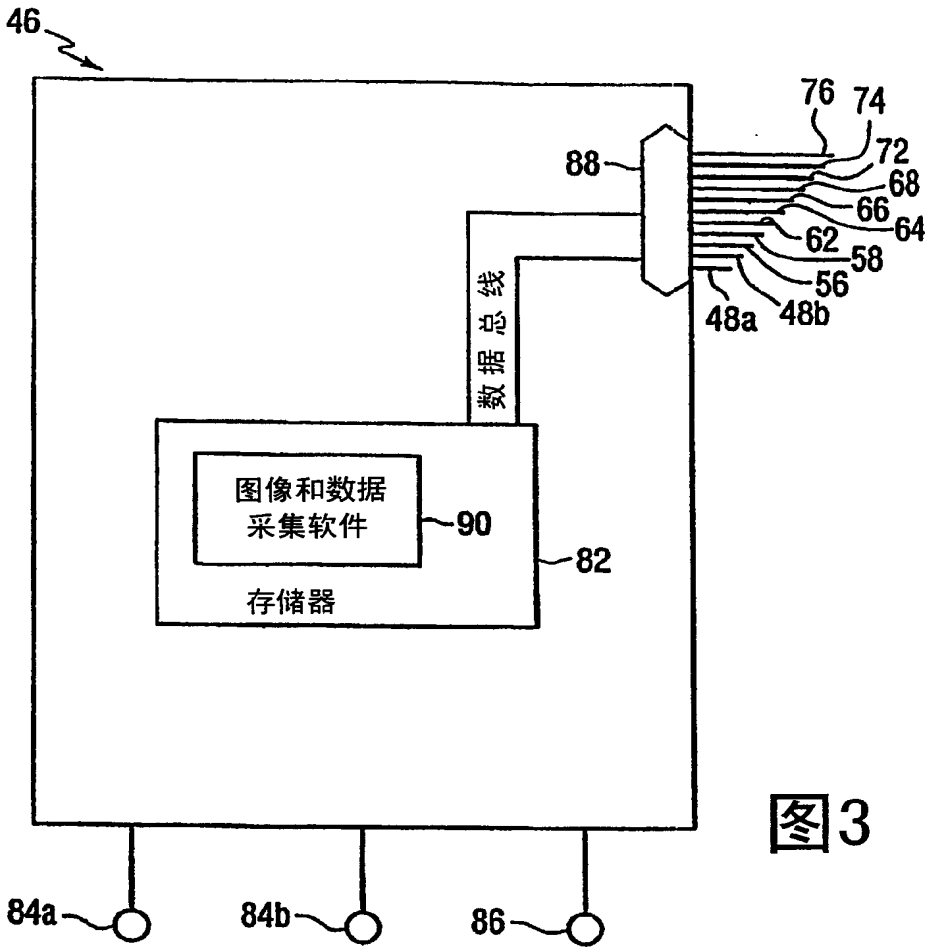

46
76
74
72
68
66
64
62
58
56
88
48a
48b
数据总线
图像和数据
采集软件
90
82
存储器
84a
84b
86

图3

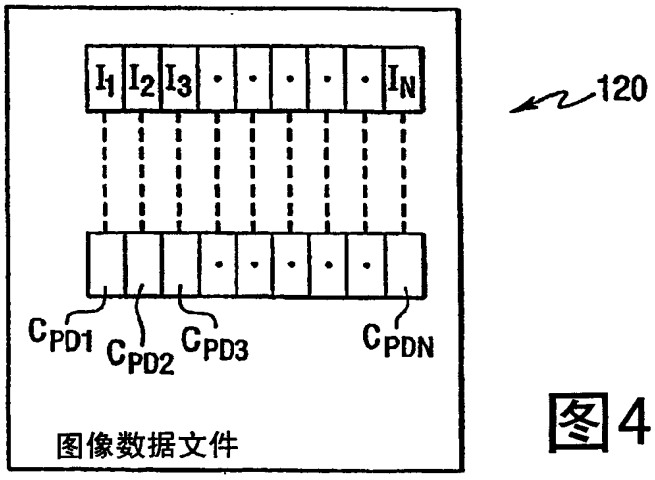

I_1 I_2 I_3 · · · · · I_N
120
C_{PD1} C_{PD2} C_{PD3} C_{PDN}
图像数据文件

图4

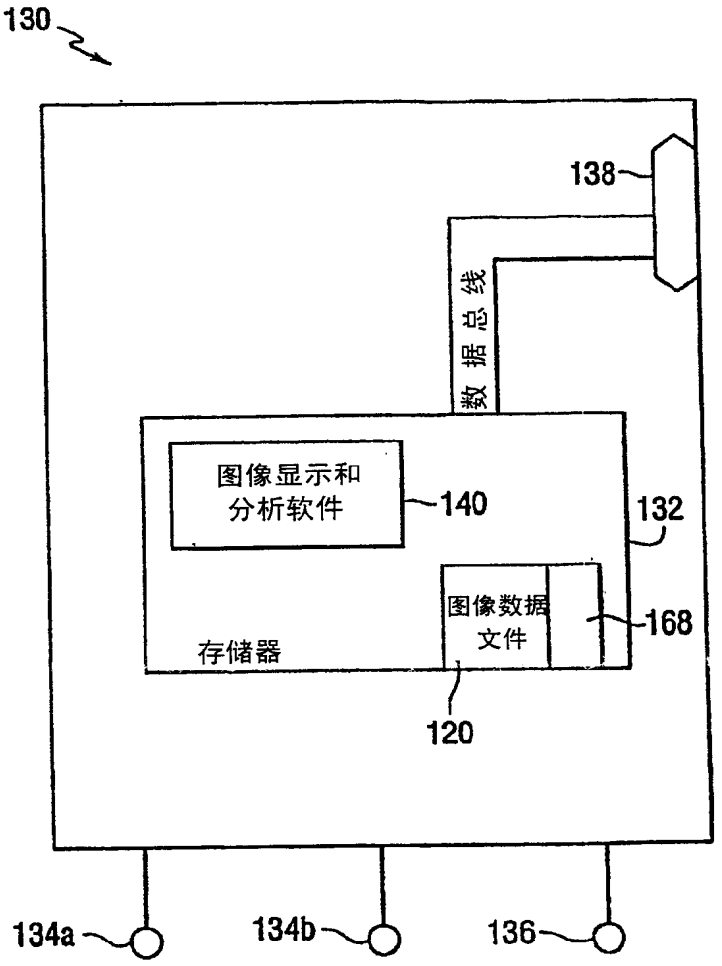

130
138
数据总线
图像显示和
分析软件
140
132
图像数据
文件
168
存储器
120
134a
134b
136

图5

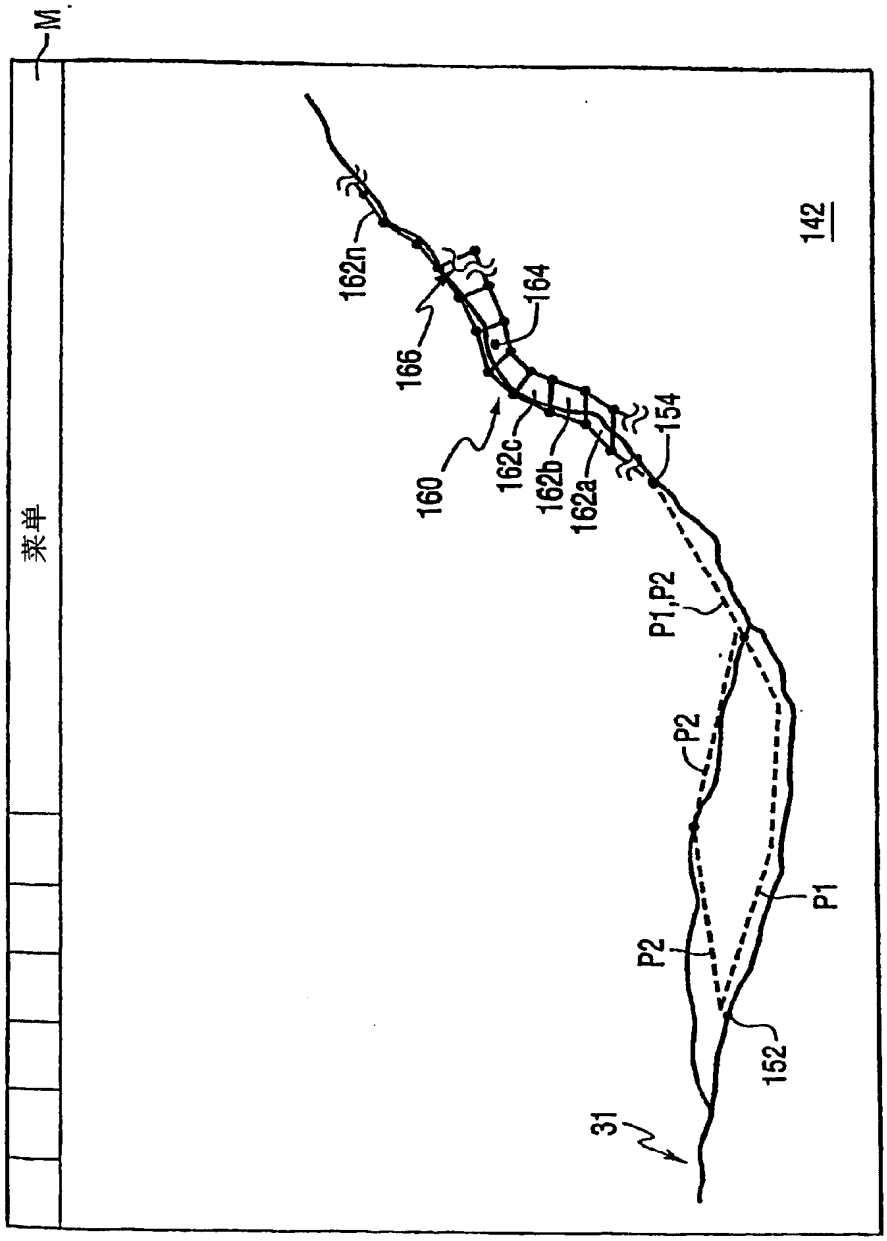


图6

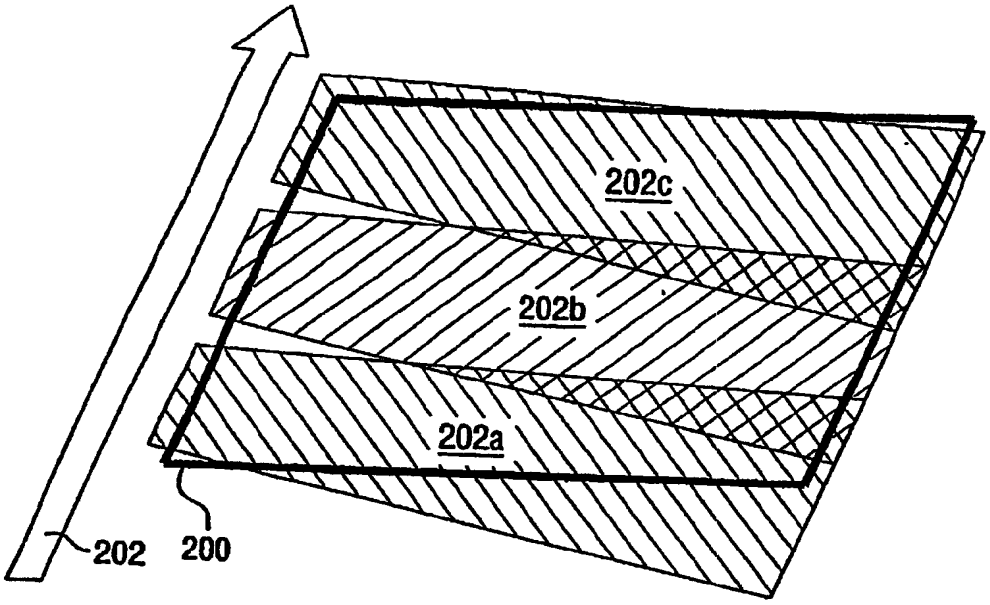


图7

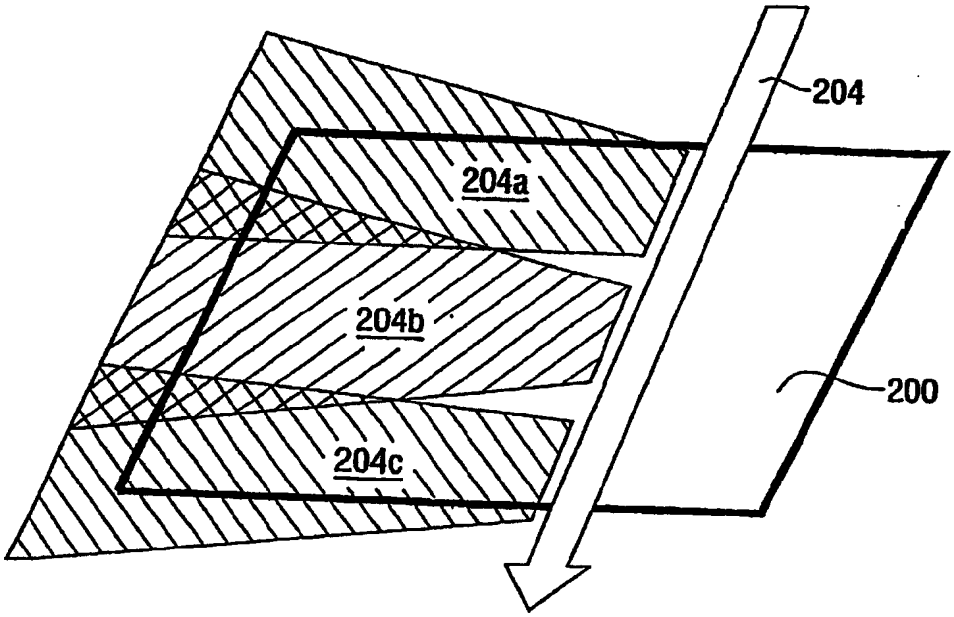


图8

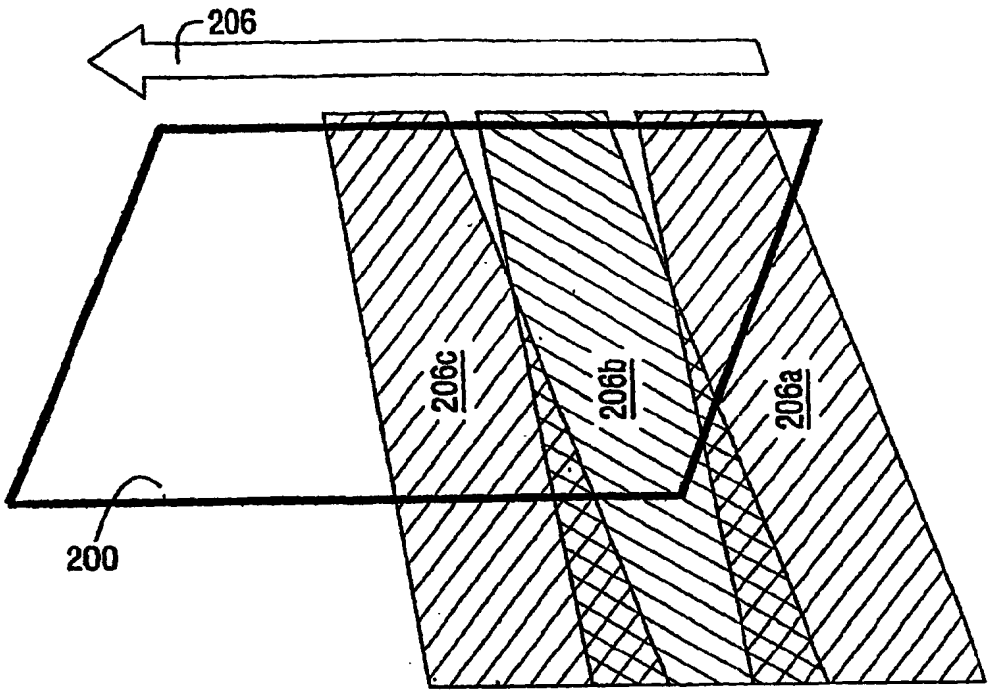


图9

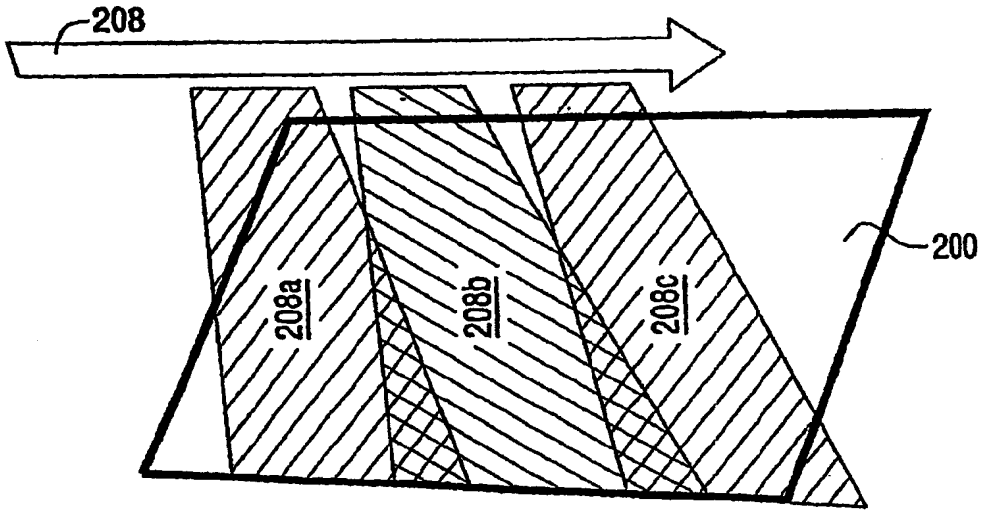


图10

Method and apparatus for capturing, geolocating and measuring oblique images

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Applicant(s): PICTOMETRY INTERNAT CORP [US]
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- European: G01C11/02
Application number: BR20030016110 20031107
Priority number(s): US20020425275P 20021108; WO2003US35528 20031107

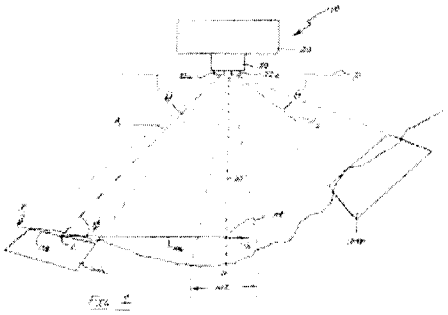
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Abstract of **BR 0316110 (A)**

"SISTEMAS PARA CAPTAR IMAGENS E DADOS DE GEOLOCALIZAçãO CORRESPONDENTES àS MESMAS E PARA VISUALIZAR, GEOLOCALIZAR E EFETUAR MEDIçõES COM BASE EM IMAGENS OBLíQUAS CAPTADAS E MéTODOS DE FAZER MEDIçõES DENTRO DE UMA IMAGEM OBLíQUA VISUALIZADA E DE CAPTAR IMAGENS OBLíQUAS DE UMA áREA DE INTERESSE". Um sistema computadorizado para exibição, geolocalização e tomada de medições de imagens obliquas captadas inclui um arquivo de dados acessível pelo sistema de computador. O arquivo de dados inclui uma pluralidade de arquivos de imagem correspondentes a uma pluralidade de imagens obliquas captadas, e dados posicionais correspondentes às imagens. Software de exibição e análise de imagem é executado pelo sistema para leitura do arquivo de dados e exibir pelo menos uma parte das imagens obliquas captadas.; O software recupera os dados posicionais para um ou mais pontos selecionados pelo usuário sobre a imagem exibida, e calcula uma distância de separação entre quaisquer dois ou mais pontos selecionados. O cálculo da distância de separação é selecionável pelo usuário para determinar varios parâmetros inclusive distância linear entre, área abrangida dentro, elevação relativa de, e diferença de altura entre pontos selecionados.



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Method and apparatus for capturing, geolocating and measuring oblique images

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Description of corresponding document: **EP 1418402 (A1)**

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/425,275, filed November 8, 2002.

TECHNICAL FIELD

[0002] The present invention relates to photogrammetry. More particularly, the present invention relates to a method and apparatus for capturing oblique images and for measuring the objects and distances between the objects depicted therein.

BACKGROUND

[0003] Photogrammetry is the science of making measurements of and between objects depicted within photographs, especially aerial photographs. Generally, photogrammetry involves taking images of terrestrial features and deriving data therefrom, such as, for example, data indicating relative distances between and sizes of objects within the images. Photogrammetry may also involve coupling the photographs with other data, such as data representative of latitude and longitude. In effect, the image is overlaid and conformed to a particular spatial coordinate system.

[0004] Conventional photogrammetry involves the capture and/or acquisition of orthogonal images. The image-capturing device, such as a camera or sensor, is carried by a vehicle or platform, such as an airplane or satellite, and is aimed at a nadir point that is directly below and/or vertically downward from that platform. The point or pixel in the image that corresponds to the nadir point is the only point/pixel that is truly orthogonal to the image-capturing device. All other points or pixels in the image are actually oblique relative to the image-capturing device. As the points or pixels become increasingly distant from the nadir point they become increasingly oblique relative to the image-capturing device and the ground sample distance (i.e., the surface area corresponding to or covered by each pixel) also increases. Such obliqueness in an orthogonal image causes features in the image to be distorted, especially images relatively distant from the nadir point.

[0005] Such distortion is removed, or compensated for, by the process of ortho-rectification which, in essence, removes the obliqueness from the orthogonal image by fitting or warping each pixel of an orthogonal image onto an orthometric grid or coordinate system. The process of ortho-rectification creates an image wherein all pixels have the same ground sample distance and are oriented to the north. Thus, any point on an ortho-rectified image can be located using an X, Y coordinate system and, so long as the image scale is known, the length and width of terrestrial features as well as the relative distance between those features can be calculated.

[0006] Although the process of ortho-rectification compensates to a degree for oblique distortions in an orthogonal image, it introduces other undesirable distortions and/or inaccuracies in the ortho-rectified orthogonal image. Objects depicted in ortho-rectified orthogonal images may be difficult to recognize and/or identify since most observers are not accustomed to viewing objects, particularly terrestrial features, from above. To an untrained observer an ortho-rectified image has a number of distortions. Roads that are actually straight appear curved and buildings may appear to tilt. Further, ortho-rectified images contain substantially no information as to the height of terrestrial features. The interpretation and analysis of orthogonal and/or ortho-rectfified orthogonal images is typically performed by highly-trained analysts whom have undergone years of specialized training and experience in order to identify objects and terrestrial features in such images.

[0007] Thus, although orthogonal and ortho-rectified images are useful in photogrammetry, they lack information as to the height of features depicted therein and require highly-trained analysts to interpret detail from what the images depict.

[0008] Oblique images are images that are captured with the image-capturing device aimed or pointed generally to the side of and downward from the platform that carries the image-capturing device. Oblique images, unlike orthogonal images, display the sides of terrestrial features, such as houses, buildings and/or mountains, as well as the tops thereof. Thus, viewing an oblique image is more natural and intuitive than viewing an orthogonal or ortho-rectified image, and even casual observers are able to recognize and interpret terrestrial features and other objects depicted in oblique images. Each pixel in the foreground of an oblique image corresponds to a relatively small area of the surface or object depicted (i.e., each foreground pixel has a relatively small ground sample distance) whereas each pixel in the background corresponds to a relatively large area of the surface or object depicted (i.e., each background pixel has a relatively large ground sample distance). Oblique images capture a generally trapezoidal area or view of the subject surface or object, with the foreground of the trapezoid having a substantially smaller ground sample distance (i.e., a higher resolution) than the background of the trapezoid.

[0009] Oblique images are considered to be of little or no use in photogrammetry. The conventional approach of forcing the variously-sized foreground and background pixels of an oblique image into a uniform size to thereby warp the image onto a coordinate system dramatically distorts the oblique image and thereby renders identification of objects and the taking of measurements of objects depicted therein a laborious and inaccurate task. Correcting for terrain displacement within an oblique image by using an elevation model further distorts the images thereby increasing the difficulty with which measurements can be made and reducing the accuracy of any such measurements.

[0010] Thus, although oblique images are considered as being of little or no use in photogrammetry, they are easily interpreted and contain information as to the height of features depicted therein.

[0011] Therefore, what is needed in the art is a method and apparatus for photogrammetry that enable geo-location and accurate measurements within oblique images.

[0012] Moreover, what is needed in the art is a method and apparatus for photogrammetry that enable the measurement of heights and relative heights of objects within an image.

[0013] Furthermore, what is needed in the art is a method and apparatus for photogrammetry that utilizes more intuitive and natural images.

SUMMARY OF THE INVENTION

[0014] The present invention provides a method and apparatus for capturing, displaying, and making measurements of objects and distances between objects depicted within oblique images.

[0015] The present invention comprises, in one form thereof, a computerized system for displaying, geolocating, and taking measurements from captured oblique images. The system includes a data file accessible by the computer system. The data file includes a plurality of image files corresponding to a plurality of captured oblique images, and positional data corresponding to the images. Image display and analysis software is executed by the system for reading the data file and displaying at least a portion of the captured oblique images. The software retrieves the positional data for one or more user-selected points on the displayed image, and calculates a separation distance between any two or more selected points. The separation distance calculation is user-selectable to determine various parameters including linear distance between, area encompassed within, relative elevation of, and height difference between selected points.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become apparent and be more completely understood by reference to the following description of one embodiment of the invention when read in conjunction with the accompanying drawings, wherein: FIG. 1 illustrates one embodiment of a platform or vehicle carrying an image-capturing system of the present invention, and shows exemplary orthogonal and oblique images taken thereby; FIG. 2 is a diagrammatic view of the image-capturing system of FIG. 1; FIG. 3 is a block diagram of the image-capturing computer system of Fig. 2; FIG. 4 is a representation of an exemplary output data file of the image-capturing system of Fig. 1; FIG. 5 is a block diagram of one embodiment of an image display and measurement computer system of the present invention for displaying and taking measurements of and between objects depicted in the images captured by the image-capturing system of Fig. 1; FIG. 6 depicts an exemplary image displayed on the system of Fig. 5, and illustrates one embodiment of the method of the present invention for the measurement of and between objects depicted in such an image; FIGS. 7 and 8 illustrate one embodiment of a method for capturing oblique images of the present invention; FIGS. 9 and 10 illustrate a second embodiment of a method for capturing oblique images of the present invention.

[0017] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate one preferred embodiment of the invention, in one form, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] Referring now to the drawings, and particularly to Fig. 1, one embodiment of an apparatus for capturing and geolocating oblique images of the present invention is shown. Apparatus 10 includes a platform or vehicle 20 that carries image-capturing and geolocating system 30.

[0019] Platform 20, such as, for example, an airplane, space shuttle, rocket, satellite, or any other suitable vehicle, carries image-capturing system 30 over a predefined area of and at one or more predetermined altitudes above surface 31, such as, for example, the earth's surface or any other surface of interest. As such, platform 20 is capable of controlled movement or flight, either manned or unmanned, along a predefined flight path or course through, for example, the earth's atmosphere or outer space. Image-capturing platform 20 includes a system for generating and regulating power (not shown) that includes, for example, one or more generators, fuel cells, solar panels, and/or batteries, for powering image-capturing system 30.

[0020] Image-capturing and geo-locating system 30, as best shown in Fig. 2, includes image capturing devices 32a and 32b, a global positioning system (GPS) receiver 34, an inertial navigation unit (INU) 36, clock 38, gyroscope 40, compass 42 and altimeter 44, each of which are interconnected with image-capturing computer system 46.

[0021] Image-capturing devices 32a and 32b, such as, for example, conventional cameras, digital cameras, digital sensors, charge-coupled devices, or other suitable image-capturing devices, are capable of capturing images photographically or electronically. Image-capturing devices 32a and 32b have known or determinable characteristics including focal length, sensor size and aspect ratio, radial and other distortion terms, principal point offset, pixel pitch, and alignment. Image-capturing devices 32a and 32b acquire images and issue image data signals (IDS) 48a and48b, respectively, corresponding to the particular images or photographs taken and which are stored in image-capturing computer system 46, as will be more particularly described hereinafter.

[0022] As best shown in Fig. 1, image-capturing devices 32a and 32b have respective central axes A1 and A2, and are mounted to platform 20 such that axes A1 and A2 are each at an angle of declination &thetas; relative to a horizontal plane P. Declination angle &thetas; is virtually any oblique angle, but is preferably from approximately 20 DEG (twenty degrees) to approximately 60 DEG (sixty degrees) and is most preferably from approximately 40 DEG (forty degrees) to approximately 50 DEG (fifty degrees).

[0023] GPS receiver 34 receives global positioning system signals 52 that are transmitted by one or more global positioning system satellites 54. The GPS signals 52, in known fashion, enable the precise location of platform 20 relative to surface 31 to be determined. GPS receiver 34 decodes GPS signals 52 and issues location signals/data 56, that are dependent at least in part upon GPS signals 52 and which are indicative of the precise location of platform 20 relative to surface 31. Location signals/data 56 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0024] INU 36 is a conventional inertial navigation unit that is coupled to and detects changes in the velocity, including translational and rotational velocity, of image-capturing devices 32a and 32b and/or platform 20. INU 36 issues velocity signals/data 58 indicative of such velocities and/or changes therein to image-capturing computer system 46, which stores velocity signals/data 58 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0025] Clock 38 keeps a precise time measurement (time of validity) that is used to synchronize events within image-capturing and geo-locating system 30. Clock 38 provides time data/clock signal 62 that is indicative of the precise time that an image is taken by image-capturing devices 32a and 32b. Time data 62 is also provided to and stored by image-capturing computer system 46. Alternatively, clock 38 is integral with image-capturing computer system 46, such as, for example, a clock software program.

[0026] Gyroscope 40 is a conventional gyroscope as commonly found on airplanes and/or within commercial navigation systems for airplanes. Gyroscope 40 provides signals including pitch signal 64, roll signal 66 and yaw signal 68, which are respectively indicative of pitch, roll and yaw of platform 20. Pitch signal 64, roll signal 66 and yaw signal 68 corresponding to each image captured by mage-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0027] Compass 42, such as, for example, a conventional electronic compass, indicates the heading of platform 20. Compass 42 issues heading signal/data 72 that is indicative of the heading of platform 20. Image-capturing computer system 46 receives and stores the heading signals/data 72 that correspond to each image captured by image-capturing devices 32a and 32b.

[0028] Altimeter 44 indicates the altitude of platform 20. Altimeter 44 issues altitude signal/data 74, and image-capturing computer system 46 receives and stores the altitude signal/data 74 that correspond to each image captured by image-capturing devices 32a and 32b.

[0029] As best shown in Fig. 3, image-capturing computer system 46, such as, for example, a conventional laptop personal computer,

includes memory 82, input devices 84a and 84b, display device 86, and input and output (I/O) ports 88. Image-capturing computer system 46 executes image and data acquiring software 90, which is stored in memory 82. Memory 82 also stores data used and/or calculated by image-capturing computer system 46 during the operation thereof, and 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 84a and 84b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and interaction of a user with software being executed by image-capturing computer system 46. Display device 86, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image-capturing computer system 46. I/O ports 88, such as, for example, serial and parallel data input and output ports, enable the input and/or output of data to and from image-capturing computer system 46.

[0030] Each of the above-described data signals is connected to image-capturing computer system 46. More particularly, image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74 are received via I/O ports 88 by and stored within memory 82 of image-capturing computer system 46.

[0031] In use, image-capturing computer system 46 executes image and data acquiring software 90, which, in general, controls the reading, manipulation, and storing of the above-described data signals. More particularly, image and data acquiring software 90 reads image data signals 48a and 48b and stores them within memory 82. Each of the location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74 that represent the conditions existing at the instant an image is acquired or captured by image-capturing devices 32a and 32b and which correspond to the particular image data signals 48a and 48b representing the captured images are received by image-capturing computer system 46 via I/O ports 88. Image-capturing computer system 46 executing image and data acquiring software 90 issues image-capture signal 92 to image-capturing devices 32a and 32b to thereby cause those devices to acquire or capture an image at predetermined locations and/or at predetermined intervals which are dependent at least in part upon the velocity of platform 20.

[0032] Image and data acquiring software 90 decodes as necessary and stores the aforementioned signals within memory 82, and associates the data signals with the corresponding image signals 48a and 48b. Thus, the altitude, orientation in terms of roll, pitch, and yaw, and the location of image-capturing devices 32a and 32b relative to surface 31, i.e., longitude and latitude, for every image captured by image-capturing devices 32a and 32b is known.

[0033] Platform 20 is piloted or otherwise guided through an image-capturing path that passes over a particular area of surface 31, such as, for example, a predefined area of the surface of the earth or of another planet. Preferably, the image-capturing path of platform 20 is at right angles to at least one of the boundaries of the area of interest. The number of times platform 20 and/or image-capturing devices 32a, 32b pass over the area of interest is dependent at least in part upon the size of the area and the amount of detail desired in the captured images. The particular details of the image-capturing path of platform 20 are described more particularly hereinafter.

[0034] As platform 20 passes over the area of interest a number of oblique images are captured by image-capturing devices 32a and 32b. As will be understood by those of ordinary skill in the art, images are captured or acquired by image-capturing devices 32a and 32b at predetermined image capture intervals which are dependent at least in part upon the velocity of platform 20.

[0035] Image data signals 48a and 48b corresponding to each image acquired are received by and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Similarly, the data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) corresponding to each captured image are received and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Thus, the location of image-capturing device 32a and 32b relative to surface 32 at the precise moment each image is captured is recorded within memory 82 and associated with the corresponding captured image.

[0036] As best shown in Fig. 1, the location of image-capturing devices 32a and 32b relative to the earth corresponds to the nadir point N of orthogonal image 102. Thus, the exact geo-location of the nadir point N of orthogonal image 102 is indicated by location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74. Once the nadir point N of orthogonal image 102 is known, the geo-location of any other pixel or point within image 102 is determinable in known manner.

[0037] When image-capturing devices 32a and 32b are capturing oblique images, such as oblique images 104a and 104b (Fig. 1), the location of image-capturing devices 32a and 32b relative to surface 31 is similarly indicated by location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72, altitude signal 74 and the known angle of declination &thetas; of the primary axes A1 and A2 of image-capturing devices 32a and 32b, respectively.

[0038] It should be particularly noted that a calibration process enables image and data acquiring software 90 to incorporate correction factors and/or correct for any error inherent in or due to image-capturing device 32, such as, for example, error due to calibrated focal length, sensor size, radial distortion, principal point offset, and alignment.

[0039] Image and data acquiring software 90 creates and stores in memory 82 one or more output image and data files 120. More particularly, image and data acquiring software 90 converts image data signals 48a, 48b and the orientation data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) into computer-readable output image and data files 120. As best shown in Fig. 4, output image and data file 120 contains a plurality of captured image files I1, I2,. .., In corresponding to captured oblique images, and the positional data CPD1, CPD2, ... , CPDn corresponding thereto.

[0040] Image files I1, I2, ..., In of the image and data file 120 are stored in virtually any computer-readable image or graphics file format, such as, for example, JPEG, TIFF, GIF, BMP, or PDF file formats, and are cross-referenced with the positional data CPD1, CPD2, ..., CPDn which is also stored as computer-readable data. Alternatively, positional data CPD1, CPD2, ..., CPDn is embedded within the corresponding image files I1, I2, ..., In in known manner. Image data files 120 are then processed, either by image and data acquiring software 90 or by post-processing, to correct for errors, such as, for example, errors due to flight path deviations and other errors known to one of ordinary skill in the art. Thereafter, image data files 120 are ready for use to display and make measurements of and between the objects depicted within the captured images, including measurements of the heights of such objects.

[0041] Referring now to Fig. 5, image display and measurement computer system 130, such as, for example, a conventional desktop personal computer or a mobile computer terminal in a police car, includes memory 132, input devices 134a and 134b, display device 136, and network connection 138. Image-capturing computer system 130 executes image display and analysis software 140, which is stored in memory 132. Memory 132 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 134a and 134b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and interaction of a user with image display and analysis software 140 being executed by image display and measurement computer system 130. Display device 136, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image display and measurement computer system 130. Network connection 138 connects image display and measurement computer system 130 to a network (not shown), such as, for example, a local-area network, wide-area network, the Internet and/or the World Wide Web.

[0042] In use, and referring now to Fig. 6, image display and measurement computer system 130 executing image display and analysis software 140 accesses one or more output image and data files 120 that have been read into memory 132, such as, for example, via network connection 138, a floppy disk drive, removable memory card or other suitable means. One or more of the captured images I1, I2, ... , In of output image and data files 120 is thereafter displayed as displayed oblique image 142 under the control of image display and analysis software 140. At approximately the same time, one or more data portions CPD1, CPD2, ..., CPDn corresponding to displayed oblique image 142 are read into a readily-accessible portion of memory 132.

[0043] It should be particularly noted that displayed oblique image 142 is displayed substantially as captured, i.e., displayed image 142 is not warped or fitted to any coordinate system nor is displayed image 142 ortho-rectified. Rather than warping displayed image 142 to a coordinate system in order to enable measurement of objects depicted therein, image display and analysis software 140, in general, determines the geo-locations of selected pixels only as needed, or "on the fly", by referencing data portions CPD1, CPD2, ..., CPDn of output image and data files 120 and calculating the position and/or geo-location of those selected pixels using one or more projection equations as is more particularly described hereinafter.

[0044] Generally, a user of display and measurement computer system 130 takes measurements of and between objects depicted in displayed oblique image 142 by selecting one of several available measuring modes provided within image display and analysis software 140. The user selects the desired measurement mode by accessing, for example, a series of pull-down menus or toolbars M, or via keyboard commands. The measuring modes provided by image display and analysis software 140 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.

[0045] After selecting the desired measurement mode, the user of image display and analysis software 140 selects with one of input devices 134a, 134b a starting point or starting pixel 152 and an ending point or pixel 154 on displayed image 142, and image display and analysis software 140 automatically calculates and displays the quantity sought, such as, for example, the distance between starting pixel 152 and ending pixel 154.

[0046] When the user selects starting point/pixel 152, the geo-location of the point corresponding thereto on surface 31 is calculated by image display and analysis software 140 which executes one or more projection equations using the data portions CPD1, CPD2, ..., CPDn of output image and data files 120 that correspond to the particular image being displayed. The longitude and latitude of the point on surface 31 corresponding to pixel 152 are then displayed by image display and analysis software 140 on display 136, such as, for example, by superimposing the longitude and latitude on displayed image 142 adjacent the selected point/pixel or in pop-up display box elsewhere on display 136. The same process is repeated by the user for the selection of the end pixel/point 154, and by image display and analysis software 140 for the retrieval and display of the longitude and latitude information.

[0047] The calculation of the distance between starting and ending points/pixels 152, 154, respectively, is accomplished by determining the geo-location of each selected pixel 152, 154 "on the fly". The data portions CPD1, CPD2, ..., CPDn of output image and data file 120 corresponding to the displayed image are retrieved, and the geo-location of the point on surface 31 corresponding to each selected pixel are then determined. The difference between the geo-locations corresponding to the selected pixels determines the distance between the pixels.

[0048] As an example of how the geo-location of a given point or pixel within displayed oblique image 142 is determined, we will assume that displayed image 142 corresponds to orthogonal image 104a (Fig. 1). The user of image display and analysis software 140 selects pixel 154 which, for simplicity, corresponds to center C (Fig. 1) of oblique image 104a. As shown in Fig. 1, line 106 extends along horizontal plane G from a point 108 thereon that is directly below image-capturing device 32a to the center C of the near border or edge 108 of oblique image 104a. An extension of primary axis A1 intersects with center C. Angle DIAMETER is the angle formed between line 106 the extension of primary axis A1. Thus, a triangle (not referenced) is formed having vertices at image-capturing device 32a, point 108 and center C, and having sides 106, the extension of primary axis A1 and vertical (dashed) line 110 between point 108 and image-capturing device 32a.

[0049] Ground plane G is a substantially horizontal, flat or non-sloping ground plane (and which typically will have an elevation that reflects the average elevation of the terrain), and therefore the above-described triangle includes a right angle between side/line 110 and side/line 106. Since angle DIAMETER and the altitude of image-capturing device 32 (i.e., the length of side 110) are known, the hypotenuse (i.e., the length of the extension of primary axis A1) and remaining other side of the right triangle are calculated by simple geometry. Further, since the exact position of image-capturing device 32a is known at the time the image corresponding to displayed image 142 was captured, the latitude and longitude of point 108 are also known. Knowing the length of side 106, calculated as described above, enables the exact geo-location of pixel 154 corresponding to center C of oblique image 104a to be determined by image display and analysis software 140. Once the geo-location of the point corresponding to pixel 154 is known, the geo-location of any other pixel in displayed oblique image 142 is determinable using the known camera characteristics, such as, for example, focal length, sensor size and aspect ratio, radial and other distortion terms, etc.

[0050] The distance between the two or more points corresponding to two or more selected pixels within displayed image 142 is calculated by image display and analysis software 140 by determining the difference between the geo-locations of the selected pixels using known algorithms, such as, for example, the Gauss formula and/or the vanishing point formula, dependent upon the selected measuring mode. The measurement of objects depicted or appearing in displayed image 142 is conducted by a substantially similar procedure to the procedure described above for measuring distances between selected pixels. For example, the lengths, widths and heights of objects, such as, for example, buildings, rivers, roads, and virtually any other geographic or man-made structure, appearing within displayed image 142 are measured by selecting the appropriate/desired measurement mode and selecting starting and ending pixels.

[0051] It should be particularly noted that in the distance measuring mode of image display and analysis software 140 the distance between the starting and ending points/pixels 152, 154, respectively, is determinable along virtually any path, such as, for example, a "straight-line" path P1 or a path P2 that involves the selection of intermediate points/pixels and one or more "straight-line" segments interconnected therewith.

[0052] It should also be particularly noted that the distance measuring mode of image display and analysis software 140 determines the distance between selected pixels according to a "walk the earth" method. The "walk the earth method" creates a series of interconnected line segments, represented collectively by paths P1 and P2, that extend between the selected pixels/points and which lie upon or conform to the planar faces of a series of interconnected facets that define a tessellated ground plane. The tessellated ground plane, as will be more particularly described hereinafter, closely follows or recreates the terrain of surface 31, and therefore paths P1 and P2 also closely follow the terrain of surface 31. By measuring the distance along the terrain simulated by the tessellated ground plane, the "walk the earth" method provides for a more accurate and useful measurement of the distance between selected points than the conventional approach, which warps the image onto a flat earth or average elevation plane system and measures the distance between selected points along the flat earth or plane and substantially ignores variations in terrain between the points.

[0053] For example, a contractor preparing to bid on a contract for paving a roadway over uneven or hilly terrain can determine the

approximate amount or area of roadway involved using image display and analysis software 140 and the "walk the earth" measurement method provided thereby. The contractor can obtain the approximate amount or area of roadway from his or her own office without having to send a surveying crew to the site to obtain the measurements necessary.

[0054] In contrast to the "walk the earth" method provided by the present invention, the "flat earth" or average elevation distance calculating approaches include inherent inaccuracies when measuring distances between points and/or objects disposed on uneven terrain and when measuring the sizes and/or heights of objects similarly disposed. Even a modest slope or grade in the surface being captured results in a difference in the elevation of the nadir point relative to virtually any other point of interest thereon. Thus, referring again to Fig. 1, the triangle formed by line 106, the extension of primary axis A1 and the vertical (dashed) line 110 between point 108 and image-capturing device 32a may not be a right triangle. If such is the case, any geometric calculations assuming that triangle to be a right triangle would contain errors, and such calculations would be reduced to approximations due to even a relatively slight gradient or slope between the points of interest.

[0055] For example, if surface 31 slopes upward between nadir point N and center C at the near or bottom edge 108 of oblique image 104 then second line 110 intersects surface 31 before the point at which such intersection would occur on a level or non-sloping surface 31. If center C is fifteen feet higher than nadir point N and with a declination angle &thetas; equal to 40 DEG (forty degrees), the calculated location of center C would be off by approximately 17.8 feet without correction for the change in elevation between the points.

[0056] As generally discussed above, in order to compensate at least in part for changes in elevation and the resultant inaccuracies in the measurement of and between objects within image 142, image display and analysis software 140 references, as necessary, points within displayed image 142 and on surface 31 to a pre-calculated tessellated or faceted ground plane generally designated 160 in Fig. 6. Tessellated ground plane 160 includes a plurality of individual facets 162a, 162b, 162c, etc., each of which are interconnected to each other and are defined by four vertices (not referenced, but shown as points) having respective elevations. Adjacent pairs of facets 162a, 162b, 162c, etc., share two vertices. Each facet 162a, 162b, 162c, etc., has a respective pitch and slope. Tessellated ground plane 160 is created based upon various data and resources, such as, for example, topographical maps, and/or digital raster graphics, survey data, and various other sources.

[0057] Generally, the geo-location of a point of interest on displayed image 142 is calculated by determining which of facets 162a, 162b, 162c, etc., correspond to that point of interest. Thus, the location of the point of interest is calculated based on the characteristics, i.e., elevation, pitch and slope, of facets 162a, 162b, 162c, etc., rather than based upon a flat or average-elevation ground plane. Error is introduced only in so far as the topography of surface 31 and the location of the point of interest thereon deviate from the planar surface of the facet 162a, 162b, 162c, etc, within which the point of interest lies. That error is reducible through a bilinear interpolation of the elevation of the point of interest within a particular one of facets 162a, 162b, 162c, etc., and using that interpolated elevation in the location calculation performed by image display and analysis software 140.

[0058] To use tessellated ground plane 160, image display and analysis software 140 employs a modified ray-tracing algorithm to find the intersection of the ray projected from the image-capturing device 32a or 32b towards surface 31 and tessellated ground plane 160. The algorithm determines not only which of facets 162a, 162b, 162c, etc., is intersected by the ray, but also where within the facet the intersection occurs. By use of bi-linear interpolation, a fairly precise ground location can be determined. For the reverse projection, tessellated ground plane 160 is used to find the ground elevation value for the input ground location also using bi-linear interpolation. The elevation and location are then used to project backwards through a model of the image-capturing device 32a or 32b to determine which of the pixels within displayed image 142 corresponds to the given location.

[0059] More particularly, and as an example, image display and analysis software 140 performs and/or calculates the geo-location of point 164 by superimposing and/or fitting tessellated ground plane 160 to at least a portion 166, such as, for example, a hill, of surface 31. It should be noted that only a small portion of tessellated ground plane 160 and facets 162a, 162b, 162c, etc., thereof is shown along the profile of portion 166 of surface 31. As discussed above, each of facets 162a, 162b, 162c, etc., are defined by four vertices, each of which have respective elevations, and each of the facets have respective pitches and slopes. The specific position of point 164 upon the plane/surface of the facet 162a, 162b, 162c, etc., within which point 164 (or its projection) lies is determined as described above.

[0060] Tessellated ground plane 160 is preferably created outside the operation of image display and measurement computer system 130 and image display and analysis software 140. Rather, tessellated ground plane 160 takes the form of a relatively simple data table or look-up table 168 stored within memory 132 of and/or accessible to image display and measurement computer system 130. The computing resources required to calculate the locations of all the vertices of the many facets of a typical ground plane do not necessarily have to reside within image display and measurement computer system 130. Thus, image display and measurement computer system 130 is compatible for use with and executable by a conventional personal computer without requiring additional computing resources.

[0061] Calculating tessellated ground plane 160 outside of image display and measurement computer system 130 enables virtually any level of detail to be incorporated into tessellated ground plane 160, i.e., the size and/or area covered by or corresponding to each of facets 162a, 162b, 162c, etc., can be as large or as small as desired, without significantly increasing the calculation time, slowing the operation of, nor significantly increasing the resources required by image display and measurement computer system 130 and/or image display and analysis software 140. Display and measurement computer system 130 can therefore be a relatively basic and uncomplicated computer system.

[0062] The size of facets 162a, 162b, 162c, etc., are uniform in size throughout a particular displayed image 142. For example, if displayed image 142 corresponds to an area that is approximately 750 feet wide in the foreground by approximately 900 feet deep, the image can be broken into facets that are approximately 50 square feet, thus yielding about 15 facets in width and 18 facets in depth. Alternatively, the size of facets 162a, 162b, 162c, etc., are uniform in terms of the number of pixels contained therein, i.e., each facet is the same number of pixels wide and the same number of pixels deep. Facets in the foreground of displayed image 142, where the pixel density is greatest, would therefore be dimensionally smaller than facets in the background of displayed image 142 where pixel density is lowest. Since it is desirable to take most measurements in the foreground of a displayed image where pixel density is greatest, creating facets that are uniform in terms of the number of pixels they contain has the advantage of providing more accurate measurements in the foreground of displayed image 142 relative to facets that are dimensionally uniform.

[0063] Another advantage of using pixels as a basis for defining the dimensions of facets 162a, 162b, 162c, etc., is that the location calculation (pixel location to ground location) is relatively simple. A user operates image display and measurement computer system 130 to select a pixel within a given facet, image display and analysis software 140 looks up the data for the facet corresponding to the selected pixel, the elevation of the selected pixel is calculated as discussed above, and that elevation is used within the location calculation.

[0064] Generally, the method of capturing oblique images of the present invention divides an area of interest, such as, for example, a county, into sectors of generally uniform size, such as, for example, sectors that are approximately one square mile in area. This is done to facilitate the creation of a flight plan to capture oblique images covering every inch of the area of interest, and to organize and name the sectors and/or images thereof for easy reference, storage and retrieval (a process known in the art as "sectorization"). Because the edges of any geographic area of interest, such as a county, rarely falls on even square mile boundaries, the method of

capturing oblique images of the present invention provides more sectors than there are square miles in the area of interest - how many more depends largely on the length of the county borders as well as how straight or jagged they are. Typically, you can expect one extra sector for every two to three miles of border. So if a county or other area of interest is roughly 20 miles by 35 miles, or 700 square miles, the area will be divided into approximately from 740 to 780 sectors.

[0065] The method of capturing oblique images of the present invention, in general, captures the oblique images from at least two compass directions, and provides full coverage of the area of interest from at least those two compass directions. Referring now to Figs. 7 and 8, a first embodiment of a method for capturing oblique images of the present invention is shown. For sake of clarity, Fig. 7 and 8 is based on a system having only one image-capturing device. However, it is to be understood that two or more image-capturing devices can be used.

[0066] The image-capturing device captures one or more oblique images during each pass over area 200. The image-capturing device, as discussed above, is aimed at an angle over area 200 to capture oblique images thereof. Area 200 is traversed in a back-and-forth pattern, similar to the way a lawn is mowed, by the image-carrying device and/or the platform to ensure double coverage of area 200.

[0067] More particularly, area 200 is traversed by image-carrying device 32 and/or platform 20 following a first path 202 to thereby capture oblique images of portions 202a, 202b, and 202c of area 200. Area 200 is then traversed by image-carrying device 32 and/or platform 20 following a second path 204 that is parallel and spaced apart from, and in an opposite direction to, i.e., 180 DEG (one-hundred and eighty degrees) from, first path 202, to thereby capture oblique images of portions 204a, 204b, 204c of area 200. By comparing Figs. 7 and 8, it is seen that a portion 207 (Fig. 8) of area 200 is covered by images 202a-c captured from a first direction or perspective, and by images 204a-c captured from a second direction or perspective. As such, the middle portion of area 200 is 100% (one-hundred percent) double covered. The above-described pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 202 and 204 is repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from each other as dictated by the size of area 200, and in the same direction as paths 202 and 204 to thereby one-hundred percent double cover area 200 from those perspectives/directions.

[0068] If desired, and for enhanced detail, area 200 is covered by two additional opposing and parallel third and fourth paths 206 and 208, respectively, that are perpendicular to paths 202 and 204 as shown in Figs. 9 and 10. Area 200 is therefore traversed by image-carrying device 32 and/or platform 20 following third path 206 to capture oblique images of portions 206a, 206b and 206c of area 200, and is then traversed along fourth path 208 that is parallel, spaced apart from, and opposite to third path 206 to capture oblique images of portions 208a, 208b and 208c of area 200. This pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 206 and 208 is similarly repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from as dictated by the size of area 200, and in the same direction as paths 206 and 208 to thereby one-hundred percent double cover area 200 from those directions/perspectives.

[0069] As described above, image-carrying device 32 and/or platform 20, traverses or passes over area 200 along a predetermined path. However, it is to be understood that image-carrying device and/or platform 20 do not necessarily pass or traverse directly over area 200 but rather may pass or traverse an area adjacent, proximate to, or even somewhat removed from, area 200 in order to ensure that the portion of area 200 that is being imaged falls within the image-capture field of the image-capturing device. Path 202, as shown in Fig. 7, is such a path that does not pass directly over area 200 but yet captures oblique images thereof.

[0070] The present invention is capable of capturing images at various levels of resolution or ground sample distances. A first level of detail, hereinafter referred to as a community level, has a ground sample distance of, for example, approximately two-feet per pixel. For orthogonal community-level images, the ground sample distance remains substantially constant throughout the image. Orthogonal community-level images are captured with sufficient overlap to provide stereo pair coverage. For oblique community-level images, the ground sample distance varies from, for example, approximately one-foot per pixel in the foreground of the image to approximately two-feet per pixel in the mid-ground of the image, and to approximately four-feet per pixel in the background of the image. Oblique community-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction captured. Approximately ten oblique community-level images are captured per sector.

[0071] A second level of detail, hereinafter referred to as a neighborhood level, is significantly more detailed than the community-level images. Neighborhood-level images have a ground sample distance of, for example, approximately six-inches per pixel. For orthogonal neighborhood-level images, the ground sample distance remains substantially constant. Oblique neighborhood-level images have a ground sample distance of, for example, from approximately four-inches per pixel in the foreground of the image to approximately six-inches per pixel in the mid-ground of the image, and to approximately ten-inches per pixel in the background of the image. Oblique neighborhood-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction captured, and such that opposing compass directions provide 100% overlap with each other. Approximately one hundred (100) oblique area images are captured per sector.

[0072] It should be particularly noted that capturing oblique community and/or neighborhood-level images from all four compass directions ensures that every point in the image will appear in the foreground or lower portion of at least one of the captured oblique images, where ground sample distance is lowest and image detail is greatest.

[0073] In the embodiment shown, image-capturing and geo-locating system 30 includes a gyroscope, compass and altimeter. However, it is to be understood that the image-capturing and geo-locating system of the present invention can be alternately configured, such as, for example, to derive and/or calculate altitude, pitch, roll and yaw, and compass heading from the GPS and INU signals/data, thereby rendering one or more of the gyroscope, compass and altimeter unnecessary. In fact,

[0074] In the embodiment shown, image-capturing devices are at an equal angle of declination relative to a horizontal plane. However, it is to be understood that the declination angles of the image-capturing devices do not have to be equal.

[0075] In the embodiment shown, image-capturing computer system executes image and data acquiring software that issues a common or single image-capture signal to the image-capturing devices to thereby cause those devices to acquire or capture an image. However, it is to be understood that the present invention can be alternately configured to separately cause the image-capturing devices to capture images at different instants and/or at different intervals.

[0076] In the embodiment shown, the method of the present invention captures oblique images to provide double coverage of an area of interest from paths/perspectives that are substantially opposite to each other, i.e., 180 DEG (one-hundred and eighty degrees) relative to each other. However, it is to be understood that the method of the present invention can be alternately configured to provide double coverage from paths/perspectives that are generally and/or substantially perpendicular relative to each other.

[0077] While the present invention has been described as having a preferred design, the invention can be further modified within the spirit and scope of this disclosure. This disclosure is therefore intended to encompass any equivalents to the structures and elements disclosed herein. Further, this disclosure is intended to encompass any variations, uses, or adaptations of the present invention that use the general principles disclosed herein. Moreover, this disclosure is intended to encompass any departures from the subject matter disclosed that come within the known or customary practice in the pertinent art and which fall within the limits of the appended

claims.

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Method and apparatus for capturing, geolocating and measuring oblique images

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Claims of corresponding document: **EP 1418402 (A1)**

1. A system for capturing images and geo-location data corresponding thereto, comprising: an image-capturing device, said image-capturing device capturing oblique images at image-capturing events, said image capturing device issuing image-data signals corresponding to captured images; at least one geo-locating device, each said at least one geo-locating device issuing a corresponding at least one geo-locating signal, each said at least one geo-locating signal being indicative at least in part of a geo-location of said image-capturing device during each image capturing event; and a computer system receiving and storing said image-data signals and said at least one geo-locating signal; and image and data acquiring software reading said image-data signals and said at least one geo-locating signal, said software associating each said image-data signal with a corresponding said at least one geo-locating signal for each image-capturing event.

2. The system of claim 1, wherein said at least one geo-locating device and said at least one geo-locating signal respectively comprise at least one of: a clock issuing to said image-capturing computer system time data signals indicative of a time of each said image-capturing event; a global-positioning system (GPS) receiver receiving GPS signals and issuing to said image-capturing computer system location data signals indicative of a longitude and latitude of said image-capturing device at each said image-capturing event; an inertial navigation unit (INU) issuing to said image-capturing computer system velocity data signals indicative of a velocity of said image-capturing device at each said image-capturing event; a gyroscope issuing to said image-capturing computer system a pitch signal, a roll signal, and a yaw signal respectively indicative of a pitch, roll and yaw of said image capturing device at each said image-capturing event; a compass issuing to said image-capturing computer system heading data signals indicative of a heading of said image-capturing device at each said image-capturing event; and an altimeter issuing to said image-capturing computer system altitude data signals indicative of an altitude of said image-capturing device at each said image-capturing event.

3. The system of claim 1, wherein said at least one geo-locating device and said at least one geo-locating signal respectively comprise: a clock issuing to said image-capturing computer system time data signals indicative of a time of each said image-capturing event; a global-positioning system (GPS) receiver receiving GPS signals and issuing to said image-capturing computer system location data signals indicative of a longitude and latitude of said image-capturing device at each said image-capturing event; an inertial navigation unit (INU) issuing to said image-capturing computer system velocity data signals indicative of a velocity of said image-capturing device at each said image-capturing event; a gyroscope issuing to said image-capturing computer system a pitch signal, a roll signal, and a yaw signal respectively indicative of a pitch, roll and yaw of said image capturing device at each said image-capturing event; a compass issuing to said image-capturing computer system heading data signals indicative of a heading of said image-capturing device at each said image-capturing event; and an altimeter issuing to said image-capturing computer system altitude data signals indicative of an altitude of said image-capturing device at each said image-capturing event.

4. The system of claim 1, further comprising correction data indicative of characteristics of said image-capturing device including focal length, sensor size, radial distortion, principal point offset and alignment, said image and data acquiring software utilizing said correction data to correct captured images.

5. The system of claim 1, further comprising an output data file created by said image and data acquiring software, said output data file including a plurality of image files and positional data corresponding to each of said plurality of image files.

6. The system of claim 1, further comprising a platform carrying said image-capturing device a predetermined distance above a surface of interest.

7. A computerized system for displaying, geolocating, and making measurements based upon captured oblique images, comprising: a computer system having a memory; an image and data file accessible by said system and including a plurality of image files corresponding to a plurality of captured oblique images, said image and data file further including positional data corresponding to said plurality of image files; image display and analysis software executed by said system for reading said image and data file and displaying at least a portion of the captured oblique images as a displayed image, said software retrieving said positional data of one or more selected points within said displayed image, said software calculating a separation distance between any two or more selected points within said displayed image.

8. The system of claim 7, further comprising a ground plane data file representing a tessellated ground plane, said ground plane data file accessible by said computer system, said ground plane data file representing a tessellated ground plane that closely approximates at least a portion of the terrain depicted within said captured oblique images.

9. The system of claim 8, wherein said tessellated ground plane further comprises a plurality of interconnected facets, each of said plurality of facets having a respective pitch and slope.

10. The system of claim 9, wherein said ground plane data file comprises a plurality of vertices, each of said plurality of vertices having respective elevations and defining corners of said plurality of interconnected facets, two of said plurality of vertices shared by each of said interconnected facets.

11. The system of claim 10, wherein said image display and analysis software identifies which of said plurality of facets corresponds to a selected point on said displayed image, and calculates an elevation of said selected point dependent at least in part upon the elevation of the vertices of the facet corresponding to the selected point, said image display and analysis software using said calculated elevation for calculating said separation distance between said selected point and one or more further selected points.

12. The system of claim 11, wherein said image display and analysis software calculates a height of an object within said displayed image by calculating the separation distance between two or more selected points.

13. The system of claim 8, wherein said tessellated ground plane is one of superimposed upon and fit to said displayed image.

14. The system of claim 7, wherein said image display and analysis software includes user-selectable measuring modes accessible through at least one of pull-down menus, toolbars and keyboard commands.

15. The system of claim 7, wherein each of said images were captured by an image-capturing device and at respective image capturing events, said positional data of said image and data file including: time data representing the time of each image-capturing event; location data representing the location of the image-capturing device at each image-capturing event; orientation data representing the orientation of the image-capturing device at each image-capturing event; correction data representing correction factors for the image-capturing device; and elevation data representing an average elevation of the surface captured by the image-capturing device.

16. The system of claim 15, wherein said location data includes latitude, longitude, and altitude of the image-capturing apparatus at each image-capturing event.

17. The system of claim 15, wherein said orientation data includes roll, pitch, yaw and heading of said image-capturing device at each image-capturing event.

18. The data set of claim 15, wherein said image-capturing device is a camera and said correction data includes at least one of focal length, sensor size, aspect ratio, principle point offset, distortion, and pixel pitch.

19. A computerized method for taking measurements within a displayed oblique image, comprising: selecting with an input device a starting point and an end point on the displayed image; retrieving from a data file positional data corresponding to said starting point and said end point; referencing a ground plane data file corresponding to a tessellated ground plane having a plurality of facets, each of said facets having a respective pitch and slope, said tessellated ground plane closely matching a terrain of said displayed oblique image; connecting said starting and end points with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and calculating the linear distance along said line segments between said starting and end points thereby taking into account said pitch and slope of said facets.

20. The method of claim 19, wherein said tessellated ground plane is superimposed upon said displayed oblique image.

21. The method of claim 19, comprising the further steps of: selecting with an input device one or more intermediate points on the displayed image; retrieving from said data file positional data corresponding to said one or more intermediate points; and connecting adjacent intermediate points to each other, and connecting said starting and end points to adjacent intermediate points, with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and calculating the distance along said line segments between said starting and end points.

22. The method of claim 19, wherein said plurality of facets each correspond to equal areas of said displayed oblique image.

23. The method of claim 19, wherein said plurality of facets each includes an equal number of pixels of said displayed oblique image.

24. A computerized method for taking measurements from an oblique image displayed on a computer system, at least one input device connected to said computer system, an image data file accessible by said computer system, said image data file including captured images and positional data corresponding thereto, said computerized method comprising: placing the computer system into a desired one of a plurality of measurement modes, the desired measurement mode configured for calculating a desired measurement; selecting a starting point on the displayed image; retrieving the positional data corresponding to said starting point; selecting an end point on the displayed image; retrieving the positional data corresponding to said end point; and calculating the desired measurement dependent at least in part upon said positional data of said starting and end points.

25. The method of claim 24, comprising the further steps of: selecting one or more intermediate points on said displayed image; and retrieving the positional data corresponding to said intermediate points.

26. The method of claim 24, wherein said plurality of measurement modes comprise a distance measuring mode calculating a distance between two or more selected points, a height measuring mode calculating a height difference between two or more selected points, a relative elevation measurement mode calculating the difference in elevation of two or more selected points, and an area measurement mode calculating the area encompassed by at least three points.

27. A method of capturing oblique images of an area of interest with an image-capturing device carried by a platform, each oblique image captured at a respective image-capturing event, said method comprising: subdividing the area of interest into a plurality of sectors; guiding the platform along a first path to thereby target one or more target sectors with the image-capturing device; capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a first perspective; guiding the platform along a second path to thereby target said target sectors; capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a second perspective; repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said first and second paths and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from each of said first and second perspectives; and recording positional data indicative of a geo-location of said image-capturing device at each image-capturing event.

28. The method of claim 27, wherein said second path is substantially parallel relative to and 180 DEG (one-hundred and eighty degrees) from said first path;

29. The method of claim 28, wherein said second path is also spaced apart from said first path.

30. The method of claim 27, comprising the further steps of: guiding the platform along a third path to thereby target one or more target sectors with the image-capturing device, said third path being substantially perpendicular to said first and second paths; capturing with the image-capturing device one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a third perspective; and repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said third path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said third perspective.

31. The method of claim 30, comprising the further steps of: guiding the platform along a fourth path to thereby target one or more target sectors with the image-capturing device, said fourth path being substantially parallel with said third path and 180 DEG (one-hundred and eighty degrees) from said third path; capturing with the image-capturing device one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a fourth perspective; and repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said fourth path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said fourth perspective.

32. The method of claim 31, wherein said fourth path is also spaced apart from said third path.

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(54) Method and apparatus for capturing, geolocating and measuring oblique images

(57) A computerized system for displaying, geolocating, and taking measurements from captured oblique images includes a data file accessible by the computer system. The data file includes a plurality of image files corresponding to a plurality of captured oblique images, and positional data corresponding to the images. Image display and analysis software is executed by the system for reading the data file and displaying at least a portion of the captured oblique images. The software retrieves the positional data for one or more user-selected points on the displayed image, and calculates a separation distance between any two or more selected points. The separation distance calculation is user-selectable to determine various parameters including linear distance between, area encompassed within, relative elevation of, and height difference between selected points.

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/425,275, filed November 8, 2002.

TECHNICAL FIELD

[0002] The present invention relates to photogrammetry. More particularly, the present invention relates to a method and apparatus for capturing oblique images and for measuring the objects and distances between the objects depicted therein.

BACKGROUND

[0003] Photogrammetry is the science of making measurements of and between objects depicted within photographs, especially aerial photographs. Generally, photogrammetry involves taking images of terrestrial features and deriving data therefrom, such as, for example, data indicating relative distances between and sizes of objects within the images. Photogrammetry may also involve coupling the photographs with other data, such as data representative of latitude and longitude. In effect, the image is overlaid and conformed to a particular spatial coordinate system.

[0004] Conventional photogrammetry involves the capture and/or acquisition of orthogonal images. The image-capturing device, such as a camera or sensor, is carried by a vehicle or platform, such as an airplane or satellite, and is aimed at a nadir point that is directly below and/or vertically downward from that platform. The point or pixel in the image that corresponds to the nadir point is the only point/pixel that is truly orthogonal to the image-capturing device. All other points or pixels in the image are actually oblique relative to the image-capturing device. As the points or pixels become increasingly distant from the nadir point they become increasingly oblique relative to the image-capturing device and the ground sample distance (i.e., the surface area corresponding to or covered by each pixel) also increases. Such obliqueness in an orthogonal image causes features in the image to be distorted, especially images relatively distant from the nadir point.

[0005] Such distortion is removed, or compensated for, by the process of ortho-rectification which, in essence, removes the obliqueness from the orthogonal image by fitting or warping each pixel of an orthogonal image onto an orthometric grid or coordinate system. The process of ortho-rectification creates an image wherein all pixels have the same ground sample distance and are oriented to the north. Thus, any point on an ortho-rectified image can be located using an X, Y coordinate system and, so long as the image scale is known, the length and width of terrestrial features as well as the relative distance between those features can be calculated.

[0006] Although the process of ortho-rectification compensates to a degree for oblique distortions in an orthogonal image, it introduces other undesirable distortions and/or inaccuracies in the ortho-rectified orthogonal image. Objects depicted in ortho-rectified orthogonal images may be difficult to recognize and/or identify since most observers are not accustomed to viewing objects, particularly terrestrial features, from above. To an untrained observer an ortho-rectified image has a number of distortions. Roads that are actually straight appear curved and buildings may appear to tilt. Further, ortho-rectified images contain substantially no information as to the height of terrestrial features. The interpretation and analysis of orthogonal and/or ortho-rectfified orthogonal images is typically performed by highly-trained analysts whom have undergone years of specialized training and experience in order to identify objects and terrestrial features in such images.

[0007] Thus, although orthogonal and ortho-rectified images are useful in photogrammetry, they lack information as to the height of features depicted therein and require highly-trained analysts to interpret detail from what the images depict.

[0008] Oblique images are images that are captured with the image-capturing device aimed or pointed generally to the side of and downward from the platform that carries the image-capturing device. Oblique images, unlike orthogonal images, display the sides of terrestrial features, such as houses, buildings and/or mountains, as well as the tops thereof. Thus, viewing an oblique image is more natural and intuitive than viewing an orthogonal or ortho-rectified image, and even casual observers are able to recognize and interpret terrestrial features and other objects depicted in oblique images. Each pixel in the foreground of an oblique image corresponds to a relatively small area of the surface or object depicted (i.e., each foreground pixel has a relatively small ground sample distance) whereas each pixel in the background corresponds to a relatively large area of the surface or object depicted (i.e., each background pixel has a relatively large ground sample distance). Oblique images capture a generally trapezoidal area or view of the subject surface or object, with the foreground of the trapezoid having a substantially smaller ground sample distance (i.e., a higher resolution) than the background of the trapezoid.

[0009] Oblique images are considered to be of little or no use in photogrammetry. The conventional approach of forcing

the variously-sized foreground and background pixels of an oblique image into a uniform size to thereby warp the image onto a coordinate system dramatically distorts the oblique image and thereby renders identification of objects and the taking of measurements of objects depicted therein a laborious and inaccurate task. Correcting for terrain displacement within an oblique image by using an elevation model further distorts the images thereby increasing the difficulty with which measurements can be made and reducing the accuracy of any such measurements.

[0010] Thus, although oblique images are considered as being of little or no use in photogrammetry, they are easily interpreted and contain information as to the height of features depicted therein.

[0011] Therefore, what is needed in the art is a method and apparatus for photogrammetry that enable geo-location and accurate measurements within oblique images.

[0012] Moreover, what is needed in the art is a method and apparatus for photogrammetry that enable the measurement of heights and relative heights of objects within an image.

[0013] Furthermore, what is needed in the art is a method and apparatus for photogrammetry that utilizes more intuitive and natural images.

SUMMARY OF THE INVENTION

[0014] The present invention provides a method and apparatus for capturing, displaying, and making measurements of objects and distances between objects depicted within oblique images.

[0015] The present invention comprises, in one form thereof, a computerized system for displaying, geolocating, and taking measurements from captured oblique images. The system includes a data file accessible by the computer system. The data file includes a plurality of image files corresponding to a plurality of captured oblique images, and positional data corresponding to the images. Image display and analysis software is executed by the system for reading the data file and displaying at least a portion of the captured oblique images. The software retrieves the positional data for one or more user-selected points on the displayed image, and calculates a separation distance between any two or more selected points. The separation distance calculation is user-selectable to determine various parameters including linear distance between, area encompassed within, relative elevation of, and height difference between selected points.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become apparent and be more completely understood by reference to the following description of one embodiment of the invention when read in conjunction with the accompanying drawings, wherein:

FIG. 1 illustrates one embodiment of a platform or vehicle carrying an image-capturing system of the present invention, and shows exemplary orthogonal and oblique images taken thereby;
FIG. 2 is a diagrammatic view of the image-capturing system of FIG. 1;
FIG. 3 is a block diagram of the image-capturing computer system of Fig. 2;
FIG. 4 is a representation of an exemplary output data file of the image-capturing system of Fig. 1;
FIG. 5 is a block diagram of one embodiment of an image display and measurement computer system of the present invention for displaying and taking measurements of and between objects depicted in the images captured by the image-capturing system of Fig. 1;
FIG. 6 depicts an exemplary image displayed on the system of Fig. 5, and illustrates one embodiment of the method of the present invention for the measurement of and between objects depicted in such an image;
FIGS. 7 and 8 illustrate one embodiment of a method for capturing oblique images of the present invention;
FIGS. 9 and 10 illustrate a second embodiment of a method for capturing oblique images of the present invention.

[0017] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate one preferred embodiment of the invention, in one form, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] Referring now to the drawings, and particularly to Fig. 1, one embodiment of an apparatus for capturing and geolocating oblique images of the present invention is shown. Apparatus 10 includes a platform or vehicle 20 that carries image-capturing and geolocating system 30.

[0019] Platform 20, such as, for example, an airplane, space shuttle, rocket, satellite, or any other suitable vehicle, carries image-capturing system 30 over a predefined area of and at one or more predetermined altitudes above surface 31, such as, for example, the earth's surface or any other surface of interest. As such, platform 20 is capable of controlled

movement or flight, either manned or unmanned, along a predefined flight path or course through, for example, the earth's atmosphere or outer space. Image-capturing platform 20 includes a system for generating and regulating power (not shown) that includes, for example, one or more generators, fuel cells, solar panels, and/or batteries, for powering image-capturing system 30.

[0020] Image-capturing and geo-locating system 30, as best shown in Fig. 2, includes image capturing devices 32a and 32b, a global positioning system (GPS) receiver 34, an inertial navigation unit (INU) 36, clock 38, gyroscope 40, compass 42 and altimeter 44, each of which are interconnected with image-capturing computer system 46.

[0021] Image-capturing devices 32a and 32b, such as, for example, conventional cameras, digital cameras, digital sensors, charge-coupled devices, or other suitable image-capturing devices, are capable of capturing images photographically or electronically. Image-capturing devices 32a and 32b have known or determinable characteristics including focal length, sensor size and aspect ratio, radial and other distortion terms, principal point offset, pixel pitch, and alignment. Image-capturing devices 32a and 32b acquire images and issue image data signals (IDS) 48a and48b, respectively, corresponding to the particular images or photographs taken and which are stored in image-capturing computer system 46, as will be more particularly described hereinafter.

[0022] As best shown in Fig. 1, image-capturing devices 32a and 32b have respective central axes A_1 and A_2, and are mounted to platform 20 such that axes A_1 and A_2 are each at an angle of declination θ relative to a horizontal plane P. Declination angle θ is virtually any oblique angle, but is preferably from approximately 20° (twenty degrees) to approximately 60° (sixty degrees) and is most preferably from approximately 40° (forty degrees) to approximately 50° (fifty degrees).

[0023] GPS receiver 34 receives global positioning system signals 52 that are transmitted by one or more global positioning system satellites 54. The GPS signals 52, in known fashion, enable the precise location of platform 20 relative to surface 31 to be determined. GPS receiver 34 decodes GPS signals 52 and issues location signals/data 56, that are dependent at least in part upon GPS signals 52 and which are indicative of the precise location of platform 20 relative to surface 31. Location signals/data 56 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0024] INU 36 is a conventional inertial navigation unit that is coupled to and detects changes in the velocity, including translational and rotational velocity, of image-capturing devices 32a and 32b and/or platform 20. INU 36 issues velocity signals/data 58 indicative of such velocities and/or changes therein to image-capturing computer system 46, which stores velocity signals/data 58 corresponding to each image captured by image-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0025] Clock 38 keeps a precise time measurement (time of validity) that is used to synchronize events within image-capturing and geo-locating system 30. Clock 38 provides time data/clock signal 62 that is indicative of the precise time that an image is taken by image-capturing devices 32a and 32b. Time data 62 is also provided to and stored by image-capturing computer system 46. Alternatively, clock 38 is integral with image-capturing computer system 46, such as, for example, a clock software program.

[0026] Gyroscope 40 is a conventional gyroscope as commonly found on airplanes and/or within commercial navigation systems for airplanes. Gyroscope 40 provides signals including pitch signal 64, roll signal 66 and yaw signal 68, which are respectively indicative of pitch, roll and yaw of platform 20. Pitch signal 64, roll signal 66 and yaw signal 68 corresponding to each image captured by mage-capturing devices 32a and 32b are received and stored by image-capturing computer system 46.

[0027] Compass 42, such as, for example, a conventional electronic compass, indicates the heading of platform 20. Compass 42 issues heading signal/data 72 that is indicative of the heading of platform 20. Image-capturing computer system 46 receives and stores the heading signals/data 72 that correspond to each image captured by image-capturing devices 32a and 32b.

[0028] Altimeter 44 indicates the altitude of platform 20. Altimeter 44 issues altitude signal/data 74, and image-capturing computer system 46 receives and stores the altitude signal/data 74 that correspond to each image captured by image-capturing devices 32a and 32b.

[0029] As best shown in Fig. 3, image-capturing computer system 46, such as, for example, a conventional laptop personal computer, includes memory 82, input devices 84a and 84b, display device 86, and input and output (I/O) ports 88. Image-capturing computer system 46 executes image and data acquiring software 90, which is stored in memory 82. Memory 82 also stores data used and/or calculated by image-capturing computer system 46 during the operation thereof, and 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 84a and 84b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and interaction of a user with software being executed by image-capturing computer system 46. Display device 86, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image-capturing computer system 46. I/O ports 88, such as, for example, serial and parallel data input and output ports, enable the input and/or output of data to and from image-capturing computer system 46.

[0030] Each of the above-described data signals is connected to image-capturing computer system 46. More particularly, image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74 are received via I/O ports 88 by and stored within memory 82 of image-capturing computer system 46.

[0031] In use, image-capturing computer system 46 executes image and data acquiring software 90, which, in general, controls the reading, manipulation, and storing of the above-described data signals. More particularly, image and data acquiring software 90 reads image data signals 48a and 48b and stores them within memory 82. Each of the location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74 that represent the conditions existing at the instant an image is acquired or captured by image-capturing devices 32a and 32b and which correspond to the particular image data signals 48a and 48b representing the captured images are received by image-capturing computer system 46 via I/O ports 88. Image-capturing computer system 46 executing image and data acquiring software 90 issues image-capture signal 92 to image-capturing devices 32a and 32b to thereby cause those devices to acquire or capture an image at predetermined locations and/or at predetermined intervals which are dependent at least in part upon the velocity of platform 20.

[0032] Image and data acquiring software 90 decodes as necessary and stores the aforementioned signals within memory 82, and associates the data signals with the corresponding image signals 48a and 48b. Thus, the altitude, orientation in terms of roll, pitch, and yaw, and the location of image-capturing devices 32a and 32b relative to surface 31, i.e., longitude and latitude, for every image captured by image-capturing devices 32a and 32b is known.

[0033] Platform 20 is piloted or otherwise guided through an image-capturing path that passes over a particular area of surface 31, such as, for example, a predefined area of the surface of the earth or of another planet. Preferably, the image-capturing path of platform 20 is at right angles to at least one of the boundaries of the area of interest. I he number of times platform 20 and/or image-capturing devices 32a, 32b pass over the area of interest is dependent at least in part upon the size of the area and the amount of detail desired in the captured images. The particular details of the image-capturing path of platform 20 are described more particularly hereinafter.

[0034] As platform 20 passes over the area of interest a number of oblique images are captured by image-capturing devices 32a and 32b. As will be understood by those of ordinary skill in the art, images are captured or acquired by image-capturing devices 32a and 32b at predetermined image capture intervals which are dependent at least in part upon the velocity of platform 20.

[0035] Image data signals 48a and 48b corresponding to each image acquired are received by and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Similarly, the data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) corresponding to each captured image are received and stored within memory 82 of image-capturing computer system 46 via I/O ports 88. Thus, the location of image-capturing device 32a and 32b relative to surface 32 at the precise moment each image is captured is recorded within memory 82 and associated with the corresponding captured image.

[0036] As best shown in Fig. 1, the location of image-capturing devices 32a and 32b relative to the earth corresponds to the nadir point *N* of orthogonal image 102. Thus, the exact geo-location of the nadir point *N* of orthogonal image 102 is indicated by iocation signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74. Once the nadir point *N* of orthogonal image 102 is known, the geo-location of any other pixel or point within image 102 is determinable in known manner.

[0037] When image-capturing devices 32a and 32b are capturing oblique images, such as oblique images 104a and 104b (Fig. 1), the location of image-capturing devices 32a and 32b relative to surface 31 is similarly indicated by location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72, altitude signal 74 and the known angle of declination θ of the primary axes A_1 and A_2 of image-capturing devices 32a and 32b, respectively.

[0038] It should be particularly noted that a calibration process enables image and data acquiring software 90 to incorporate correction factors and/or correct for any error inherent in or due to image-capturing device 32, such as, for example, error due to calibrated focal length, sensor size, radial distortion, principal point offset, and alignment.

[0039] Image and data acquiring software 90 creates and stores in memory 82 one or more output image and data files 120. More particularly, image and data acquiring software 90 converts image data signals 48a, 48b and the orientation data signals (i.e., image data signals 48, location signals 56, velocity signals 58, time data signal 62, pitch, roll and yaw signals 64, 66 and 68, respectively, heading signal 72 and altitude signal 74) into computer-readable output image and data files 120. As best shown in Fig. 4, output image and data file 120 contains a plurality of captured image files I_1, I_2, . .., I_n corresponding to captured oblique images, and the positional data C_{PD1}, C_{PD2}, ... , C_{PDn} corresponding thereto.

[0040] Image files I_1, I_2, ... , I_n of the image and data file 120 are stored in virtually any computer-readable image or graphics file format, such as, for example, JPEG, TIFF, GIF, BMP, or PDF file formats, and are cross-referenced with the positional data C_{PD1}, C_{PD2}, ... , C_{PDn} which is also stored as computer-readable data. Alternatively, positional data C_{PD1}, C_{PD2}, ..., C_{PDn} is embedded within the corresponding image files I_1, I_2, ..., I_n in known manner. Image data files

120 are then processed, either by image and data acquiring software 90 or by post-processing, to correct for errors, such as, for example, errors due to flight path deviations and other errors known to one of ordinary skill in the art. Thereafter, image data files 120 are ready for use to display and make measurements of and between the objects depicted within the captured images, including measurements of the heights of such objects.

[0041] Referring now to Fig. 5, image display and measurement computer system 130, such as, for example, a conventional desktop personal computer or a mobile computer terminal in a police car, includes memory 132, input devices 134a and 134b, display device 136, and network connection 138. Image-capturing computer system 130 executes image display and analysis software 140, which is stored in memory 132. Memory 132 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 134a and 134b, such as, for example, a mouse, keyboard, joystick, or other such input devices, enable the input of data and interaction of a user with image display and analysis software 140 being executed by image display and measurement computer system 130. Display device 136, such as, for example, a liquid crystal display or cathode ray tube, displays information to the user of image display and measurement computer system 130. Network connection 138 connects image display and measurement computer system 130 to a network (not shown), such as, for example, a local-area network, wide-area network, the Internet and/or the World Wide Web.

[0042] In use, and referring now to Fig. 6, image display and measurement computer system 130 executing image display and analysis software 140 accesses one or more output image and data files 120 that have been read into memory 132, such as, for example, via network connection 138, a floppy disk drive, removable memory card or other suitable means. One or more of the captured images I_1, I_2, ..., I_n of output image and data files 120 is thereafter displayed as displayed oblique image 142 under the control of image display and analysis software 140. At approximately the same time, one or more data portions C_{PD1}, C_{PD2}, ..., C_{PDn} corresponding to displayed oblique image 142 are read into a readily-accessible portion of memory 132.

[0043] It should be particularly noted that displayed oblique image 142 is displayed substantially as captured, i.e., displayed image 142 is not warped or fitted to any coordinate system nor is displayed image 142 ortho-rectified. Rather than warping displayed image 142 to a coordinate system in order to enable measurement of objects depicted therein, image display and analysis software 140, in general, determines the geo-locations of selected pixels only as needed, or "on the fly", by referencing data portions C_{PD1}, C_{PD2}, ..., C_{PDn} of output image and data files 120 and calculating the position and/or geo-location of those selected pixels using one or more projection equations as is more particularly described hereinafter.

[0044] Generally, a user of display and measurement computer system 130 takes measurements of and between objects depicted in displayed oblique image 142 by selecting one of several available measuring modes provided within image display and analysis software 140. The user selects the desired measurement mode by accessing, for example, a series of pull-down menus or toolbars M, or via keyboard commands. The measuring modes provided by image display and analysis software 140 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.

[0045] After selecting the desired measurement mode, the user of image display and analysis software 140 selects with one of input devices 134a, 134b a starting point or starting pixel 152 and an ending point or pixel 154 on displayed image 142, and image display and analysis software 140 automatically calculates and displays the quantity sought, such as, for example, the distance between starting pixel 152 and ending pixel 154.

[0046] When the user selects starting point/pixel 152, the geo-location of the point corresponding thereto on surface 31 is calculated by image display and analysis software 140 which executes one or more projection equations using the data portions C_{PD1}, C_{PD2}, ..., C_{PDn} of output image and data files 120 that correspond to the particular image being displayed. The longitude and latitude of the point on surface 31 corresponding to pixel 152 are then displayed by image display and analysis software 140 on display 136, such as, for example, by superimposing the longitude and latitude on displayed image 142 adjacent the selected point/pixel or in pop-up display box elsewhere on display 136. The same process is repeated by the user for the selection of the end pixel/point 154, and by image display and analysis software 140 for the retrieval and display of the longitude and latitude information.

[0047] The calculation of the distance between starting and ending points/pixels 152, 154, respectively, is accomplished by determining the geo-location of each selected pixel 152, 154 "on the fly". The data portions C_{PD1}, C_{PD2}, ..., C_{PDn} of output image and data file 120 corresponding to the displayed image are retrieved, and the geo-location of the point on surface 31 corresponding to each selected pixel are then determined. The difference between the geo-locations corresponding to the selected pixels determines the distance between the pixels.

[0048] As an example of how the geo-location of a given point or pixel within displayed oblique image 142 is determined, we will assume that displayed image 142 corresponds to orthogonal image 104a (Fig. 1). The user of image display and analysis software 140 selects pixel 154 which, for simplicity, corresponds to center C (Fig. 1) of oblique image 104a. As

shown in Fig. 1, line 106 extends along horizontal plane G from a point 108 thereon that is directly below image-capturing device 32a to the center C of the near border or edge 108 of oblique image 104a. An extension of primary axis A_1 intersects with center C. Angle Ø is the angle formed between line 106 the extension of primary axis A_1. Thus, a triangle (not referenced) is formed having vertices at image-capturing device 32a, point 108 and center C, and having sides 106, the extension of primary axis A_1 and vertical (dashed) line 110 between point 108 and image-capturing device 32a.

[0049] Ground plane G is a substantially horizontal, flat or non-sloping ground plane (and which typically will have an elevation that reflects the average elevation of the terrain), and therefore the above-described triangle includes a right angle between side/line 110 and side/line 106. Since angle Ø and the altitude of image-capturing device 32 (i.e., the length of side 110) are known, the hypotenuse (i.e., the length of the extension of primary axis A_1) and remaining other side of the right triangle are calculated by simple geometry. Further, since the exact position of image-capturing device 32a is known at the time the image corresponding to displayed image 142 was captured, the latitude and longitude of point 108 are also known. Knowing the length of side 106, calculated as described above, enables the exact geo-location of pixel 154 corresponding to center C of oblique image 104a to be determined by image display and analysis software 140. Once the geo-location of the point corresponding to pixel 154 is known, the geo-location of any other pixel in displayed oblique image 142 is determinable using the known camera characteristics, such as, for example, focal length, sensor size and aspect ratio, radial and other distortion terms, etc.

[0050] The distance between the two or more points corresponding to two or more selected pixels within displayed image 142 is calculated by image display and analysis software 140 by determining the difference between the geo-locations of the selected pixels using known algorithms, such as, for example, the Gauss formula and/or the vanishing point formula, dependent upon the selected measuring mode. The measurement of objects depicted or appearing in displayed image 142 is conducted by a substantially similar procedure to the procedure described above for measuring distances between selected pixels. For example, the lengths, widths and heights of objects, such as, for example, buildings, rivers, roads, and virtually any other geographic or man-made structure, appearing within displayed image 142 are measured by selecting the appropriate/desired measurement mode and selecting starting and ending pixels.

[0051] It should be particularly noted that in the distance measuring mode of image display and analysis software 140 the distance between the starting and ending points/pixels 152, 154, respectively, is determinable along virtually any path, such as, for example, a "straight-line" path *P1* or a path *P2* that involves the selection of intermediate points/pixels and one or more "straight-line" segments interconnected therewith.

[0052] It should also be particularly noted that the distance measuring mode of image display and analysis software 140 determines the distance between selected pixels according to a "walk the earth" method. The "walk the earth method" creates a series of interconnected line segments, represented collectively by paths *P1* and *P2,* that extend between the selected pixels/points and which lie upon or conform to the planar faces of a series of interconnected facets that define a tessellated ground plane. The tessellated ground plane, as will be more particularly described hereinafter, closely follows or recreates the terrain of surface 31, and therefore paths *P1* and *P2* also closely follow the terrain of surface 31. By measuring the distance along the terrain simulated by the tessellated ground plane, the "walk the earth" method provides for a more accurate and useful measurement of the distance between selected points than the conventional approach, which warps the image onto a flat earth or average elevation plane system and measures the distance between selected points along the flat earth or plane and substantially ignores variations in terrain between the points.

[0053] For example, a contractor preparing to bid on a contract for paving a roadway over uneven or hilly terrain can determine the approximate amount or area of roadway involved using image display and analysis software 140 and the "walk the earth" measurement method provided thereby. The contractor can obtain the approximate amount or area of roadway from his or her own office without having to send a surveying crew to the site to obtain the measurements necessary.

[0054] In contrast to the "walk the earth" method provided by the present invention, the "flat earth" or average elevation distance calculating approaches include inherent inaccuracies when measuring distances between points and/or objects disposed on uneven terrain and when measuring the sizes and/or heights of objects similarly disposed. Even a modest slope or grade in the surface being captured results in a difference in the elevation of the nadir point relative to virtually any other point of interest thereon. Thus, referring again to Fig. 1, the triangle formed by line 106, the extension of primary axis A_1 and the vertical (dashed) line 110 between point 108 and image-capturing device 32a may not be a right triangle. If such is the case, any geometric calculations assuming that triangle to be a right triangle would contain errors, and such calculations would be reduced to approximations due to even a relatively slight gradient or slope between the points of interest.

[0055] For example, if surface 31 slopes upward between nadir point *N* and center C at the near or bottom edge 108 of oblique image 104 then second line 110 intersects surface 31 before the point at which such intersection would occur on a level or non-sloping surface 31. If center C is fifteen feet higher than nadir point *N* and with a declination angle θ equal to 40° (forty degrees), the calculated location of center C would be off by approximately 17.8 feet without correction for the change in elevation between the points.

[0056] As generally discussed above, in order to compensate at least in part for changes in elevation and the resultant

inaccuracies in the measurement of and between objects within image 142, image display and analysis software 140 references, as necessary, points within displayed image 142 and on surface 31 to a pre-calculated tessellated or faceted ground plane generally designated 160 in Fig. 6. Tessellated ground plane 160 includes a plurality of individual facets 162a, 162b, 162c, etc., each of which are interconnected to each other and are defined by four vertices (not referenced, but shown as points) having respective elevations. Adjacent pairs of facets 162a, 162b, 162c, etc., share two vertices. Each facet 162a, 162b, 162c, etc., has a respective pitch and slope. Tessellated ground plane 160 is created based upon various data and resources, such as, for example, topographical maps, and/or digital raster graphics, survey data, and various other sources.

[0057] Generally, the geo-location of a point of interest on displayed image 142 is calculated by determining which of facets 162a, 162b, 162c, etc., correspond to that point of interest. Thus, the location of the point of interest is calculated based on the characteristics, i.e., elevation, pitch and slope, of facets 162a, 162b, 162c, etc., rather than based upon a flat or average-elevation ground plane. Error is introduced only in so far as the topography of surface 31 and the location of the point of interest thereon deviate from the planar surface of the facet 162a, 162b, 162c, etc, within which the point of interest lies. That error is reducible through a bilinear interpolation of the elevation of the point of interest within a particular one of facets 162a, 162b, 162c, etc., and using that interpolated elevation in the location calculation performed by image display and analysis software 140.

[0058] To use tessellated ground plane 160, image display and analysis software 140 employs a modified ray-tracing algorithm to find the intersection of the ray projected from the image-capturing device 32a or 32b towards surface 31 and tessellated ground plane 160. The algorithm determines not only which of facets 162a, 162b, 162c, etc., is intersected by the ray, but also where within the facet the intersection occurs. By use of bi-linear interpolation, a fairly precise ground location can be determined. For the reverse projection, tessellated ground plane 160 is used to find the ground elevation value for the input ground location also using bi-linear interpolation. The elevation and location are then used to project backwards through a model of the image-capturing device 32a or 32b to determine which of the pixels within displayed image 142 corresponds to the given location.

[0059] More particularly, and as an example, image display and analysis software 140 performs and/or calculates the geo-location of point 164 by superimposing and/or fitting tessellated ground plane 160 to at least a portion 166, such as, for example, a hill, of surface 31. It should be noted that only a small portion of tessellated ground plane 160 and facets 162a, 162b, 162c, etc., thereof is shown along the profile of portion 166 of surface 31. As discussed above, each of facets 162a, 162b, 162c, etc., are defined by four vertices, each of which have respective elevations, and each of the facets have respective pitches and slopes. The specific position of point 164 upon the plane/surface of the facet 162a, 162b, 162c, etc., within which point 164 (or its projection) lies is determined as described above.

[0060] Tessellated ground plane 160 is preferably created outside the operation of image display and measurement computer system 130 and image display and analysis software 140. Rather, tessellated ground plane 160 takes the form of a relatively simple data table or look-up table 168 stored within memory 132 of and/or accessible to image display and measurement computer system 130. The computing resources required to calculate the locations of all the vertices of the many facets of a typical ground plane do not necessarily have to reside within image display and measurement computer system 130. Thus, image display and measurement computer system 130 is compatible for use with and executable by a conventional personal computer without requiring additional computing resources.

[0061] Calculating tessellated ground plane 160 outside of image display and measurement computer system 130 enables virtually any level of detail to be incorporated into tessellated ground plane 160, i.e., the size and/or area covered by or corresponding to each of facets 162a, 162b, 162c, etc., can be as large or as small as desired, without significantly increasing the calculation time, slowing the operation of, nor significantly increasing the resources required by image display and measurement computer system 130 and/or image display and analysis software 140. Display and measurement computer system 130 can therefore be a relatively basic and uncomplicated computer system.

[0062] The size of facets 162a, 162b, 162c, etc., are uniform in size throughout a particular displayed image 142. For example, if displayed image 142 corresponds to an area that is approximately 750 feet wide in the foreground by approximately 900 feet deep, the image can be broken into facets that are approximately 50 square feet, thus yielding about 15 facets in width and 18 facets in depth. Alternatively, the size of facets 162a, 162b, 162c, etc., are uniform in terms of the number of pixels contained therein, i.e., each facet is the same number of pixels wide and the same number of pixels deep. Facets in the foreground of displayed image 142, where the pixel density is greatest, would therefore be dimensionally smaller than facets in the background of displayed image 142 where pixel density is lowest. Since it is desirable to take most measurements in the foreground of a displayed image where pixel density is greatest, creating facets that are uniform in terms of the number of pixels they contain has the advantage of providing more accurate measurements in the foreground of displayed image 142 relative to facets that are dimensionally uniform.

[0063] Another advantage of using pixels as a basis for defining the dimensions of facets 162a, 162b, 162c, etc., is that the location calculation (pixel location to ground location) is relatively simple. A user operates image display and measurement computer system 130 to select a pixel within a given facet, image display and analysis software 140 looks up the data for the facet corresponding to the selected pixel, the elevation of the selected pixel is calculated as discussed

above, and that elevation is used within the location calculation.

[0064] Generally, the method of capturing oblique images of the present invention divides an area of interest, such as, for example, a county, into sectors of generally uniform size, such as, for example, sectors that are approximately one square mile in area. This is done to facilitate the creation of a flight plan to capture oblique images covering every inch of the area of interest, and to organize and name the sectors and/or images thereof for easy reference, storage and retrieval (a process known in the art as "sectorization"). Because the edges of any geographic area of interest, such as a county, rarely falls on even square mile boundaries, the method of capturing oblique images of the present invention provides more sectors than there are square miles in the area of interest — how many more depends largely on the length of the county borders as well as how straight or jagged they are. Typically, you can expect one extra sector for every two to three miles of border. So if a county or other area of interest is roughly 20 miles by 35 miles, or 700 square miles, the area will be divided into approximately from 740 to 780 sectors.

[0065] The method of capturing oblique images of the present invention, in general, captures the oblique images from at least two compass directions, and provides full coverage of the area of interest from at least those two compass directions. Referring now to Figs. 7 and 8, a first embodiment of a method for capturing oblique images of the present invention is shown. For sake of clarity, Fig. 7 and 8 is based on a system having only one image-capturing device. However, it is to be understood that two or more image-capturing devices can be used.

[0066] The image-capturing device captures one or more oblique images during each pass over area 200. The image-capturing device, as discussed above, is aimed at an angle over area 200 to capture oblique images thereof. Area 200 is traversed in a back-and-forth pattern, similar to the way a lawn is mowed, by the image-carrying device and/or the platform to ensure double coverage of area 200.

[0067] More particularly, area 200 is traversed by image-carrying device 32 and/or platform 20 following a first path 202 to thereby capture oblique images of portions 202a, 202b, and 202c of area 200. Area 200 is then traversed by image-carrying device 32 and/or platform 20 following a second path 204 that is parallel and spaced apart from, and in an opposite direction to, i.e., 180° (one-hundred and eighty degrees) from, first path 202, to thereby capture oblique images of portions 204a, 204b, 204c of area 200. By comparing Figs. 7 and 8, it is seen that a portion 207 (Fig. 8) of area 200 is covered by images 202a-c captured from a first direction or perspective, and by images 204a-c captured from a second direction or perspective. As such, the middle portion of area 200 is 100% (one-hundred percent) double covered. The above-described pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 202 and 204 is repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from each other as dictated by the size of area 200, and in the same direction as paths 202 and 204 to thereby one-hundred percent double cover area 200 from those perspectives/directions.

[0068] If desired, and for enhanced detail, area 200 is covered by two additional opposing and parallel third and fourth paths 206 and 208, respectively, that are perpendicular to paths 202 and 204 as shown in Figs. 9 and 10. Area 200 is therefore traversed by image-carrying device 32 and/or platform 20 following third path 206 to capture oblique images of portions 206a, 206b and 206c of area 200, and is then traversed along fourth path 208 that is parallel, spaced apart from, and opposite to third path 206 to capture oblique images of portions 208a, 208b and 208c of area 200. This pattern of traversing or passing over area 200 along opposing paths that are parallel to paths 206 and 208 is similarly repeated until the entirety of area 200 is completely covered by at least one oblique image captured from paths that are parallel to, spaced apart from as dictated by the size of area 200, and in the same direction as paths 206 and 208 to thereby one-hundred percent double cover area 200 from those directions/perspectives.

[0069] As described above, image-carrying device 32 and/or platform 20, traverses or passes over area 200 along a predetermined path. However, it is to be understood that image-carrying device and/or platform 20 do not necessarily pass or traverse directly over area 200 but rather may pass or traverse an area adjacent, proximate to, or even somewhat removed from, area 200 in order to ensure that the portion of area 200 that is being imaged falls within the image-capture field of the image-capturing device. Path 202, as shown in Fig. 7, is such a path that does not pass directly over area 200 but yet captures oblique images thereof.

[0070] The present invention is capable of capturing images at various levels of resolution or ground sample distances. A first level of detail, hereinafter referred to as a community level, has a ground sample distance of, for example, approximately two-feet per pixel. For orthogonal community-level images, the ground sample distance remains substantially constant throughout the image. Orthogonal community-level images are captured with sufficient overlap to provide stereo pair coverage. For oblique community-level images, the ground sample distance varies from, for example, approximately one-foot per pixel in the foreground of the image to approximately two-feet per pixel in the mid-ground of the image, and to approximately four-feet per pixel in the background of the image. Oblique community-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction captured. Approximately ten oblique community-level images are captured per sector.

[0071] A second level of detail, hereinafter referred to as a neighborhood level, is significantly more detailed than the community-level images. Neighborhood-level images have a ground sample distance of, for example, approximately six-inches per pixel. For orthogonal neighborhood-level images, the ground sample distance remains substantially con-

stant. Oblique neighborhood-level images have a ground sample distance of, for example, from approximately four-inches per pixel in the foreground of the image to approximately six-inches per pixel in the mid-ground of the image, and to approximately ten-inches per pixel in the background of the image. Oblique neighborhood-level images are captured with sufficient overlap such that each area of interest is typically covered by at least two oblique images from each compass direction captured, and such that opposing compass directions provide 100% overlap with each other. Approximately one hundred (100) oblique area images are captured per sector.

[0072] It should be particularly noted that capturing oblique community and/or neighborhood-level images from all four compass directions ensures that every point in the image will appear in the foreground or lower portion of at least one of the captured oblique images, where ground sample distance is lowest and image detail is greatest.

[0073] In the embodiment shown, image-capturing and geo-locating system 30 includes a gyroscope, compass and altimeter. However, it is to be understood that the image-capturing and geo-locating system of the present invention can be alternately configured, such as, for example, to derive and/or calculate altitude, pitch, roll and yaw, and compass heading from the GPS and INU signals/data, thereby rendering one or more of the gyroscope, compass and altimeter unnecessary. In fact,

[0074] In the embodiment shown, image-capturing devices are at an equal angle of declination relative to a horizontal plane. However, it is to be understood that the declination angles of the image-capturing devices do not have to be equal.

[0075] In the embodiment shown, image-capturing computer system executes image and data acquiring software that issues a common or single image-capture signal to the image-capturing devices to thereby cause those devices to acquire or capture an image. However, it is to be understood that the present invention can be alternately configured to separately cause the image-capturing devices to capture images at different instants and/or at different intervals.

[0076] In the embodiment shown, the method of the present invention captures oblique images to provide double coverage of an area of interest from paths/perspectives that are substantially opposite to each other, i.e., 180° (one-hundred and eighty degrees) relative to each other. However, it is to be understood that the method of the present invention can be alternately configured to provide double coverage from paths/perspectives that are generally and/or substantially perpendicular relative to each other.

[0077] While the present invention has been described as having a preferred design, the invention can be further modified within the spirit and scope of this disclosure. This disclosure is therefore intended to encompass any equivalents to the structures and elements disclosed herein. Further, this disclosure is intended to encompass any variations, uses, or adaptations of the present invention that use the general principles disclosed herein. Moreover, this disclosure is intended to encompass any departures from the subject matter disclosed that come within the known or customary practice in the pertinent art and which fall within the limits of the appended claims.

Claims

1. A method of capturing oblique images of an area of interest with an image-capturing device carried by a platform, each oblique image captured at a respective image-capturing event, said method comprising:

   subdividing the area of interest into a plurality of sectors;
   guiding the platform along a first path to thereby target one or more target sectors with the image-capturing device;
   capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a first perspective; guiding the platform along a second path to thereby target said target sectors;
   capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a second perspective; repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said first and second paths and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from each of said first and second perspectives; and
   recording positional data indicative of a geo-location of said image-capturing device at each image-capturing event.

2. The method of claim 1, wherein said second path is substantially parallel relative to and 180° from said first path.

3. The method of claim 1, wherein said second path is also spaced apart from said first path.

4. The method of claim 1, comprising the further steps of:

   guiding the platform along a third path to thereby target one or more target sectors with the image-capturing

device, said third path being substantially perpendicular to said first and second paths;
capturing with the image-capturing device one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a third perspective; and
repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said third path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said third perspective.

5. The method of claim 4, comprising the further steps of:

guiding the platform along a fourth path to thereby target one or more target sectors with the image-capturing device, said fourth path being substantially parallel with said third path and 180° from said third path;
capturing with the image-capturing device one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a fourth perspective; and
repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said fourth path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said fourth perspective.

6. The method of claim 5, wherein said fourth path is also spaced apart from said third path.

7. A computerized method for taking measurements from an oblique image displayed on a computer system, at least one input device connected to said computer system, an image data file accessible by said computer system, said image data file including captured images and positional data corresponding thereto, said computerized method comprising:

placing the computer system into a desired one of a plurality of measurement modes, the desired measurement mode configured for calculating a desired measurement;
selecting a starting point on the displayed image;
retrieving the positional data corresponding to said starting point;
selecting an end point on the displayed image;
retrieving the positional data corresponding to said end point; and
calculating the desired measurement dependent at least in part upon said positional data of said starting and end points.

8. The method of claim 7, comprising the further steps of:

selecting one or more intermediate points on said displayed image; and
retrieving the positional data corresponding to said intermediate points.

9. The method of claim 7, wherein said plurality of measurement modes comprise a distance measuring mode calculating a distance between two or more selected points, a height measuring mode calculating a height difference between two or more selected points, a relative elevation measurement mode calculating the difference in elevation of two or more selected points, and an area measurement mode calculating the area encompassed by at least three points.

10. A computerized method for taking measurements within a displayed oblique image, comprising:

selecting with an input device a starting point and an end point on the displayed image; retrieving from a data file positional data corresponding to said starting point and said end point;
referencing a ground plane data file corresponding to a tessellated ground plane having a plurality of facets, each of said facets having a respective pitch and slope, said tessellated ground plane closely matching a terrain of said displayed oblique image;
connecting said starting and end points with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and
calculating the linear distance along said line segments between said starting and end points thereby taking into account said pitch and slope of said facets.

11. The method of claim 10, wherein said tessellated ground plane is superimposed upon said displayed oblique image.

12. The method of claim 10, comprising the further steps of:

selecting with an input device one or more intermediate points on the displayed image; retrieving from said data file positional data corresponding to said one or more intermediate points; and
connecting adjacent intermediate points to each other, and connecting said starting and end points to adjacent intermediate points, with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and
calculating the distance along said line segments between said starting and end points.

13. The method of claim 10, wherein said plurality of facets each correspond to equal areas of said displayed oblique image.

14. The method of claim 10, wherein said plurality of facets each includes an equal number of pixels of said displayed oblique image.

15. A computerized method for taking measurements within a displayed oblique image, comprising:

displaying an oblique captured image with positional data;
selecting with an input device two points including a starting point and an end point on the displayed image;
calculating the geo-locations of the selected points in the displayed oblique image based at least in part the upon positional data of the displayed oblique image;
referencing a tessellated ground plane representing at least a portion of the terrain depicted within said captured oblique images, said tessellated ground plane comprising a plurality of interconnected facets, each of said facets having a respective pitch and slope, said tessellated ground plane comprising a plurality of vertices, each vertex having an elevation and defining a corner of a facet, two of said vertices shared by each of said facets;
identifying which of said plurality of facets corresponds to selected points on said displayed oblique image and calculating elevations of said selected points dependent at least in part upon the elevation of the vertices of the facet corresponding to the selected point; and
calculating the distance between the selected points.

16. The method of claim 15 comprising the further step of superimposing an image of the upon said displayed oblique image.

17. The method of claim 15, comprising the further steps of:

selecting with an input device one or more intermediate points on the displayed image; retrieving from said data file positional data corresponding to said one or more intermediate points;
connecting adjacent intermediate points to each other;
connecting said starting and end points to adjacent intermediate points, with line segments, said line segments conforming to said pitch and slope of said facets to thereby follow said terrain; and
calculating the distance along said line segments between said starting and end points.

18. The method of claim 15, wherein said plurality of facets each correspond to equal areas of said displayed oblique image.

19. The method of claim 15, wherein said plurality of facets each includes an equal number of pixels of said displayed oblique image.

20. The method of claim 15, comprising the further steps of:

selecting one or more intermediate points on said displayed image; and retrieving the positional data corresponding to said intermediate points.

21. The method of claim 15 wherein the step of calculating distance comprises measuring the different in elevation between two selected points or measuring area defined by at least three points.

22. The method of claim 15 comprising the further steps of capturing oblique images of an area of interest with an image-capturing device carried by a platform, each oblique image captured at a respective image-capturing event, said

method comprising:

subdividing the area of interest into a plurality of sectors;
guiding the platform along a first path to thereby target one or more target sectors with the image-capturing device;
capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a first perspective;
guiding the platform along a second path to thereby target said target sectors; capturing with the image-capturing device one or more oblique images to thereby cover an entirety of each said target sector in oblique images captured from a second perspective;
repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said first and second paths and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from each of said first and second perspectives; and
recording positional data indicative of a geo-location of said image-capturing device at each image-capturing event.

23. The method of claim 22, wherein said second path is substantially parallel relative to and 180° from said first path;

24. The method of claim 23, wherein said second path is also spaced apart from said first path.

25. The method of claim 22, comprising the further steps of: guiding the platform along a third path to thereby target one or more target sectors with the image-capturing device, said third path being substantially perpendicular to said first and second paths;

capturing with the image-capturing device one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a third perspective; and
repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said third path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said third perspective.

26. The method of claim 25, comprising the further steps of:

guiding the platform along a fourth path to thereby target one or more target sectors with the image-capturing device, said fourth path being substantially parallel with said third path and 180° from said third path;
capturing with the image-capturing device one or more oblique images to thereby capture an entirety of each said target sector in oblique images captured from a fourth perspective; and
repeating said guiding and capturing steps along paths substantially parallel to and spaced apart from said fourth path and capturing one or more oblique images to thereby cover an entirety of each of said plurality of sectors in oblique images captured from said fourth perspective.

27. The method of claim 26, wherein said fourth path is also spaced apart from said third path.

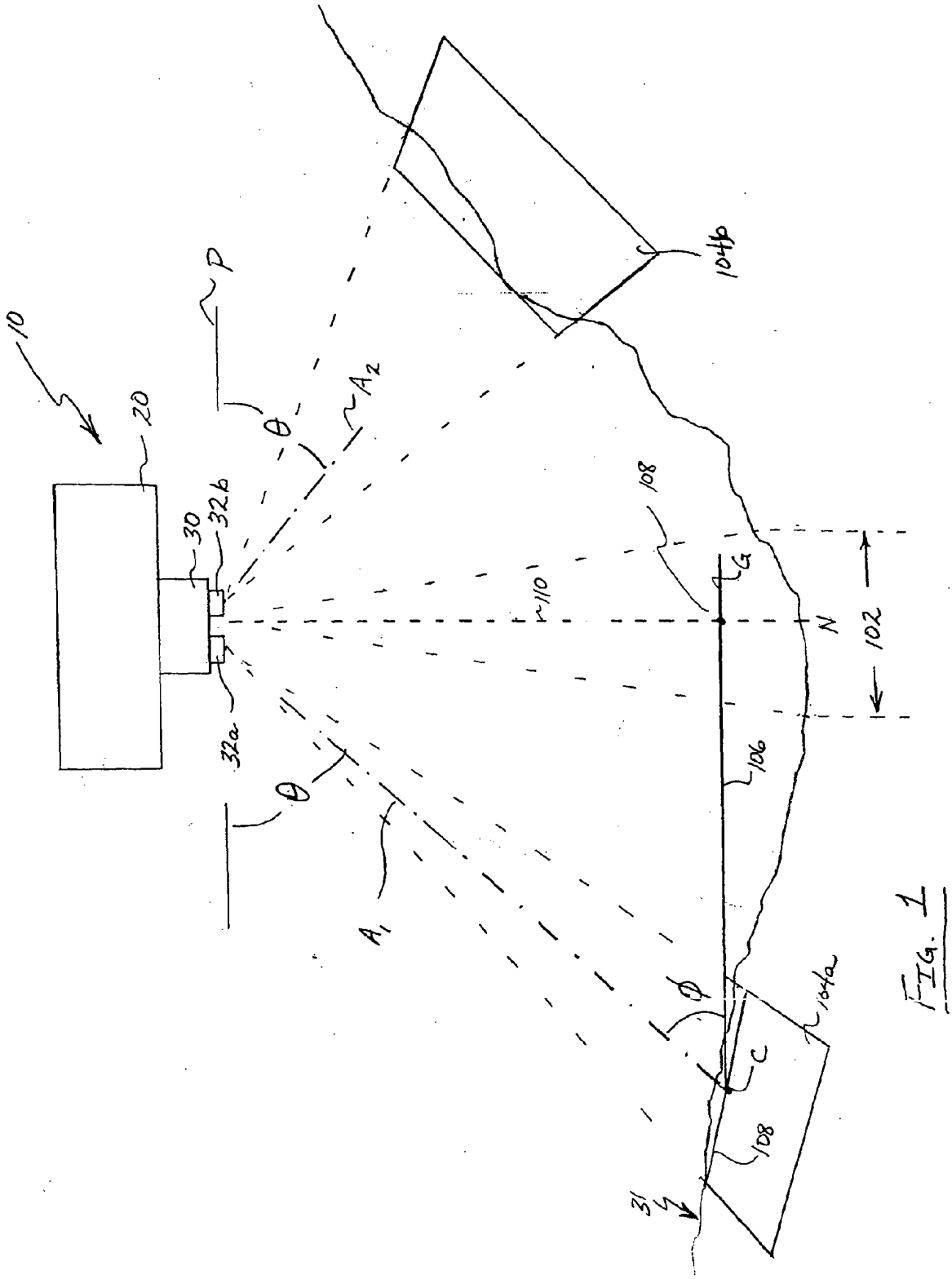


FIG. 1

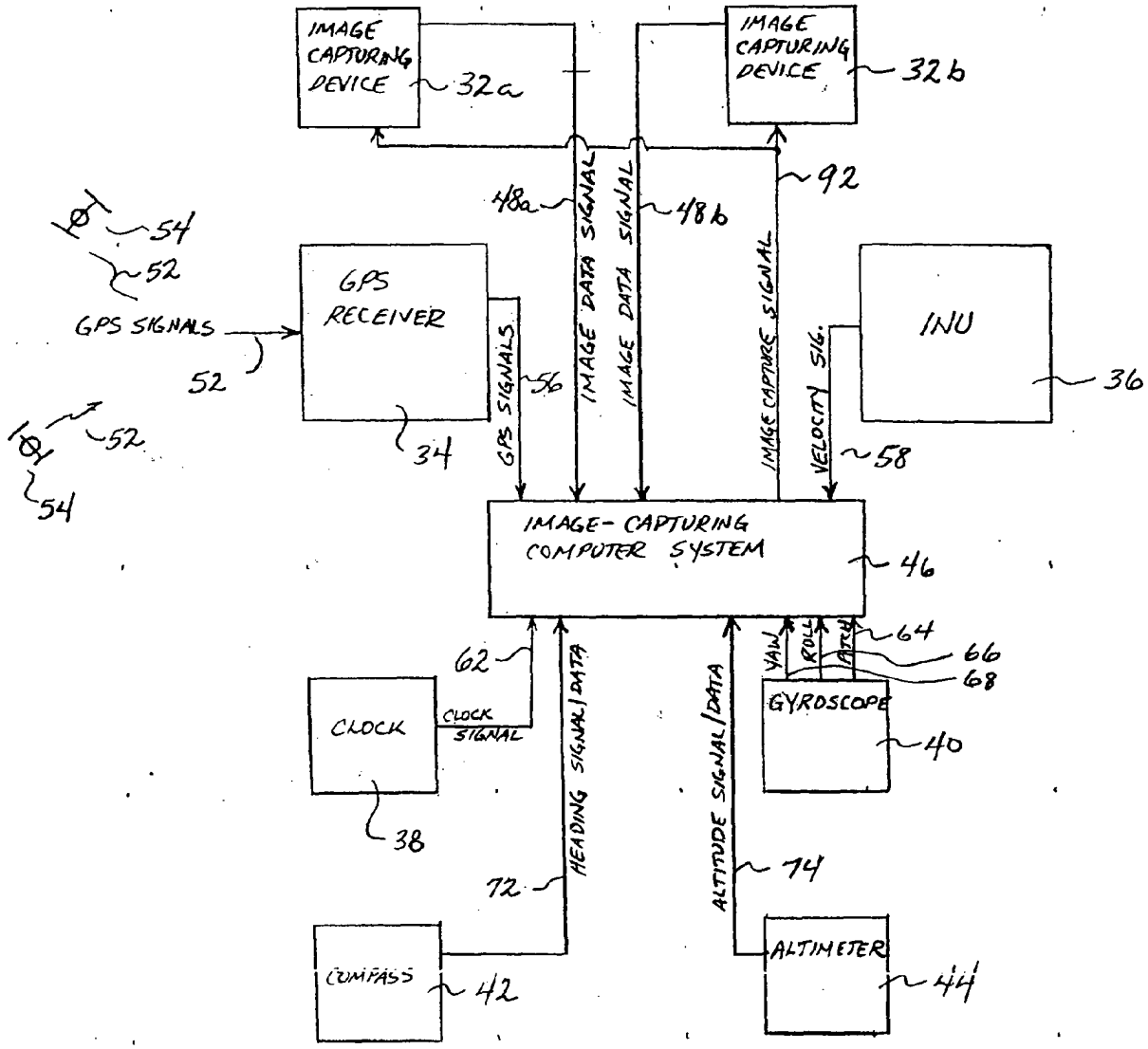

IMAGE CAPTURING DEVICE
32a
IMAGE CAPTURING DEVICE
32b
92
48a
48b
IMAGE DATA SIGNAL
IMAGE DATA SIGNAL
IMAGE CAPTURE SIGNAL
54
52
GPS SIGNALS
52
GPS RECEIVER
34
GPS SIGNALS
56
INU
36
VELOCITY SIG.
58
52
54
IMAGE-CAPTURING COMPUTER SYSTEM
46
62
64
66
68
YAW
ROLL
PITCH
CLOCK
CLOCK SIGNAL
38
GYROSCOPE
40
HEADING SIGNAL/DATA
72
ALTITUDE SIGNAL/DATA
74
COMPASS
42
ALTIMETER
44

FIG. 2

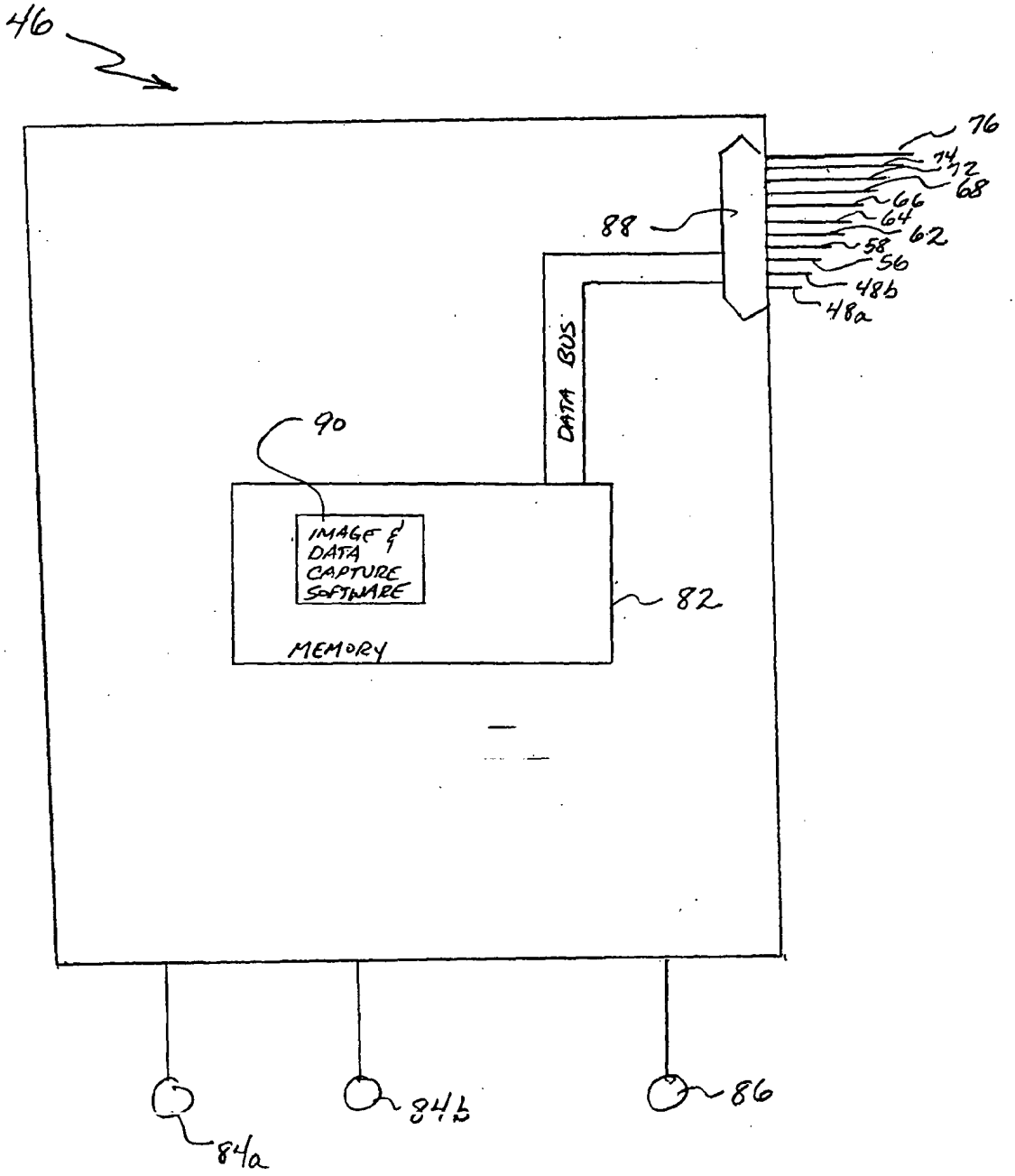

46
76
74
72
68
66
64
62
58
56
48b
48a
88
DATA BUS
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IMAGE & DATA CAPTURE SOFTWARE
MEMORY
82
84a
84b
86

FIG. 3

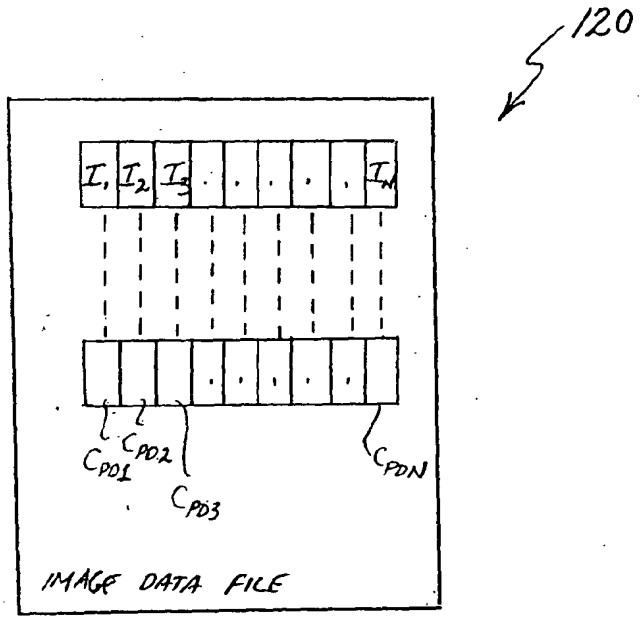


FIG. 4

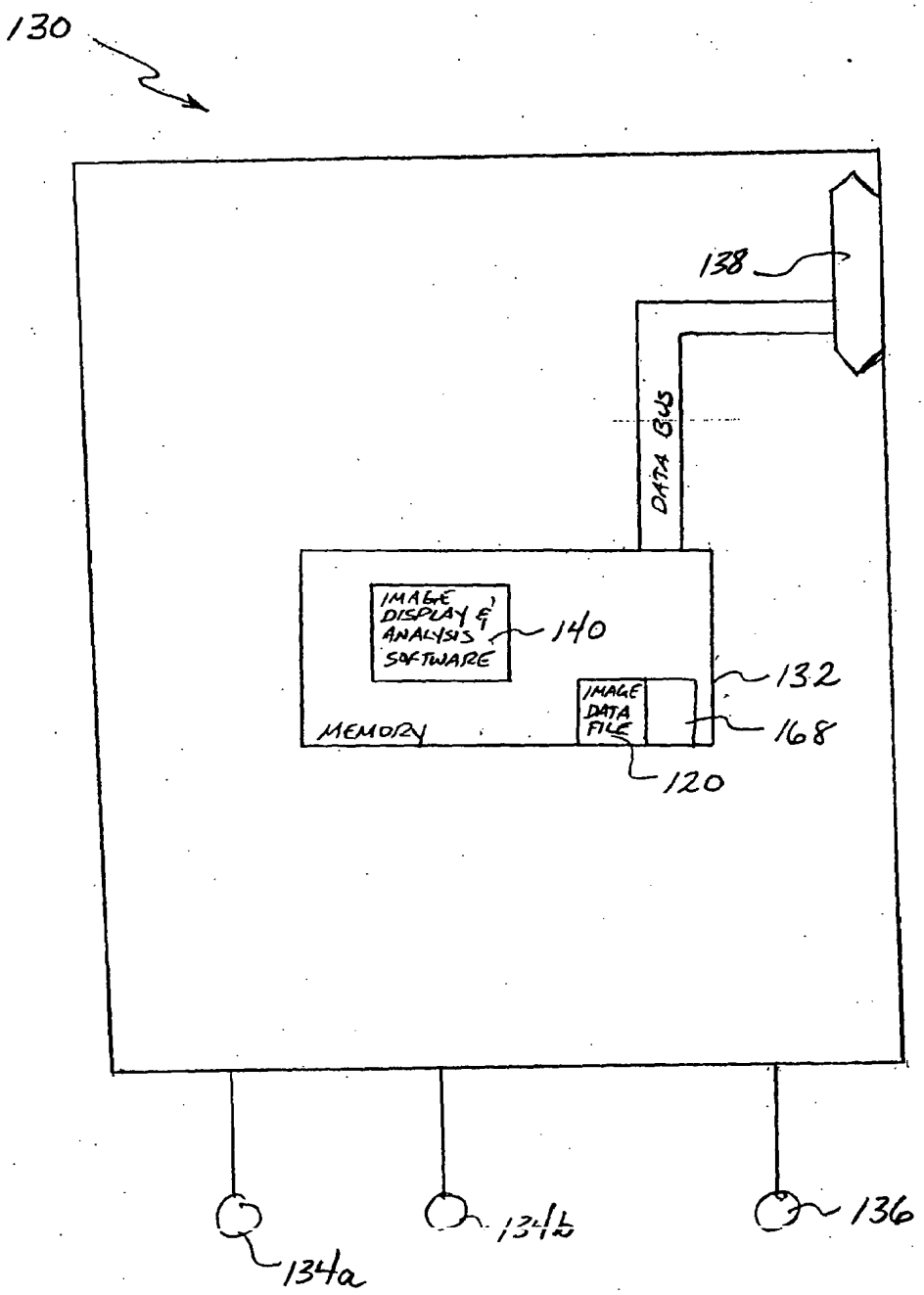

130
138
DATA BUS
IMAGE DISPLAY & ANALYSIS SOFTWARE
140
132
IMAGE DATA FILE
168
MEMORY
120
134a
134b
136

FIG. 5

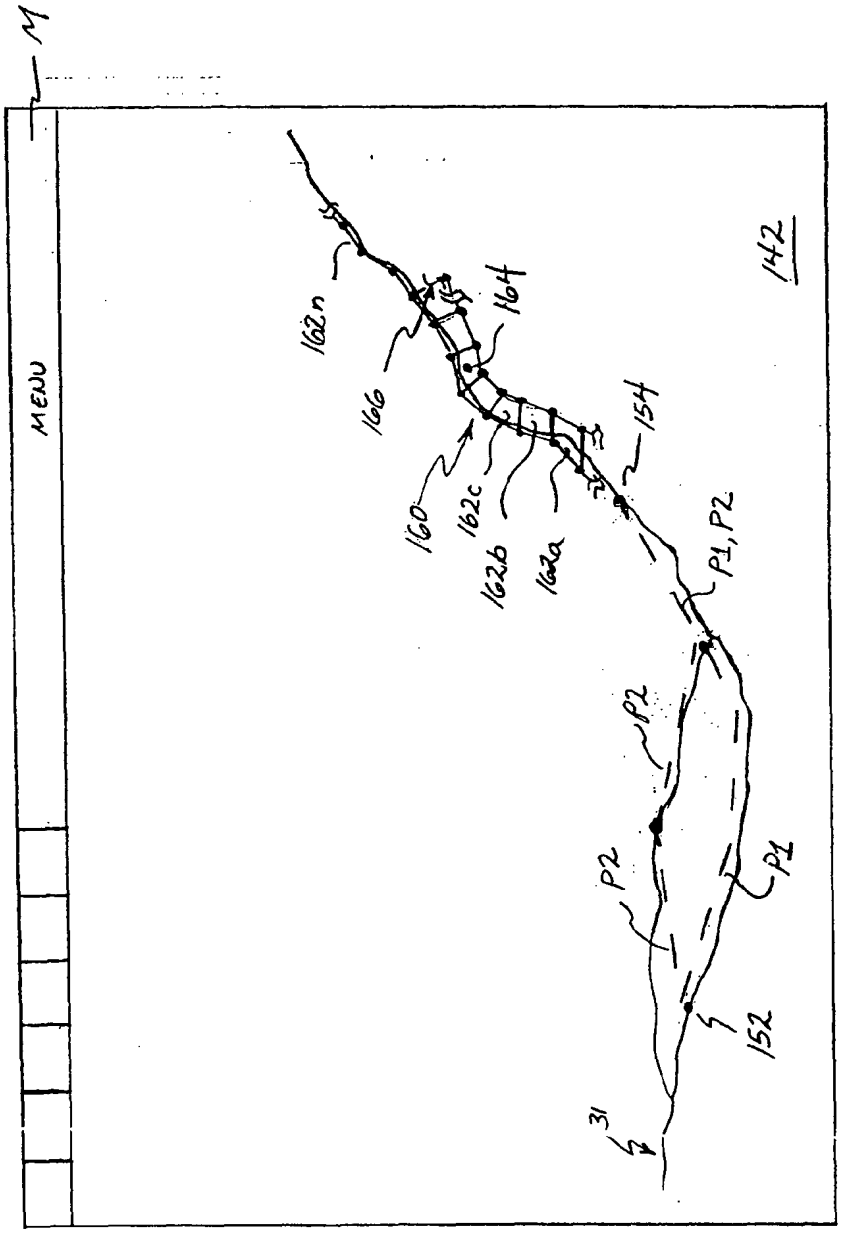

M
MENU
142
162n
164
166
160
162c
162b
162a
154
P1, P2
P2
P2
P1
152
31

FIG. 6

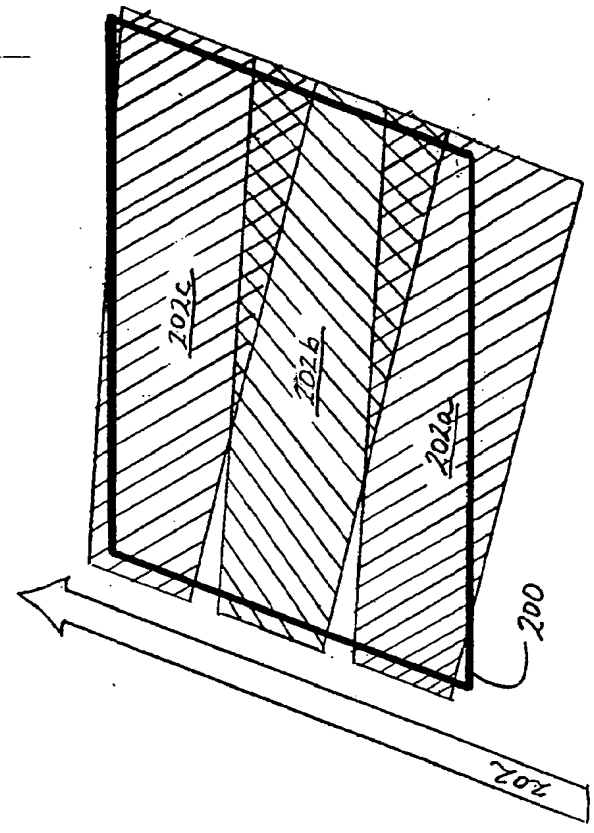


FIG. 1

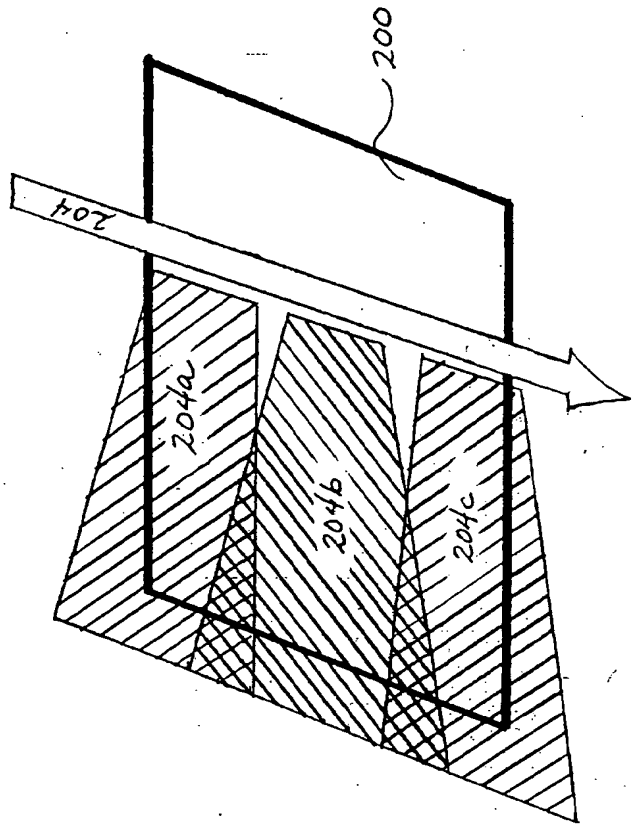


FIG. 8

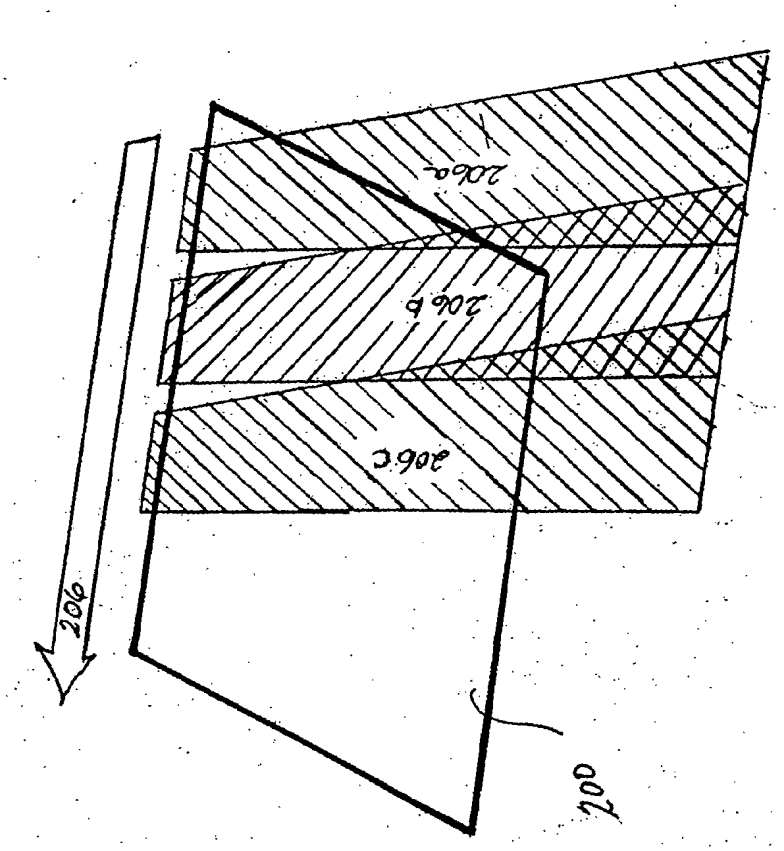


FIG. 9

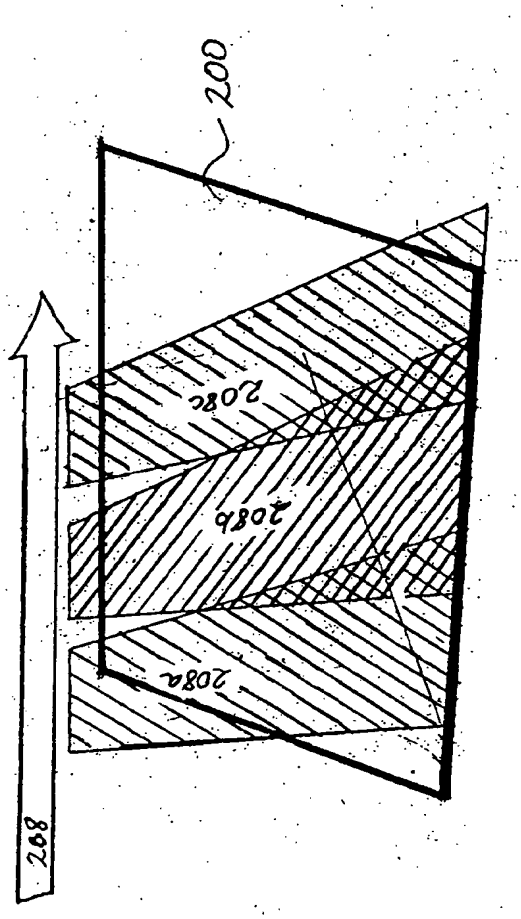


FIG. 10

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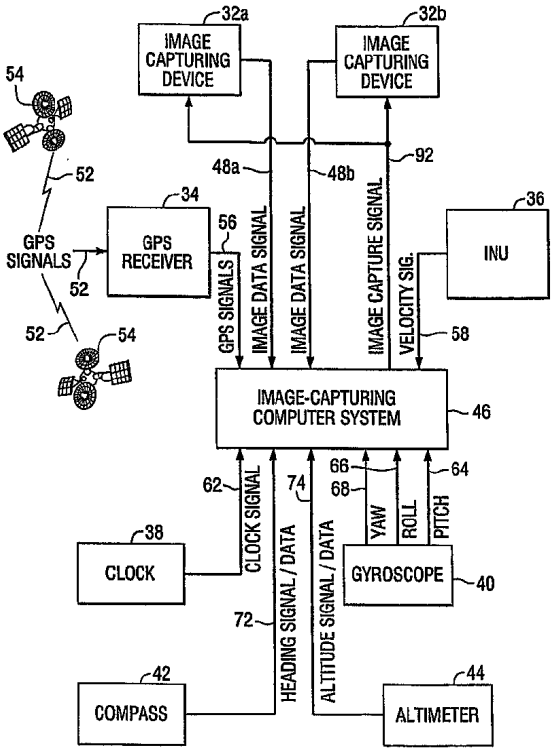
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(54) Titre : SYSTEME DE LOCALISATION GEOGRAPHIQUE ET DE MESURE A PARTIR D'IMAGES OBLIQUES
(54) Title: OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM



(57) Abrégé/Abstract:
A computerized system (46) for displaying, geolocating, and taking measurements from captured oblique images (32a and 32b) includes a data file accessible by the computer system. The data file includes a plurality of image files corresponding to a plurality of captured oblique images (32a and 32b), and positional data corresponding to the images. Image display and analysis software is executed by the system (46) for reading the data file and displaying at least a portion of the captured oblique images. The software retrieves the positional data for one or more user-selected points on the displayed image, and calculates a separation distance between any two or more selected points. The separation distance calculation is user-selectable to determine various parameters including linear distance between, area encompassed within, relative elevation of, and height difference between selected points.

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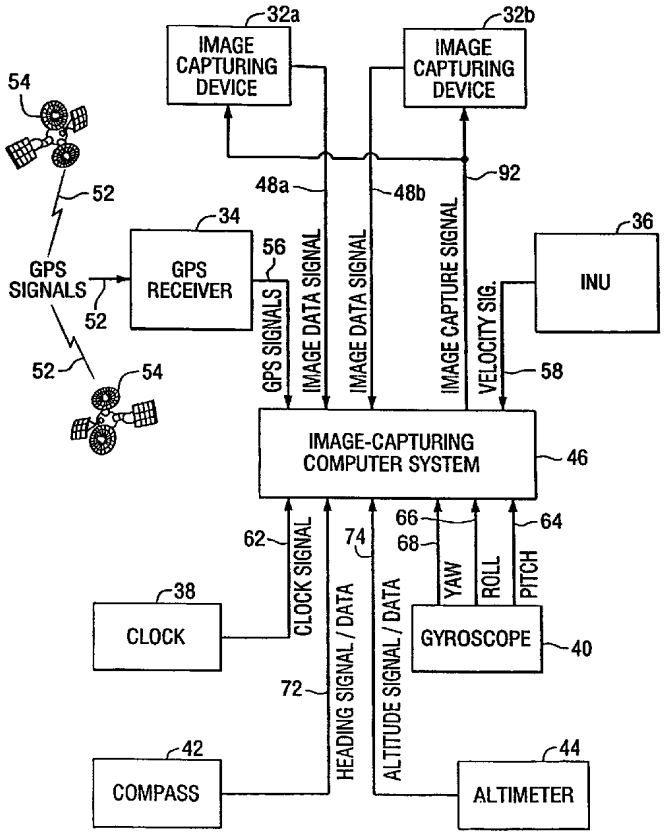
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[Continued on next page]

(54) Title: OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM



(57) Abstract: A computerized system (46) for displaying, geolocating, and taking measurements from captured oblique images (32a and 32b) includes a data file accessible by the computer system. The data file includes a plurality of image files corresponding to a plurality of captured oblique images (32a and 32b), and positional data corresponding to the images. Image display and analysis software is executed by the system (46) for reading the data file and displaying at least a portion of the captured oblique images. The software retrieves the positional data for one or more user-selected points on the displayed image, and calculates a separation distance between any two or more selected points. The separation distance calculation is user-selectable to determine various parameters including linear distance between, area encompassed within, relative elevation of, and height difference between selected points.

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OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/425,275, filed November 8, 2002.

TECHNICAL FIELD

The present invention relates to photogrammetry. More particularly, the present invention relates to a method and apparatus for capturing oblique images and for measuring the objects and distances between the objects depicted therein.

BACKGROUND

Photogrammetry is the science of making measurements of and between objects depicted within photographs, especially aerial photographs. Generally, photogrammetry involves taking images of terrestrial features and deriving data therefrom, such as, for example, data indicating relative distances between and sizes of objects within the images. Photogrammetry may also involve coupling the photographs with other data, such as data representative of latitude and longitude. In effect, the image is overlaid and conformed to a particular spatial coordinate system.

Conventional photogrammetry involves the capture and/or acquisition of orthogonal images. The image-capturing device, such as a camera or sensor, is

orthogonal images. The image-capturing device, such as a camera or sensor, is carried by a vehicle or platform, such as an airplane or satellite, and is aimed at a nadir point that is directly below and/or vertically downward from that platform. The point or pixel in the image that corresponds to the nadir point is the only point/pixel that is truly orthogonal to the image-capturing device. All other points or pixels in the image are actually oblique relative to the image-capturing device. As the points or pixels become increasingly distant from the nadir point they become increasingly oblique relative to the image-capturing device and the ground sample distance (i.e., the surface area corresponding to or covered by each pixel) also increases. Such obliqueness in an orthogonal image causes features in the image to be distorted, especially images relatively distant from the nadir point.

Such distortion is removed, or compensated for, by the process of ortho-rectification which, in essence, removes the obliqueness from the orthogonal image by fitting or warping each pixel of an orthogonal image onto an orthometric grid or coordinate system. The process of ortho-rectification creates an image wherein all pixels have the same ground sample distance and are oriented to the north. Thus, any point on an ortho-rectified image can be located using an X, Y coordinate system and, so long as the image scale is known, the length and width of terrestrial features as well as the relative distance between those features can be calculated.

Although the process of ortho-rectification compensates to a degree for oblique distortions in an orthogonal image, it introduces other undesirable distortions and/or