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

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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.

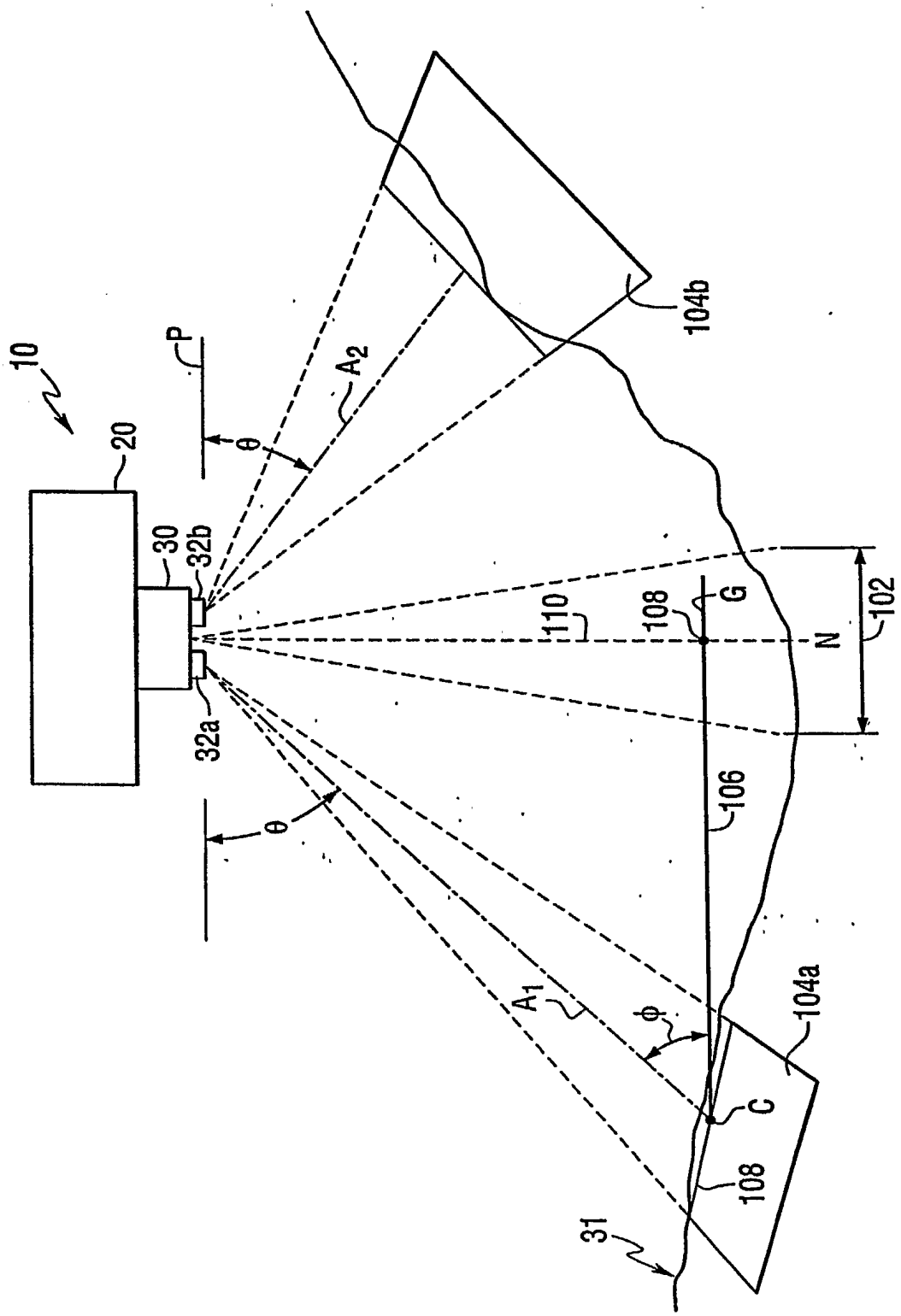


FIG. 1

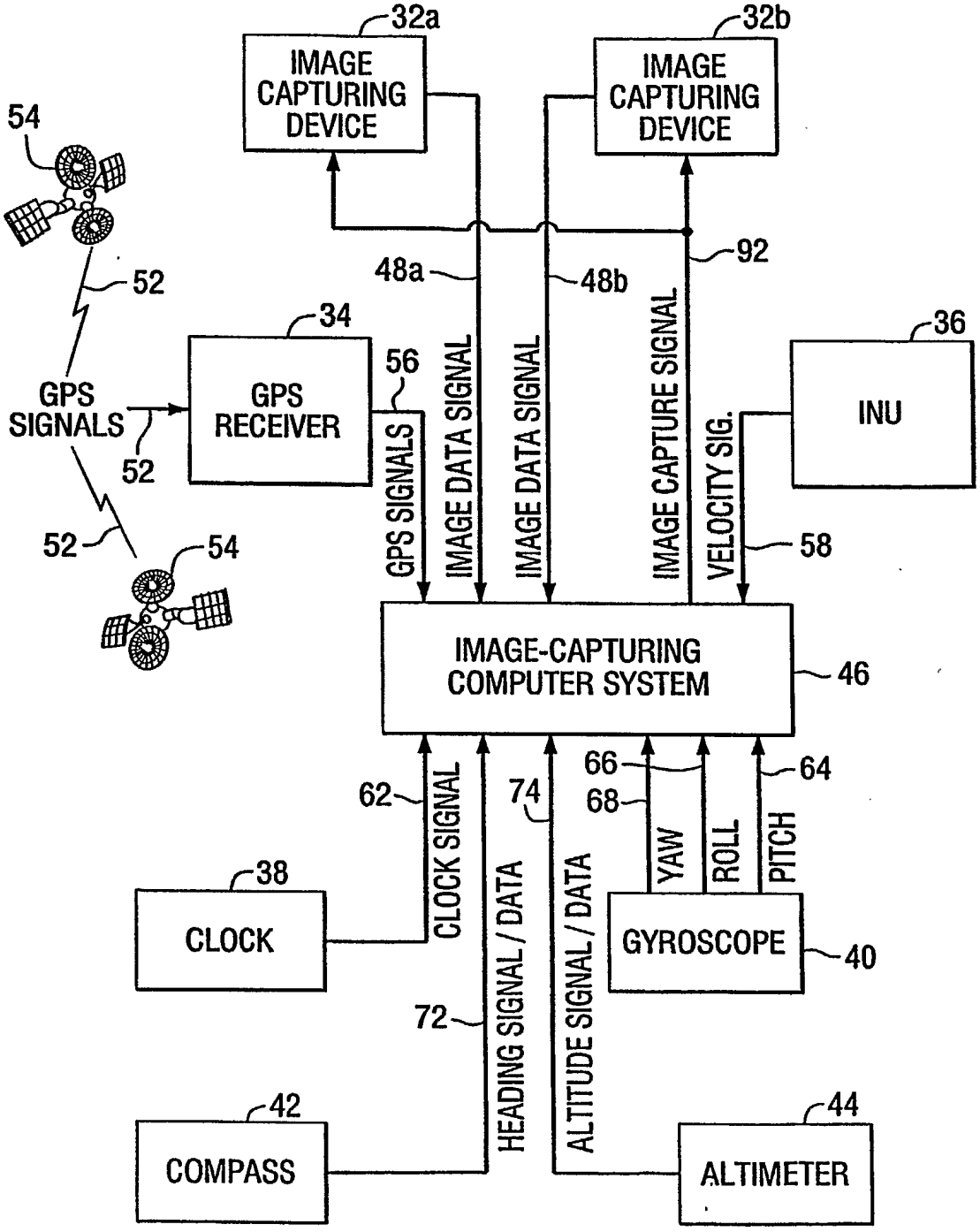

32a
IMAGE CAPTURING DEVICE
32b
IMAGE CAPTURING DEVICE
54
52
GPS SIGNALS
52
34
GPS RECEIVER
56
GPS SIGNALS
48a
IMAGE DATA SIGNAL
48b
IMAGE DATA SIGNAL
92
IMAGE CAPTURE SIGNAL
36
INU
VELOCITY SIG.
58
52
54
IMAGE-CAPTURING COMPUTER SYSTEM
46
62
CLOCK SIGNAL
74
HEADING SIGNAL / DATA
ALTITUDE SIGNAL / DATA
66
68
YAW
ROLL
PITCH
64
38
CLOCK
GYROSCOPE
40
72
42
COMPASS
44
ALTIMETER

FIG. 2

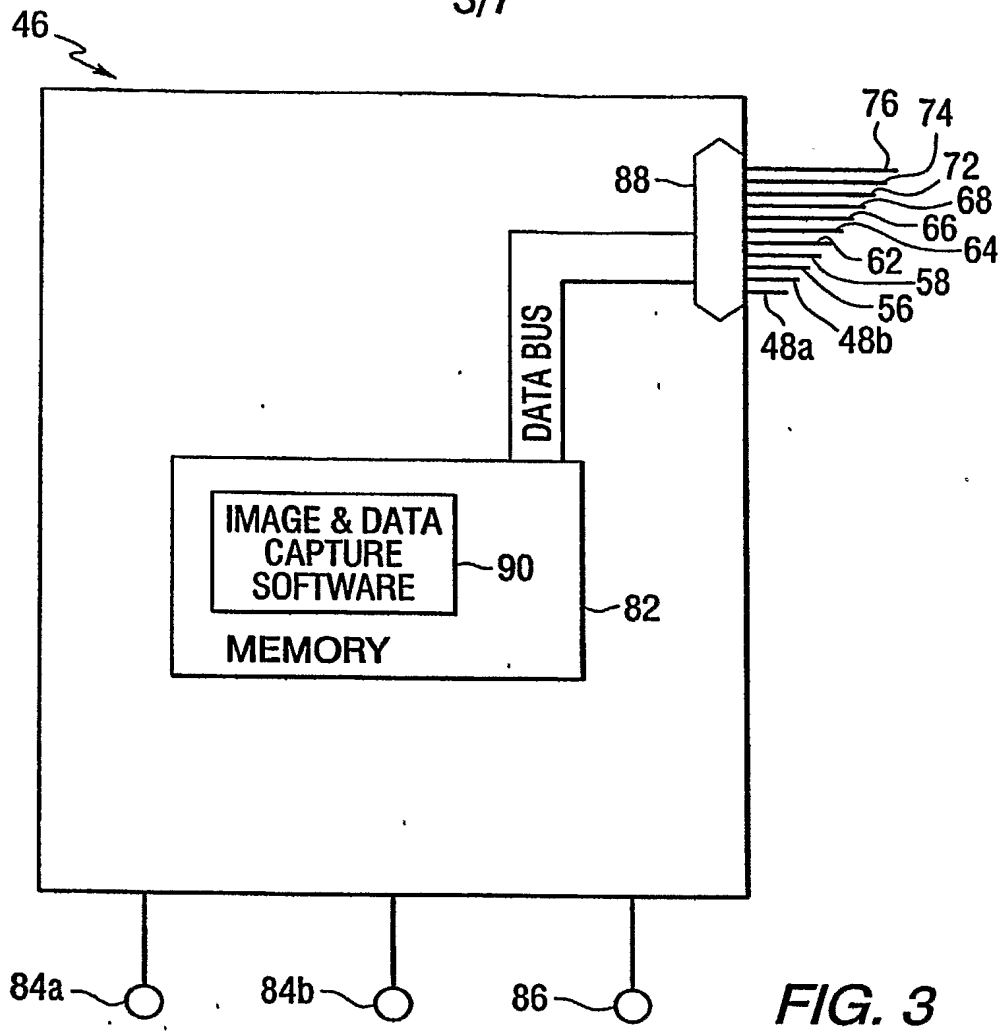

46
76
74
72
68
66
64
62
58
56
88
48a
48b
DATA BUS
IMAGE & DATA CAPTURE SOFTWARE
90
82
MEMORY
84a
84b
86

FIG. 3

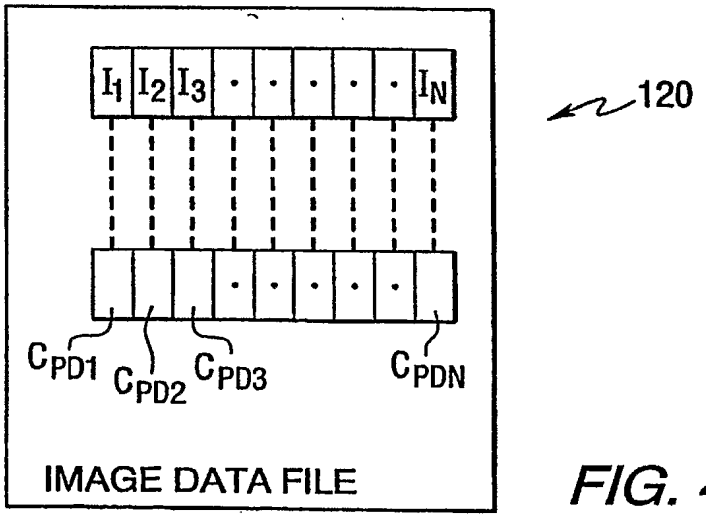

I_1 I_2 I_3 · · · · · I_N
120
C_{PD1} C_{PD2} C_{PD3} C_{PDN}
IMAGE DATA FILE

FIG. 4

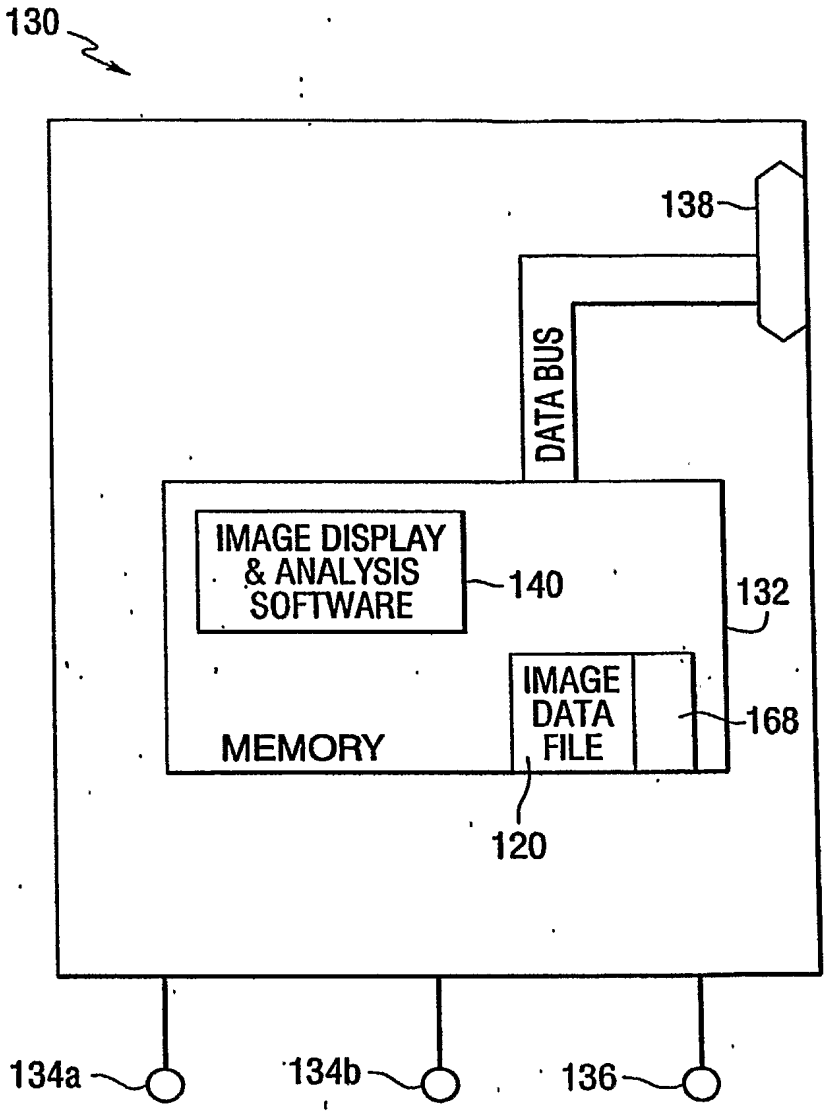

130
138
DATA BUS
IMAGE DISPLAY & ANALYSIS SOFTWARE
140
132
IMAGE DATA FILE
168
MEMORY
120
134a
134b
136

FIG. 5

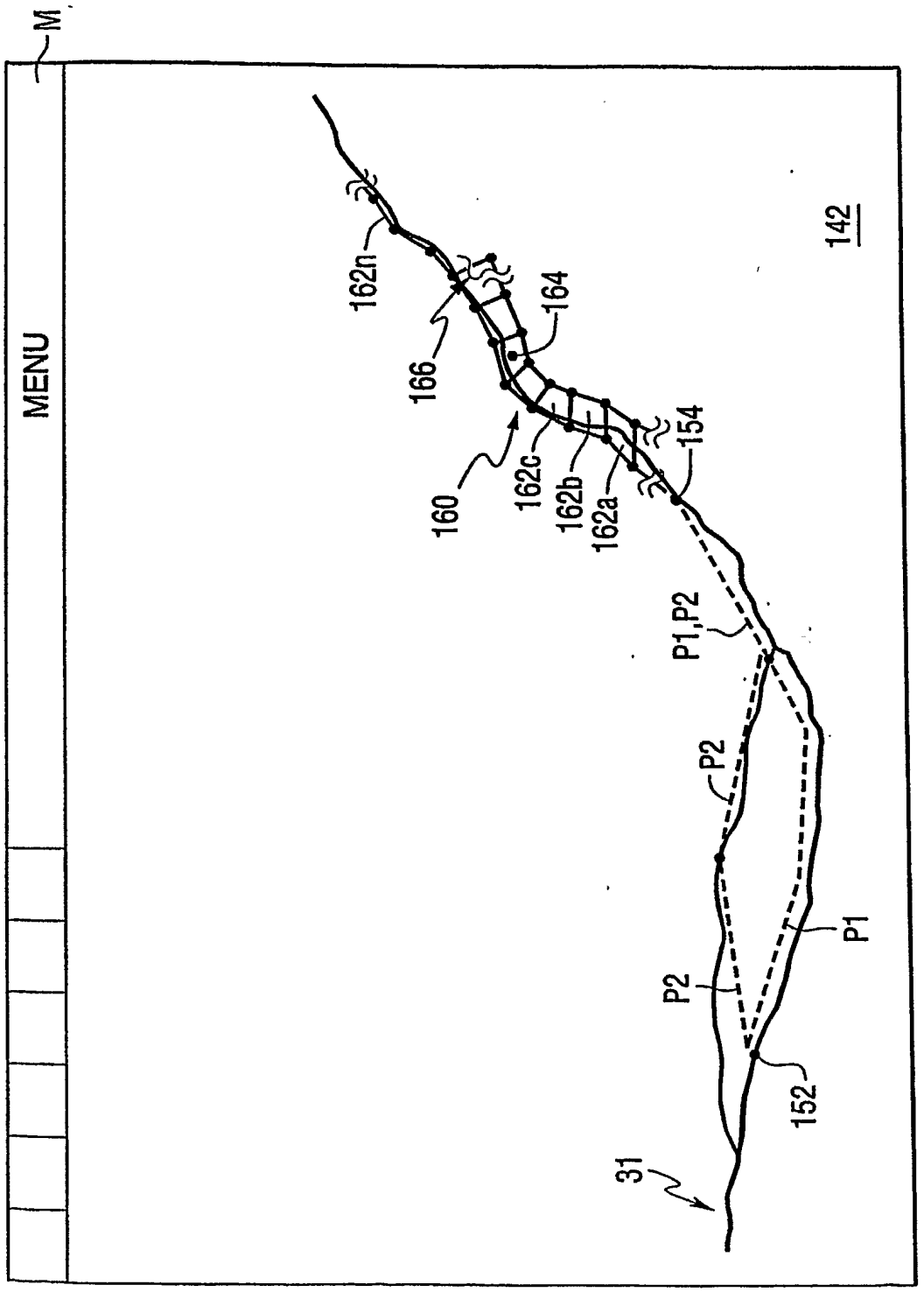

M
MENU
142
162n
164
166
160
162c
162b
162a
154
P1,P2
P2
P1
P2
152
31

FIG. 6

6/7

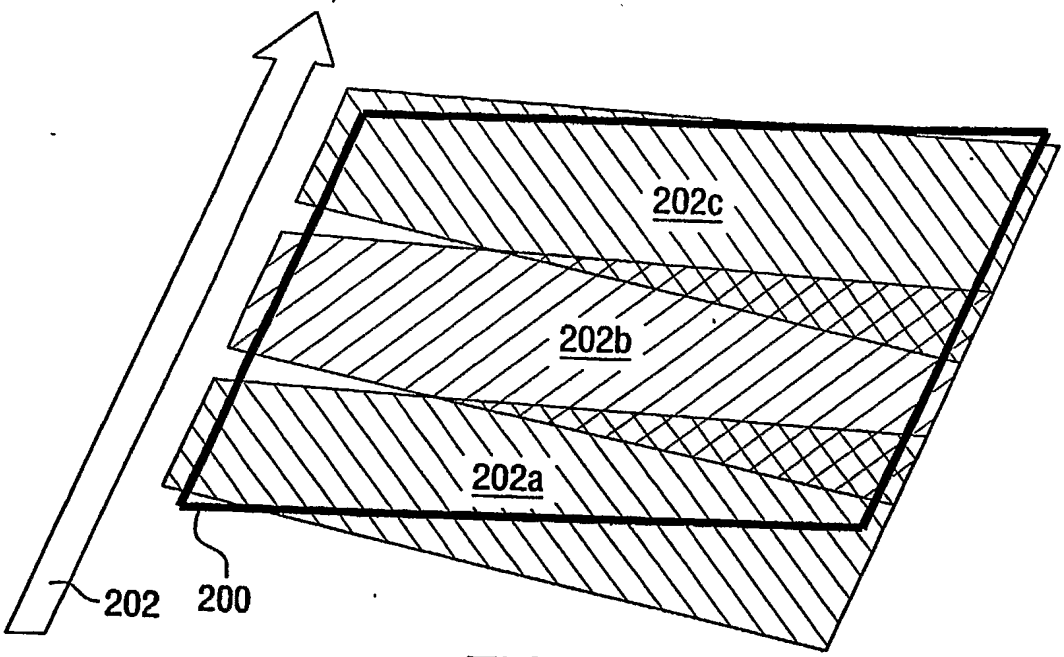


FIG. 7

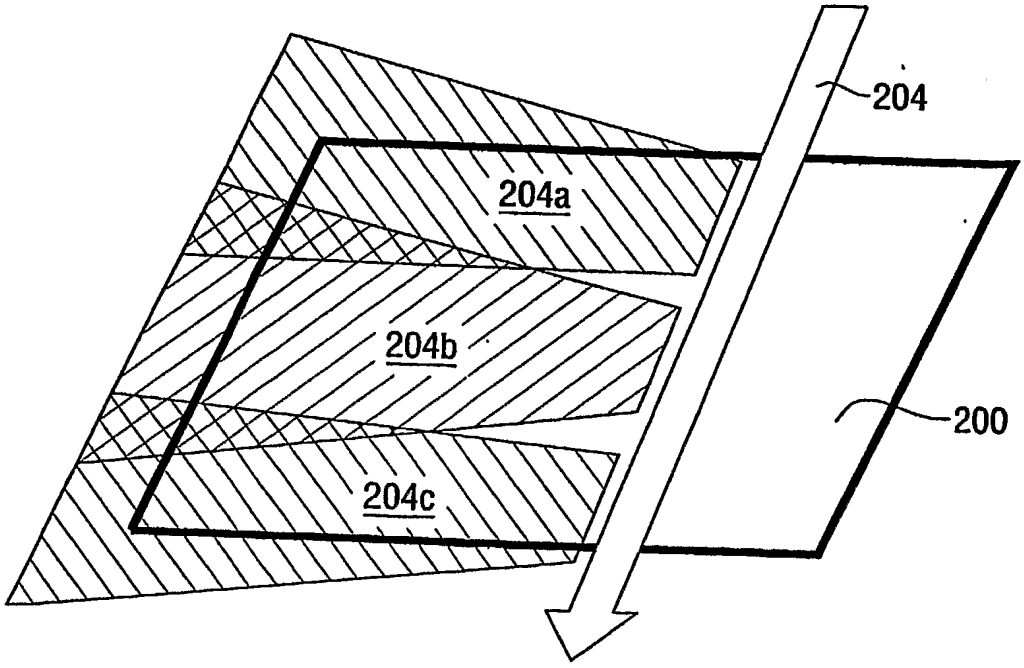


FIG. 8

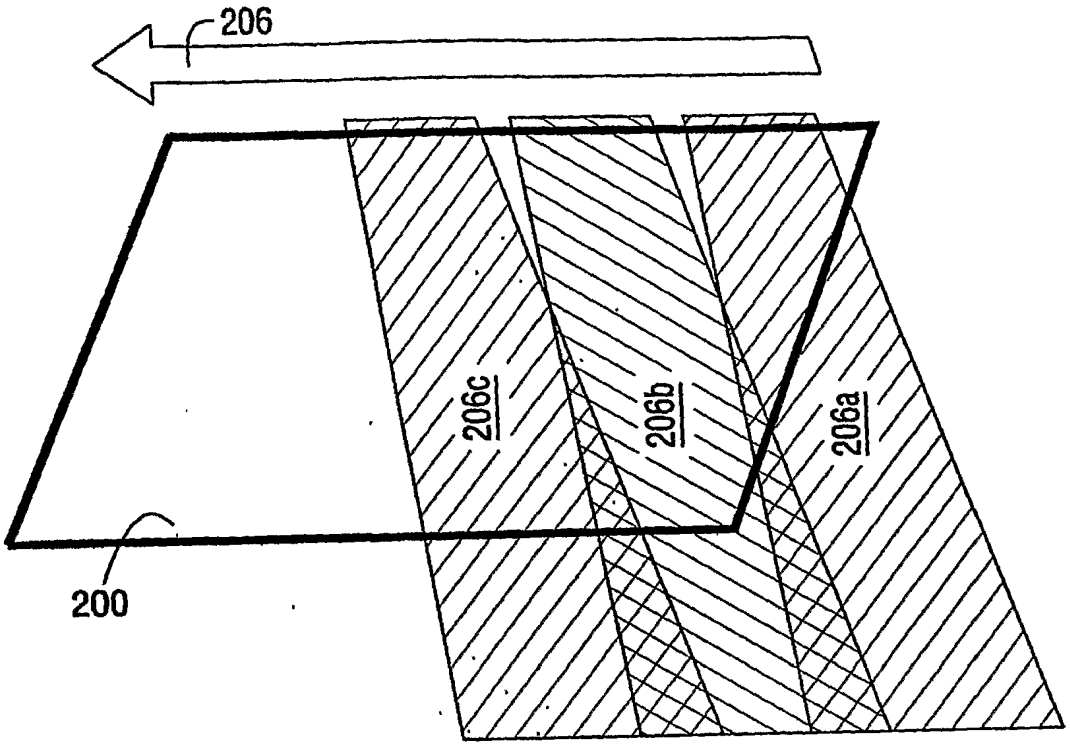


FIG. 9

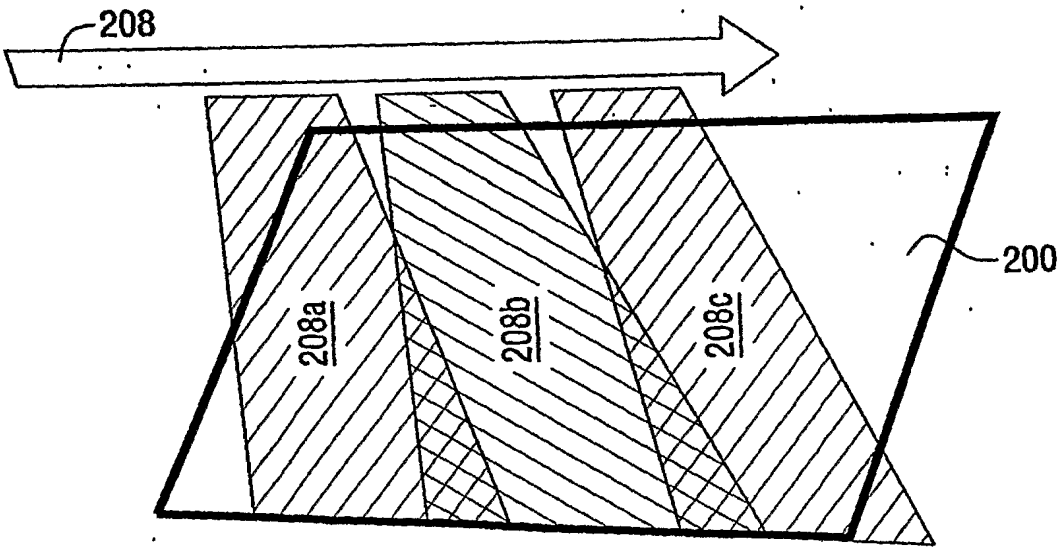
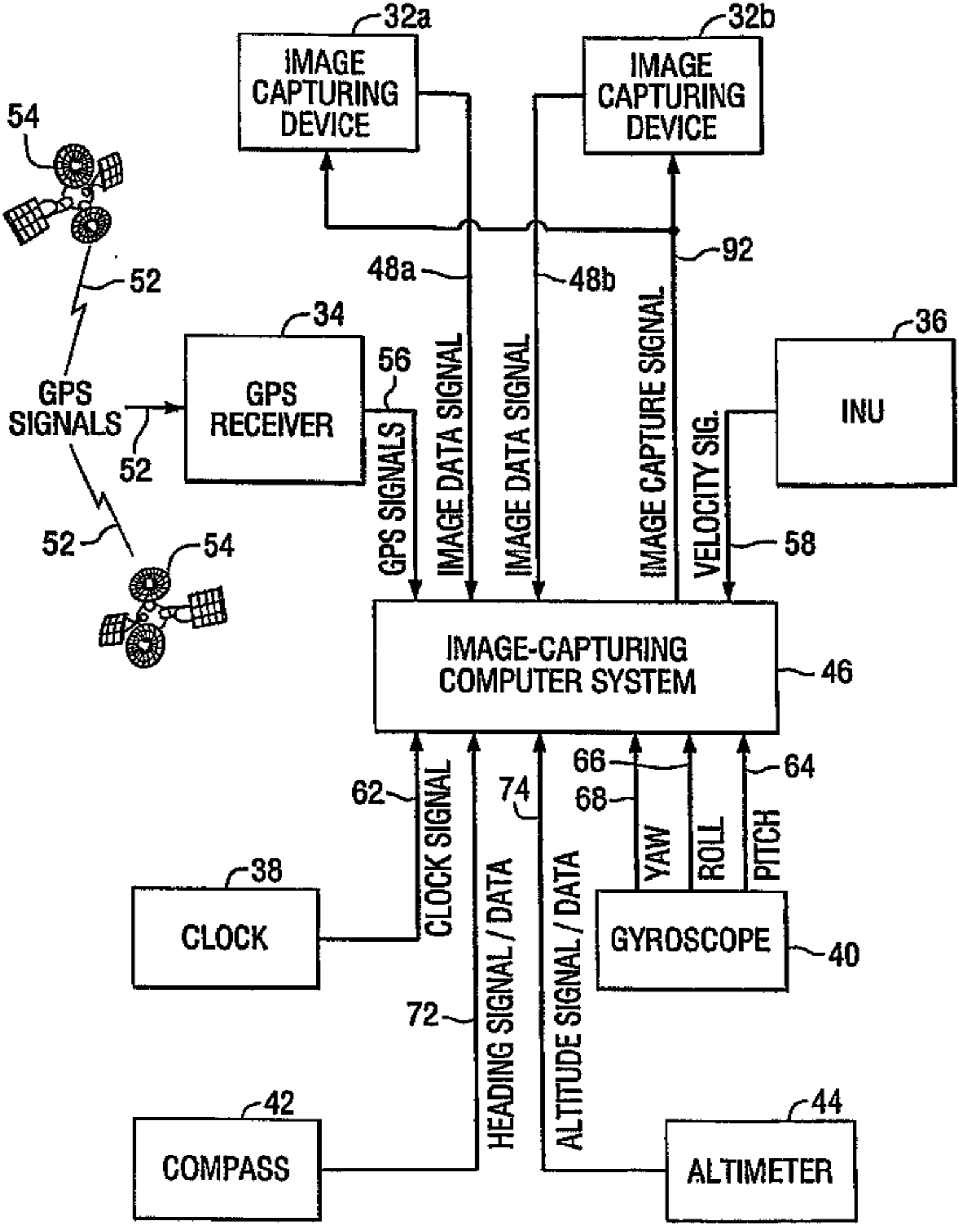


FIG. 10


32a
IMAGE CAPTURING DEVICE
32b
IMAGE CAPTURING DEVICE
54
52
48a
48b
92
34
GPS RECEIVER
56
GPS SIGNALS
52
36
INU
52
54
GPS SIGNALS
IMAGE DATA SIGNAL
IMAGE DATA SIGNAL
IMAGE CAPTURE SIGNAL
VELOCITY SIG.
58
IMAGE-CAPTURING COMPUTER SYSTEM
46
62
CLOCK SIGNAL
74
66
68
64
YAW
ROLL
PITCH
38
CLOCK
GYROSCOPE
40
72
HEADING SIGNAL / DATA
ALTITUDE SIGNAL / DATA
42
COMPASS
44
ALTIMETER

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(54) Título: **GEOLOCALIZACION OBLICUA Y SISTEMA DE MEDICION.**

(54) Title: **OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM.**

(57) Resumen

Un sistema computarizado para visualizar, geolocalizar, y hacer mediciones de imagenes oblicuas capturadas incluye un archivo de datos accesible por medio del sistema de computo. El archivo de datos incluye una pluralidad de archivos de imagenes que corresponden a una pluralidad de imagenes oblicuas capturadas, y datos de posicion que corresponden a las imagenes. Se ejecuta un software de visualizacion y analisis de imagenes a traves del sistema para leer los archivos de datos y visualizar al menos una parte de las imagenes oblicuas capturadas. El software recupera los datos de posicion para uno o mas puntos seleccionados por el usuario en la imagen visualizada, y calcula una distancia de separacion entre cualquiera de dos o mas puntos elegidos. El calculo de la distancia de separacion la selecciona el usuario para determinar varios parametros incluyendo la distancia lineal, area abarcada, elevacion relativa, y diferencia de altura entre puntos seleccionados.

(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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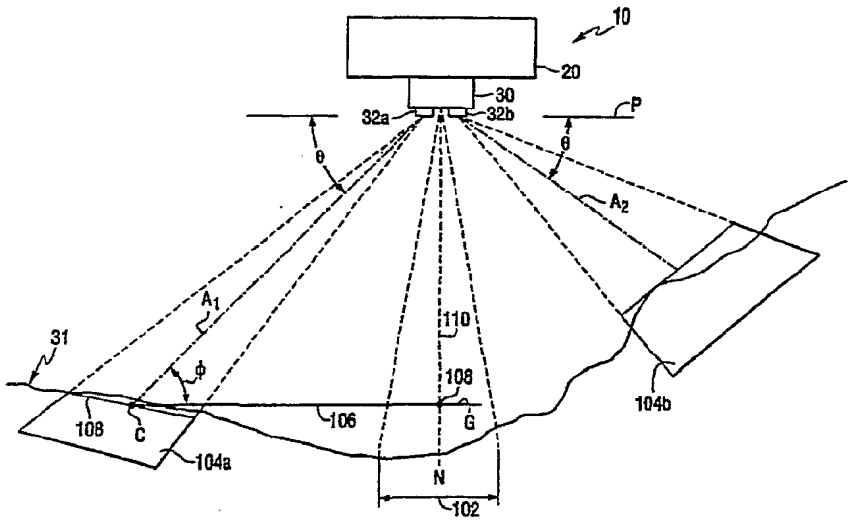
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(54) Title: OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM



(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.

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GEOLOCALIZACION OBLICUA Y SISTEMA DE MEDICION

CAMPO DE LA INVENCIÓN

La presente invención se relaciona con la fotogrametría. Más en particular, la presente invención se relaciona con un método y aparato para capturar imágenes oblicuas y para medir los objetos y distancias entre los objetos representados en las mismas.

ANTECEDENTES DE LA INVENCIÓN

La fotogrametría es la ciencia de hacer mediciones de objetos y entre los mismos, representados en fotografías, especialmente fotografías aéreas. Generalmente, la fotogrametría involucra tomar imágenes de características terrestres y derivar datos de las mismas, tales como, por ejemplo, datos que indican las distancias relativas entre objetos y tamaños de los mismos en las imágenes. La fotogrametría puede involucrar también juntar las fotografías con otros datos, tales como datos representativos de latitud y longitud. En efecto, la imagen se superpone y se conforma a un sistema coordenado espacial particular.

La fotogrametría convencional involucra la captura y/o adquisición de imágenes ortogonales. El dispositivo de captura de imágenes, tal como un cámara o sensor, es llevado por un vehículo o plataforma, tal como un aeroplano o satélite, y es dirigido a un punto nadir que está

directamente debajo y/o verticalmente hacia abajo de la plataforma. El punto o píxel en la imagen que corresponde al punto nadir es el único punto/píxel que es verdaderamente ortogonal al dispositivo de captura de imágenes. Todos los demás puntos o píxeles en la imagen son en realidad oblicuos en relación al dispositivo de captura de imágenes. Al alejarse cada vez más los puntos o píxeles del punto nadir se hacen cada vez más oblicuos en relación con el dispositivo de captura de imágenes y la distancia de la muestra del suelo (es decir, el área superficial que corresponde o que está cubierta por cada píxel) también aumenta. Tales oblicuidad en una imagen ortogonal ocasiona que las características en la imagen se distorsionen, especialmente imágenes relativamente alejadas del punto nadir.

Tal distorsión es removida, o compensada, por el proceso de ortorrectificación el cual, en esencia, remueve la oblicuidad de la imagen ortogonal ajustando o combando cada píxel de una imagen ortogonal en una rejilla ortométrica o sistema coordenado. El proceso de la ortorrectificación crea una imagen en donde todos los píxeles tienen la misma distancia de muestra de suelo y están orientados hacia el norte. Por lo tanto, cualquier punto en una imagen ortorrectificada se puede localizar usando un sistema coordenado X, Y y, tan pronto como se conoce la escala de la

imagen, se puede calcular la longitud y anchura de las características terrestres así como la distancia relativa entre esas características.

A pesar de que el proceso de ortorrectificación compensa hasta cierto grado distorsiones oblicuas en una imagen ortogonal, introduce otras distorsiones indeseables y/o imprecisiones en la imagen ortogonal ortorrectificada. Los objetos representados en las imágenes ortogonales ortorrectificadas pueden ser difíciles de reconocer y/o identificar dado que la mayoría de los observadores no están acostumbrados a ver objetos, particularmente características terrestres, desde arriba. Para un observador sin entrenamiento una imagen ortorrectificada tiene un número de distorsiones. Los caminos que en realidad son rectos parecen curvados y los edificios puede parecer inclinados. Además, las imágenes ortorrectificadas no contienen substancialmente información con respecto a la altura de las características terrestres. La interpretación y análisis de imágenes ortogonales y/u ortogonales ortorrectificadas la realizan típicamente analistas altamente entrenados quienes se han sometido a años de entrenamiento y experiencia con el objeto de identificar objetos y características terrestres en tales imágenes.

Por lo tanto, a pesar de que las imágenes ortogonales y ortorrectificadas son útiles en fotogrametría, carecen de

información acerca de la altura de las características ilustradas en las mismas y requieren analistas altamente entrenados para interpretar detalles de lo que la imagen representa.

Las imágenes oblicuas son imágenes que son capturadas con el dispositivo de captura de imágenes dirigido o apuntado generalmente al lado y hacia debajo de la plataforma que lleva el dispositivo de captura de imágenes. Las imágenes oblicuas, a diferencia de las imágenes ortogonales, muestran los lados de características terrestres, tales como casas, edificios y/o montañas, así como las partes superiores de las mismas. Por lo tanto, ver una imagen oblicua es más natural e intuitivo que ver una imagen ortogonal u ortorrectificada, y aún los observadores casuales son capaces de reconocer e interpretar características terrestres y otros objetos representados en imágenes oblicuas. Cada píxel en el primer plano de una imagen oblicua corresponde a un área relativamente pequeña de la superficie u objeto representado (es decir, cada píxel de primer plano tiene una distancia de muestra del suelo relativamente pequeña) mientras que cada píxel en el fondo corresponde a un área relativamente grande de la superficie u objeto ilustrado (es decir, cada píxel del fondo tiene una distancia de muestra del suelo relativamente grande). Las imágenes oblicuas capturan un área o vista generalmente trapezoidal de la superficie u objeto, teniendo el primer plano del trapezoide un distancia de muestra del

suelo substancialmente más pequeña (es decir, una mayor resolución) que el fondo del trapezoide.

Las imágenes oblicuas se consideran de poco uso o ninguno en fotogrametría. El enfoque convencional de forzar los píxeles de fondo y de primer plano de tamaños variados de una imagen oblicua en un tamaño uniforme para así combar la imagen a un sistema coordenado distorsiona dramáticamente la imagen oblicua y de esta manera hace que la identificación de objetos y la toma de mediciones de objetos ilustrados ahí sea una tarea laboriosa e imprecisa. La corrección de desplazamiento del terreno en una imagen oblicua usando un modelo de elevación distorsiona aún más las imágenes incrementando con ello la dificultad con la cual pueden hacerse las mediciones y reducir la precisión de cualquiera de esas mediciones.

Por lo tanto, a pesar de que las imágenes oblicuas se consideran como de poco uso o ninguno en fotogrametría, éstas se interpretan con facilidad y contienen información acerca de la altura de las características ilustradas en las mismas.

Por lo tanto, lo que se necesita en la técnica es un método y aparato para fotogrametría que permita la geolocalización y medición precisa en imágenes oblicuas.

Además, lo que se necesita en la técnica es un método y aparato para fotogrametría que permita la medición de alturas y de alturas relativas de objetos en la imagen.

Adicionalmente, lo que se necesita en la técnica es un método y aparato para fotogrametría que utilice imágenes más intuitivas y naturales.

BREVE DESCRIPCIÓN DE LA INVENCIÓN

La presente invención proporciona un método y aparato para capturar, visualizar, y hacer mediciones de objetos y distancias entre objetos representados en imágenes oblicuas.

La presente invención comprende, en una forma de la misma, un sistema computarizado para visualizar, geolocalizar, y hacer mediciones de imágenes oblicuas capturadas. El sistema incluye un archivo de datos accesible por medio del sistema de cómputo. El archivo de datos incluye una pluralidad de archivos de imágenes que corresponden a una pluralidad de imágenes oblicuas capturadas, y datos de posición que corresponden a las imágenes. Se ejecuta un software de visualización y análisis de imágenes a través del sistema para leer los archivos de datos y visualizar al menos una parte de las imágenes oblicuas capturadas. El software recupera los datos de posición para uno o más puntos seleccionados por el usuario en la imagen visualizada, y calcula una distancia de separación entre cualquiera de dos o más puntos elegidos. El cálculo de la distancia de separación la selecciona el usuario para determinar varios parámetros incluyendo la

distancia lineal, entre puntos seleccionados, área abarcada por los mismos, elevación relativa de los mismos, y diferencia de altura entre ellos.

BREVE DESCRIPCIÓN DE LAS FIGURAS

Las características antes mencionadas y otras y ventajas de la presente invención, y la manera de lograrlas, se evidenciarán y se entenderán completamente haciendo referencia a la siguiente descripción de una modalidad de la invención cuando se lea conjuntamente con las figuras anexas, en donde:

La figura 1 ilustra una modalidad de una plataforma o vehículo que lleva un sistema de captura de imágenes de la presente invención, y muestra imágenes ortogonales y oblicuas de ejemplo tomadas mediante el mismo;

la figura 2 es una vista diagramática del sistema de captura de imágenes de la figura 1;

la figura 3 es un diagrama de bloques del sistema de captura de imágenes de la figura 2;

la figura 4 es una representación de un archivo de datos de salida del sistema de captura de imágenes de la figura 1;

la figura 5 es un diagrama de bloques de una modalidad de un sistema de cómputo de visualización de imágenes y de medición de la presente invención para visualizar y hacer mediciones de y entre objetos representados en las imágenes capturadas por el sistema de captura de imágenes de la figura 1;

la figura 6 ilustra una imagen de ejemplo visualizada en el sistema de la figura 5, e ilustra una modalidad del método de la presente invención para la medición de y entre objetos representados en tal imagen;

las figuras 7 y 8 ilustran una modalidad de un método para capturar de imágenes oblicuas de la presente invención;

las figuras 9 y 10 ilustran una segunda modalidad de un método para capturar imágenes oblicuas de la presente invención;

Los caracteres de referencia correspondientes indican partes correspondientes a lo largo de las varias vistas. Las ejemplificaciones establecidas aquí ilustran una modalidad preferida de la invención, en una forma, y tales ejemplificaciones no se considerarán como limitantes del alcance de la invención en ninguna forma.

DESCRIPCIÓN DETALLADA DE LA INVENCIÓN

Con referencia a las figuras, y particularmente a la figura 1, se muestra una modalidad de un aparato para capturar imágenes oblicuas de geolocalización de la presente invención. El aparato 10 incluye una plataforma o vehículo 20 que lleva el sistema de captura de imágenes y de geolocalización 30.

La plataforma 20, como tal, por ejemplo, un aeroplano, trasbordador espacial, cohete, satélite, o cualquier otro vehículo, lleva el sistema de captura de imágenes 30 sobre un

área predefinida y a una o más altitudes predeterminadas arriba de la superficie 31, tal como por ejemplo, la superficie de la tierra o cualquier otra superficie de interés. Como tal, la plataforma 20 es capaz de un movimiento controlado o vuelo, ya sea tripulado o no tripulado, a lo largo de una trayectoria o curso de vuelo predefinido, por ejemplo, la atmósfera terrestre o espacio exterior. La plataforma de captura de imágenes 20 incluye un sistema para generar y regular energía (no mostrado) que incluye, por ejemplo, uno o más generadores, celdas combustibles, paneles solares, y/o baterías, para energizar el sistema de captura de imágenes 30.

El sistema de captura de imágenes y de geolocalización 30, como mejor se muestra en la figura 2, incluye dispositivos de captura de imágenes 32a y 32b, un receptor de sistema de posicionamiento global (GPS, por sus siglas en inglés) 34, una unidad de navegación inercial (INU, por sus siglas en inglés) 36, un reloj 38, un giroscopio 40, un compás 42 y un altímetro 44, cada uno de los cuales está interconectado con el sistema de cómputo de captura de imágenes 46.

Los dispositivos de captura de imágenes 32a y 32b, tales como, por ejemplo, cámaras convencionales, cámaras digitales, sensores digitales, dispositivos acoplados a carga, u otros dispositivos de captura de imágenes, son capaces de capturar

imágenes fotográficamente o electrónicamente. Los dispositivos de captura de imágenes 32a y 32b se conocen por características determinables incluyendo longitud focal, tamaño del sensor y relación de aspecto, términos de distorsión radial y otros, desviación del punto principal, paso de píxeles, y alineamiento. Los dispositivos de captura de imágenes 32a y 32b adquieren imágenes y emiten señales de datos de imágenes (IDS, por sus siglas en inglés) 48a y 48b, respectivamente, correspondientes a las imágenes particulares o fotografías tomadas y que se almacenan en un sistema de cómputo de captura de imágenes 46, como se describirá más en particular de aquí en adelante.

Como mejor se muestra en la figura 1, los dispositivos de captura de imágenes 32a y 32b tienen ejes centrales respectivos A_1 y A_2 y se montan a la plataforma 20 de tal forma que los ejes A_1 y A_2 están cada uno a un ángulo de declinación θ en relación con un plano horizontal P. El ángulo de declinación θ es virtualmente cualquier ángulo oblicuo, pero es preferentemente de aproximadamente 20° (veinte grados) a aproximadamente 60° (sesenta grados) y con mayor preferencia de aproximadamente 40° (cuarenta grados) a aproximadamente 50° (cincuenta grados).

El receptor del GPS 34 recibe señales del sistema de posicionamiento global 52 que son transmitidas por uno o más satélites del sistema de posicionamiento global 54. Las

señales de GPS 52, en forma conocida, permiten la localización precisa de la plataforma 20 en relación con la superficie 31 que va a determinarse. El receptor del GPS 34 decodifica señales del GPS 52 y emite señales/datos de localización 56, que son dependientes al menos en parte de las señales del GPS 52 y las cuales son indicativas de la localización precisa de la plataforma 20 en relación con la superficie 31, las señales/datos de localización 56 correspondientes a cada imagen capturada por los dispositivos de captura de imágenes 32a y 32b son recibidas y almacenadas por un sistema de cómputo de captura de imágenes 46.

La INU 36 es una unidad de navegación inercial convencional que está acoplada a, y detecta cambios en la velocidad, incluyendo velocidad de traslación y rotacional, de los dispositivos de captura de imágenes 32a y 32b y/o de la plataforma 20. La INU 36 emite señales/datos de velocidad 58 indicativos de tales velocidades y/o cambios en la misma al sistema de cómputo de captura de imágenes 46, el cual almacena señales/datos de velocidad 58 correspondientes a cada imagen capturada por los dispositivos de captura de imágenes 32a y 32b recibidos y almacenados por el sistema de cómputo de captura de imágenes 46.

El reloj 36 mantiene una medición del tiempo preciso (tiempo de validez) que se usa para sincronizar eventos en el sistema de captura de imágenes y de geolocalización 30. El

reloj 38 proporciona una señal de datos/reloj de tiempo 62 que es indicativa del tiempo preciso en que una imagen es tomada por los dispositivos de captura de imágenes 32a y 32b. Los datos de tiempo 62 se proveen también y se almacenan por el sistema de cómputo captura de imágenes 46. Alternativamente, el reloj 38 está integrado con el sistema de cómputo de captura de imágenes 46, tal como, por ejemplo, un programa de software de reloj.

El giroscopio 40 es un giroscopio convencional encontrado en aeroplanos y/o en sistemas de navegación comerciales para aeroplanos. El giroscopio 40 proporciona señales incluyendo señales de inclinación 64, señales balanceo 66, y señales de guiñada 68, los cuales son indicativos de la inclinación, balanceo y guiñada de la plataforma 20. La señal de inclinación 64, la señal de balanceo 66 y la señal de guiñada 68 correspondientes a cada imagen capturada por los dispositivos de captura de imágenes 32a y 32b son recibidas y almacenadas por el sistema de cómputo de captura de imágenes 46.

El compás 42, tal como, por ejemplo, un compás electrónico convencional, indica el rumbo de la plataforma 20. El compás 42 emite una señal/dato de rumbo 72 indicativo del rumbo de la plataforma 20. El sistema de cómputo de captura de imágenes 46 recibe y almacena señales/datos de rumbo 72 que corresponden a cada imagen capturada por los dispositivos de captura de imágenes 32a y 32b.

El altímetro 44 indica la altitud de la plataforma 20. El altímetro 44 emite una señal/dato de altitud 74, y un sistema de cómputo de captura de imágenes 46 recibe y almacena la señal/dato de altitud 74 que corresponde a cada imagen capturada por los dispositivos de captura de imágenes 32a y 32b.

Como mejor se muestra en la figura 3, el sistema de cómputo de captura de imágenes 46, tal como, por ejemplo, una computadora personal portátil convencional, incluye una memoria 82, dispositivos de entrada de datos 84a y 84b, un dispositivo de visualización 86, y puertos de entrada y salida (I/O, por sus siglas en inglés) 88. El sistema de cómputo de captura de imágenes 46 ejecuta un software de adquisición de imágenes y datos 90, el cual se almacena en la memoria 82. La memoria 82 también almacena datos usados y/o calculados por el sistema de cómputo de captura de imágenes 46 durante la operación del mismo, e incluye, por ejemplo, una memoria no volátil de solo lectura, una memoria de acceso aleatorio, una memoria de disco duro, tarjetas de memorias removibles y/u otros dispositivos y/o medios de memoria adecuados. Los dispositivos de entrada de datos 84a y 84b, tales como, por ejemplo, un ratón, teclado, palanca de control, u otro de tales dispositivos de entrada de datos, permiten la entrada de datos y la interacción de un usuario con software que se ejecuta por el sistema de cómputo de

captura de imágenes 46. El dispositivo 86, tal como, por ejemplo, una pantalla de cristal líquido o tubo de rayos catódicos, presenta información al usuario del sistema de cómputo de captura de imágenes 46. Los puestos de I/O 88, tales como, por ejemplo, puertos seriales y paralelos de entrada y salida de datos, permiten la entrada y/o salida de datos del sistema de cómputo de captura de imágenes 46.

Cada una de las señales de datos antes descritas se conecta con el sistema de cómputo de captura de imágenes 46. Más particularmente, las señales de datos de imágenes 48, señales de localización 56, señales de velocidad 58, señal de datos de tiempo 62, señales de inclinación, balanceo y guiñada 64, 66 y 68, respectivamente, señal de rumbo 72 y señal de altitud 74 son recibidas vía los puestos I/O 88 y almacenadas en la memoria 82 del sistema de cómputo de captura de imágenes 46.

En el uso, el sistema de cómputo de captura de imágenes 46 ejecuta el software de adquisición de datos de imágenes 90, el cual, en general, controla la lectura, manipulación, y almacenamiento de las señales de datos antes descritas. Más particularmente, el software de adquisición de imágenes y datos 90 lee señales de datos de imágenes 48a y 48b y los almacena en la memoria 82. Cada una de las señales de localización 56, señales de velocidad 58, señales de datos de tiempo 62, señales de inclinación, balanceo y guiñada 64, 66

y 68, respectivamente, señal de rumbo 72 y señal de altitud 74 que representan las condiciones existentes en el instante en que se adquiere o captura una imagen por los dispositivos de captura de imágenes 32a y 32b y que corresponden a las señales de datos de imágenes particulares 48a y 48b que representan las imágenes capturadas son recibidas por el sistema de cómputo de captura de imágenes 46 a través de los puertos I/O 88. El sistema de cómputo de captura de imágenes 46 que ejecuta el software de adquisición de imágenes y datos 90 emite una señal de captura de imágenes 92 a los dispositivos de captura de imágenes 32a y 32b para ocasionar con ello que los dispositivos adquieran o capturen una imagen en sitios predeterminados y/o a intervalos predeterminados que son dependientes al menos en parte de la velocidad de la plataforma 20.

El software de adquisición de imágenes y datos 90 decodifica según sea necesario y almacena las señales antes mencionadas en la memoria 82, y asocia las señales de datos con señales de imágenes correspondientes 48a y 48b. Por lo tanto, se conoce la altitud, la orientación en términos de balanceo, inclinación, y guiñada, y la ubicación de los dispositivos de captura de imágenes 32a y 32b en relación con la superficie 31, es decir, longitud y latitud, para cada imagen capturada por los dispositivos de captura de imágenes 32a y 32b.

La plataforma 20 es piloteada o de otra manera guiada a través de una trayectoria de captura de imágenes que pasa a través de un área particular de superficie 31, tal como, por ejemplo, un área predefinida de la superficie de la tierra o de otro planeta. Preferentemente, la trayectoria de captura de imágenes de la plataforma 20 está a ángulos rectos con al menos uno de los límites del área de interés. El número de veces que la plataforma 20 y/o los dispositivos de captura de imágenes 32a, 32b pasa a través del área de interés es dependiente al menos en parte del tamaño del área y cantidad de detalle deseado en las imágenes capturadas. Los detalles particulares de la trayectoria de captura de imágenes de la plataforma 20 se describen con más particularidad de aquí en adelante.

Al pasar la plataforma 20 a través del área de interés se captura un número de imágenes oblicuas por los dispositivos de captura de imágenes 32a y 32b. Tal como lo entenderán aquellos con experiencia en la técnica, las imágenes son capturadas o adquiridas por los dispositivos de captura de imágenes 32a y 32b a intervalos de captura de imágenes predeterminados los cuales son dependientes al menos en parte de la velocidad de la plataforma 20.

Las señales de datos de imágenes 48a y 48b que corresponden a cada imagen adquirida son recibidas por y almacenadas en la memoria 82 del sistema de cómputo de

captura de imágenes 46 a través de los puertos I/O 88. Similarmente, las señales de datos (es decir, señales de datos de imágenes 48, señales de localización 56, señales de velocidad 58, señal de datos de tiempo 62, señales de inclinación, balanceo y guiñada 64, 66 y 68, respectivamente, señal de rumbo 72 y señal de altitud 74) correspondientes a cada imagen capturada son recibidas y almacenadas en la memoria 82 del sistema de cómputo de captura de imágenes 46 a través de los puertos I/O 88. Por lo tanto, el dispositivo de captura de imágenes 32a y 32b en relación con la superficie 32 en el momento preciso que cada imagen es capturada es registrada en la memoria 82 y asociada con la imagen capturada correspondiente.

Como mejor se muestra en la figura 1, la localización de los dispositivos de captura de imágenes 32a y 32b en relación con la tierra corresponde al punto nadir N de la imagen ortogonal 102. Por lo tanto, la geolocalización exacta del punto nadir N de la imagen ortogonal 102 es indicada por las señales de localización 56, las señales de velocidad 58, la señal de datos de tiempo 62, señales de inclinación, balanceo y guiñada 64, 66 y 68, respectivamente, la señal de rumbo 72 y la señal de altitud 74. Una vez que se conoce el punto nadir N de la imagen ortogonal 102, la geolocalización de otro píxel o punto en la imagen 102 puede determinarse de manera conocida.

Cuando los dispositivos de captura de imágenes 32a y 32b capturan imágenes oblicuas, tales como las imágenes 104 a y 104b (figura 1), la localización de los dispositivos de captura de imágenes 32a y 32b en relación con la superficie 31 es indicada similarmente por las señales de localización 56, las señales de velocidad 58, la señal de datos de tiempo 62, las señales de inclinación, balanceo y guiñada 64, 66 y 68, respectivamente, la señal de rumbo 72, la señal de altitud 74 y el ángulo de declinación conocido θ de los ejes principales A_1 y A_2 de los dispositivos de captura de imágenes 32a y 32b, respectivamente.

Particularmente deberá notarse que un proceso calibración permite que el software de adquisición de imágenes y datos 90 incorpore factores de corrección y/o corrija cualquier error inherente o debido al dispositivo de captura de imágenes 32, tal como, por ejemplo, error debido a la longitud focal calibrada, tamaño del sensor, distorsión radial, desviación del punto principal, y alineación.

El software de adquisición de imágenes y datos 90 crea y almacena en la memoria 82 uno o más archivos de imágenes y datos de salida 120. Más particularmente, el software de adquisición de imágenes y datos 90 convierte señales de imágenes de datos 48a, 48b y las señales de datos de orientación (es decir, señales de datos de imágenes 48, señales de localización 56, señales de velocidad 58, señal de

datos de tiempo 62, señales de inclinación, balanceo y guiñada 64, 66 y 68, respectivamente, señal de rumbo 72 y señal de altitud 74) en archivos de imágenes y datos de salida de lectura por computadora 120. Como mejor se muestra en la figura 4, el archivo de imágenes y datos de salida 120 contiene una pluralidad de archivos de imágenes capturadas I_1, I_2, ..., I_n correspondientes a imágenes oblicuas capturadas, y los datos de posición C_{PD1}, C_{PD2}, ..., C_{PDn} que corresponden a las mismas.

Los archivos de imágenes I_1, I_2, ..., I_n del archivo de imágenes y datos 120 se almacenan virtualmente en cualquier formato de archivo de imágenes o gráficos de lectura por computadora, tal como, por ejemplo, formatos de archivo JPEG, TIFF, GIF, BMP, o PDF, y tienen referencias cruzadas con los datos de posición C_{PD1}, C_{PD2}, ..., C_{PDn} los cuales se almacenan también como datos de lectura por computadora. Alternativamente, los datos de posición C_{PD1}, C_{PD2}, ..., C_{PDn} están integrados con los archivos de imágenes correspondientes I_1, I_2, ..., I_n en forma conocida. Los archivos de datos de imágenes 12o son procesados después, ya sea por medio de software de adquisición de imágenes y datos 90 o por procesamiento posterior, para corregir errores, tales como, por ejemplo, errores debido a desviaciones de la trayectoria de vuelo y otros errores conocidos por aquellos con experiencia en la técnica. Posteriormente, los archivos

de datos de imágenes 120 están listos para usarse para visualizar y hacer mediciones de, y entre los objetos representados en las imágenes capturadas, incluyendo mediciones de las alturas de tales objetos.

Con referencia ahora a la figura 5, el sistema de cómputo de visualización y medición de imágenes 130, tal como, por ejemplo, una computadora personal de escritorio convencional o una terminal computadora móvil en un automóvil de policía, incluye la memoria 132, dispositivos de entrada de datos 134a y 134b, el dispositivo de visualización 136, y la conexión a red 138. El sistema de cómputo de captura de imágenes 130 ejecuta el software de visualización y análisis de imágenes 140, el cual se almacena en la memoria 132. La memoria 132 incluye, por ejemplo, la memoria de solo lectura no volátil, la memoria de acceso aleatorio, la memoria de disco duro, tarjetas de memoria removibles y/u otros dispositivos y/o medios de almacenamiento de memoria adecuados. Los dispositivos de entrada de datos 134a y 134b, tales como, por ejemplo, un ratón, teclado, palanca de control, u otros dispositivos de entrada de datos, permiten la entrada de datos y la interacción de un usuario con el software de visualización y análisis de imágenes 140 que se ejecuta por el sistema de cómputo de visualización y medición de imágenes 130. El dispositivo de visualización 136, tal como, por ejemplo, una pantalla de cristal líquido o un tubo

de rayos catódicos, visualiza información al usuario del sistema de cómputo de visualización y medición de imágenes 130. La conexión de red 138 conecta el sistema de cómputo de visualización y medición de imágenes 130 a una red (no mostrada), tal como, por ejemplo, una red de área local, una red de área amplia, la Internet y/o la Red Mundial.

En el uso, y con referencia ahora a la figura 6, el sistema de cómputo de visualización y medición de imágenes 130 que ejecuta software de visualización y análisis de imágenes 140 accede a uno o más archivos de imágenes y datos de salida 120 que han sido leídos en la memoria 132, tal como, por ejemplo, a través de una conexión de red 138, una unidad de disco flexible, una tarjeta de memoria removible u otro medio adecuado. Una o más de las imágenes capturadas I_1, I_2, ..., I_n de los archivos de imágenes y datos de salida 120 se visualizan posteriormente como imágenes oblicuas visualizadas 142 bajo el control del software de visualización y análisis de imágenes 140. Aproximadamente al mismo tiempo, una o más porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} que corresponden a la imagen oblicua 142 son leídas en una porción fácilmente accesible de la memoria 132.

Deberá notarse particularmente que la imagen oblicua visualizada 142 se visualiza substancialmente tal como es capturada, es decir, la imagen visualizada 142 no está combada o ajustada a algún sistema coordenado tampoco está

ortorrectificada la imagen visualizada 142. En lugar de combar la imagen visualizada 142 a un sistema coordenado con el objeto de permitir la medición de los objetos representados en la misma, el software de visualización y análisis de imágenes 140, en general, determina las geolocalizaciones de píxeles seleccionados solo según sea necesario, o "dinámicamente", referenciando porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} de archivos de imágenes y datos de salida 120 y calculando la posición y/o geolocalización de aquellos píxeles seleccionados usando una o más ecuaciones de proyección como se describe con más particularidad de aquí en adelante.

Generalmente, un usuario del sistema de cómputo de visualización y medición de imágenes 130 hace mediciones de y entre los objetos representados en la imagen oblicua visualizada 142 y seleccionando uno de varios modos de medición disponibles provistos en el software de visualización y análisis de imágenes 140. El usuario selecciona el modo de medición deseado accediendo, por ejemplo, a una serie de menús desplegables o barras de herramientas M, o por medio de comandos del teclado. Los modos de medición proporcionados por el software de visualización y análisis de imágenes 140 incluye, por ejemplo, un modo de distancia que permite la medición de la distancia entre dos o más puntos seleccionados, un modo de

área que permite la medición del área abarcada por varios puntos seleccionados e interconectados, un modo de altura que permite la medición de la altura entre dos o más puntos seleccionados, y un modo de elevación que permite la medición del cambio en la elevación de un punto seleccionado en relación con uno o más de los otros puntos seleccionados.

Después de seleccionar el modo de medición deseado, el usuario del software de visualización y análisis de imágenes 140 selecciona con uno de los dispositivos de entrada de datos 134a, 134b un punto inicial o píxel inicial 152 y un punto o píxel final 154 en la imagen visualizada 142, y el software de visualización y análisis de imágenes 140 calcula y visualiza automáticamente la cantidad observada, tal como por ejemplo, la distancia entre el píxel inicial 152 y el píxel final 154.

Cuando el usuario selecciona el punto/píxel inicial 152, la gelocalización del punto correspondiente al mismo sobre la superficie 31 se calcula por medio del software de visualización y análisis de imágenes 140 el cual ejecuta una o más ecuaciones de proyección usando las porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} de los archivos de imágenes y datos de salida 120 que corresponden a la imagen particular que está siendo visualizada. La longitud y altitud del punto sobre la superficie 31 correspondiente al píxel 152 se visualizan entonces por medio del software de visualización y análisis

de imágenes 140 en la pantalla 136, tal como, por ejemplo, por súper imposición de la longitud y latitud en la imagen visualizada 142 adyacente al punto/píxel seleccionado o en el bloque de visualización emergente en cualquier parte de la pantalla 136. El mismo proceso es repetido por el usuario para la selección del píxel/punto final 154, y por el software de visualización y análisis de imágenes 140 para la recuperación y visualización de la información de longitud y latitud.

El cálculo de la distancia entre los puntos/píxeles iniciales y finales 152, 154, respectivamente, se logra determinando la geolocalización de cada píxel seleccionado 152, 154 "dinámicamente". Las porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} del archivo de imágenes y datos de salida 120 que corresponden a la imagen visualizada se recuperan, y se determina la geolocalización del punto en la superficie 31 correspondiente a cada píxel seleccionado. La diferencia entre las geolocalizaciones correspondientes a los píxeles seleccionados determina la distancia entre los píxeles.

Como ejemplo de cómo se determina la geolocalización de un punto o píxel dado en la imagen oblicua visualizada 142, supondremos que la imagen visualizada 142 corresponde a la imagen ortogonal 104a (figura 1). El usuario del software de visualización y análisis de imágenes 140 selecciona el píxel 154, el cual, por simplicidad, corresponde al centro C

(figura 1) de la imagen oblicua 104a. Tal como se muestra en la figura 1, la línea 106 se extiende a lo largo del plano horizontal G desde un punto 108 sobre el mismo que está directamente debajo del dispositivo de captura de imágenes 32a al centro C del límite o borde cercano 108 de la imagen oblicua 104a. Una extensión del eje principal A_1 interseca con el centro C. El ángulo ϕ es el ángulo formado entre la línea 106 y la extensión del eje principal A_1. Por lo tanto, se forma un triángulo (sin referencias) que tiene vértices en el dispositivo de captura de imágenes 32a, el punto 108 y el centro C, y que tiene lados 106, la extensión del eje principal A_1 y la línea vertical (punteada) 110 entre el punto 108 u el dispositivo de captura de imágenes 32a.

El plano del suelo G es un plano de suelo substancialmente horizontal, plano o sin pendientes (y el cual típicamente tendrá una elevación que refleja la elevación promedio del terreno), y por lo tanto el triángulo antes descrito incluye un ángulo recto entre el lado/línea 110 y el lado/línea 106. Dado que el ángulo ϕ y la altitud del dispositivo de captura de imágenes 32 (es decir, la longitud del lado 110) se conocen, la hipotenusa (es decir, la longitud de la extensión del eje principal A_1) y el otro lado restante del triángulo recto se calcula por geometría simple. Además, dado que la posición exacta del dispositivo de captura de imágenes 32a se conoce en el momento en el que

se capturó la imagen correspondiente a la imagen visualizada 142, se conocen la latitud y longitud del punto 108. Conociendo la longitud del lado 106, calculada como se describió anteriormente, permite la geolocalización exacta del píxel 154 correspondiente al centro CX de la imagen oblicua 104a que va determinarse por el software de visualización y análisis de imágenes 140. Una vez que se conoce la geolocalización del punto que corresponde al píxel 154, la geolocalización de cualquier otro píxel en la imagen oblicua visualizada 142 puede determinarse usando las características de cámara conocidas, tales como, por ejemplo, longitud focal, tamaño del sensor y relación de aspecto, término radial y otros términos de distorsión, etc.

La distancia entre dos o más puntos que corresponden a dos o más píxeles seleccionados en la imagen visualizada 142 se calcula por medio del software de visualización y análisis de imágenes 140 determinando la diferencia entre las geolocalizaciones de los píxeles seleccionados usando algoritmos conocidos, tales como por ejemplo, la fórmula de Gauss y/o la fórmula del punto de desvanecimiento, dependiente del modo de medición seleccionado. La medición de los objetos representados o que aparecen en la imagen visualizada 142 se lleva a cabo por medio de un procedimiento substancialmente similar al procedimiento descrito arriba para medir distancias entre píxeles seleccionados. Por

ejemplo, las longitudes anchuras y alturas de objetos, tales como, por ejemplo, edificios, ríos, caminos, y virtualmente cualquier otra estructura geográfica o construida por el hombre, que aparece en la imagen visualizada 142 es medida seleccionando el modo de medición apropiado/deseado y seleccionando los píxeles iniciales y finales.

Deberá notarse particularmente que en el modo de medición de distancia el software de visualización y análisis de imágenes 140 la distancia entre los puntos/píxeles iniciales y finales 152, 154, respectivamente, es determinable a lo largo de virtualmente cualquier trayectoria, tal como, por ejemplo, una trayectoria en "línea recta" P1 o una trayectoria P2 que involucra la selección de puntos/píxeles intermedios y uno o más segmentos de "línea recta" interconectados ahí.

También deberá notarse particularmente que el modo de medición de la distancia del software de visualización y análisis de imágenes 140 determina la distancia entre píxeles seleccionados de conformidad con el método "recorre la tierra". El método "recorre la tierra" crea una serie de segmentos de líneas interconectadas, representadas colectivamente por las trayectorias P1 y P2, que se extienden entre los píxeles/puntos selecciones y los cuales se ubican o se conforman a las caras planas de una serie de facetas interconectadas que definen un plano terrestre teselado. El

plano terrestre teselado, como se describirá con más particularidad a continuación, sigue cercanamente o recrea el terreno de la superficie 31, y por lo tanto las trayectorias P1 y P2 siguen también cercanamente el terreno de la superficie 31. Al medir la distancia a lo largo del terreno simulado por el plano terrestre teselado, el método de "recorre la tierra" proporciona una medición más precisa y útil de la distancia entre puntos seleccionados que el enfoque convencional, el cual comba la imagen sobre una tierra plana o sistema plano de elevación promedio y mide la distancia entre puntos seleccionados a lo largo de la tierra plana o plano e ignora substancialmente variaciones en el terreno entre los puntos.

Por ejemplo, un contratista que prepara un oferta acerca de un contrato para pavimentar una calzada sobre un terreno desigual o con cuestas puede determinar la cantidad aproximada o área de camino involucrado usando el software de visualización y análisis de imágenes 140 y el método de medición de "recorre la tierra" provisto en el mismo. El contratista puede obtenerla cantidad aproximada o área de calzada desde su propia oficina sin haber enviado una cuadrilla de reconocimiento al sitio para obtener las mediciones necesarias.

En contraste con el método de "recorre la tierra" proporcionado por la presente invención, los enfoques de

cálculo de "tierra plana" o de distancia de elevación promedio incluyen imprecisiones inherentes cuando se miden las distancias entre puntos y/u objetos dispuestos en un terreno disparejo y cuando se miden los tamaños y/o alturas de los objetos similarmente dispuestos. Aún una pendiente modesta o grado en la superficie que es capturada resulta en una diferencia en la elevación del punto nadir en relación con virtualmente cualquier otro punto de interés en la misma. Por lo tanto, con referencia nuevamente a la figura 1, el triángulo formado por la línea 106, la extensión del eje principal A_1 y la línea vertical (punteada) 110 entre el punto 108 y el dispositivo de captura de imágenes 32a no pueden estar en un ángulo recto. Si tal es el caso, cualquier cálculo geométrico que suponga que el triángulo sea un triángulo recto podría contener errores, y tales cálculos se reducirían a aproximaciones debido todavía a un gradiente o pendiente relativamente ligero entre los puntos de interés.

Por ejemplo, si la superficie 31 se inclina hacia arriba entre el punto nadir N y el centro C cerca o en el borde inferior 108 de la imagen oblicua 104 entonces la segunda línea 110 interseca la superficie 31 antes de que el punto en el cual tal intersección ocurriese en un nivel o superficie sin pendiente 31. Si el centro C es 4.57 metros (quince pies) más grande que el punto nadir N y con un ángulo de declinación θ igual a 40° (cuarenta grados), la localización

calculada del centro C sería aproximadamente de 5.42 metros (17.8 pies) sin corrección para el cambio en la elevación entre los puntos.

Tal como se discutió en general anteriormente, con el objeto de compensar al menos en parte los cambios en elevación y las imprecisiones resultantes en la medición de y entre objetos en la imagen 142, el software de visualización y análisis de imágenes 140 coloca referencias, como se requiera, en puntos en la imagen visualizada 142 y sobre la superficie 31 a un plano terrestre teselado o con facetas precalculado designado en general como 160 en la figura 6. El plano terrestre teselado 160 incluye una pluralidad de facetas individuales 162a, 162b, 162c, etc., cada uno de los cuales está interconectada una con la otra y están definidas por cuatro vértices (sin referencias, pero mostrados como puntos) teniendo elevaciones respectivas. Los pares adyacentes de las facetas 162a, 162b, 162c, etc., comparten dos vértices. Cada faceta 162a, 162b, 162c, etc., tiene una inclinación y pendiente respectiva. El plano terrestre teselado 160 se crea con base en varios datos y recursos, tales como, por ejemplo, mapas topográficos, y/o gráficos de tramas digitales, datos de reconocimiento, y varias otras fuentes.

Generalmente, la geolocalización de un punto de interés en la imagen visualizada 142 se calcula determinando cuál de las facetas 162a, 162b, 162c, etc., corresponde a ese punto

de interés. Por lo tanto, la localización del punto de interés se calcula con base en las características, es decir, elevación, inclinación y pendiente, de las facetas 162a, 162b, 162c, etc., en lugar que sea con base en un plano o plano terrestre de elevación promedio. El error se introduce en el grado en el que la topografía de la superficie 31 y la localización del punto de interés en la misma de desvía de la superficie plana de las facetas 162a, 162b, 162c, etc., en las cuales se ubica el punto de interés. Ese error es reducible a través de una interpolación bilineal de la elevación del punto de interés en una de las facetas particulares 162 a, 162b, 162c, etc., y usando esa elevación interpolada en el calculo de localización efectuado por el software de visualización y análisis de imágenes 140.

Para usar el plano terrestre teselado 160, el software de visualización y análisis de imágenes 140 emplea un algoritmo de rastreo de rayo modificado para encontrar la intersección del rayo proyectado del dispositivo de captura de imágenes 32a ó 32b hacia la superficie 31 y el plano terrestre teselado 160. El algoritmo determina no solo cuál de las facetas 162a, 162b, 162c, etc., es intersecada por el rayo, sino también en qué lugar en la faceta tiene lugar la intersección. Mediante el uso de la interpolación bilineal, puede determinarse una localización terrestre bastante precisa. Para la proyección inversa, el plano terrestre

teselado 160 se usa para encontrar el valor de elevación del terreno para la localización terrestre de entrada usando también la interpolación bilineal. La elevación y localización se usan después para proyectar hacia atrás a través de un modelo del dispositivo de captura de imágenes 32a y 32b para determinar cuál de los píxeles en la imagen visualizada 142 corresponde a la localización dada.

Más en particular, y como un ejemplo, el software de visualización y análisis de imágenes 140 ejecuta y/o calcula la geolocalización del punto 164 superponiendo y/o ajustando el plano terrestre teselado 160 a al menos una porción 166, tal como, por ejemplo, una loma, de superficie 31. Deberá notarse que solo una pequeña porción del plano terrestre teselado 160 y las facetas 162a, 162b, 162c, etc., del mismo se muestra a lo largo del perfil de la porción 166 de la superficie 31. Como se discutió anteriormente, cada una de las facetas 162a, 162b, 162c, etc., se define por medio de cuatro vértices, cada uno de os cuales tiene elevaciones respectivas y cada una de las facetas tiene inclinaciones y pendientes respectivas. La posición de la pendiente del punto 164 sobre el plano/superficie de la faceta 162a, 162b, 162c, etc., en el cual se ubica el punto 164 (o su proyección) se determina como se describió anteriormente.

El plano terrestre teselado 160 se crea preferentemente fuera de la operación del sistema de cómputo de visualización

y medición de imágenes 130 y del software de visualización y análisis de imágenes 140. En su lugar, el plano terrestre 160 toma la forma de una tabla de datos relativamente simple o tabla de consulta 168 almacenada en la memoria 132 de y/o accesible al sistema de cómputo de visualización y medición de imágenes 130. Los recursos de cómputo requeridos para calcular las localizaciones de todos los vértices de las muchas facetas de un plano terrestre típico no necesariamente tiene que residir en el sistema de cómputo de visualización y medición de imágenes 130. Por lo tanto, el sistema de cómputo de visualización y medición de imágenes 130 es compatible para usarse y ejecutarse por una computadora personal convencional sin requerir recursos de cómputo adicionales.

El cálculo del plano terrestre teselado 160 fuera del sistema de cómputo de visualización y medición de imágenes 130 permite que se incorpore virtualmente cualquier nivel de detalle en el plano terrestre teselado 160, es decir, el tamaño y/o área cubierta por, o que corresponde a, cada una de las facetas 162a, 162b, 162c, etc., puede ser tan grande o tan pequeño como se desee, sin aumentar significativamente el tiempo de cálculo, ni retardar la operación, ni aumentar significativamente los recursos requeridos por el sistema de cómputo de visualización y medición de imágenes 130 y/o el software de visualización y análisis de imágenes 140. El sistema de cómputo de visualización y medición 130 puede por

lo tanto ser un sistema de cómputo relativamente básico y no complicado.

El tamaño de las facetas 162a, 162b, 162c, etc., son de tamaño uniforme a través de una imagen visualizada particular 142. Por ejemplo, si la imagen visualizada 142 corresponde a un área que es aproximadamente de 228.6 metros (750 pies) de ancho en el primer plano por aproximadamente 274.3 metros (900 pies) de profundidad, la imagen puede partirse en facetas que son de aproximadamente 4.6 metros cuadrados (50 pies cuadrados), produciendo por lo tanto 15 facetas de ancho y 18 facetas de profundidad. Alternativamente, los lados de las facetas 162a, 162b, 162c, etc., son uniformes en términos de número de píxeles contenidos en las mismas, es decir cada faceta es del mismo número de píxeles de ancho y el mismo número de píxeles de profundidad. Las facetas en el primer plano de la imagen visualizada 142, en donde la densidad de píxeles es la mayor, serían por lo tanto dimensionalmente más pequeñas que las facetas en el fondo de la imagen visualizada 142 en donde la densidad de píxeles en la menor. Dado que es deseable hacer más mediciones en el primer plan o de una imagen visualizada en donde la densidad de píxeles es la mayor, la creación de facetas que son uniformes en términos del número de píxeles que contienen tiene la ventaja de proporcionar mediciones más precisas en el primer plano de la imagen visualizada 142 en relación con las facetas que son dimensionalmente uniformes.

Otra ventaja del uso de píxeles como una base para definir las dimensiones de las facetas 162a, 162b, 162c, etc., es que el cálculo de localización (localización del píxel con respecto a la localización del terreno) es relativamente simple. Un usuario opera el sistema de cómputo de visualización y medición de imágenes 130 para seleccionar un píxel en una faceta dada, el software de visualización y análisis de imágenes 140 consulta los datos para la faceta que corresponde al píxel seleccionado, la elevación del píxel seleccionado se calcula como se discutió anteriormente, y esa elevación se usa en el cálculo de localización.

Generalmente, el método de captura de imágenes oblicuas de la presente invención divide un área de interés, tal como, por ejemplo, un condado, en sectores de tamaño generalmente uniforme, tales como, por ejemplo, sectores que son de aproximadamente 2.6 kilómetros cuadrados (una milla cuadrada) de área. Esto se hace para facilitar la creación de un plan de vuelo para capturar imágenes oblicuas que cubren cada centímetro (pulgada) del área de interés, y para organizar y nombrar los sectores y/o imágenes de la misma para fácil referencia, almacenamiento y recuperación (un proceso conocido en la técnica como "sectorización"). Debido a que los bordes de cualquier área geográfica de interés, tal como un condado, rara vez caen dentro de límites de kilómetros cuadrados (millas cuadradas) uniformes, el método de captura

de imágenes oblicuas de la presente invención proporciona más sectores que las millas cuadradas que existen en el área de interés - cuánto más depende en gran medida de la longitud de los límites del condado así como que tan rectos o dentados están. Típicamente, se puede esperar un sector adicional por cada 3.2 a 4.8 kilómetros (dos a tres millas) de límite. Por lo tanto si un condado u otra área de interés es de aproximadamente 32.2 kilómetros (20 millas) por 56.3 kilómetros (35 millas), ó 1813 kilómetros cuadrados (700 millas cuadradas), el área se dividirá en aproximadamente 740 a 780 sectores.

El método de captura de imágenes oblicuas de la presente invención, en general captura las imágenes oblicuas de al menos dos direcciones de compás, y proporciona cobertura total del área de interés de al menos esas dos direcciones de compás. Con referencia ahora a las figuras 7 y 8, se muestra una primera modalidad de un método para capturar imágenes oblicuas de la presente invención. Por claridad, las figuras 7 y 8 se basan en un sistema que tiene solo un dispositivo de captura de imágenes. Sin embargo, se entenderá que pueden usarse dos o más dispositivos de captura de imágenes.

El dispositivo de captura de imágenes captura una o más imágenes durante cada área recorrida 200. El dispositivo de captura de imágenes, como se discutió anteriormente, es dirigido a un ángulo sobre el área 200 para capturar las

imágenes oblicuas de la misma. El área 200 es atravesada en un patrón de ida y vuelta, similar a la manera en la que el césped es segado, por el dispositivo portador de imágenes y/o la plataforma para asegurar la doble cobertura del área 200.

Más en particular, el área 200 es atravesada por el dispositivo portador de imágenes 32 y/o plataforma 20 siguiendo una primera trayectoria 202 para capturar de esta manera imágenes oblicuas de las porciones 202a, 202b, y 202c del área 200. El área 200 es atravesada después por el dispositivo portador de imágenes 32 y/o la plataforma 20 siguiendo un segundo patrón 204 que es paralelo y está espaciado de, y en una dirección opuesta a, es decir, 180° (ciento ochenta grados) de, la primera trayectoria 202, para capturar así imágenes oblicuas de las porciones 204a, 204b, 204c del área 200. Comparando las figuras 7 y 8, se observa que una porción 207 (figura 8) del área 200 está cubierta por las imágenes 202a-c capturadas de una primera dirección o perspectiva, y por la imágenes 204a-c capturadas de una segunda dirección o perspectiva. Como tal, la porción intermedia 200 es doblemente cubierta al 100% (cien por ciento). El patrón antes descrito de atravesar o pasar sobre el área 200 a lo largo de trayectorias opuestas que son paralelas a las trayectorias 202 y 204 se repite hasta que toda el área 200 está completamente cubierta por al menos una imagen oblicua capturada de las trayectorias que son

paralelas, y están espaciadas, una de la otra como lo establece el tamaño del área 200, y en la misma dirección que las trayectorias 202 y 204 para así cubrir doblemente el área 200 en un cien por ciento desde estas perspectivas/direcciones.

Si se desea, y para un detalle mejorado, el área 200 es cubierta por la tercera y cuarta trayectorias opuestas y paralelas adicionales 206 y 208, respectivamente, que son perpendiculares a las trayectorias 202 y 204 como se muestran en las figuras 9 y 10. El área 200 es por lo tanto atravesada por el dispositivo portador de imágenes 32 y/o la plataforma 20 siguiendo la trayectoria 206 para capturar imágenes oblicuas de las porciones 206a, 206b y 206c del área 200, y después es atravesada a lo largo de la cuarta trayectoria 208 que es paralela, está espaciada de, y opuesta a la tercera trayectoria 206 para capturar imágenes oblicuas de las porciones 208a, 208b y 208c del área 200. Este patrón e atravesar o pasar sobre el área 200 a lo largo de trayectorias opuestas que son paralelas a las trayectorias 206 y 208 se repite similarmente hasta que toda el área 200 está completamente cubierta por al menos una imagen oblicua capturada de las trayectorias que son paralelas a, y estás espaciadas de, como lo establece el tamaño del área 200, y en la misma dirección que las trayectorias 206 y 208 para así cubrir doblemente el área 200 en un cien por ciento de esas direcciones/perspectivas.

Como se describió anteriormente, el dispositivo portador de imágenes 32 y/o la plataforma 20, atraviesa o pasa sobre el área 200 a lo largo de una trayectoria predeterminada. Sin embargo, deberá entenderse que el dispositivo portador de imágenes y/o la plataforma 20 no necesariamente pasa o atraviesa directamente sobre el área 200 sino más bien puede pasar o atravesar un área adyacente, cercana a, o aún un tanto retirada del área 200 con el objeto de asegurar que la porción de área 200 que está siendo captada cae dentro del campo de captura de imagen del dispositivo de captura de imágenes. La trayectoria 202, como se muestra en la figura 7, es una trayectoria tal que no pasa directamente sobre el área 200 pero captura aún imágenes oblicuas de la misma.

La presente invención es capaz de capturar imágenes en varios niveles de resolución y distancias de muestras de terreno. Un primer nivel de detalle, al cual se le hace referencia de aquí en adelante como nivel de comunidad, tiene una distancia de muestra de terreno de, por ejemplo, aproximadamente 0.6 metros (dos pies) por píxel. Para imágenes a nivel de comunidad ortogonales, la distancia de muestra terrestre permanece substancialmente constante a través de la imagen. Las imágenes a nivel de comunidad ortogonales son capturadas con suficiente traslape para proporcionar una cobertura de par estéreo. Para imágenes a nivel de comunidad oblicuas, la distancia de muestra

terrestre varía de, por ejemplo, aproximadamente 0.3 metros (un pie) por píxel en el primer plano de la imagen a aproximadamente 0.6 metros (dos pies) por píxel en la mitad del terreno de la imagen, y hasta aproximadamente 1.2 metros (cuatro pies) por píxel en el fondo de la imagen. Las imágenes a nivel de comunidad oblicuas son capturadas con suficiente traslape de tal manera que cada área de interés está cubierta típicamente por al menos dos imágenes oblicuas de cada dirección de compás capturada. Aproximadamente se capturas diez imágenes a nivel de comunidad oblicuas por sector.

Un segundo nivel de detalle, de aquí en adelante referenciado como nivel de vecindario, está significativamente más detallado que las imágenes a nivel de comunidad. La imágenes a nivel de vecindario tienen una distancia de muestra terrestre de, por ejemplo, aproximadamente 15.24 centímetros (seis pulgadas) por píxel. Para imágenes a nivel de vecindario ortogonales, la distancia de muestra terrestre permanece substancialmente constante. Las imágenes a nivel de vecindario oblicuas tienen una distancia de muestra terrestre de, por ejemplo, aproximadamente (cuatro pulgadas) por píxel en el primer plano de la imagen a aproximadamente seis pulgadas por píxel en el terreno medio de la imagen, y hasta aproximadamente 25.4 centímetros (diez pulgadas) por píxel en el fondo de la imagen. Las imágenes a nivel de vecindario oblicuas son capturadas con suficiente traslape de tal manera que cada área de interés es cubierta

típicamente por al menos dos imágenes oblicuas de cada dirección de compás capturada, y de tal manera que las direcciones de compás opuestas proporcionan un 100% de traslape una con la otra. Aproximadamente cien (100) imágenes de área oblicua son capturadas por sector.

Deberá notarse particularmente que las imágenes oblicuas a nivel de comunidad y/o de vecindario de las cuatro direcciones de compás asegura que cada punto en la imagen aparecerá en el primer plano o una posición inferior de al menos una de las imágenes oblicuas capturadas, en donde la distancia de muestra terrestre es la más baja y el detalle de la imagen es el mayor.

En la modalidad mostrada, el sistema de captura de imágenes y geolocalización 30 incluye un giroscopio, un compás y un altímetro. Sin embargo, deberá entenderse que el sistema de captura de imágenes y geolocalización de la presente invención puede configurarse alternativamente, tal como, por ejemplo, derivar y/o calcular altitud, inclinación, balanceo y guiñada y rumbo del compás de las señales/datos de GPS y INU, haciendo que sea innecesario uno o más del giroscopio, compás y altímetro.

En la modalidad mostrada, los dispositivos de captura de imágenes están a un ángulo igual de declinación en relación con un plano horizontal. Sin embargo, se entenderá que los ángulos de declinación de los dispositivos de captura de imágenes no tienen que ser iguales.

En la modalidad mostrada, el sistema de cómputo de captura de imágenes ejecuta el software de adquisición de imágenes y datos que emite una señal de captura de imágenes común o sencilla a los dispositivos de captura de imágenes para ocasionar con ello que los dispositivos adquieran o capturen una imagen. Sin embargo, se entenderá que la presente invención puede configurarse alternativamente para provocar por separado que los dispositivos de captura de imágenes capturen imágenes en instantes diferentes y/o a intervalos diferentes.

En la modalidad mostrada, el método de la presente invención captura imágenes oblicuas para proporcionar doble cobertura de una área de interés de las trayectorias/perspectivas que están substancialmente opuestas una de la otra, es decir 180° (ciento ochenta grados) una en relación con la otra. Sin embargo, se entenderá que el método de la presente invención puede configurarse alternativamente para proporcionar doble cobertura de las trayectorias/perspectivas que generalmente y/o substancialmente son perpendiculares una en relación con la otra.

Mientras que la presente invención se ha descrito teniendo un diseño preferido, la invención puede modificarse adicionalmente dentro del espíritu y alcance de la presente descripción. Esta descripción pretende por lo tanto abarcar cualquier equivalente de las estructuras y elementos aquí

descritos. Adicionalmente, la presente descripción pretende abarcar cualquier variación, uso, o adaptaciones de la presente invención que emplee los principios generales aquí descritos. Además, esta descripción pretende abarcar cualquier alejamiento del tema descrito que acompaña al conocimiento o práctica acostumbrada en la técnica pertinente y que cae dentro de los límites de las reivindicaciones anexas.

Se hace constar que con relación a esta fecha, el mejor método conocido por la solicitante para llevar a la práctica la citada invención, es el que resulta claro de la presente descripción de la invención.

REIVINDICACIONES

Habiéndose descrito la invención como antecede se reclama como propiedad lo contenido en las siguientes reivindicaciones:

1. Un sistema para la captura de imágenes y la geolocalización de datos que corresponden a las mismas, caracterizado porque comprende:

un dispositivo de captura de imágenes, el dispositivo de captura de imágenes captura imágenes oblicuas en eventos de captura de imágenes, el dispositivo de captura de imágenes emite señales de datos de imágenes que corresponden a imágenes capturadas;

al menos un dispositivo de geolocalización, cada uno de los al menos un dispositivo de geolocalización emite al menos una señal de geolocalización correspondiente, cada una de las al menos una señal de geolocalización es indicativa al menos en parte de una geolocalización de ese dispositivo de captura de imágenes durante cada evento de captura de imágenes; y

un sistema de cómputo que recibe y almacena esas señales de imágenes y datos y la al menos una señal de geolocalización; y

software de adquisición de imágenes y datos que leen esas señales de imágenes y datos y la al menos una señal de

geolocalización, el software asocia cada una de las señales de imágenes y datos con al menos una señal de geolocalización correspondiente para cada evento de captura de imágenes.

2. El sistema de conformidad con la reivindicación 1, caracterizado porque el al menos un dispositivo de geolocalización y la al menos una señal de geolocalización comprende respectivamente uno de los siguientes:

un reloj que emite al sistema de cómputo de captura de imágenes señales de datos de tiempo indicativas de un tiempo de cada evento de captura de imágenes;

un receptor de sistema de posicionamiento global (GPS) que recibe señales del sistema de posicionamiento global y que emite al sistema de cómputo de captura de imágenes señales de datos de localización indicativas de una longitud y latitud del dispositivo de captura de imágenes en cada evento de captura de imágenes;

una unidad de navegación inercial (INU) que emite al sistema de cómputo de captura de imágenes señales de datos de velocidad indicativas de una velocidad del dispositivo de captura de imágenes en cada evento de captura de imágenes;

un giroscopio que emite al sistema de cómputo de captura de imágenes una señal de inclinación, una señal de balanceo, y una señal de guiñada indicativas respectivamente de una inclinación, un balanceo y una guiñada del dispositivo de captura de imágenes en cada evento de captura de imágenes;

un compás que emite al sistema de cómputo de captura de imágenes señales de datos de rumbo indicativas de un rumbo del dispositivo de captura de imágenes en cada evento de captura de imágenes; y

un altímetro que emite al sistema de cómputo de captura de imágenes señales de datos indicativas de una altitud del dispositivo de captura de imágenes en cada evento de captura de imágenes.

3. El sistema de conformidad con la reivindicación 1, caracterizado porque el al menos un dispositivo de geolocalización y la al menos una señal de geolocalización comprenden respectivamente:

un reloj que emite al sistema de cómputo de captura de imágenes señales de datos de tiempo indicativas de un tiempo de cada evento de captura de imágenes;

un receptor de sistema de posicionamiento global (GPS) que recibe señales del sistema de posicionamiento global y que emite al sistema de cómputo de captura de imágenes señales de datos de localización indicativas de una longitud y latitud del dispositivo de captura de imágenes en cada evento de captura de imágenes;

una unidad de navegación inercial (INU) que emite al sistema de cómputo de captura de imágenes señales de datos de velocidad indicativas de una velocidad del dispositivo de captura de imágenes en cada uno de los eventos de captura de imágenes;

un giroscopio que emite al sistema de cómputo de captura de imágenes una señal de inclinación, una señal de balanceo, y una señal de guiñada indicativas respectivamente de una inclinación, un balanceo y una guiñada del dispositivo de captura de imágenes en cada evento de captura de imágenes;

un compás que emite al sistema de cómputo de captura de imágenes señales de datos de rumbo indicativas de un rumbo del dispositivo de captura de imágenes en cada evento de captura de imágenes; y

un altímetro que emite al sistema de cómputo de captura de imágenes señales de datos indicativas de una altitud del dispositivo de captura de imágenes en cada evento de captura de imágenes.

4. El sistema de conformidad con la reivindicación 1, caracterizado porque adicionalmente comprende datos de corrección indicativos de características del dispositivo de captura de imágenes incluyendo longitud focal, tamaño de sensor, distorsión radial, desviación del punto principal y alineamiento, el software de adquisición de imágenes y datos utiliza esos datos de corrección para corregir imágenes capturadas.

5. El sistema de conformidad con la reivindicación 1, caracterizado porque adicionalmente comprende un archivo de datos de salida creado por el software de adquisición de imágenes y datos, el archivo de datos de salida incluye una

pluralidad de archivos de imagen y datos de posición que corresponden a cada una de esa pluralidad de archivos de imagen.

6. El sistema de conformidad con la reivindicación 1, caracterizado porque adicionalmente comprende una plataforma que transporta al dispositivo de captura de imágenes a una distancia predeterminada sobre una superficie de interés.

7. Un sistema computarizado para visualizar, geolocalizar, y hacer mediciones con base en imágenes oblicuas, caracterizado porque comprende:

un sistema de cómputo que tiene una memoria;

un archivo de imágenes y datos accesible por ese sistema e incluyendo una pluralidad de archivos de imágenes que corresponden a una pluralidad de imágenes oblicuas capturadas, el archivo de imágenes y datos adicionalmente incluyendo datos de posición que corresponden a esa pluralidad de archivos de imágenes;

software de visualización y análisis ejecutado por el sistema para la lectura de esos archivos de imágenes y datos y visualizando al menos una parte de las imágenes oblicuas capturadas como una imagen visualizada, el software recupera esos datos de posición de uno o más puntos seleccionados en esa imagen visualizada, el software calcula una distancia de separación entre cualquiera de dos o más puntos seleccionados en esa imagen visualizada.

8. El sistema de conformidad con la reivindicación 7, caracterizado porque adicionalmente comprende un archivo de datos del plano terrestre que representa un plano terrestre teselado, el archivo de datos del plano terrestre es accesible por medio del sistema de cómputo, el archivo de plano terrestre representa un plano terrestre teselado que se aproxima bastante al menos a una porción del terreno representado en esas imágenes oblicuas capturadas.

9. El sistema de conformidad con la reivindicación 8, caracterizado porque el plano terrestre teselado adicionalmente comprende una pluralidad de facetas interconectadas, cada una de esa pluralidad de facetas tiene una respectiva inclinación y pendiente.

10. El sistema de conformidad con la reivindicación 9, caracterizado porque el archivo de datos del plano terrestre comprende una pluralidad de vértices, cada uno de esa pluralidad de vértices tiene elevaciones respectivas y que definen esquinas de esa pluralidad de facetas interconectadas, dos de esa pluralidad de vértices están compartidas por cada una de esas facetas interconectadas.

11. El sistema de conformidad con la reivindicación 10, caracterizado porque el software de visualización y análisis de imágenes identifica cuál de esa pluralidad de facetas corresponde a un punto seleccionado en esa imagen visualizada, y calcula una elevación de ese punto

seleccionado dependiente al menos en parte de la elevación de los vértices de la faceta que corresponden al punto seleccionado, el software de visualización y análisis de imágenes utiliza esa elevación calculada para calcular la distancia de separación entre el punto seleccionado y uno más puntos seleccionados adicionales.

12. El sistema de conformidad con la reivindicación 11, caracterizado porque el software de visualización y análisis de imágenes calcula una altura de un objeto en la imagen visualizada calculando la distancia de separación entre dos o más puntos seleccionados.

13. El sistema de conformidad con la reivindicación 8, caracterizado porque el plano terrestre teselado es uno superpuesto y ajustado a esa imagen visualizada.

14. El sistema de conformidad con la reivindicación 7, caracterizado porque el software de visualización y análisis visualizada incluye modos de medición seleccionables por el usuario accesibles a través de al menos uno de menús desplegables, barras de herramientas y comandos de teclado.

15. El sistema de conformidad con la reivindicación 7, caracterizado porque cada una de las imágenes fueron capturadas por un dispositivo de captura de imágenes y en eventos de captura de imágenes respectivos, caracterizado porque los datos de posición del archivo de imágenes y datos incluye:

datos de tiempo que representan el tiempo de cada evento de captura de imágenes;

datos de localización que representan la localización del dispositivo de captura de imágenes en cada evento de captura de imágenes;

datos de orientación que representan la orientación del dispositivo de captura de imágenes en cada evento de captura de imágenes;

datos de corrección que representan factores de corrección para el dispositivo de captura de imágenes; y

datos de elevación que representan una elevación promedio de la superficie capturada por el dispositivo de captura de imágenes.

16. El sistema de conformidad con la reivindicación 15, caracterizado porque los datos de localización incluyen latitud, longitud, y altitud del aparato de captura de imágenes en cada evento de captura de imágenes.

17. El sistema de conformidad con la reivindicación 15, caracterizado porque los datos de orientación incluyen balanceo, inclinación, guiñada y rumbo del dispositivo de captura de imágenes en cada evento de captura de imágenes.

18. El conjunto de datos de conformidad con la reivindicación 15, caracterizado porque el dispositivo de captura de imágenes es una cámara y los datos de corrección incluyen al menos uno de longitud focal, tamaño de sensor,

relación de aspecto, desviación del punto principal, distorsión, e inclinación de píxeles.

19. Un método computarizado para hacer mediciones en una imagen oblicua visualizada, caracterizado porque comprende:

seleccionar con un dispositivo de entrada un punto inicial y un punto final en la imagen visualizada;

recuperar de un archivo de datos, datos de posición que corresponden al punto inicial y al punto final;

referenciar un archivo de datos de plano terrestre que corresponde a un plano terrestre teselado que tiene una pluralidad de facetas, cada una de las facetas tiene una inclinación y pendiente respectiva, el plano terrestre teselado coincide bastante con un terreno de esa imagen oblicua visualizada;

conectar los puntos iniciales y finales con segmentos de líneas, los segmentos de líneas se conforman con la inclinación y pendiente de las facetas para seguir de esta manera al terreno; y

calcular la distancia lineal a lo largo de esos segmentos de línea entre los puntos inicial y final de esta manera tomando en cuenta la inclinación y pendiente de las facetas.

20. El método de conformidad con la reivindicación 19, caracterizado porque el plano terrestre teselado se superpone a la imagen oblicua visualizada.

21. El método de conformidad con la reivindicación 19, caracterizado porque adicionalmente comprende las etapas de:

seleccionar con un dispositivo de entrada uno o más puntos intermedios en la imagen visualizada;

recuperar del archivo de datos, datos de posición que corresponden a uno o más puntos intermedios; y

conectar uno con otro puntos intermedios adyacentes, y conectar los puntos inicial y final a puntos intermedios adyacentes, con segmentos de línea, los segmentos de línea se conforman a la inclinación y pendiente de las facetas para así seguir el terreno; y

calcular la distancia a lo largo de esos segmentos de línea entre los puntos inicial y final.

22. El método de conformidad con la reivindicación 19, caracterizado porque cada una de la pluralidad de facetas corresponde a áreas iguales de la imagen oblicua visualizada.

23. El método de conformidad con la reivindicación 19, caracterizado porque cada una de la pluralidad de facetas incluye un número igual de píxeles de la imagen oblicua visualizada.

24. Un método computarizado para hacer mediciones de una imagen oblicua visualizada en un sistema de cómputo, al menos un dispositivo de entrada está conectado a ese sistema de cómputo, un archivo de datos de imágenes es accesible por medio del sistema de cómputo, el archivo de datos de imágenes

incluye imágenes capturadas y datos de posición que corresponden a las mismas, caracterizado porque el método computarizado comprende:

colocar el sistema de cómputo en un modo deseado de una pluralidad de modos de medición, el modo de medición deseado se configura para calcular una medición deseada;

seleccionar un punto inicial en la imagen visualizada;

recuperar los datos de posición que corresponden al punto inicial;

seleccionar un punto final en la imagen visualizada;

recuperar los datos de posición que corresponden al punto final; y

calcular la medición deseada dependiente al menos en parte de los datos de posición de esos puntos inicial y final.

25. El método de conformidad con la reivindicación 24, caracterizado porque adicionalmente comprende las etapas de:

seleccionar uno o más puntos intermedios en la imagen visualizada; y

recuperar los datos de posición que corresponden a los puntos intermedios.

26. El método de conformidad con la reivindicación 24, caracterizado porque la pluralidad de modos de medición comprende un modo de medición de distancia que calcula una distancia entre dos o más puntos seleccionados, un modo de

medición de altura que calcula una diferencia de altura entre dos o más puntos seleccionados, un modo de medición de elevación relativa que calcula la diferencia en elevación de dos o más puntos seleccionados, y un modo de medición de área que calcula el área abarcada por al menos tres puntos.

27. Un método de captura de imágenes oblicuas de un área de interés con un dispositivo de captura de imágenes portado por una plataforma, cada imagen oblicua capturada en un evento de captura de imagen respectivo, caracterizado porque el método comprende:

subdividir el área de interés en una pluralidad de sectores;

guiar la plataforma a lo largo de una primera trayectoria para así apuntar a uno o más sectores objetivo con el dispositivo de captura de imágenes;

capturar con el dispositivo de captura de imágenes una o más imágenes oblicuas para así cubrir una totalidad de cada sector objetivo en imágenes oblicuas capturadas de una primera perspectiva;

guiar la plataforma a lo largo de una segunda trayectoria para así apuntar a esos sectores objetivo;

capturar con el dispositivo de captura de imágenes una o más imágenes oblicuas para así cubrir

una totalidad de cada sector objetivo en imágenes oblicuas capturadas de una segunda perspectiva;

repetir las etapas de guiar y capturar a lo largo de trayectorias substancialmente paralelas y espaciadas de la primera y segunda trayectorias y capturar una o más imágenes oblicuas para cubrir así una totalidad de cada uno de la pluralidad de sectores en imágenes oblicuas capturadas de cada una de la primera y segunda perspectivas; y

registrar datos de posición indicativos de una geolocalización del dispositivo de captura de imágenes en cada evento de captura de imágenes.

28. El método de conformidad con la reivindicación 27, caracterizado porque la segunda trayectoria es substancialmente paralela en relación a 180° (ciento ochenta grados) de la primera trayectoria;

29. El método de conformidad con la reivindicación 28, caracterizado porque la segunda trayectoria está también espaciada de la primera trayectoria.

30. El método de conformidad con la reivindicación 27, caracterizado porque adicionalmente comprende las etapas de:

guiar la plataforma a lo largo de una tercera

trayectoria para así apuntar a uno o más sectores objetivo con el dispositivo de captura de imágenes, siendo la tercera trayectoria substancialmente perpendicular a la primera y segunda trayectorias;

capturar con el dispositivo de captura de imágenes una o más imágenes oblicuas para así cubrir una totalidad de cada sector objetivo en imágenes oblicuas capturadas de una tercera perspectiva; y

repetir las etapas de guiar y capturar a lo largo de trayectorias substancialmente paralelas y espaciadas de la tercera trayectoria y capturar una o más imágenes oblicuas para cubrir así una totalidad de cada uno de la pluralidad de sectores en imágenes oblicuas capturadas de esa tercera perspectiva.

31. El método de conformidad con la reivindicación 30, caracterizado porque adicionalmente comprende las etapas de:

guiar la plataforma a lo largo de una cuarta trayectoria para así apuntar a uno o más sectores objetivo con el dispositivo de captura de imágenes, siendo la cuarta trayectoria substancialmente paralela con la tercera trayectoria y 180° (ciento ochenta grados) de esa tercera trayectoria;

capturar con el dispositivo de captura de imágenes una o más imágenes oblicuas para así cubrir una totalidad de cada sector objetivo en imágenes oblicuas capturadas de una cuarta

perspectiva; y

repetir las etapas de guiar y capturar a lo largo de trayectorias substancialmente paralelas y espaciadas de la cuarta trayectoria y capturar una o más imágenes oblicuas para cubrir así una totalidad de cada uno de la pluralidad de sectores en imágenes oblicuas capturadas de esa cuarta perspectiva.

32. El método de conformidad con la reivindicación 31, caracterizado porque la cuarta trayectoria está también espaciada de la tercera trayectoria.

RESUMEN DE LA INVENCIÓN

Un sistema computarizado para visualizar, geolocalizar, y hacer mediciones de imágenes oblicuas capturadas incluye un archivo de datos accesible por medio del sistema de cómputo. El archivo de datos incluye una pluralidad de archivos de imágenes que corresponden a una pluralidad de imágenes oblicuas capturadas, y datos de posición que corresponden a las imágenes. Se ejecuta un software de visualización y análisis de imágenes a través del sistema para leer los archivos de datos y visualizar al menos una parte de las imágenes oblicuas capturadas. El software recupera los datos de posición para uno o más puntos seleccionados por el usuario en la imagen visualizada, y calcula una distancia de separación entre cualquiera de dos o más puntos elegidos. El cálculo de la distancia de separación la selecciona el usuario para determinar varios parámetros incluyendo la distancia lineal, área abarcada, elevación relativa, y diferencia de altura entre puntos seleccionados.

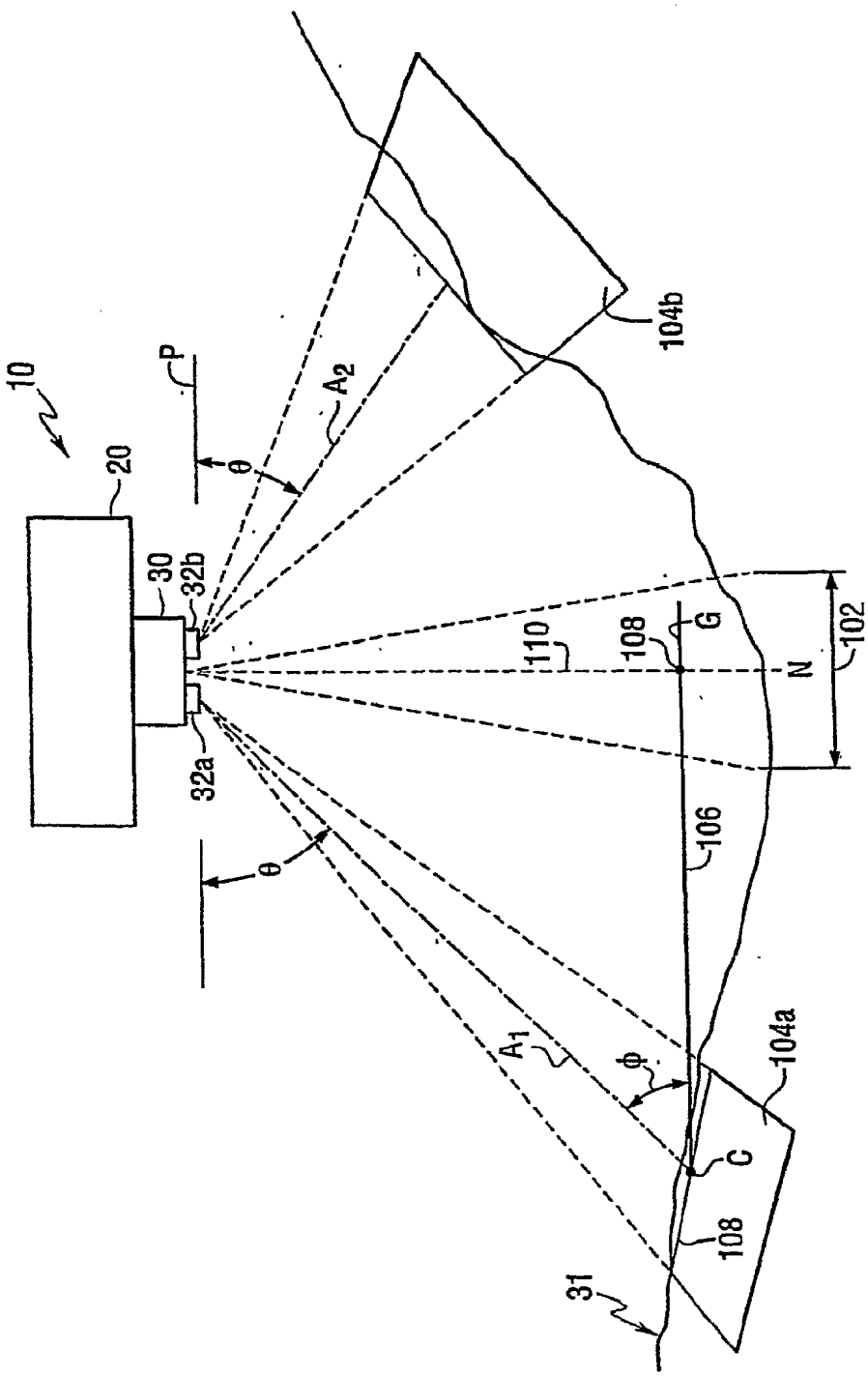


FIG. 1

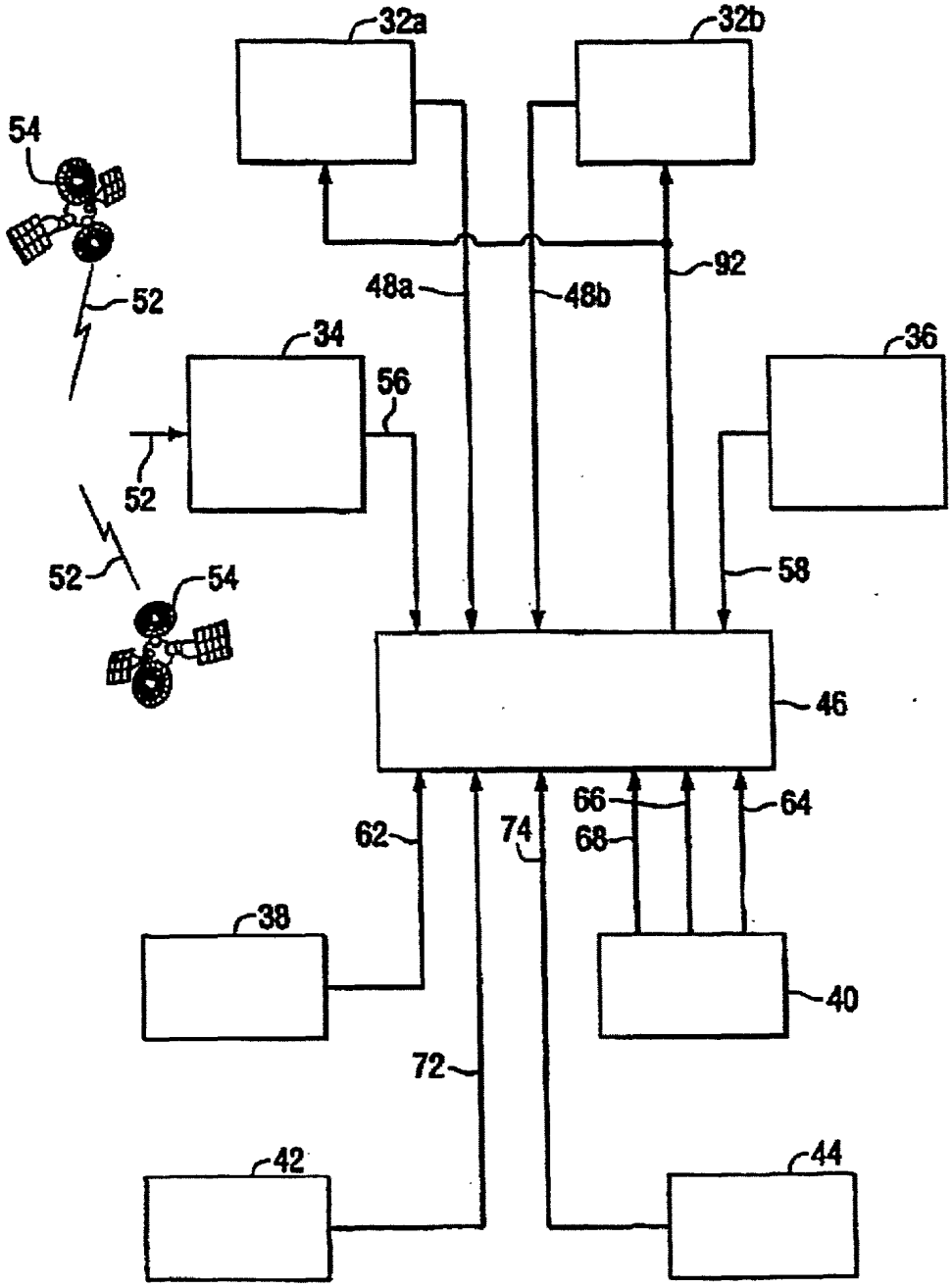

32a
32b
54
52
48a
48b
92
34
36
56
52
52
54
58
46
66
64
62
74
68
38
40
72
42
44

FIG. 2

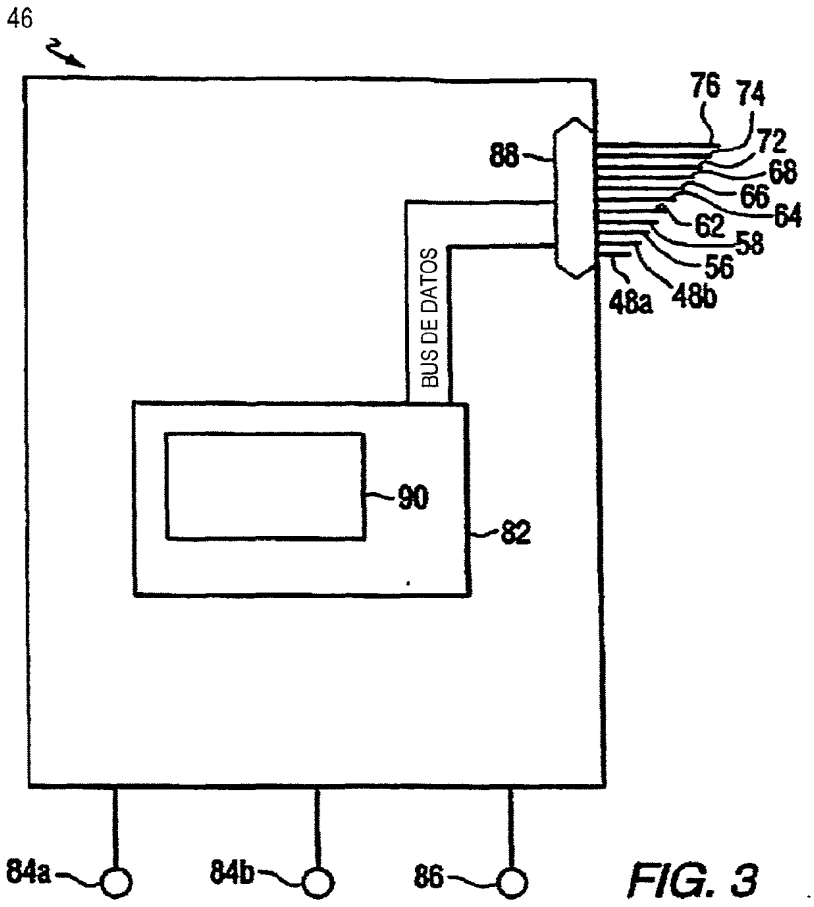

46
76
74
72
68
66
64
62
58
56
88
48a
48b
BUS DE DATOS
90
82
84a
84b
86

FIG. 3

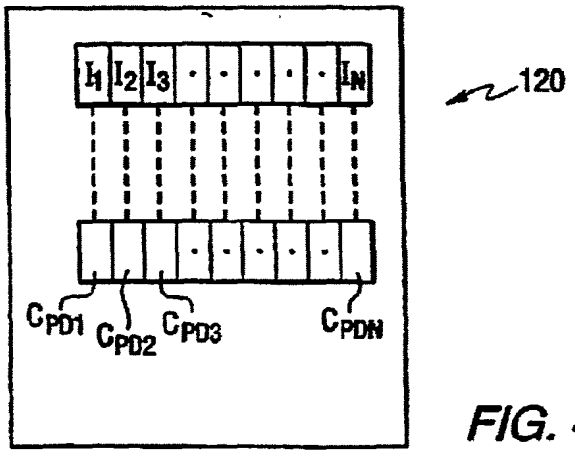

I_1 I_2 I_3 I_N
120
C_{PD1} C_{PD2} C_{PD3} C_{PDN}

FIG. 4

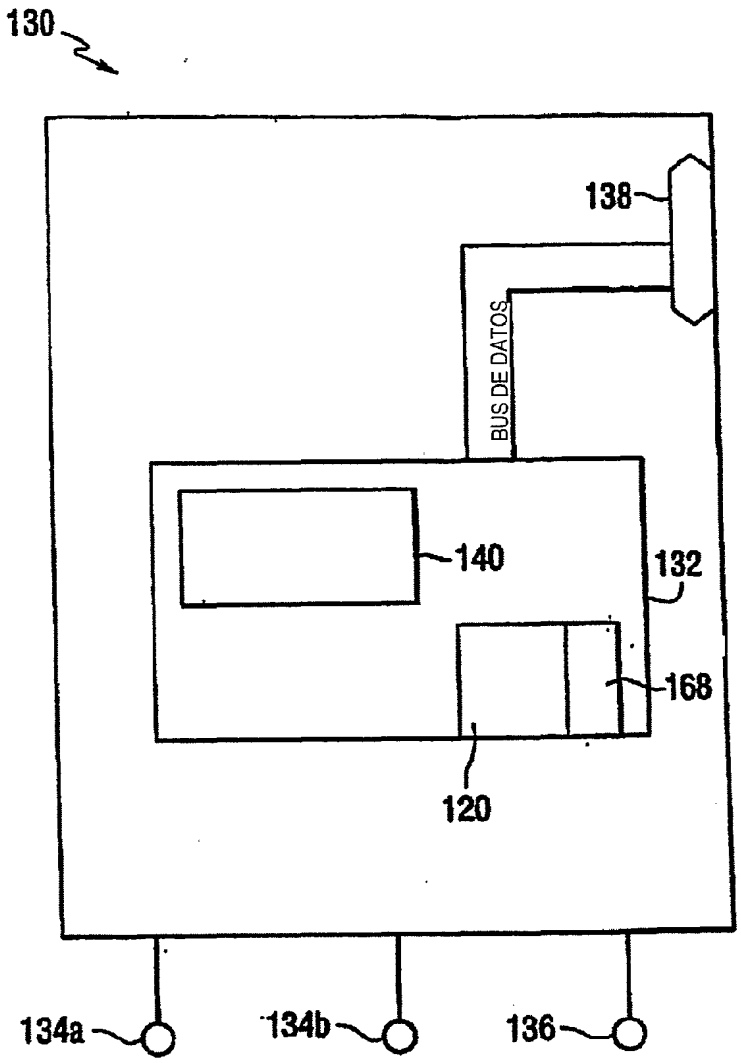


FIG. 5

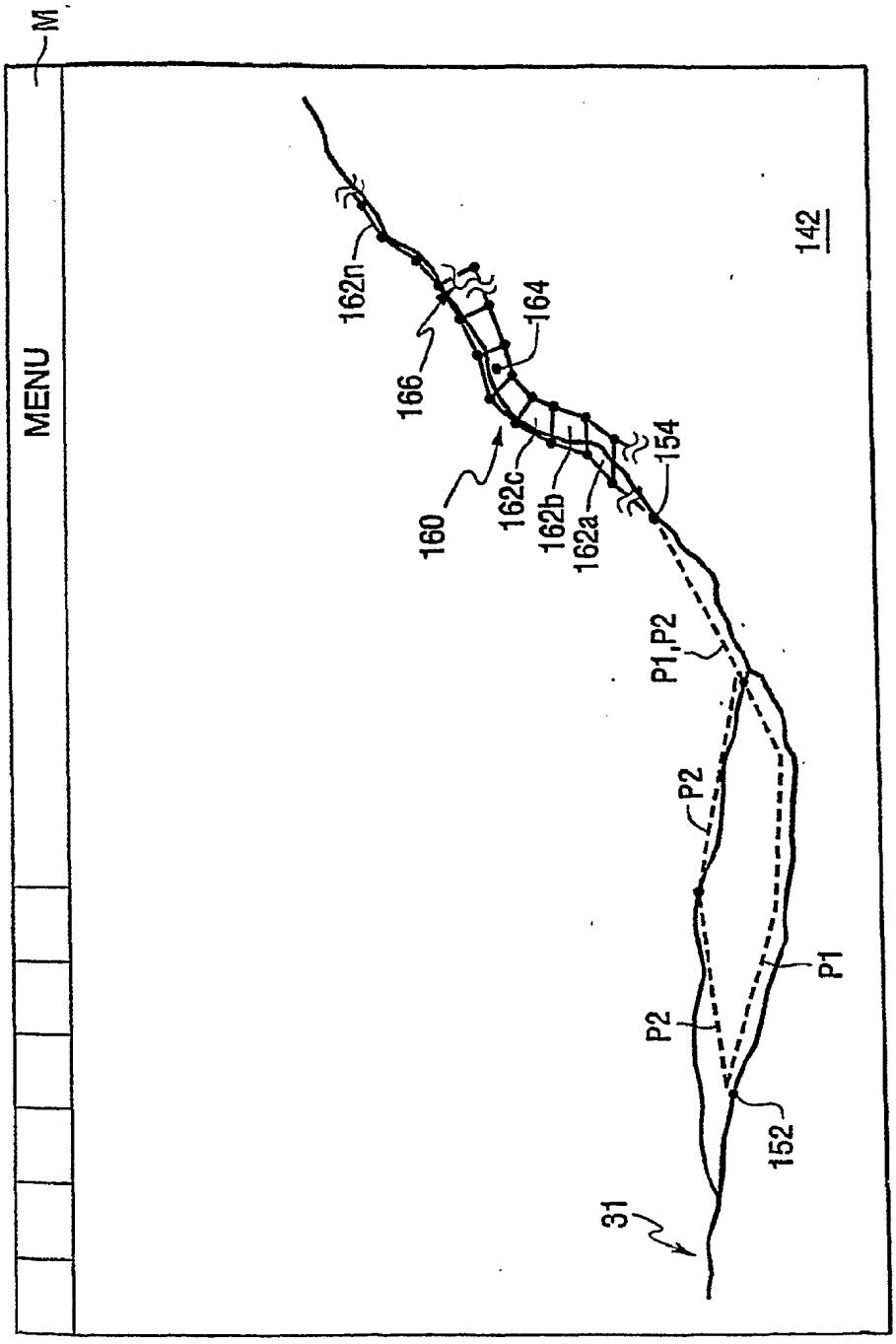

M
MENU
142
162n
164
166
160
162c
162b
162a
154
P1,P2
P2
P1
P2
152
31

FIG. 6

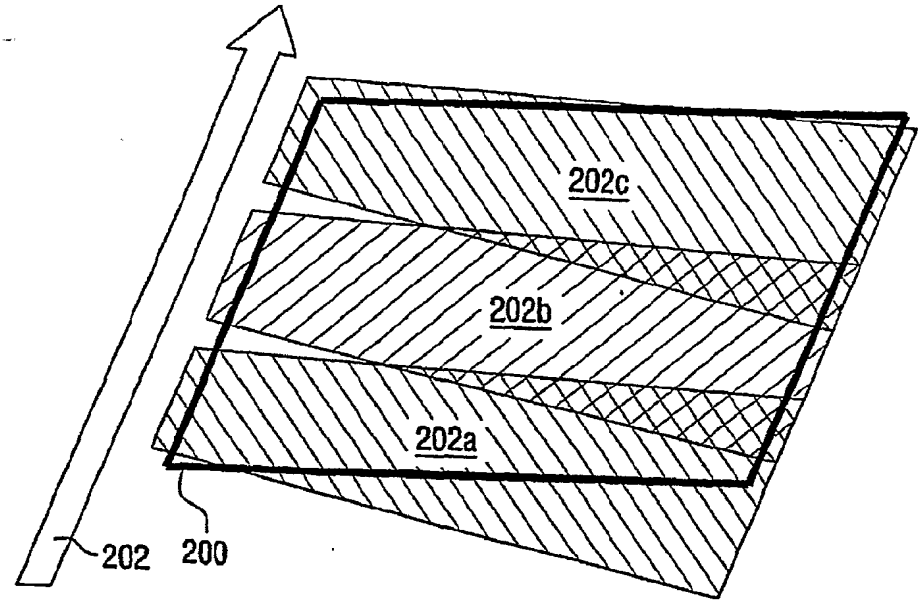


FIG. 7

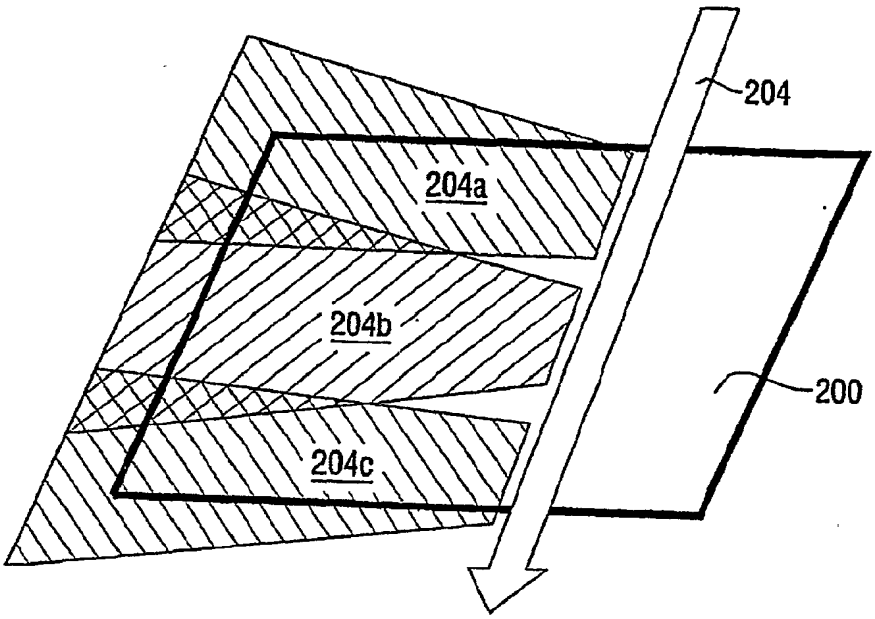


FIG. 8

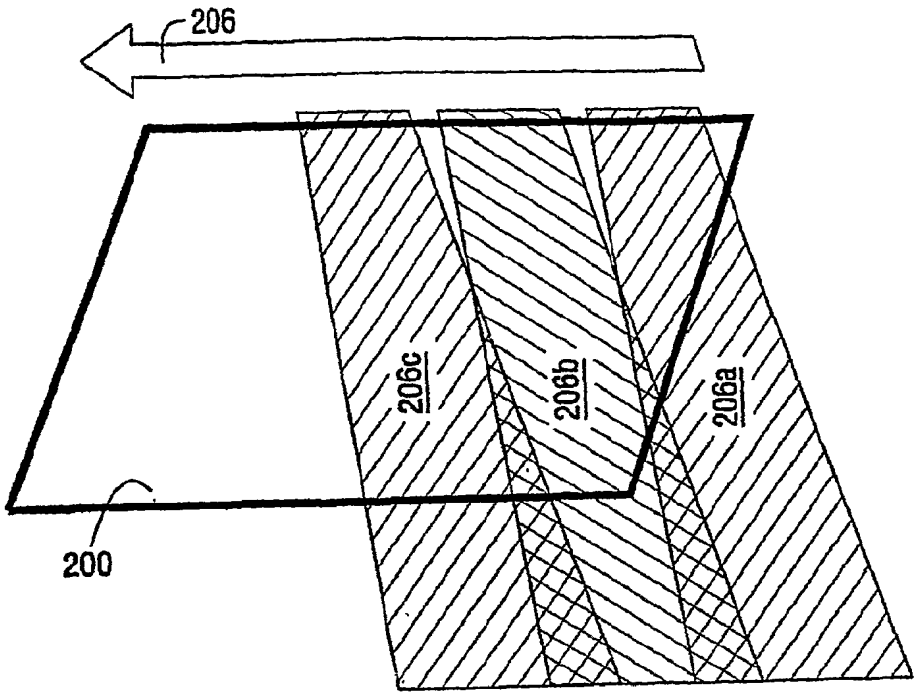


FIG. 9

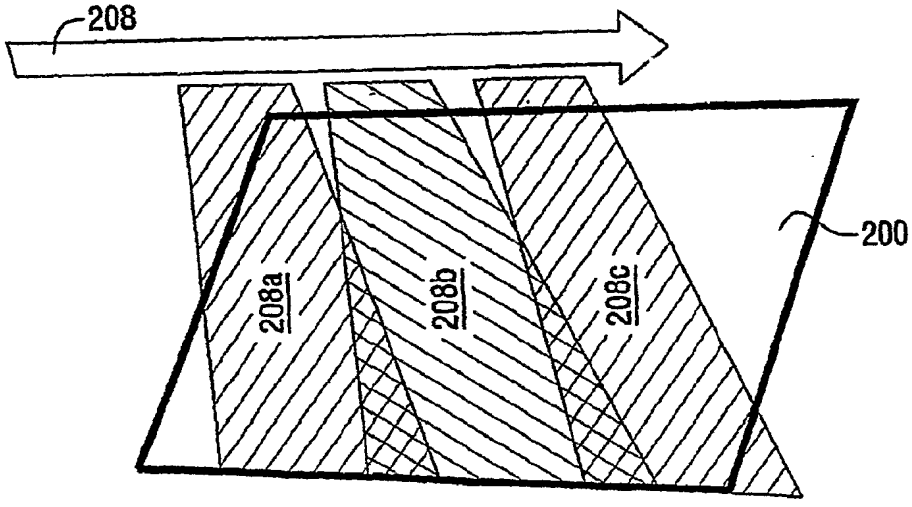


FIG. 10

Deutsches Patent- und Markenamt

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Criterion	Field	Content
Title	TI	[DE] METHOD AND APPARATUS FOR DETERMINING, geolocation SURVEYING AND BIAS recorded images
Applicant / Owner	PA	Pictometry INTERNAT CORP., U.S.
Inventor	IN	GIUFFRIDA FRANK D, U.S. GRAY ROBERT L, U.S. MONDELLO CHARLES, U.S. SCHULTZ STEPHEN L, U.S.
Joined	AD	07.11.2003
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Released	PUB	15.07.2006
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IPC -coset	ICS	
IPC additional class	ICA	
IPC index class	ICI	
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MCD-coset	MCS	G01C 11/02 (2006.01) G06T 17/05 (2011.01)
MCD additional class	MCA	
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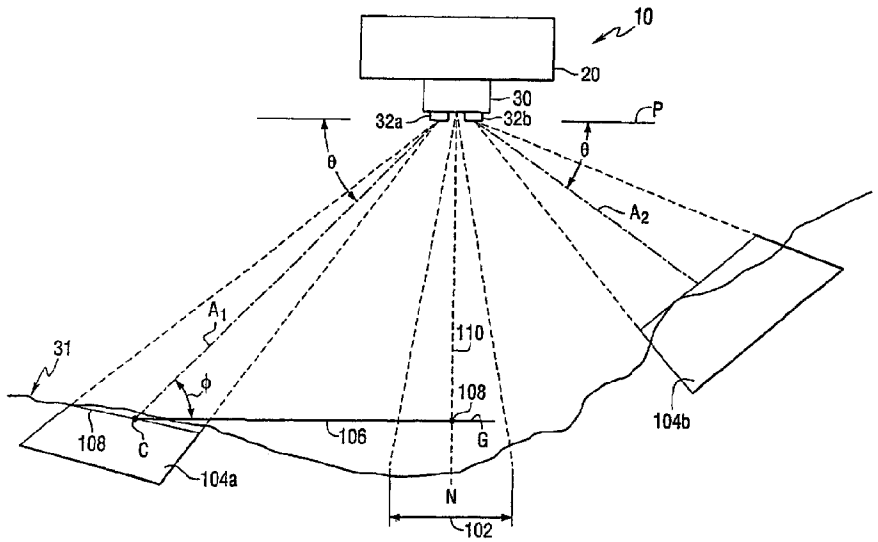
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(54) Title: OBLIQUE GEOLOCATION AND MEASUREMENT SYSTEM



(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 $I_1, I_2, \ldots, I_n$ 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}, $C_{PD2}, \ldots, C_{PDn}$ which is also stored as computer-readable data. Alternatively, positional data $C_{PD1}, C_{PD2}, \ldots, C_{PDn}$ is embedded within the corresponding image files $I_1, I_2, \ldots, I_n$ 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.

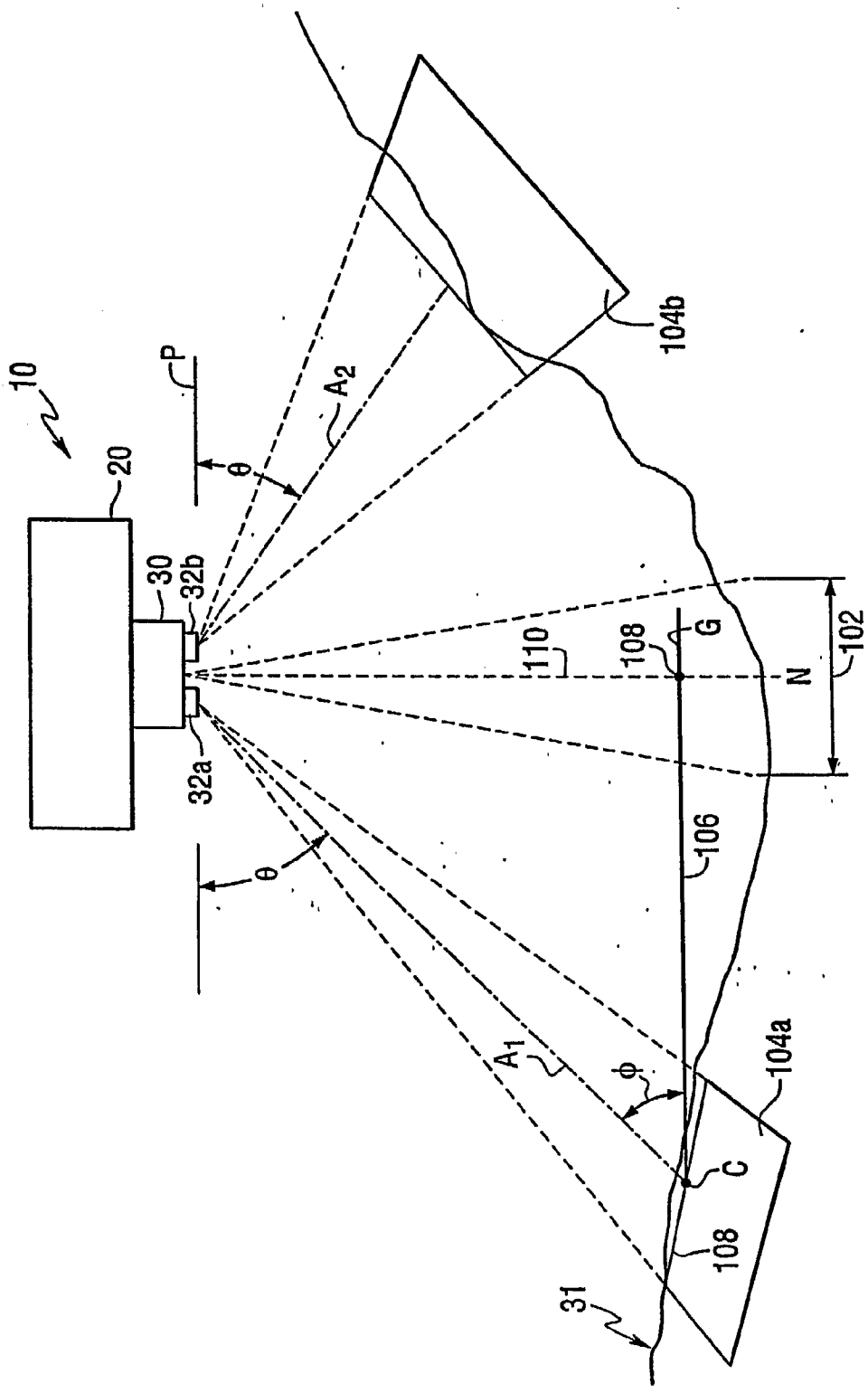


FIG. 1

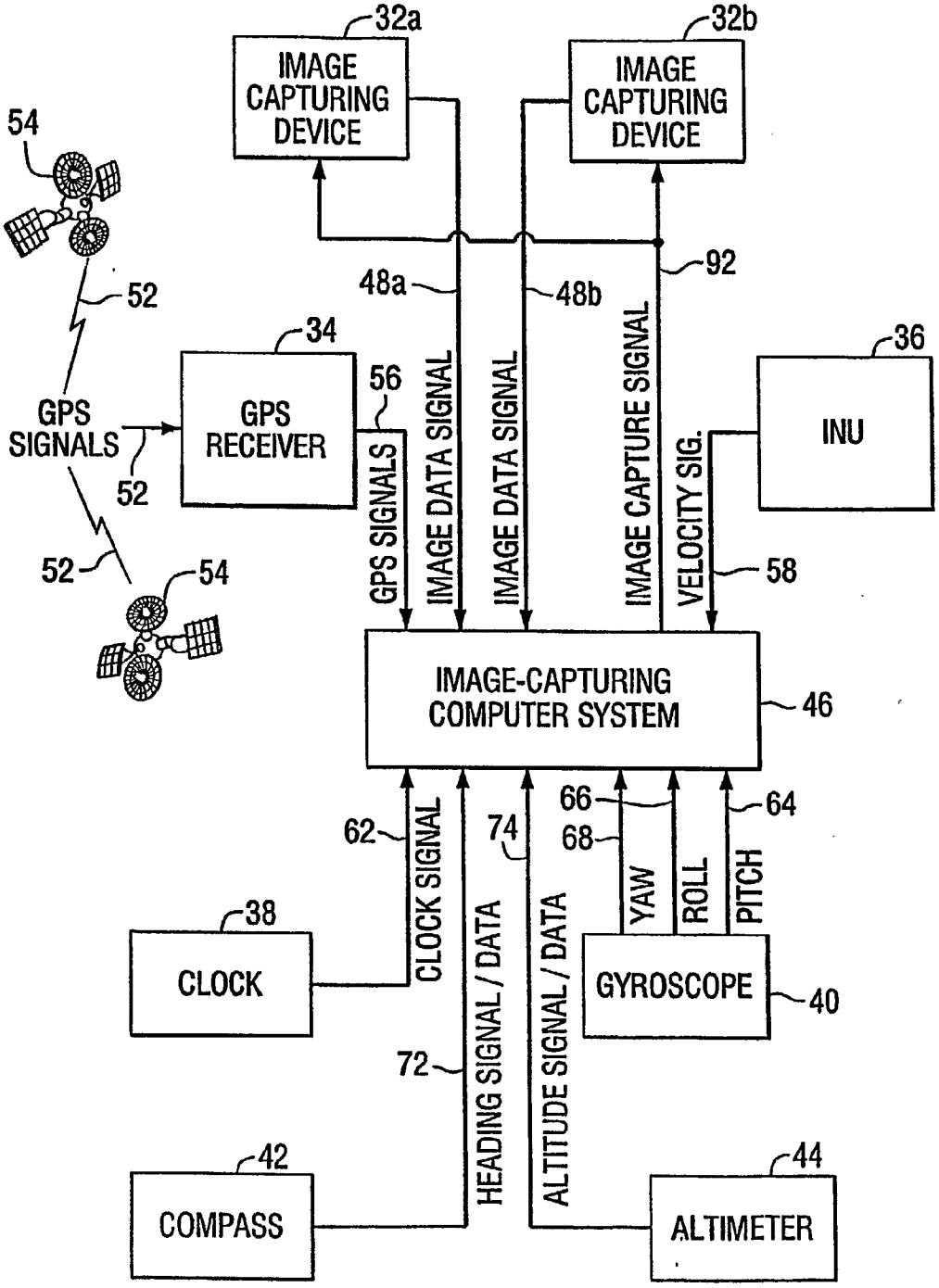

32a
IMAGE CAPTURING DEVICE
32b
IMAGE CAPTURING DEVICE
54
52
GPS SIGNALS
52
34
GPS RECEIVER
56
GPS SIGNALS
48a
IMAGE DATA SIGNAL
48b
IMAGE DATA SIGNAL
92
IMAGE CAPTURE SIGNAL
36
INU
VELOCITY SIG.
58
52
54
IMAGE-CAPTURING COMPUTER SYSTEM
46
62
CLOCK SIGNAL
74
HEADING SIGNAL / DATA
ALTITUDE SIGNAL / DATA
66
68
YAW
ROLL
PITCH
64
38
CLOCK
GYROSCOPE
40
72
42
COMPASS
44
ALTIMETER

FIG. 2

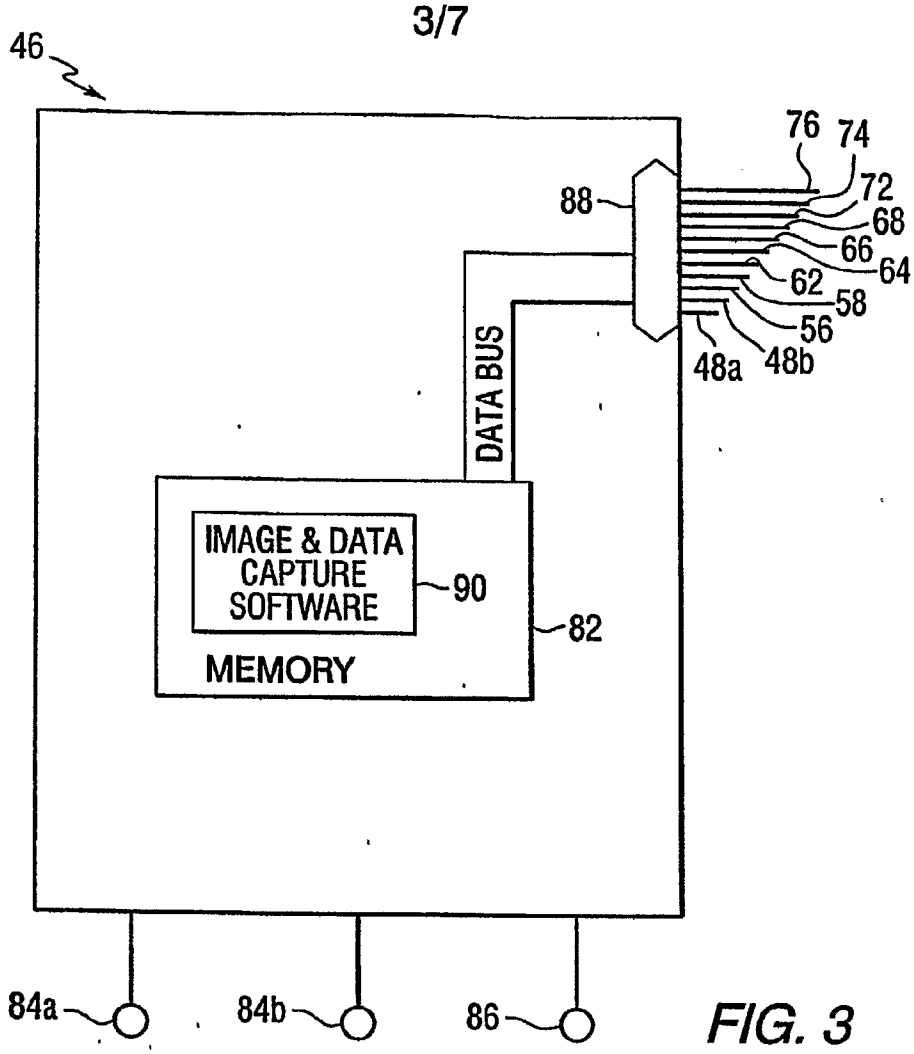

46
76
74
72
68
66
64
62
58
56
88
48a
48b
DATA BUS
IMAGE & DATA CAPTURE SOFTWARE
90
MEMORY
82
84a
84b
86

FIG. 3

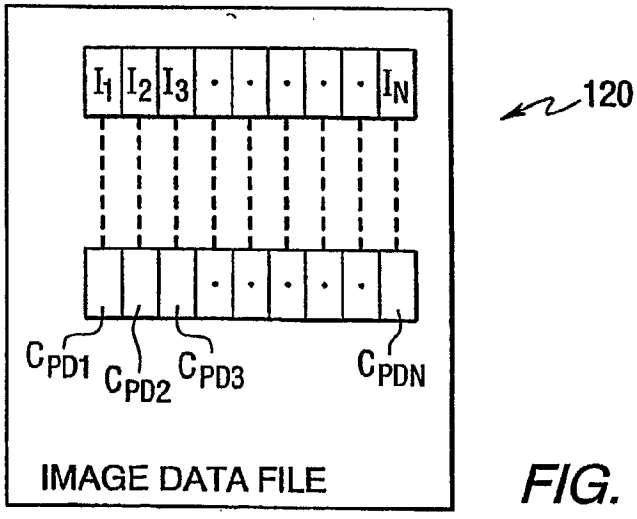

I_1 I_2 I_3 I_N
120
C_{PD1} C_{PD2} C_{PD3} C_{PDN}
IMAGE DATA FILE

FIG. 4

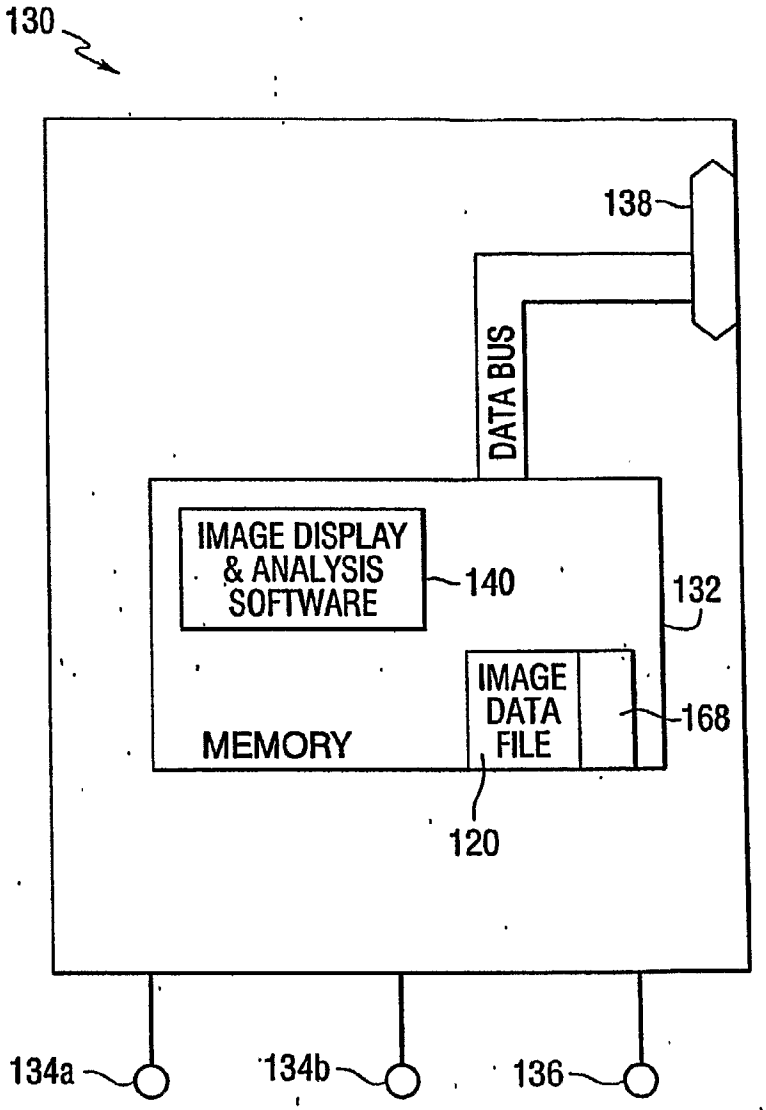

130
138
DATA BUS
IMAGE DISPLAY & ANALYSIS SOFTWARE
140
132
IMAGE DATA FILE
168
MEMORY
120
134a
134b
136

FIG. 5

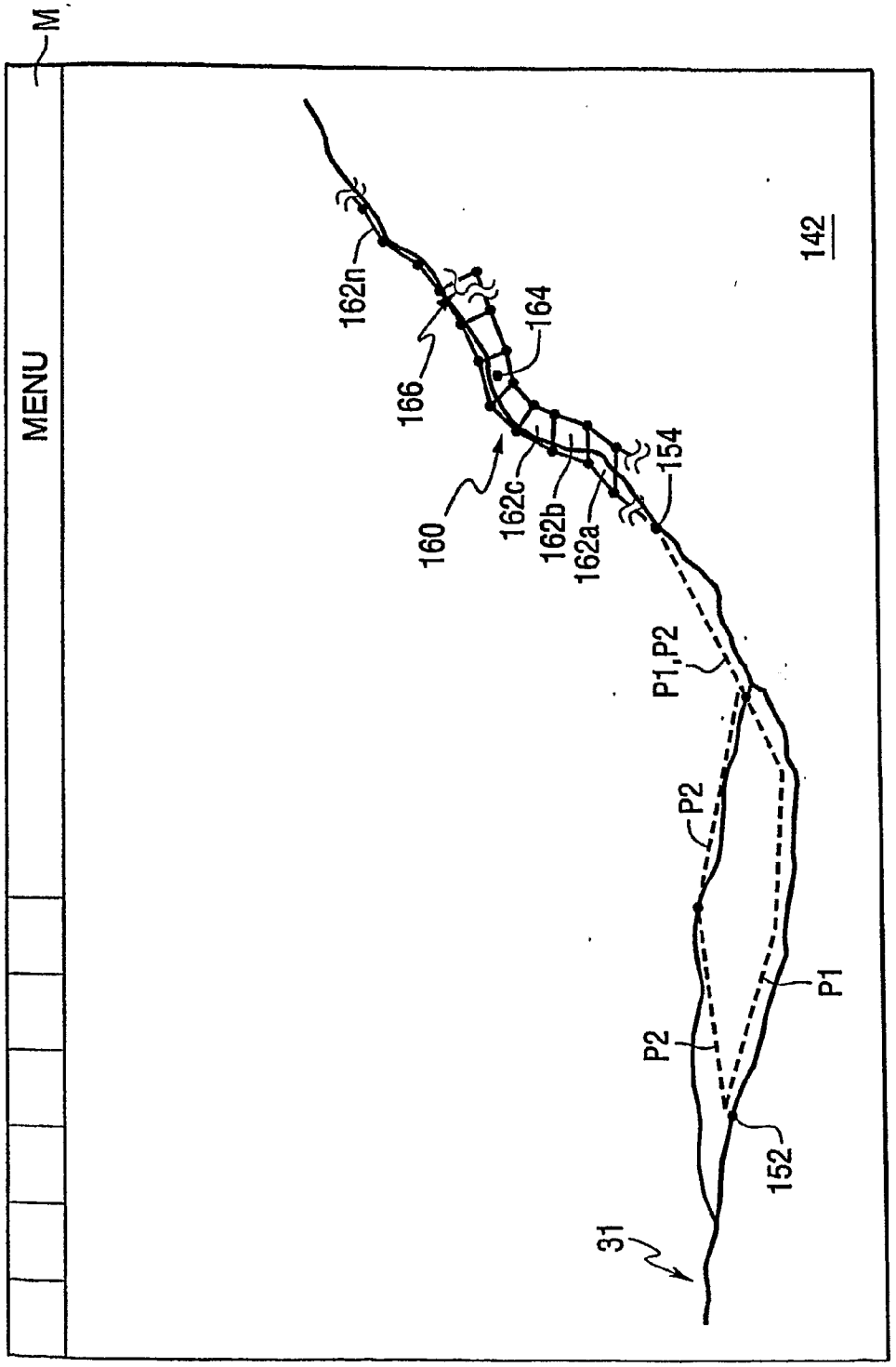

M
MENU
142
162n
166
164
160
162c
162b
162a
154
P1,P2
P2
P1
P2
152
31

FIG. 6

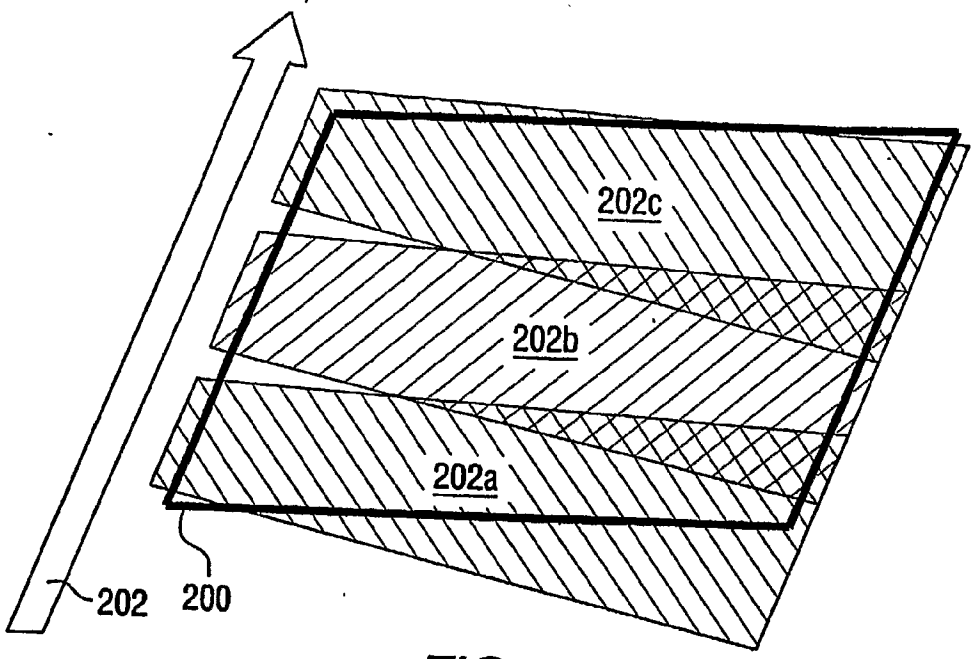


FIG. 7

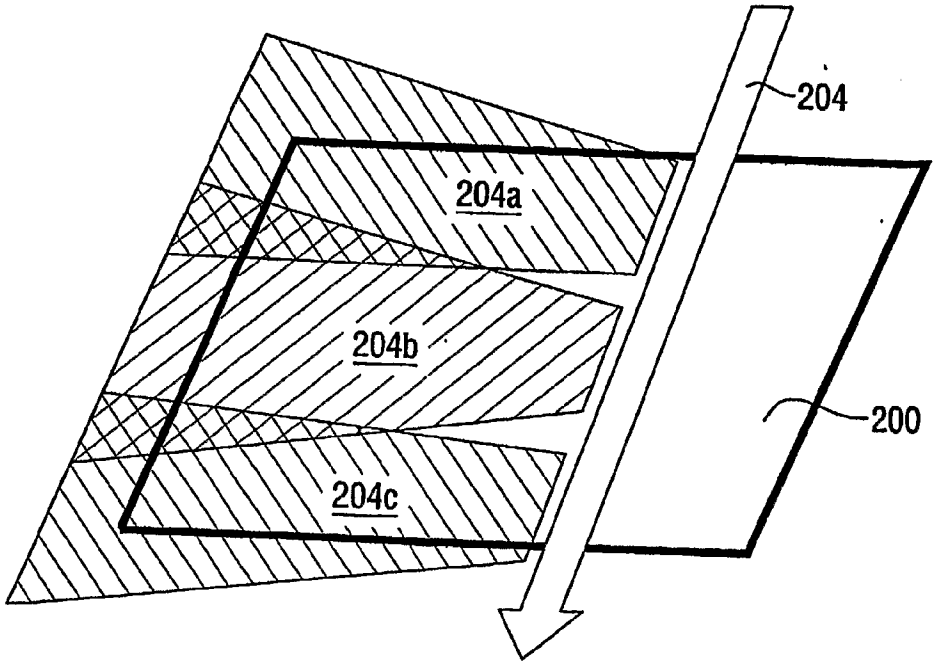


FIG. 8

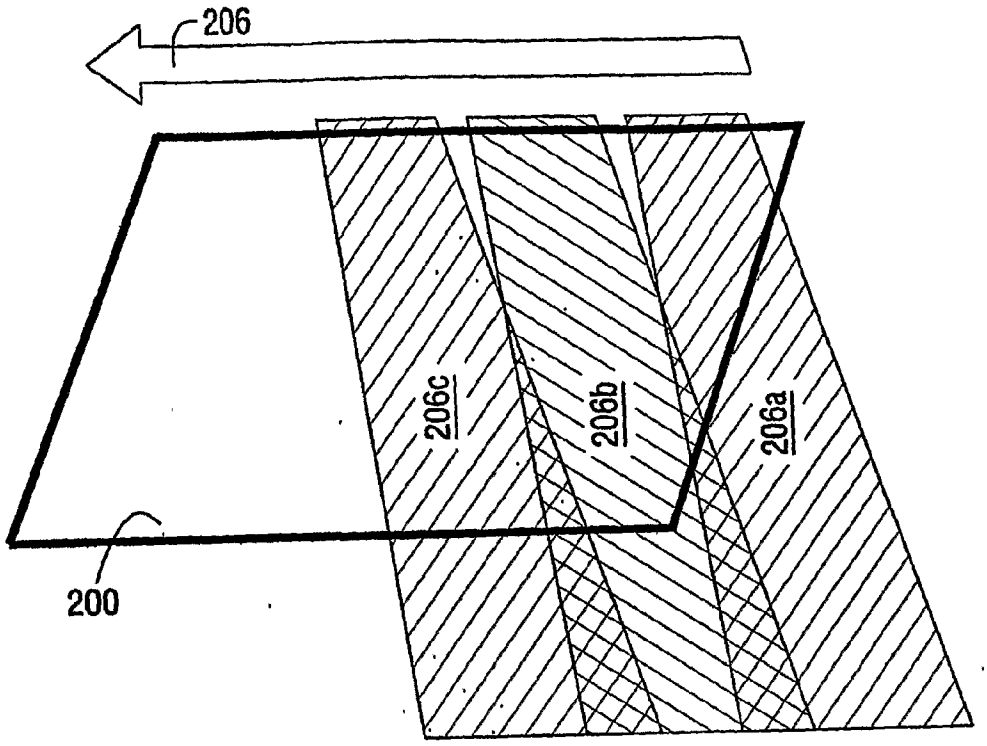


FIG. 9

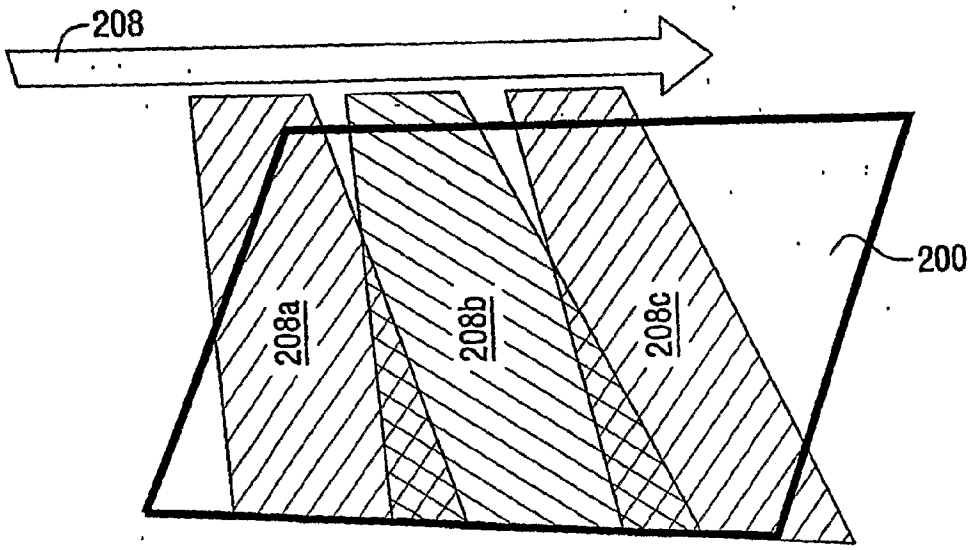


FIG. 10

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Opfindelsen vedrører fotogrammetri. Opfindelsen angår især en fremgangsmåde og et apparat til at optage skråbilleder og til at måle objekter og afstande mellem objekter afbildet deri.

Fotogrammetri er læren om at foretage målinger af og med objekter, der er vist i fotos, navnlig luftfotos. Generelt indebærer fotogrammetri at tage billeder af terrestriske træk og udtrække data deraf, som f.eks. data indikerende relative afstande mellem og størrelser af objekter i billederne. Fotogrammetri kan også indebære sammenkobling af fotografier med andre data, såsom data repræsenterende breddegrad og længdegrad. I virkeligheden bliver billedet overlejret og gjort konformt med et særligt rumkoordinatsystem.

Konventionel fotogrammetri indebærer optagelse og/eller anskaffelse af orthogonale billeder. Billedtagningsindretningen, såsom et kamera eller sensor, bliver båret på et køretøj eller platform, såsom et fly eller en satellit, og bliver rettet mod et nadirpunkt, som ligger direkte under og/eller lodret nedad fra platformen. Punktet eller pixlen i billedet, der svarer til nadirpunktet er det eneste punkt/pixel, som er sandt orthogonalt for billedtagningsindretningen. Alle andre punkter eller pixler i billedet er i virkeligheden skrå i forhold til billedtagningsindretningen. Efterhånden som punkter eller pixler ligger i stigende afstand fra nadirpunktet, så ligger de i stigende grad skrå i forhold til billedtagningsindretningen, og ligeledes vil den målte jordprøveafstand (dvs. overfladeområdet der svarer til eller dækkes af hver pixel) også øges. Denne skråhed i et orthogonalt billede medfører, at træk i billedet bliver forvrænget, navnlig billeder, der er relativt langt fra nadirpunktet.

En sådan forvrængning fjernes eller kompenseres gennem en proces til orthokorrektion, som i bund og grund fjerner skråheden fra det orthogonale billede ved at fitte eller krumme hver pixel i et orthogonalt billede ned på et orthometrisk gitter eller koordinatsystem. Orthokorrektionsprocessen skaber et billede, hvori alle pixler har samme afstand til jorden og er orienteret mod nord. Således kan et vilkårligt punkt på et orthokorrigeret billede blive lokaliseret ved brug af et X-Y koordinatsystem, og så længe billedskaleringen er kendt, så kan længden og bredden af terrestriske træk såvel som den relative afstand mellem disse træk blive beregnet.

Skønt orthokorrektionsprocessen kompenserer i et vist omfang for skævvridninger i et orthogonalt billede, så indfører den andre uønskede forvrængninger og/eller unøjagtig-

heder i det orthokorrigerede orthogonale billede. Objekter afbildet i orthokorrigerede orthogonale billeder kan være svære at genkende og/eller identificere, fordi de fleste observatører ikke er vant til at betragte objekter, navnlig terrestriske træk, set ovenfra. For en utrænet observatør vil et orthokorrigeret billede have en række forvrængninger. Veje, der i virkeligheden er lige, fremstår krumme, og bygninger kan se ud til at hælde. Ydermere vil orthokorrigerede billeder rumme i det væsentlige ingen information med hensyn til højden af terrestriske elementer. Tolkningen og analysen af orthogonale og/eller orthokorrigerede orthogonale billeder bliver typisk udført af veltrænede analytikere, der har års specialtræning og erfaring i at kunne identificere objekter og terrestriske elementer i sådanne billeder.

Skønt orthogonale og orthokorrigerede billeder er nyttige i fotogrammetri, mangler de således information om højden af elementerne, der er afbildet deri, og kræver veltrænede analytikere til at tolke detaljer fra det, som billederne viser.

Skråbilleder er billeder, der optaget med billedtagningsindretningen sigtende eller pegende generelt til siden for eller nedad fra platformen, der bærer billedtagningsindretningen. I modsætning til orthogonale billeder viser skråbilleder siderne af terrestriske elementer, såsom huse, bygninger og/eller bjerge såvel som toppene deraf. Således bliver betragtning af et skråbillede mere naturligt og intuitivt end at betragte et orthogonalt eller orthokorrigeret billede, og selv tilfældige observatører vil være i stand til at genkende og tolke terrestriske elementer og andre objekter, der er afbildet i skråbilleder. Hver pixel i forgrunden af et skråbillede svarer til et relativt lille område af den afbillede overflade eller objekt (dvs. hver forgrundspixel har en relativt lille grundprøveafstand), mens hver pixel i baggrund svarer til et relativt stort område af den afbildede overflade eller objekt (dvs. hver baggrundspixel har en relativt stor grundprøveafstand). Skråbilleder optager et generelt trapezformet område eller billede af den undersøgte overflade eller objekt, hvorved forgrunden af trapezen har en betydelig mindre grundudsnitslængde (dvs. en højere opløsning) end baggrunden af trapezen.

Skråbilleder anses for at være af lille eller ingen nytte i fotogrammetri. Den traditionelle fremgangsmåde til at tvinge de forskellige størrelser forgrunds- og baggrundspixler af et skråbillede ind i en fælles størrelse for derved at vride billedet ned over et koordinatsystem giver en dramatisk forvrængning af skråbilledet og gør derved identifikation af objekter og udførelse af målinger af objekter, der er afbildet deri, til en

arbejdskrævende og unøjagtig opgave. Korrektion for terrænforskydning i et skråbillede gennem brug af en elevationsmodel vil yderligere forvrænge billederne og derved forøge det besvær, hvormed målinger kan foretages, og nøjagtigheden af enhver sådan måling reduceres.

Skønt skråbilleder anses for at være af lille eller ingen nytte i fotogrammetri, så er de lette at tolke og indeholder information vedrørende højden af de deri afbillede elementer. WO 99/18732 A1 beskriver et system og en fremgangsmåde til at optage, geolokalisere og måle skråbilleder omfattende en billedtagningsindretning, en geolokaliseringsindretning, et computersystem og et billed- og dataopsamlingsprogram, som knytter billeddata til geolokaliseringssignaldata.

Derfor behøves der på dette tekniske felt en fremgangsmåde og et apparat til fotogrammetri, der muliggør geolokation og nøjagtige målinger i skråbilleder.

Ydermere er der behov for en fremgangsmåde og et apparat til fotogrammetri, som muliggør måling af højder og relative højder af objekter i et billede.

Ydermere behøves en fremgangsmåde og et apparat til fotogrammetri, der benytter mere intuitive og naturlige billeder.

Ifølge opfindelsen er der tilvejebragt et system ifølge krav 1.

De ovennævnte og andre træk og fordele ved opfindelsen, og måden at opnå dem på, vil fremgå mere klart og forståeligt under henvisning til den efterfølgende beskrivelse af én udførelsesform for opfindelsen i forbindelse med de vedføjede tegninger, hvor:

fig. 1 viser en udførelsesform for en platform eller køretøj, der bærer et billedtagningssystem ifølge opfindelsen, og viser eksempler på orthogonale og skrå billeder taget dermed;

fig. 2 er et skematisk billede af billedtagningssystemet i fig. 1;

fig. 3 er et blokdiagram af billedtagningscomputersystemet i fig. 2;

fig. 4 viser en repræsentation af en som eksempel valgt outputdatafil fra billedtagningssystemet i fig. 1;

fig. 5 er et blokdiagram af en udførelsesform for et billedvisnings- og måltagnings-computersystem ifølge opfindelsen til at fremvise og tage målinger af og mellem objekter afbildet i billederne, der er optaget med billedtagningssystemet i fig. 1;

fig. 6 viser et eksempel på et billede vist med systemet i fig. 5 og illustrerer en udførelsesform for fremgangsmåden ifølge opfindelsen til måling af og mellem objekter afbildet i et sådant billede;

fig. 7 og 8 viser en udførelsesform for en fremgangsmåde til at tage skråbilleder ifølge opfindelsen;

fig. 9 og 10 viser en anden udførelsesform for en fremgangsmåde til at tage skråbilleder ifølge opfindelsen.

Der benyttes ens referencetal til at indikere tilsvarende dele overalt i de forskellige billeder. De viste eksempler angiver en foretrukket udførelsesform for opfindelsen i en udførelsesform, og sådanne eksempler skal ikke opfattes som på nogen måde begrænsende for opfindelsens sigte.

Under henvisning til tegningerne, navnlig fig. 1, ses en udførelsesform for et apparat til at optage og geolokalisere skråbilleder ifølge opfindelsen. Apparatet 10 inkluderer en platform eller fartøj 20, der bærer billedtagnings- og geolokaliseringssystemet 30.

Platformen 20, som f.eks. et fly, et rumskib, raket, satellit eller et vilkårligt andet fartøj, bærer billedtagningssystemet 30 over et prædefineret område af og i én eller flere forudbestemte højder over overfladen 31, som f.eks. jordens omflade eller en vilkårlig anden udvalgt overflade. Platformen 20 er som sådan i stand til at foretage en kontrolleret bevægelse eller flyvning, enten bemandet eller ubemandet, langs en forud-defineret flyvelinie eller kurs gennem f.eks. jordens atmosfære eller det ydre rum. Billedtagningsplatformen 20 inkluderer et system til at generere og regulere strøm-energi (ikke vist), der inkluderer f.eks. én eller flere generatorer, brændselsceller, solpaneler og/eller batterier til at strømforsyne billedtagningssystemet 30.

Billedtagnings- og geolokaliseringssystemet 30 inkluderer, som det bedst ses i fig. 2, billedtagningsindretninger 32a og 32b, en global positioneringssystem (GPS) modtager 34, en inertinavigeringsenhed (INU) 36, en klokke 38, et gyroskop 40, et kompas 42 og en højdemåler 44, hvorved hver af disse er forbundet med billedtagnings-computersystemet 46.

Billedtagningsindretningerne 32a og 32b, som f.eks. traditionelle kameraer, digitale kameraer, digitale sensorer, ladningskoblede indretninger (CCD) eller andre egnede billedtagningsindretninger, er i stand til at tage billeder fotografisk eller elektronisk. Billedtagningsindretningerne 32a og 32b har kendte eller bestemmelige egenskaber inkluderende brændvidde, sensorstørrelse og billedformat, radiale og andre forvrængningsbetingelser, hovedpunktsforskydning, pixelpitch og orientering. Billedtagningsindretningerne 32a og 32b indsamler billeder og afgiver billeddatasignaler (IDS) 48a og 48b svarende til de optagne valgte billeder eller fotografier, og hvilke er lagret i billedtagningscomputersystemet 46, som det vil fremgå mere præcist beskrevet nedenfor.

Som det bedst ses af fig. 1, har billedtagningsindretningerne 32a og 32b respektive midterakser A_1 og A_2 og er monteret på platformen 20, således at akserne A_1 og A_2 hver står i en afbøjningsvinkel θ i forhold til et vandret plant P. Afbøjningsvinklen θ er stort set enhver skrå vinkel, men den vil fortrinsvis være ca. 20° til ca. 60° og er helst fra ca. 40° til ca. 50°.

GPS modtageren 34 modtager globalpositioneringssystemsignaler 52, der bliver transmitteret af én eller flere global positioneringssystemsatellitter 54. GPS signalerne 52 gør det på kendt måde muligt at fastsætte den præcise lokation af platformen 20 i forhold til overfladen 31. GPS modtageren 34 dekoder GPS signalerne 52 og afgiver lokationssignaler/data 56, der afhænger mindst delvis af GPS signaler 52, og som er indikative for den nøjagtige lokation af platformen 20 i forhold til overfladen 31. Lokationssignaler/data 56 svarende til hvert billede optaget af billedtagningsindretningerne 32a og 32b bliver modtaget og lagret i billedtagningscomputersystemet 46.

INU 36 er en traditionel inertinavigationsenhed, som er koblet til og bestemmer ændringer i hastigheden, inkluderende translations- og rotationshastighed, af billedtagningsindretningerne 32a og 32b og/eller platformen 20. INU 36 afgiver hastighedssignaler/data 58, der er indikative for sådanne hastigheder og/eller ændringer deri til billedtagningscomputersystemet 46, der lagrer hastighedssignaler/data 58 svarende til hvert billede, der er taget med billedtagningsindretningerne 32a og 32b, bliver modtaget og lagret af billedtagningscomputersystemet 46.

Klokken 38 holder en nøjagtig tidsmåling (valideringstid), som bliver anvendt til at synkronisere begivenheder i billedtagnings- og geolokaliseringssystemet 30. Klokken

38 tilvejebringer et tidsdata/klokkesignal 62, som indikerer det nøjagtige tidspunkt, hvor et billede er taget med billedtagningsindretningerne 32a og 32b. Tidsdata 62 bliver også tilvejebragt til og lagret i billedtagningscomputersystemet 46. Alternativt er klokken 38 udformet integralt med billedtagningscomputersystemet 46, som f.eks. med et klokkeprogram.

Et gyroskop 40 er et traditionelt gyroskop, der almindeligvis findes på fly og/eller i kommercielle navigationssystemer for fly. Gyroskopet 40 leverer signaler inkluderende pitch-signal 64, roll-signal 66 og yaw-signal 68, hvilke hver især er indikative for hældning, vipning og drejning af platformen 20. Pitch-signalet 64, roll-signalet 66 og yaw-signalet 58 svarende til hvert billede, der er taget med billedtagningsindretningerne 32a og 32b, bliver modtaget og lagret i billedtagningscomputersystemet 46.

Kompasset 42, f.eks. et traditionelt elektronisk kompas, indikerer orienteringen af platformen 20. Kompasset 42 afgiver et orienteringssignal/data 72, der er indikativt for orienteringen af platformen 20. Billedtagningscomputersystemet 46 modtager og lagrer orienteringssignalerne/dataene 72, som svarer til hvert billede optaget med billedtagningsindretningerne 32a og 32b.

Højdemåleren 44 indikerer højden af platformen 20. Højdemåleren 44 afgiver højdesignal/data 74, og billedtagningscomputersystemet 46 modtager og lagrer højdesignal/data 74, der svarer til hvert billede optaget med billedtagningsindretningerne 32a og 32b.

Det ses bedst af fig. 3, at billedtagningscomputersystemet 46, såsom f.eks. en traditionelt laptop PC, inkluderer en hukommelse 82, inputindretninger 84a og 84b, visningsmekanismen 86, og input og output (I/O) porte 88. Billedtagningscomputersystemet 46 eksekverer billed- og dataindsamlingsprogrammet 90, som er lagret i hukommelsen 82. Hukommelsen 82 lagrer også data, der er anvendt og/eller beregnet af billedtagningscomputersystemet 46 under driften deraf, og inkluderer f.eks. en non-volatile, kun læsbar hukommelse (ROM), en tilfældigadgangshukommelse (RAM), en harddiskhukommelse, udtagelige hukommelseskort og/eller andre egnede hukommelseslagerindretninger og/eller media. Inputindretninger 84a og 84b, såsom f.eks. en mus, tastatur, joystick eller andre lignende inputindretninger muliggør indtastning af data og interaktion mellem en bruger og programmet styret af billedtagningscomputersystemet 46. Visningsindretningen 86, såsom f.eks. et flydende krystal-

display (LCD) eller et katodestrålerør (CRT), viser information til brugeren af billedtagningscomputersystemet 46. I/O porte 88, såsom f.eks. serielle og parallelle dataindtastninger og outputporte, iværksætter indtastning og/eller udtræk af data til og fra billedtagningscomputersystemet 46.

Hver af de ovenfor beskrevne datasignaler er knyttet til billedtagningscomputersystemet 46. Mere præcist, så bliver billeddatasignaler 48, lokationssignaler 56, hastighedssignaler 58, tidsdatasignalet 62, pitch-, roll- og yaw-signaler 64, 66 og 68, orienteringssignalet 72 og højdesignalet 74 modtaget via I/O porte 88 på og lagret i hukommelsen 82 af billedtagningscomputersystemet 46.

Billedtagningscomputersystemet 46 aktiverer under drift billed- og dataindsamlingsprogrammet 90, som generelt styrer læsning/manipulering og lagring af de ovenfor beskrevne datasignaler. Mere præcist indlæser billed- og dataindsamlingsprogrammet 90 billeddatasignaler 48a og 48b og lagrer dem i hukommelsen 82. Hvert af lokationssignalerne 56, hastighedssignalerne 58, tidsdatasignalet 62, pitch, roll og yaw-signalerne 64, 66 og 68, orienteringssignalet 72 og højdesignalet 74, der repræsenterer de forhold, der eksisterede i det øjeblik, hvor et billede bliver anskaffet eller optaget med billedtagningsindretningerne 32a og 32b, og som svarer til de særlige billeddatasignaler 48a og 48b, der repræsenterer de optagne billeder, bliver modtaget af billedtagningscomputersystemet 46 gennem I/O portene 88. Billedtagningscomputersystemet 46, som aktiverer billed- og dataindsamlingsprogrammet 90 udsender billedtagningssignalet 92 til billedtagningsindretninger 32a og 32b for derved at få disse indretninger til at indsamle eller tage et billede ved forudbestemte lokationer og/eller ved forudbestemte intervaller, som afhænger mindst delvis af hastigheden af platformen 20.

Billed- og dataindsamlingsprogrammet 90 dekoder om nødvendigt og lagrer de førnævnte signaler i hukommelsen 82, og knytter datasignalerne sammen med tilsvarende billedsignaler 48a og 48b. Således kendes højden, orienteringen i form af roll, pitch og yaw og lokationen af billedtagningsindretningerne 32a og 32b i forhold til overfladen 31, dvs. længde- og breddegrad for hvert billede taget med billedtagningsindretningerne 32a og 32b.

Platformen 20 bliver styret eller på anden vis ført gennem en billedtagningsbane, som passerer over et særligt område af overfladen 31, som f.eks. et forudbestemt område

af overfladen af jorden eller en anden planet. Fortrinsvis vil billedtagningsbanen for platformen 20 ligge i rette vinkler i forhold til i det mindste én af grænserne for det udvalgte område. Antallet af gange platformen 20 og/eller billedtagningsindretningerne 32a og 32b passerer over det udvalgte område afhænger i det mindste delvis af størrelsen af området, og mængden af ønskede detaljer i de optagne billeder. De særlige detaljer af billedtagningsbanen for platformen 20 er beskrevet mere konkret nedenfor.

Når platformen 20 passerer over det udvalgte område så bliver en række skråbilleder taget med billedtagningsindretningerne 32a og 32b. Det vil være indlysende for en fagmand, at billeder bliver taget eller samlet ved hjælp af billedtagningsindretningerne 32a og 32b ved forudbestemte billedtagningsintervaller, der er afhængige i det mindste delvis af hastigheden af platformen 20.

Billeddatasignalerne 48a og 48b svarende til hvert indhentet billede bliver modtaget af og lagret i hukommelsen 82 i billedtagningscomputersystemet 46 via I/O porte 88. På tilsvarende måde bliver datasignalerne (dvs. billeddatasignaler 48, lokationssignaler 56, hastighedssignaler 58, tidsdatasignalet 62, pitch-, roll- og yaw-signaler 64, 66 og 68, orienteringssignal 72 og højdesignal 74) svarende til hvert optaget billede modtaget og lagret i hukommelsen 82 i billedtagningscomputersystemet 46 via I/O porte 88. Således bliver lokationen af billedtagningsindretningen 32a og 32b i forhold til overfladen 32 registreret i hukommelsen 82 med det nøjagtige tidspunkt, hvor hvert billede bliver taget og knyttet sammen med det tilsvarende optagne billede.

Det fremgår bedst af fig. 1, at lokationen af billedtagningsindretningerne 32a og 32b i forhold til jorden svarer til nadirpunktet N af det orthogonale billede 102. Således bliver den nøjagtige geolokation af nadirpunktet N i det orthogonale billede 102 indikeret ved lokationssignalet 56, hastighedssignaler 58, tidsdatasignalet 62, respektive pitch-, roll- og yaw-signaler 64, 66 og 68, retningssignalet 72 og højdesignalet 74. Når først nadirpunktet N i det orthogonale billede 102 er kendt, så kan geolokationen af en vilkårlig anden pixel eller punkt i billedet 102 blive bestemt på kendt måde.

Når billedtagningsindretningerne 32a og 32b optager skråbilleder, såsom skråbillederne 104a og 104b (fig. 1), så vil lokationen af billedtagningsindretningerne 32a og 32b i forhold til overfladen 31 blive indikeret på tilsvarende måde af lokationssignaler 56, hastighedssignaler 58, tidsdatasignalet 62, respektive pitch-, roll- og yaw-signaler 64, 66 og 68, retningssignal 72, højdesignal 74 og den kendte afbøjnings-

vinkel θ af primærakserne A_1 og A_2 af de respektive billedtagningsindretninger 32a og 32b.

Det bør især bemærkes, at en kalibreringsproces sætter billed- og datahentningsprogrammet 90 i stand til at indarbejde korrektionsfaktorer og/eller korrigere for enhver fejl, der er indbygget i eller skyldes billedtagningsindretningen 32, såsom f.eks. fejl som følge af kalibreret brændvidde, sensorstørrelse, radial forvrængning, hovedpunktsforskydning og orientering.

Billed- og datahentningsprogrammet 90 skaber og lagrer i hukommelsen 88 et eller flere outputbilled- og datafiler 120. Billed- og datahentningsprogrammet 90 vil især omdanne billeddatasignaler 48a, 48b og orienteringsdatasignaler (dvs. billeddatasignaler 48, lokationssignaler 56, hastighedssignaler 58, tidsdatasignal 62, respektive pitch-, roll- og yaw-signaler 64, 66 og 68, retningssignal 72 og højdesignal 74) til computerlæsbare, færdige billed- og datafiler 120. I fig. 4 ses en færdig billed- og datafil 120 at indeholde et antal optagne billedfiler I_1, I_2, ..., I_n svarende til optagne skråbilleder, og positionsdata C_{PD1}, C_{PD2}, ..., C_{PDn} svarende dertil.

Billedfilerne I_1, I_2, ..., I_n i billed- og datafilen 120 bliver lagret i hovedsageligt ethvert computerlæsbart billed- eller grafikfilformat, som f.eks. JPEG, TIFF, GIF, BMP eller PDF filformater, og bliver krydsrefereret med positionsdata C_{PD1}, C_{PD2}, ..., C_{PDn}, der også lagres som computerlæsbare data. Alternativt bliver positionsdata C_{PD1}, C_{PD2}, ..., C_{PDn} indlagt i de tilhørende billedfiler I_1, I_2, ..., I_n på kendt måde. Billeddatafiler 120 bliver derefter bearbejdet enten ved hjælp af billed- og datahentningsprogrammet 90 eller ved efterbehandling for at korrigere for fejl som f.eks. fejl, der skyldes flyvelinieafvigelser og andre fejl, som vil være kendt for en fagmand. Derefter vil billeddatafilerne 120 være klar til brug for at fremvise og foretage målinger af og mellem objekterne afbildet i de tagne billeder, inkluderende målinger af højderne af sådanne objekter.

Nu henvises til fig. 5, hvor der vises et billedvisnings- og målingscomputersystem 130, såsom f.eks. en traditionel bordcomputer eller en bærbar computer i en politibil, som indeholder en hukommelse 132, indtastningsindretninger 134a og 134b, en fremvisningsindretning 136 og en netværksforbindelse 138. Billedtagningscomputersystemet 130 aktiverer billedvisnings- og analyseprogrammet 140, som ligger lagret i hukommelsen 132. Hukommelsen 132 inkluderer f.eks. en ikke-flygtig ROM, en RAM,

harddiskhukommelse, udtagelige hukommelseskort og/eller andre egnede lagringsindretninger og/eller -media. Indtastningsindretningerne 134a og 134b som f.eks. en mus, et tastatur, et joystick eller andre lignende indtastningsindretninger, gør det muligt for en bruger at indtaste data og interagere med billedvisnings- og analyseprogrammet 140, der køres af billedvisnings- og målingscomputersystemet 130. Visningsindretningen 136 såsom en LCD skærm eller CRT skærm viser information til brugeren af billedvisnings- og målingscomputersystemet 130. Netværksforbindelsen 138 forbinder billedvisnings- og målingscomputersystemet 130 til et netværk (ikke vist) såsom f.eks. et LAN, WAN, internet og/eller WWW.

Under brug, og med henvisning til fig. 6, ses billedvisnings- og målingscomputersystemet 130, der afvikler billedvisnings- og analyseprogrammet 140, at åbne én eller flere outputbilled- og datafiler 120, der er blevet indlæst i hukommelsen 132, som f.eks. via netværksforbindelsen 138, et floppediskdrev, et udtageligt hukommelseskort eller andre passende midler. Ét eller flere af de optagne billeder I_1, I_2, ..., I_n af de færdige billed- og datafiler 120 bliver herefter vist som det viste skråbillede 142 under kontrol af billedvisnings- og analyseprogrammet 140. På næsten samme tid bliver én eller flere dataportioner C_{PD1}, C_{PD2}, ..., C_{PDn} svarende til det viste skråbillede 142 indlæst i en let tilgængelig del af hukommelsen 132.

Det bør især bemærkes, at det viste skråbillede 142 vises i det væsentlige som det blev optaget dvs. det viste billede 142 er ikke krummet eller fittet til noget koordinatsystem, og det viste billede 142 er heller ikke blevet orthokorrigeret. I stedet for at vride det viste billede 142 over et koordinatsystem for at muliggøre måling af objekter afbildet deri, så bestemmer billedvisnings- og analyseprogrammet 140 generelt kun de geolokationer for udvalgte pixel, som er nødvendige, eller bestemmer dem "i farten" gennem reference til dataportioner C_{PD1}, C_{PD2}, ..., C_{PDn} af de færdige billed- og datafiler 120 og beregning af positionen og/eller geolokationen af de udvalgte pixels under anvendelse af én eller flere projektionsformler, som det vil blive beskrevet mere detaljeret herefter.

Generelt foretager en bruger af visnings- og målingscomputersystemet 130 målinger af og mellem objekter afbildet i det viste skråbillede 142 gennem at vælge én af flere tilgængelige målemetoder tilvejebragt i billedvisnings- og analyseprogrammet 140. Brugeren vælger den ønskede målemetode gennem at gå ind i f.eks. en række rullegardinmenuer eller værktøjslinier M, eller via tastaturkommandoer. Målemetoderne,

som er tilvejebragt af billedvisnings- og analyseprogrammet 140, inkluderer f.eks. en afstandsmetode, der muliggør måling af afstanden mellem to eller flere udvalgte punkter, en arealmetode, der muliggør måling af det areal, som omsluttes af flere udvalgte og sammenknyttede punkter, en højdemetode, der muliggør måling af højden mellem to eller flere udvalgte punkter, og en elevationsmetode, der muliggør måling af ændringen i elevation af et udvalgt punkt i forhold til ét eller flere andre udvalgte punkter.

Efter valg af den ønskede målemetode vælger brugeren af billedvisnings- og analyse-programmet 140 ved hjælp af én af indtastningsindretningerne 134a, 134b et start-punkt eller en startpixel 152 og et slutpunkt eller -pixel 154 på det viste billede 142, og billedvisnings- og analyseprogrammet 140 vil automatisk beregne og vise den søgte mængde som f.eks. afstanden mellem startpixlen 152 og slutpixlen 154.

Når brugeren vælger startpunkt/pixel 152, bliver geolokationen af det dertil svarende punkt på overfladen 31 ved hjælp af billedvisnings- og analyseprogrammet 140, som gennemfører én eller flere projektionsformler ved brug af dataportionerne C_{PD1}, C_{PD2}, ..., C_{PDn} af output billed- og datafilerne 120, der svarer til det konkret viste billede. Længde- og breddegrad af punktet på overfladen 31 svarende til pixlen 152 bliver derpå vist på skærmen 136 ved hjælp af billedvisnings- og analyseprogrammet 140 som f.eks. ved at overlejre længde- og breddegraden på det viste billede 142 tæt ved det udvalgte punkt/pixel eller i et pop-op vindue et andet sted på skærmen 136. Den samme fremgangsmåde gentages af brugeren vedrørende valget af slutpixel/punkt 154 og med billedvisnings- og analyseprogrammet 140 for udtrækning og visning af længde- og breddegradsinformationen.

Beregningen af afstanden mellem start- og slutpunkter/pixler 152, 154 sker ved at fastslå geolokationen af hver enkelt pixel 152, 154 "i farten". Dataportionerne C_{PD1}, C_{PD2}, ..., C_{PDn} af output billed- og datafilen 120 svarende til det viste billede bliver trukket frem, og geolokationen af punktet på overfladen 31 svarende til hver enkelt valgt pixel, bliver derpå bestemt. Forskellen mellem geolokationerne svarende til de valgte pixler bestemmer afstanden mellem pixlerne.

Som et eksempel på hvorledes geolokationen af et bestemt punkt eller pixel i det viste skråbillede 142 bliver bestemt, vil vi antage, at det viste billede 142 svarer til det orthogonale billede 104a (fig. 1). Brugeren af billedvisnings- og analyseprogrammet

140 vælger pixlen 152, der for enkelthedens skyld svarer til centrum C (fig. 1) af skråbilledet 104a. Som vist i fig. 1 strækker linien 106 sig langs det vandrette plan G fra et punkt 108 deri, som ligger direkte under billedtagningsindretningen 32a, til centrum C af den nære rand eller kant 109 af skråbilledet 104a. Forlængelsen af primæraksen A_1 skærer gennem centrum C. Vinklen Ø er den vinkel, som dannes mellem linien 106 og forlængelsen af primæraksen A_1. Således bliver der dannet en trekant (uden referencenummer), der har toppunkter ved billedtagningsindretningen 132a, punktet 108 og centrum C, og har sider 106, forlængelsen af primæraksen A_1 og den lodrette (stiplede) linie 110 mellem punktet 108 og billedtagningsindretningen 32a.

Grundplanet G er et hovedsageligt vandret, plant eller ikke-skrånende grundplan (og som typisk vil have en elevation, der afspejler den gennemsnitlige elevation af terrænet), og derfor inkluderer den ovenfor beskrevne trekant en ret vinkel mellem siden/linien 110 og siden/linien 106. Fordi vinklen Ø og højden af billedtagningsindretningen 32a (dvs. længden af siden 110) er kendt, så bliver hypotenusen (dvs. længden af forbindelsen af primæraksen A_1) og den resterende anden side af den retvinklede trekant beregnet ved simpel geometri. Ydermere og fordi den nøjagtige position af billedtagningsindretningen 32a er kendt på tidspunktet, hvor billedet svarende til det viste billede 142a blev taget, vil også længde- og breddegraden af punktet 108 være kendt. Med kendskab til længden af siden 106, beregnet som beskrevet ovenfor, bliver det muligt at bestemme den nøjagtige geolokation af pixlen 154 svarende til centrum C af skråbilledet 104a ved hjælp af billedvisnings- og analyseprogrammet 140. Når først geolokationen af punktet svarende til pixlen 154 er kendt, så vil geolokationen af en vilkårlig anden pixel i det viste skråbillede 142 kunne bestemmes ved brug af de kendte kamerakarakteristika, såsom f.eks. brændvidde, sensorstørrelse og billedformat, radial og andet forvrængningsforhold, osv.

Afstanden mellem de to eller flere punkter svarende til to eller flere udvalgte pixler i det viste billede 142 beregnes ved hjælp af billedvisnings- og analyseprogrammet 140 gennem at fastlægge forskellen mellem geolokationerne af de udvalgte pixler under brug af kendte algoritmer, såsom f.eks. Gaussfordelingen og/eller forsvindingspunktmodellen, afhængigt af den valgte målemetode. Målingen af objekter afbildet eller optrædende i det viste billede 142 sker ved hjælp af en procedure, der i det væsentlige svarer til proceduren beskrevet ovenfor til måling af afstande mellem udvalgte pixler. F.eks. bliver længderne, bredderne og højderne af objekter, såsom f.eks. bygninger, floder, veje og i det væsentlige enhver anden geografisk eller

menneskeskabt struktur, der optræder i det viste billede 142, målt gennem at vælge en passende/ønsket målemetode og at vælge start- og slutpixlerne.

Det bør især bemærkes, at i afstandsmålemetoden i billedvisnings- og analyseprogrammet 140 bliver afstanden mellem de respektive start- og slutpunkter/pixler 152, 154 bestemt langs i det væsentlige en vilkårlig bane, som f.eks. en "lige-linie"-bane P1 eller en bane P2, som indebærer valg af mellempunkter/pixler og én eller flere "lige-linie"-segmenter, som er forbundet dertil.

Det bør også blive særligt bemærket, at afstandsmålemetoden i billedvisnings- og analyseprogrammet 140 bestemmer afstanden mellem udvalgte pixler ifølge en "gå på jorden" metode. Denne "gå på jorden" metode skaber en række indbyrdes forbundne liniesegmenter, repræsenteret kollektivt i form af banerne P1 og P2, som strækker sig mellem de udvalgte pixler/punkter, og som ligger på eller konformt med de plane plader af en række af indbyrdes forbundne facetter, der definerer et mosaikgrundplan. Mosaikgrundplanet, som vil blive mere detaljeret beskrevet nedenfor, følger nøje eller genskaber overfladens 31 terræn, og derfor følger banerne P1 og P2 også tæt overfladens 31 terræn. Ved at måle afstanden langs terrænet simuleret ved mosaikgrundplanet, så vil "gå på jorden" metoden tilvejebringe en mere nøjagtig og nyttig måling af afstanden mellem udvalgte punkter end den traditionelle fremgangsmåde, som krummer billedet ned over et system af "flad jord" eller gennemsnitselevationsplan og måler afstanden mellem udvalgte punkter langs den flade jord eller plan og ignorerer i det væsentlige variationer i terræn mellem punkterne.

F.eks. kan en entreprenør, der gør klar til at byde på en kontrakt om vejbelægning på en landevej over ujævnt eller bakket terræn bestemme den omtrentlige størrelse eller areal af vejen under brug af billedvisnings- og analyseprogrammet 140 og den dermed tilbudte "gå på jorden" målemetode. Entreprenøren kan opnå den omtrentlige mængde eller areal af vejen fra hans eller hendes eget kontor uden at skulle sende et undersøgelseshold til arbejdsstedet for at foretage de nødvendige målinger.

I modsætning til "gå på jorden" metoden ifølge opfindelsen, så indebærer "flad jord"- eller gennemsnitselevationsafstandsberegningsmetoderne medfødte unøjagtigheder, når der måles afstande mellem punkter og/eller objekter placeret i det ujævne terræn, og når der måles størrelser og/eller højder af objekter placeret på tilsvarende måde. Selv en behersket hældning eller stigning i den afbildede overflade resulterer i en

forskel i elevationen af nadirpunktet i forhold til hovedsageligt et vilkårligt andet punkt derpå. Hvis der igen henvises til fig. 1, så kan trekanten fremstillet af linien 106, forlængelsen af primæraksen A_1 og den lodrette (stiplede) linie 110 mellem punktet 108 og billedtagningsindretningen 32a ikke være en retvinklet trekant. Hvis dette er tilfældet, så vil enhver geometrisk beregning, som forudsætter, at trekanten er en retvinklet trekant, indeholde fejl, og sådanne beregninger ville blive reduceret til approksimationer som følge af selv en relativt svag gradient eller hældning mellem udvalgte punkter.

Hvis overfladen 31 f.eks. hælder opad mellem nadirpunktet N og centrum C nær ved randen eller kanten 108 af skråbilledet 104, så vil den anden linie 110 skære overfladen 31 før det punkt, hvorved sådan skæring ville optræde på en plan eller ikke-hældende overflade 31. Hvis centrum C ligger 15 fod (5 m) højere end nadirpunktet N og har en afbøjningsvinkel θ på 40°, så vil den beregnede lokation af centrum C ligge forskudt ca. 17,8 fod (5,3 m) uden korrektion for ændringen i elevation mellem punkterne.

Som beskrevet generelt ovenfor vil billedvisnings- og analyseprogrammet 140, for at kompensere i det mindste delvis for ændringer i elevation og deraf følgende unøjagtigheder i målingen af og mellem objekter i billedet 142, om nødvendigt referere til punkter i det viste billede 142 og på overfladen 31 til et forud beregnet mosaikmønstret eller facetteret grundplan 160 i fig. 6. Mosaikgrundplanet 160 inkluderer et antal individuelle facetter 162a, 162b, 162c, osv., som hver er indbyrdes forbundet med hinanden og er defineret af fire paspunkter (ikke refereret, men vist som punkter) med respektive elevationer. Hosliggende par facetter 162a, 162b, 162c osv., deler to paspunkter. Hver facet 162a, 162b, 162c, osv. har en tilhørende pitch og hældning. Mosaikgrundplanet 160 er skabt baseret på forskellige data og ressourcer som f.eks. topografiske kort og/eller digitale rastergrafikker, undersøgelsesdata og forskellige andre kilder.

Generelt bliver geolokationen af et udvalgt punkt på det viste billede 142 beregnet ved at fastlægge hvilke af facetterne 162a, 162b, 162c, osv., der svarer til det udvalgte punkt. Således bliver lokationen af det udvalgte punkt beregnet baseret på karakteristika, dvs. elevation, pitch og hældning, for facetterne 162a, 162b, 162c, osv., i stedet for at være baseret på en plan eller gennemsnitselevationsgrundplan. Fejl bliver kun indført, såfremt topografien af overfladen 31 og lokationen af det valgte punkt derpå

afviger fra den plane overflade af facetten 162a, 162b, 162c, osv., hvori det udvalgte punkt ligger. Den fejl kan reduceres gennem bilineær interpolation af elevationen af det valgte punkt i en bestemt af facetterne 162a, 162b, 162c, osv., og ved at anvende den interpolerede elevation i lokationsberegningen udført af billedvisnings- og analyse-programmet 140.

For at bruge mosaikgrundplanet 160 anvender billedvisnings- og analyseprogrammet 140 en modificeret "ray-tracing" eller strålesporingsalgoritme for at finde skærings-punktet for den projicerede stråle fra billedtagningsindretningen 32a eller 32b mod overfladen 31 og den mosaikformede grundplan 160. Algoritmen bestemmer ikke kun hvilken af facetterne 162a, 162b, 162c, osv., der gennemskæres af strålen, men også hvor i facetten skæringen sker. Ved brug af bilineær interpolation kan der fastlægges en ret præcis grundlokation. Med henblik på omvendt projektion bliver mosaikgrund-planet 160 anvendt til at finde grundelevationsværdien for den indtastede grund-lokation; altså gennem brug af bilineær interpolation. Elevationen og lokationen bliver derefter anvendt til at projicere tilbage gennem en model af billedtagningsmekanismen 32a eller 32b for at bestemme, hvilken af pixlerne i det viste billede 142, der svarer til den givne lokation.

Navnlig og som et eksempel vil billedvisnings- og analyseprogrammet 140 udføre og/eller beregne geolokationen af punktet 164 gennem at overlejre og/eller fitte mosaikgrundplanen 160 til i det mindste en del 166 af overfladen 31, som f.eks. en bakke. Det bør bemærkes, at kun en mindre del af mosaikgrundplanen 160 og facetterne 162a, 162b, 162c, osv., deraf er vist sammen med profilen af delen 166 af overfladen 31. Som forklaret ovenfor bliver hver af facetterne 162a, 162b, 162c, osv., defineret af fire paspunkter, som hver især har respektive elevationer, og hver af facetterne har egen pitch og hældning. Den specifikke position af punktet 164 på planet/overfladen af facetten 162a, 162b, 162c, osv., hvori punktet 164 (eller dets projektion) ligger, bliver bestemt som beskrevet ovenfor.

Mosaikgrundplanen 160 bliver fortrinsvis skabt uafhængigt af driften af billedvisnings- og målingscomputersystemet 130 og billedvisnings- og analyseprogrammet 140. *Mosaikgrundplanen 160 udgør snarere en relativt simpel datatabel eller opslagstabel* 168 lagret i hukommelsen 132 af og/eller tilgængelig for billedvisnings- og målings-computersystemet 130. Beregningsressourcerne, der kræves til at beregne loka-tionerne af alle paspunkterne af de mange facetter af en typisk grundplan, behøver

ikke nødvendigvis at ligge i billedvisnings- og målingscomputersystemet 130. Således er billedvisnings- og målingscomputersystemet 130 i stand til at blive brugt med og aktiveret fra en traditionel PC uden behov for yderligere beregningsressourcer.

Beregning af mosaikgrundplanet 160 uden for billedvisnings- og målingscomputersystemet 130 muliggør i det væsentlige, at et vilkårligt detaljeringsniveau kan blive indbygget i mosaikgrundplanet 160 dvs. størrelsen og/eller arealet, der dækkes af eller svarer til hver af facetterne 162a, 162b, 162c, osv., kan blive så stort eller så lille som ønsket, uden derved i væsentlig grad at forøge beregningstiden, forsinke driften af, eller i væsentlig grad forøge de ressourcer, som kræves af billedvisnings- og målingscomputersystemet 130 og/eller billedvisnings- og analyseprogrammet 140. Visnings- og målingscomputersystemet 130 kan derfor være et relativt basalt og ukompliceret computersystem.

Facetterne 162a, 162b, 162c, osv., har en ensartet størrelse overalt i et bestemt, vist billede 142. Hvis det viste billede 142 f.eks. svarer til et område, der er ca. 750 fod (225 m) bredt i forgrunden og ca. 900 fod (270 m) dybt, kan billedet blive nedbrudt i facetter, der er ca. 60 kvadratfod (4,6 m^2), hvorved der opnås ca. 15 facetter i bredden og 18 facetter i dybden. Alternativt ville størrelsen af facetterne 162a, 162b, 162c, osv., være ens med hensyn til antallet af pixler indeholdt deri, dvs. hver facet er det samme antal pixler i bredden og det samme antal pixler i dybden. Facetter i forgrunden af det viste billede 142, hvor pixeldensiteten er størst, ville derfor være dimensionsmæssigt mindre end facetterne i baggrunden af det viste billede 142, hvor pixeldensiteten er mindst. Fordi det er ønskeligt at foretage de fleste målinger i forgrunden af et vist billede, hvor pixeldensiteten er størst, så vil frembringelsen af facetter, der er ens med hensyn til antallet af pixler, som de indeholder, have fordelen ved at tilvejebringe mere nøjagtige målinger i forgrunden af det viste billede 142 i forhold til facetter, der er dimensionsmæssigt ens.

En anden fordel ved at benytte pixler som grundlag for at definere dimensioner af facetter 162a, 162b, 162c, osv., er, at lokationsberegningen (pixellokation i forhold til grundlokation) er relativt simpel. En bruger aktiverer billedvisnings- og målingscomputersystemet 130 for at vælge en pixel i en given facet, billedvisnings- og analyseprogrammet 140 slår op på data for facetten svarende til den valgte pixel, elevationen af den valgte pixel bliver beregnet som beskrevet ovenfor, og denne elevation anvendes i lokationsberegningen.

Generelt vil fremgangsmåden til at optage skråbilleder ifølge opfindelsen opdele et valgt område, som f.eks. et amt, i sektorer af hovedsagelig ensartet størrelse, f.eks. sektorer, med et areal på ca. én kvadratmil (2,6 km^2). Dette sker for at lette planlægningen af en flyveplan til at tage skråbilleder, som dækker hver tomme af det udvalgte område, og for at organisere og navngive sektorerne og/eller billederne deraf så der opnås let reference, lagring og genfinding (en proces, der er almindelig kendt som "sektorisering"). Fordi kanterne af ethvert geografisk område, såsom et amt, sjældent falder på lige kvadratmil-grænser, så tilvejebringer fremgangsmåden til at tage skråbilleder ifølge opfindelsen flere sektorer, end der er kvadratmil i det valgte område - hvor mange flere afhænger stort set af længden af amtsgrænserne såvel som, hvor lige eller takkede de er. Typisk vil man kunne forvente en ekstra sektor for hver to til tre mil (3-5 km) grænselinie. Hvis et amt eller andet valgt område er groft set 20 gange 35 mil (32 x 46 km) eller 700 kvadratmil (1800 km^2), så vil området blive opdelt i ca. 740 til 780 sektorer.

Fremgangsmåden til at tage skråbilleder ifølge opfindelsen vil generelt optage skråbilleder fra mindst to kompasretninger og tilvejebringer fuld dækning af det valgte område fra i det mindste disse to kompasretninger. Med henvisning til fig. 7 og 8 vises en første udførelsesform for en fremgangsmåde til at optage skråbilleder ifølge opfindelsen. For overskuelighedens skyld er fig. 7 og 8 baseret på et system, der kun har én billedtagningsindretning. Imidlertid er det klart, at der ville kunne anvendes to eller flere billedtagningsindretninger.

Billedtagningsindretningen optager et eller flere skråbilleder under hver passage over området 200. Billedtagningsindretningen, som beskrevet ovenfor, sigter under en vinkel ned over området 200 for at optage skråbilleder deraf. Området 200 bliver, på samme måde som en græsplane bliver klippet på, gennemfløjet i et frem- og tilbagegående mønster af den billedbærende indretning og/eller platform for at sikre dobbeltdækning af området 200.

Området 200 bliver især gennemfløjet af den billedbærende indretning 32 og/eller platformen 20 ved at følge en første linie 202 for derved at optage skråbilleder af dele 202a, 202b og 202c af området 200. Derpå bliver området 200 gennemfløjet af den billedbærende indretning 32 og/eller platformen 20 ved at følge en anden linie 204, der ligger parallelt med og i afstand fra og i en modsat retning af dvs. 180° fra, den første linie 202 for derved at optage skråbilleder af billederne 204a, 204b, 204c af området

200. Ved at sammenligne fig. 7 og 8 ses det, at en del 207 (fig. 8) af området 200 er dækket af billederne 202a-c, der er optaget fra en første retning eller perspektiv, og af billeder 204a-c, der er optaget fra en anden retning eller perspektiv. Som sådan vil midterdelen af området 200 være 100% dobbeltdækket. Det ovenfor beskrevne mønster for gennemflyvning eller passage over området 200 langs modsatte linier, der ligger parallelt med linierne 202 og 204, bliver gentaget indtil området 200 i sin helhed er helt dækket af mindst ét skråbillede optaget fra linier, der ligger parallelt med, i afstand fra hinanden, som dikteret af størrelsen af området 200, og i samme retning som linierne 202 og 204 for derved at udføre 100% dobbeltdækning af området 200 fra disse perspektiver/retninger.

Om ønsket og til at forøge detaljeringsgraden bliver området 200 dækket af to yderligere hhv. modsat rettede og parallelle tredje og fjerde linier 206 og 208, som ligger vinkelret på linierne 202 og 204, som vist i fig. 9 og 10. Området 200 bliver derfor overfløjet af den billedbærende indretning 32 og/eller platformen 20 ved at følge en tredje linie 206 for at tage skråbilleder af delene 206a, 206b og 206c af området 200 og derpå flyve langs en fjerde linie 208, der ligger parallelt med og i afstand fra og modsat rettet den tredje linie 206 for at tage skråbilleder af delene 208a, 208b og 208c af området 200. Dette mønster for overflyvning eller passage over området 200 langs modsat rettede linier, der ligger parallelt med linierne 206 og 208 bliver ligeledes gentaget indtil området 200 i sin helhed er helt dækket af mindst ét skråbillede optaget fra linier, som ligger parallelt med og i afstand fra (dikteret af størrelsen af området 200) og i samme retning som linierne 206 og 208 for derved at sikre 100% dobbeltdækning af området 200 fra de disse retninger/perspektiver.

Som beskrevet ovenfor vil den billedbærende indretning 32 og/eller platformen 20 overflyve eller passere over området 200 langs en forudbestemt linie. Imidlertid skal det forstås, at den billedbærende indretning og/eller platformen 20 ikke nødvendigvis flyver eller bevæger sig direkte over området 200, men vil snarere kunne passere eller flyve over et område op til, tæt ved eller endog lidt i afstand fra området 200 for at sikre, at den del af området 200, som bliver fotograferet, falder inden for billedtagningsfeltet for billedtagningsindretningen. Linien 202, der vises i fig. 7, er således en linie, der ikke går direkte hen over området 200 men alligevel tager skråbilleder deraf.

Ifølge opfindelsen er det muligt at optage billeder ved forskellige opløsningsforhold eller grundudsnitsafstande. Et første detaljeringsniveau, der herefter betegnes som nærområdeniveau, har en grundudsnitsafstand på f.eks. ca. to fod (60 cm) pr. pixel. For orthogonale nærområdebilleder forbliver grundudsnitafstanden hovedsageligt konstant over hele billedet. Orthogonale nærområdebilleder bliver taget med tilstrækkelig overlapning til at tilvejebringe stereodækning. For nærområdeskråbilleder varierer grundudsnitsafstanden fra f.eks. ca. én fod (30 cm) pr. pixel i forgrunden af billedet til ca. to fod (60 cm) pr. pixel i midten af billedet og til ca. fire fod (120 cm) pr. pixel i billedets baggrund. Nærområdeskråbilleder bliver taget med tilstrækkelig overlapning, således at hvert valgt område typisk dækkes af mindst to skråbilleder fra hver af de benyttede kompasretninger. Omtrent ti nærområdeskråbilleder bliver optaget pr. sektor.

Et andet detaljeringsniveau, der herefter omtales som et omegnsniveau, er betydeligt mere detaljeret end nærområdebillederne. Omegnsbillederne har en grundudsnitsafstand på f.eks. ca. seks tommer (15 cm) pr. pixel. For orthogonale omegnsbilleder forbliver grundudsnitsafstanden hovedsageligt konstant. Omegnsskråbilleder har en grundudsnitsafstand f.eks. fra ca. fire tommer (10 cm) pr. pixel i forgrunden af billedet til ca. seks tommer (15 cm) pr. pixel i midten af billedet og til ca. ti tommer (25 cm) pr. pixel i baggrunden af billedet. Omegnsskråbilleder bliver optaget med tilstrækkelig overlapning til, at hvert område typisk er dækket af mindst to skråbilleder fra hver kompasretning og således, at modsatte kompasretninger tilvejebringer 100% overlapning med hinanden. Der bliver pr. sektor taget ca. et hundrede skrå områdebilleder.

Det bør især bemærkes, at optagelse af nærområde- og/eller omegnsskråbilleder fra alle fire kompasretninger sikrer, at hvert punkt i billedet vil optræde i forgrunden eller den nederste del af i det mindste ét af de optagne skråbilleder, hvor grundudsnitsafstanden er mindst, og billeddetaljen er størst.

I den viste udførelsesform inkluderer billedtagnings- og geolokaliseringssystemet 30 et gyroskop, et kompas og en højdemåler. Det skal selvfølgelig stå klart, at billedtagnings- og geolokaliseringssystemet ifølge opfindelsen kan blive konfigureret på anden måde, for f.eks. at kunne udlede og/eller beregne højde, pitch, roll og yaw og kompasretningen fra GPS og INU signaler/data og derved gøre én eller flere af gyroskopet, kompasset eller højdemåleren overflødig.

I den viste udførelsesform er billedtagningsindretningerne placeret i en ens afbøjningsvinkel i forhold til et vandret plan. Imidlertid skal det forstås, at afbøjningsvinklerne for billedtagningsindretningerne ikke behøver at være ens.

I den viste udførelsesform eksekverer billedtagningscomputersystemet billed- og datahentningsprogrammet, der afgiver et fælles eller enkeltbilled-tagningssignal til billedtagningsindretningerne for derved at få disse indretninger til at hente eller tage et billede. Imidlertid skal det forstås, at opfindelsen alternativt kan konfigureres til separat at få billedtagningsindretningerne til at tage billeder på forskellige tidspunkter og/eller ved forskellige intervaller.

I den viste udførelsesform for fremgangsmåden ifølge opfindelsen tages skråbilleder for at tilvejebringe dobbeltdækning af et valgt område fra linier/perspektiver, der ligger hovedsageligt modsat hinanden dvs. 180° i forhold til hinanden. Imidlertid skal det forstås, at fremgangsmåden ifølge opfindelsen alternativt kan konfigureres til at tilvejebringe dobbeltdækning ved hjælp af linier/perspektiver, der generelt og/eller i det væsentlige ligger vinkelret i forhold til hinanden.

Skønt opfindelsen er blevet beskrevet i forbindelse med et foretrukket design, så kan opfindelsen blive yderligere modificeret inden for rammerne af kravene. Denne beskrivelse er derfor tænkt at omfatte enhver ækvivalent til de heri beskrevne strukturer og elementer. Ydermere er beskrivelsen beregnet til at omfatte enhver variation, brug eller tilpasning af opfindelsen, som benytter de heri beskrevne generelle principper. Ydermere er beskrivelsen tænkt at skulle omfatte enhver fravigelse fra den heri beskrevne sagsgenstand, som vil ligge inden for kendt eller almindelig praksis på fagområdet, og som falder inden for grænserne af de vedføjede krav.

PATENTKRAV

1. Computersystem til at vise, geolokalisere og foretage målinger baseret på optagne skråbilleder, omfattende:
   - et computersystem (130) med en hukommelse (132)
   - en billed- og datafil (120), som kan benyttes af systemet (130) og inkluderer en mængde af billedfiler svarende til et stort antal optagne skråbilleder, hvilken billed- og datafil (120) yderligere inkluderer positionsdata svarende til de mange billedfiler, og
   - et billedvisnings- og analyseprogram (140) aktiveret af systemet (130) til at læse billed- og datafilen (120) og vise i det mindste en del af de optagne skråbilleder som et vist skråbillede, hvilket billedvisnings- og analyseprogram (140) beregner geolokationerne af to eller flere udvalgte punkter i det viste skråbillede baseret i det mindste delvis på nævnte positionsdata, og billedvisnings- og analyseprogrammet (140) beregner en separationsafstand mellem to eller flere vilkårligt valgte punkter i det viste skråbillede, **kendetegnet ved**
   - en grundplansdatafil, der repræsenterer en mosaikgrundplan (160), hvilken grundplansdatafil leverer data til billedvisnings- og analyseprogram (140), og grundplansdatafilen repræsenterer en mosaikgrundplan, der ret tæt approksimerer mindst en del af terrænet, der er afbildet i de optagne skråbilleder, hvorved mosaikgrundplanen yderligere omfatter en mængde sammenknyttede billeder, mosaikgrundplanen omfatter yderligere en mængde sammenknyttede facetter (162a, 162b, 162c, ...), hvor hver af facetterne har hhv. en stigning (pitch) og en hældning, og grundplansdatafilen omfatter en mængde paspunkter, hvor hvert af paspunkterne har en højde og definerer hjørner af de sammenknyttede facetter (162a, 162b, 162c, ...), idet to af mængden af paspunkter deles af hver af de sammenknyttede facetter, og
   - billedvisnings- og analyseprogrammet (140) identificerer hvilke af mængden af facetter, der svarer til et valgt punkt på det viste skråbillede, og beregner en højde af det valgte punkt afhængigt i det mindste delvis af højden af paspunkterne for facetten, der hører til det valgte punkt, hvorved billedvisnings- og analyseprogrammet (140) benytter den beregnede højde til at beregne separationsafstanden mellem det valgte punkt og et eller flere yderligere punkter.

2. System ifølge krav 1, hvorved billedvisnings- og analyseprogrammet (140) kun beregner geolokationerne, når de behøves.
3. System ifølge krav 1 eller 2, hvorved billedvisnings- og analyseprogrammet (140) beregner en højde for et objekt i det viste skråbillede ved at beregne separationsafstanden mellem to eller flere udvalgte punkter.
4. System ifølge et af kravene 1-3, hvorved mosaikgrundplanen (160) er lagt oven på og tilpasset det viste skråbillede.
5. System ifølge et af kravene 1-4, hvorved billedvisnings- og analyseprogrammet (140) inkluderer brugervalgte målemodi, der er tilgængelige gennem mindst en rullegardinmenu, værktøjslinier og tastekommandoer.
6. System ifølge et af kravene 1-5, hvorved hvert billede blev optaget med en billedtagningsindretning (32a, 32b) og ved respektive billedtagningsbegivenheder, hvorved positionsdata for billede og datafil inkluderer:
   - tidsdata repræsenterende tidspunktet for hver billedtagningsbegivenhed;
   - lokationsdata repræsenterende lokationen af billedtagningsindretningen (32a, 32b) for hver billedtagningsbegivenhed;
   - orienteringsdata repræsenterende orienteringen af billedtagningsindretningen (32a, 32b) for hver billedtagningsbegivenhed;
   - korrektionsdata repræsenterende korrektionsfaktorer for billedtagningsindretningen (32a, 32b); og
   - elevationsdata repræsenterende en gennemsnitlig elevation af den med billedtagningsindretningen (32a, 32b) optagne overflade.
7. System ifølge krav 6, hvorved nævnte lokationsdata omfatter breddegrad, længdegrad og højde for billedtagningsapparatet (32a, 32b) ved hver billedtagningsbegivenhed.
8. System ifølge krav 6 eller 7, hvorved nævnte orienteringsdata omfatter roll, pitch og yaw samt retningen af billedtagningsindretningen (32a, 32b) ved hver billedtagningsbegivenhed.
9. System ifølge et af kravene 6-8, hvorved billedtagningsindretningen (32a, 32b) er et kamera, og nævnte korrektionsdata inkluderer mindst en brændvidde, sensorstørrelse, billedformat, hovedpunktsforskydning, forvrængning og pixel pitch (skærmopløsning).
10. System ifølge et af kravene 6-9, omfattende:
    - en indtastningsmekanisme (134a, 134b) til at vælge et startpunkt og et slutpunkt på det viste skråbillede; og

- billedvisnings- og analyseprogrammet (140) til fra datafilen at udtrække positionsdata svarende til startpunktet og til slutpunktet; til at give reference til grundplansdatafilen svarende til mosaikgrundplanen, der har adskillige facetter, hvor hver facet har hhv. stigning og hældning, hvorved mosaikgrundplanen svarer meget tæt til et terræn af det viste skråbillede; til at forbinde start- og slutpunkterne med liniesegmenter, hvorved liniesegmenterne svarer i form til stigning og hældning af facetterne for derved at følge terrænet; og til langs liniesegmenterne at beregne den lineære afstand mellem start- og slutpunkterne og derved tage hensyn til stigning og hældning af facetterne.

11. System ifølge et af kravene 1-10, hvorved billedvisnings- og analyseprogrammet (140) overlejrer mosaikgrundplanen på det viste skråbillede.

12. System ifølge krav 10 eller 11, omfattende:
    - indtastningsmekanismen (134a, 134b) til at vælge et eller flere mellempunkter på det viste skråbillede; og
    - billedvisnings- og analyseprogrammet (140) til fra datafilen at udtrække positionsdata svarende til nævnte et eller flere mellempunkter; til at forbinde hosliggende mellempunkter med hinanden, og til med liniesegmenter at forbinde start- og slutpunkterne med de hosliggende mellempunkter, hvorved liniesegmenterne svarer i form til stigning og hældning af facetterne for derved at følge terrænet; og til langs liniesegmenterne at beregne afstanden mellem start- og slutpunkterne.

13. System ifølge et af kravene 1-12, hvorved de adskillige facetter (162a, 162b, 162c, ...) hver svarer til ens områder af det viste skråbillede.

14. System ifølge et af kravene 1-13, hvorved de adskillige facetter (162a, 162b, 162c, ...) hver inkluderer ens antal pixels af det viste skråbillede.

15. System ifølge et af kravene 1-14, omfattende en indtastningsindretning (134a, 134b) til at vælge et eller flere mellempunkter på det viste skråbillede; og billedvisnings- og analyseprogrammet (140) til at udtrække positionsdata *svarende til mellempunkterne.*

16. System ifølge et af kravene 1-15, hvorved separationsafstanden omfatter en afstand mellem to eller flere valgte punkter, en højdeforskel mellem to eller flere valgte punkter, en forskel i elevation af to eller flere valgte punkter, og et område omgivet af mindst tre punkter.

17. System ifølge et af kravene 1-16, omfattende:

- en billedtagningsindretning (32a, 32b), hvilken indretning optager skråbilleder ved billedtagningsbegivenheder og afgiver billeddatasignaler svarende til de optagne billeder;
- mindst en geolokaliseringsindretning (34, ..., 44), som hver især afgiver et tilhørende mindst et geolokaliseringssignal, der hver især er indikativt for mindst en del af geolokationen af billedtagningsindretningen (32a, 32b) under hver billedtagningsbegivenhed; og
- et computersystem (46) til at modtage og lagre billeddatasignalerne og det mindst ene geolokaliseringssignal; og
- et billed- og dataindsamlingsprogram (90), der indlæser billeddata-signalerne og det mindst ene geolokaliseringssignal, hvorved programmet (90) udstyrer hvert billeddatasignal med et tilsvarende af de nævnte mindst ene geolokaliseringssignal for hver billedtagningsbegivenhed.

18. System ifølge krav 17, hvorved den mindst ene geolokaliseringsindretning henholdsvis det mindst ene geolokaliseringssignal omfatter:
- en klokke (38), der til billedtagningscomputersystemet (46) afgiver tidsdata-signaler indikerende et tidspunkt for hver billedtagningsbegivenhed;
- en global positioneringssystem (GPS) modtager (34), der modtager GPS signaler og til billedtagningscomputersystemet (46) afgiver lokationsdata-signaler indikerende længdegrad og breddegrad for billedtakningsindretningen (32a, 32b) ved hver billedtagningsbegivenhed;
- en inertinavigationsenhed (36), der til billedtagningscomputersystemet (46) afgiver hastighedsdatasignaler indikerende en hastighed for billedtagnings-indretningen (32a, 32b) ved hver billedtagningsbegivenhed;
- et gyroskop (40) der til billedtagningscomputersystemet (46) afgiver et pitch signal, et roll signal og et yaw signal indikerende hhv. pitch, roll og yaw for billedtagningsindretningen (32a, 32b) ved hver billedtagningsbegivenhed;
- et kompas (42) der til billedtagningscomputersystemet (46) afgiver retnings-datasignaler, der er indikative for retningen af billedtagningsindretningen (32a, 32b) ved hver billedtagningsbegivenhed; og
- en højdemåler (44) der til billedtagningscomputersystemet (46) afgiver højde-datasignaler, der er indikative for højdeangivelsen for billedtagnings-indretningen (32a, 32b) ved hver billedtagningsbegivenhed.

19. System ifølge krav 17 eller 18, yderligere omfattende korrektionsdata, der er indikative for egenskaber ved billedtagningsindretningen (32a, 32b) inklude-rende brændvidde, sensorstørrelse, radial forvrængning, hovedpunkts-

forskydning og orientering, hvorved billed- og dataopsamlingsprogrammet (90) benytter nævnte korrektionsdata til at korrigere optagne billeder.

20. System ifølge et af kravene 17-19, yderligere omfattende en outputdatafil oprettet af billed- og dataopsamlingsprogrammet (90), hvilken outputdatafil inkluderer adskillige billedfiler og positionsdata svarende til hver enkelt af de adskillige billedfiler.

21. System ifølge et af kravene 17-20, yderligere omfattende en platform (20), der bærer billedtagningsindretningen (32a, 32b) i en forudbestemt afstand over en udvalgt overflade.

22. System ifølge krav 21, hvorved billedtagningsindretningen (32a, 32b) tager skråbilleder af et udvalgt område i form af skråbilleder ved at:

- underinddele det valgte område (200) i et antal sektorer (202a, 202b, 202c);
- at styre platformen (20) langs en første linie (202) for derved at fokusere på en eller flere målsektorer med billedtagningsindretningen (32a, 32b);
- at med billedtagningsindretningen (32a, 32b) optage et eller flere skråbilleder for derved i sin helhed at dække målsektoren med skråbilleder taget fra en første synsvinkel;
- at styre platformen (20) langs en anden linie (204) for derved at fokusere på målsektorerne;
- at med billedtagningsindretningen (32a, 32b) optage et eller flere skråbilleder for derved i sin helhed at dække hver målsektor med skråbilleder taget fra en anden synsvinkel;
- at gentage styre- og optagefaserne langs linier, der ligger i det væsentlige parallelt med og adskilt fra den første og anden linie (202, 204) og at optage et eller flere skråbilleder for derved i sin helhed at dække alle målsektorerne med skråbilleder taget fra både den første og anden synsvinkel; og
- at registrere positionsdata, der er indikative for en geolokation af billedtagningsindretningen (32a, 32b) ved hver billedtagningsbegivenhed.

23. System ifølge krav 22, hvorved den anden linie (204) er hovedsageligt parallel med og 180° fra den første linie (202).

24. System ifølge krav 23, hvorved den anden linie (204) også befinder sig i afstand fra den første linie (202).

25. System ifølge et af kravene 22-24, hvorved:

- platformen (20) bliver styret langs en tredje linie (206) for derved at fokusere på en eller flere målsektorer med billedtagningsindretningen (32a, 32b); hvorved den tredje linie ligger hovedsageligt vinkelret på den første og anden linie (202, 204);
- billedtagningsindretningen (32a, 32b) optager et eller flere skråbilleder for derved i sin helhed at dække hver målsektor med skråbilleder taget fra en tredje synsvinkel; hvorved
- platformen (20) bliver styret og billedtagningsindretningen (32a, 32b) optager skråbillederne langs linier, der ligger hovedsageligt parallelt med og i afstand fra den tredje linie (206); og
- billedtagningsindretningen (32a, 32b) optager et eller flere skråbilleder for derved i sin helhed at dække hver af de mange målsektorer med skråbilleder taget fra den tredje synsvinkel.

26. System ifølge krav 25, hvorved:

- platformen (20) bliver styret langs en fjerde linie (208) for derved at fokusere på en eller flere målsektorer med billedtagningsindretningen (32a, 32b); hvorved den fjerde linie (208) ligger hovedsageligt parallelt med den tredje linie (206) og 180° fra den tredje linie (206);
- billedtagningsindretningen (32a, 32b) optager et eller flere skråbilleder for derved i sin helhed at dække hver målsektor med skråbilleder taget fra en fjerde synsvinkel; hvorved
- styre- og optagefaserne gentages langs linier, der ligger i det væsentlige parallelt med og adskilt fra den fjerde linie (208), for at optage et eller flere skråbilleder for derved i sin helhed at dække alle målsektorerne med skråbilleder taget fra den fjerde synsvinkel.

27. System ifølge krav 26, hvorved den fjerde linie (208) også ligger i afstand fra den tredje linie (206).

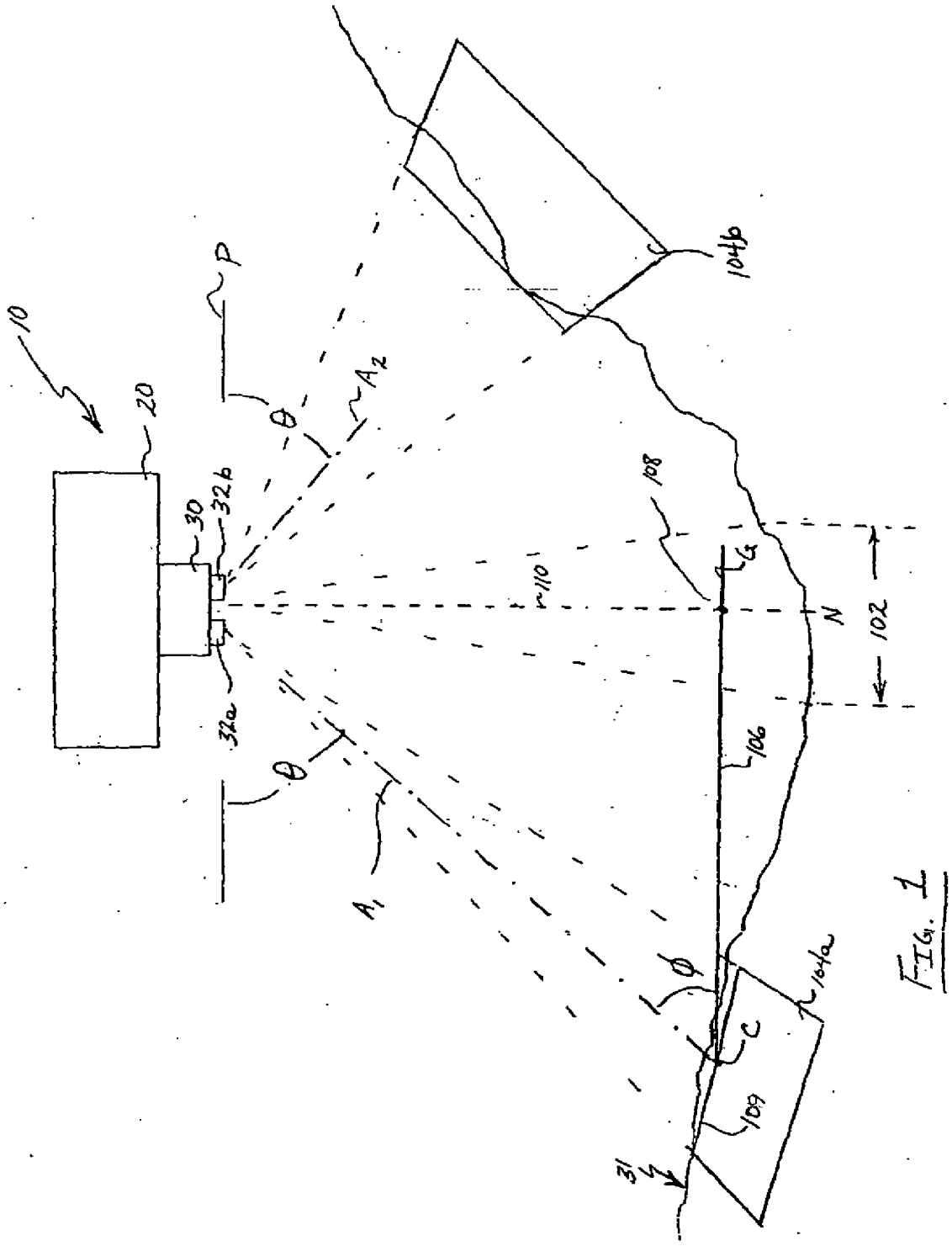


FIG. 1

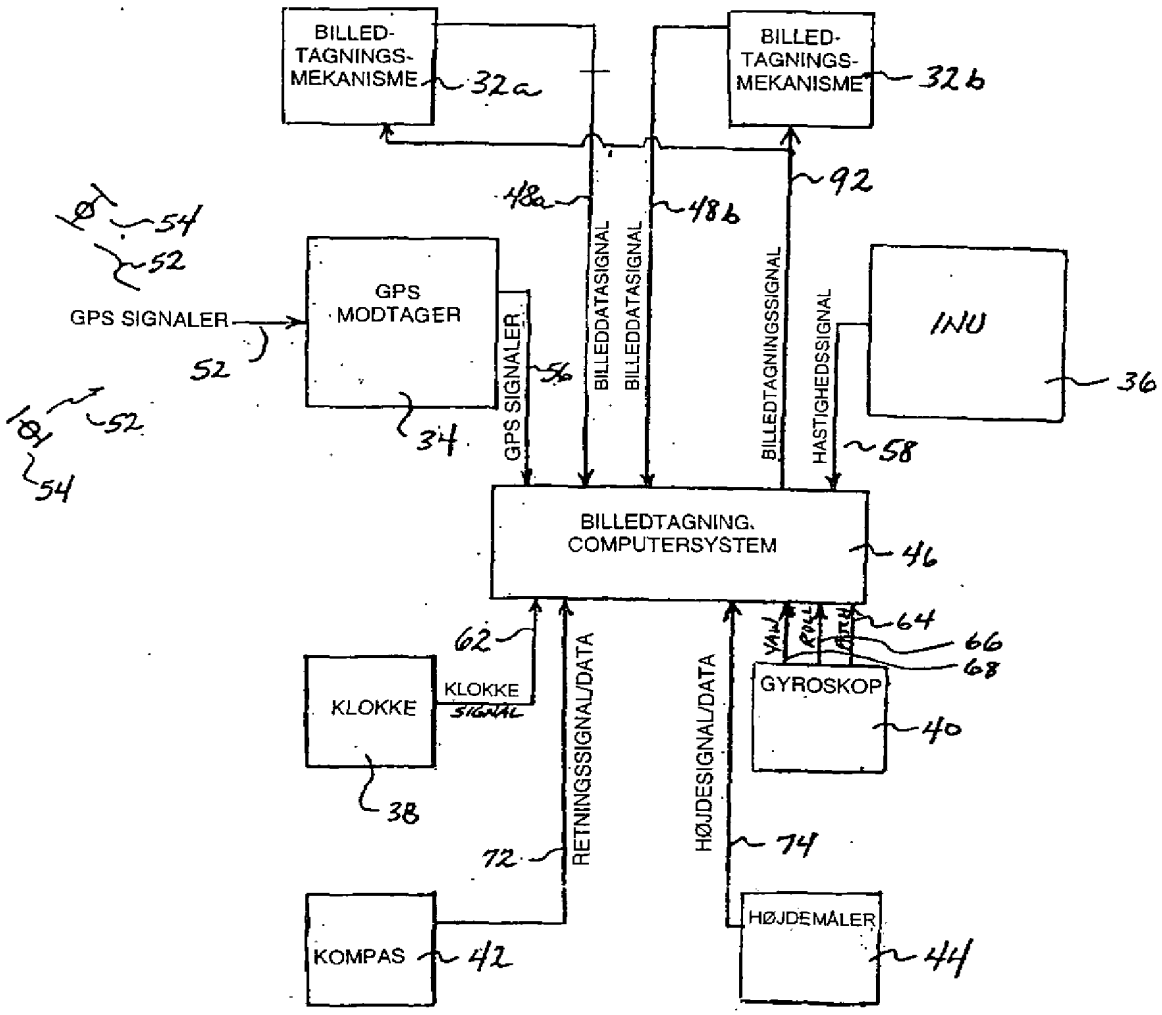

BILLED-TAGNINGS-MEKANISME
32a
BILLED-TAGNINGS-MEKANISME
32b
92
48a
48b
54
52
GPS SIGNALER
52
GPS MODTAGER
34
GPS SIGNALER
56
BILLEDDATASIGNAL
BILLEDDATASIGNAL
BILLEDTAGNINGSSIGNAL
HASTIGHEDSSIGNAL
58
INU
36
BILLEDTAGNING. COMPUTERSYSTEM
46
62
64
66
68
KLOKKE
KLOKKE SIGNAL
38
GYROSKOP
40
RETNINGSSIGNAL/DATA
72
HØJDESIGNAL/DATA
74
KOMPAS
42
HØJDEMÅLER
44

FIG. 2

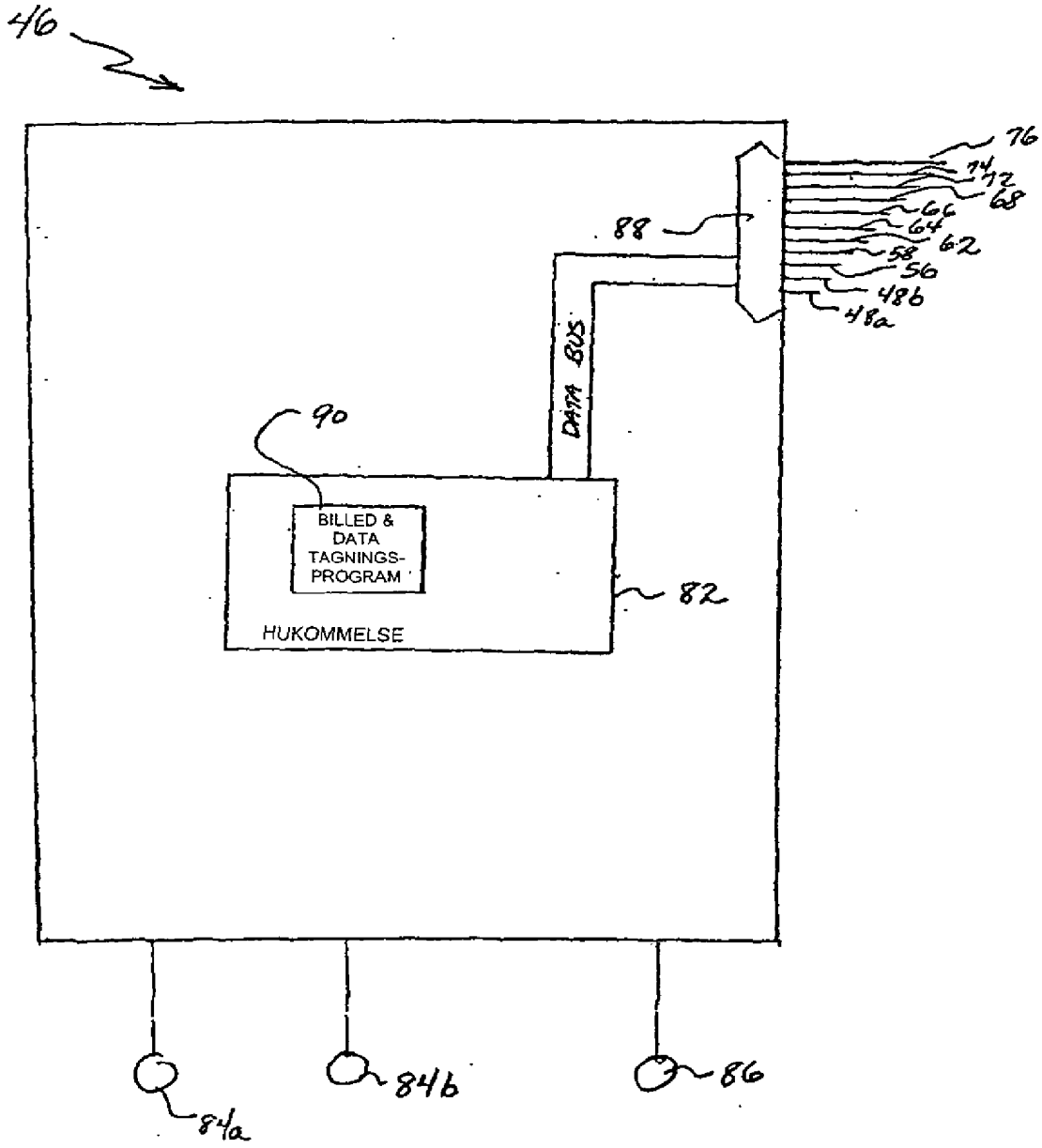

46
76
74
72
68
66
64
62
58
56
48b
48a
88
DATA BUS
90
BILLED & DATA TAGNINGS-PROGRAM
HUKOMMELSE
82
84a
84b
86

FIG. 3

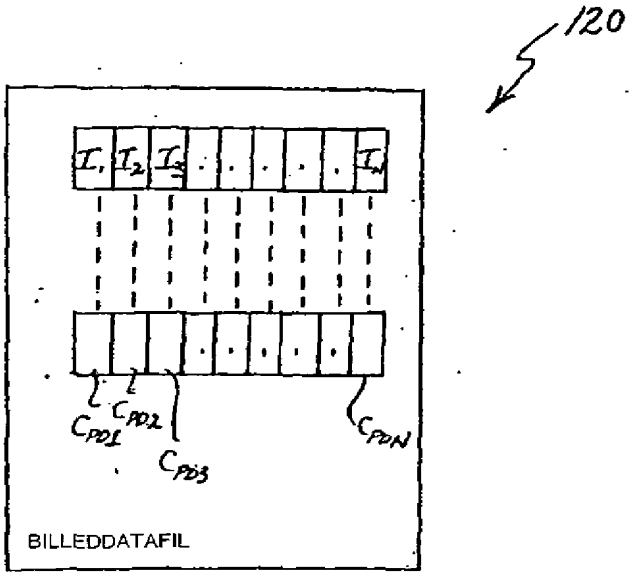


FIG. 4

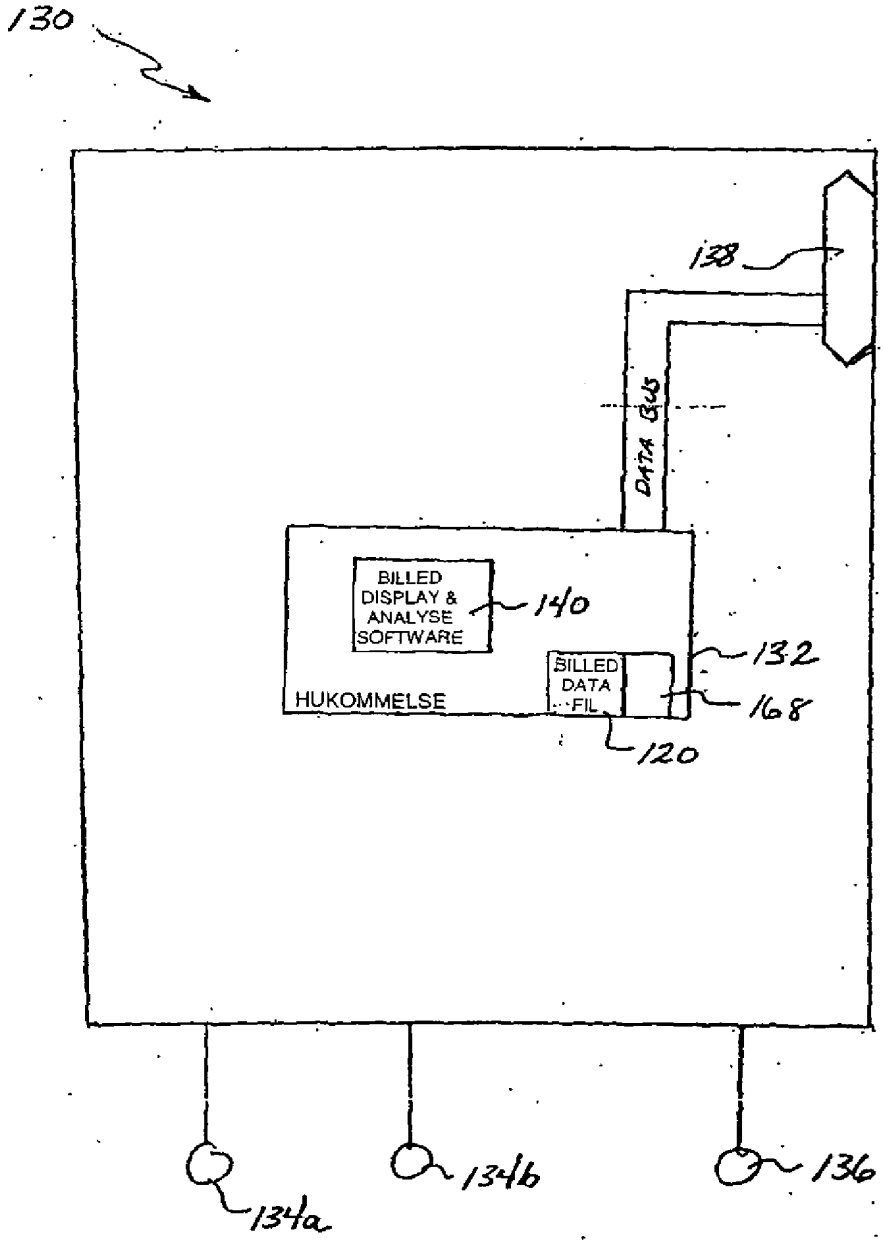

130
138
DATA BUS
BILLED DISPLAY & ANALYSE SOFTWARE
140
132
BILLED DATA FIL
168
HUKOMMELSE
120
134a
134b
136

FIG. 5

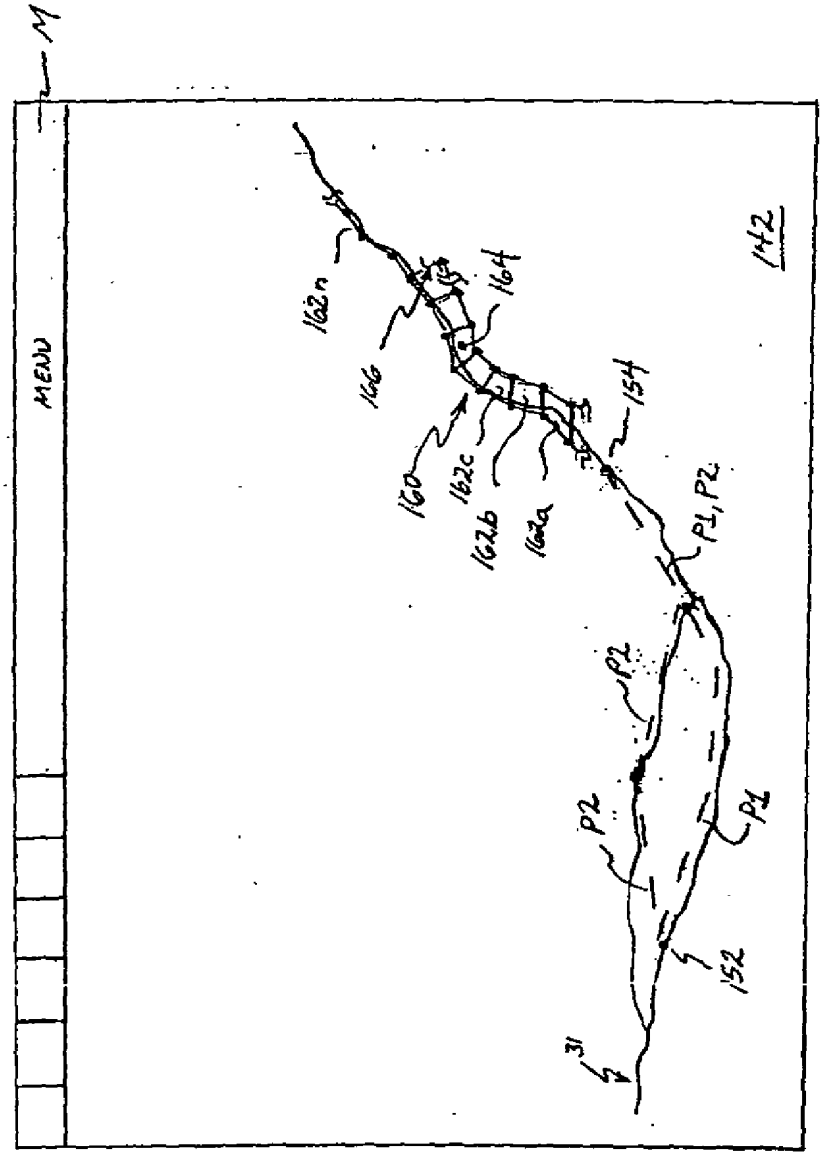

M
MENU
162a
166
164
160
162c
162b
168a
154
142
P1, P2
P2
P2
P1
152
31

FIG. 6

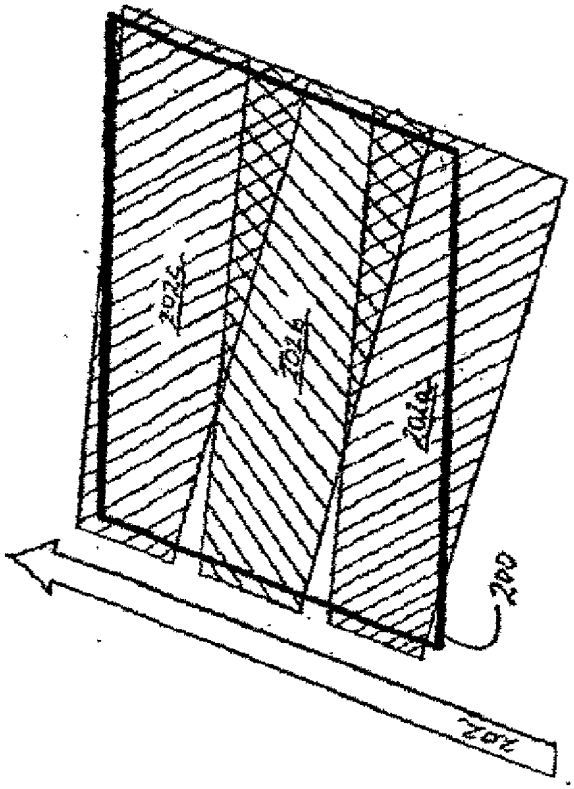


Fig. 7

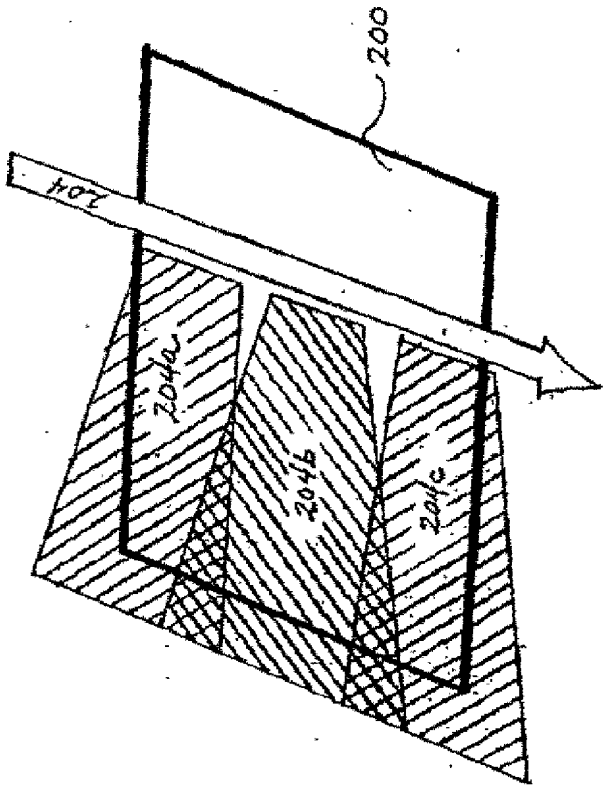


FIG. 6

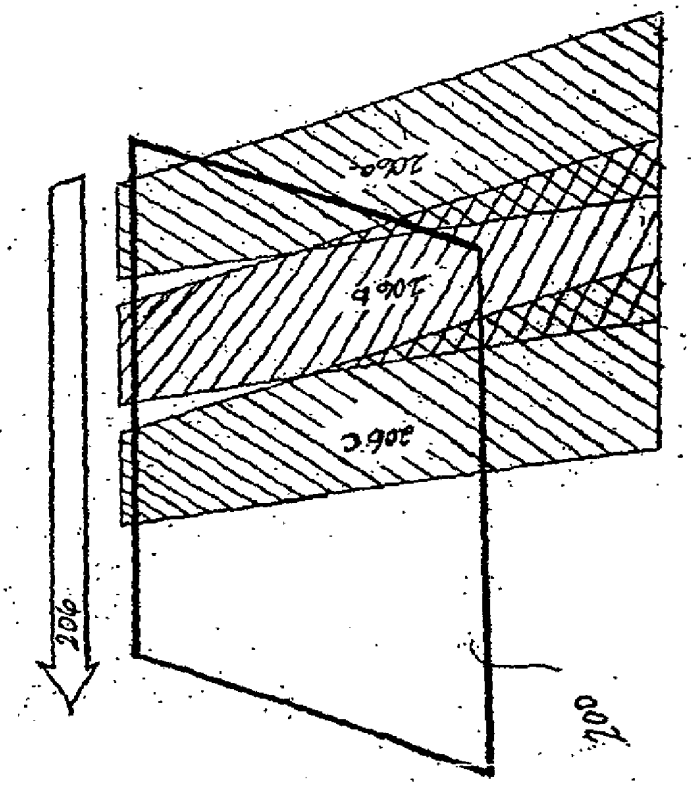


Fig. 9

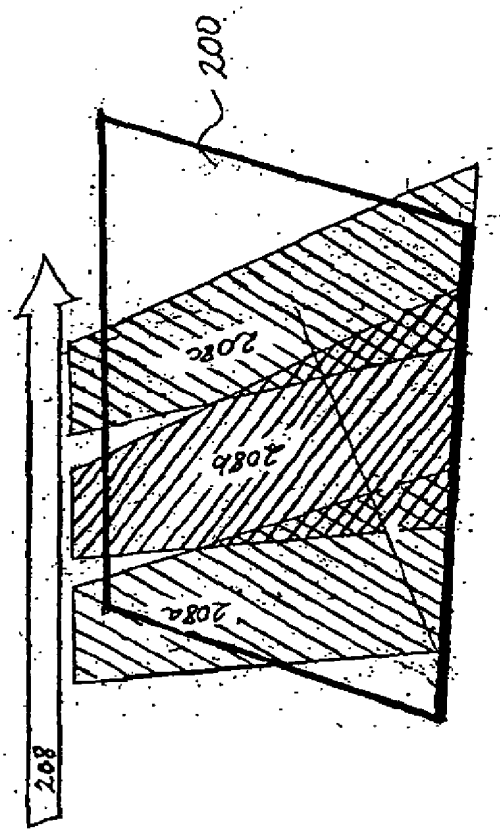


FIG. 10

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(54) Bezeichnung: **Verfahren und Gerät zur Erfassung, Geolokalisierung und Vermessung schräg aufgenommener Bilder**

Anmerkung: Innerhalb von neun Monaten nach der Bekanntmachung des Hinweises auf die Erteilung des europäischen Patents kann jedermann beim Europäischen Patentamt gegen das erteilte europäische Patent Einspruch einlegen. Der Einspruch ist schriftlich einzureichen und zu begründen. Er gilt erst als eingelegt, wenn die Einspruchsgebühr entrichtet worden ist (Art. 99 (1) Europäisches Patentübereinkommen).

Die Übersetzung ist gemäß Artikel II § 3 Abs. 1 IntPatÜG 1991 vom Patentinhaber eingereicht worden. Sie wurde vom Deutschen Patent- und Markenamt inhaltlich nicht geprüft.

Beschreibung

QUERBEZUG ZU VERWANDTEN ANMELDUNGEN

[0001] Diese Anmeldung beansprucht die Priorität der provisorischen US-Patentanmeldung 60/425,275, angemeldet am 08. November 2002.

TECHNISCHES GEBIET

[0002] Die vorliegende Erfindung betrifft die Bildmessung bzw. Photogrammetrie. Im Besonderen betrifft die vorliegende Erfindung ein Verfahren und eine Vorrichtung zum Aufnehmen schräger Bilder und zum Messen der Objekte und Abstände zwischen den darin abgebildeten Objekten.

HINTERGRUND

[0003] Die Bildmessung ist die Wissenschaft des Durchführens von Messungen von und zwischen Objekten, die in Bildern dargestellt sind, insbesondere in Luftaufnahmen. Allgemein verwendet die Bildmessung ein Aufnehmen von Bildern erdgebundener Merkmale und ein Ableiten von Daten daraus, wie beispielsweise von Daten, welche relative Abstände zwischen und Größen von Objekten innerhalb der Bilder anzeigen. Die Bildmessung kann auch ein Koppeln der Fotografien mit anderen Daten umfassen, wie beispielsweise Daten, welche einem Breitengrad und einem Längengrad entsprechen. Im Effekt wird das Bild einem bestimmten räumlichen Koordinatensystem überlagert und diesem angepasst.

[0004] Herkömmliche Bildmessung umfasst das Aufnehmen und/oder Erfassen orthogonaler Bilder. Die Bildaufnahmevorrichtung, wie beispielsweise eine Kamera oder ein Sensor, wird von einem Fahrzeug oder einer Plattform getragen, wie beispielsweise einem Flugzeug oder einem Satelliten, und ist auf einen Fusspunkt ausgerichtet, welcher direkt unter und/oder vertikal nach unten von dieser Plattform aus liegt. Der Punkt oder Bildpunkt (Pixel) in dem Bild, welcher dem Fusspunkt entspricht, ist der einzige Punkt/Bildpunkt, der tatsächlich orthogonal zur Bildaufnahmevorrichtung liegt. Alle anderen Punkte oder Bildpunkte in dem Bild sind tatsächlich schräg bezüglich der Bildaufnahmevorrichtung. Wenn die Punkte oder Bildpunkte sich zunehmend von dem Fusspunkt entfernen, werden sie immer schräger relativ zur Bildaufnahmevorrichtung, und auch der Grundabtastabstand (d. h., die Größe der Oberfläche, die jedem Bildpunkt zugehörig ist oder diesen abdeckt) erhöht sich. Eine solche Schrägheit in einem orthogonalen Bild führt dazu, dass die Merkmale in dem Bild verzerrt werden, insbesondere Abbilder relativ weit vom Nadir bzw. Fusspunkt entfernt.

[0005] Eine solche Verzerrung wird bereinigt oder kompensiert durch den Vorgang des Geradeziehens, welcher im Wesentlichen die Schrägheit aus dem orthogonalen Bild durch Anpassen oder Verformen jedes Bildpunkts eines orthogonalen Bildes auf ein orthogonales Gitter oder Koordinatensystem beseitigt. Dieser Ablauf des Geradeziehens erzeugt ein Bild, in dem alle Bildpunkte den gleichen Grundabtastabstand aufweisen und nach Norden ausgerichtet sind. Daher kann jeder Punkt auf einem geradegezogenen Bild unter Verwendung eines X,Y-Koordinatensystems lokalisiert werden, und, so lange der Bildmaßstab bekannt ist, können die Länge und Breite erdbezogener Merkmale auch als relativer Abstand zwischen solchen Merkmalen berechnet werden.

[0006] Obwohl der Ablauf des Geradeziehens bis zu einem gewissen Grad schräge Verzerrungen in einem orthogonalen Bild kompensiert, führt er andere unerwünschte Verzerrungen und/oder Ungenauigkeiten in das geradegezogene orthogonale Bild ein. In geradegezogenen orthogonalen Bildern dargestellte Objekte können schwierig zu erkennen und/oder zu identifizieren sein, da die meisten Beobachter nicht daran angepasst sind, Objekte, insbesondere erdgebundene Merkmale, von oben zu betrachten. Für einen ungeübten Betrachter weist ein geradegezogenes Abbild eine Zahl von Verzerrungen auf. Straßen, die tatsächlich gerade sind, sehen gekrümmt aus, und Gebäude können sich neigend aussehen. Ferner enthalten geradegezogene Bilder im Wesentlichen keine Information bezüglich der Höhe erdgebundener Merkmale. Die Interpretation und Ausweite orthogonaler und/oder geradegezogener orthogonaler Bilder wird typischerweise von hochtrainierten Auswertern durchgeführt, welche Jahre spezialisierten Trainings und Erfahrung aufzuweisen haben, um Objekte und erdgebundene Merkmale in solchen Bildern zu identifizieren.

[0007] Daher, obwohl orthogonale und geradegezogene Bilder bei der Bildmessung nützlich sind, fehlt ihnen Information über die Höhe von darin abgebildeten Merkmale, und sie benötigen hochtrainierte Auswerter, um genau zu interpretieren, was die Bilder darstellen.

[0008] Schräge Bilder sind Bilder, die mit der allgemein von der Plattform aus, welche die Bildaufnahmevorrichtung trägt, zur Seite oder nach unten gezielten oder ausgerichteten Bildaufnahmevorrichtung aufgenommen worden sind. Schräge Bilder zeigen, im Gegensatz zu orthogonalen Bildern, die Seiten erdgebundener Merkmale, wie beispielsweise von Häusern, Gebäuden und/oder Bergen, als auch die zugehörigen Spitzen. Daher ist das Betrachten eines schrägen Bilds natürlicher und intuitiver als das Betrachten eines orthogonalen oder geradegezogenen Bildes, und sogar flüchtige Betrachter sind in der Lage, erdgebundene Merkmale zu erkennen und zu interpretieren, als auch andere in schrägen Bildern dargestellte Objekte. Jeder Bildpunkt im Vordergrund ei-

nes schrägen Bilds entspricht einer relativ kleinen Fläche der dargestellten Oberfläche oder Objekts (d. h., dass jeder Vordergrund-Bildpunkt einen relativ kleinen Bodenabtastabstand aufweist), wohingegen jeder Bildpunkt im Hintergrund einer relativ großen Fläche der dargestellten Oberfläche oder des dargestellten Objekts entspricht (d. h., dass jeder Hintergrund-Bildpunkt einen relativ großen Bodenabtastabstand aufweist). Schräge Bilder nehmen eine im Allgemeinen trapezförmige Fläche oder Ansicht der Subjektoberfläche oder des Objekts auf, wobei der Vordergrund des Trapezoids einen wesentlich kleineren Grundabtastabstand (d. h., eine höhere Auflösung) aufweist als der Hintergrund des Trapezoids.

[0009] Schräge Bilder werden als überhaupt nicht oder nur wenig nützlich für die Bildmessung angesehen. Der herkömmliche Ansatz des Zwingens der unterschiedlich großen Vordergrund- und Hintergrund-Bildpunkte eines schrägen Abbilds auf eine gleichförmige Größe, um dadurch das Bild auf ein Koordinatensystem zu verformen, verzerrt das schräge Bild dramatisch und macht dadurch die Identifizierung von Objekten und das Aufnehmen von Messungen von darin dargestellten Objekten zu einer arbeitsaufwendigen und ungenauen Aufgabe. Ein Korrigieren von Geländeverschiebungen in einem schrägen Bild durch Verwenden eines Höhenlagenmodells verzerrt die Bilder weiter, wodurch die Schwierigkeit erhöht wird, mit der Messungen durchgeführt werden können, und wodurch die Genauigkeit einer jeden solchen Messung verringert wird.

[0010] Daher sind, obwohl schräge Bilder als wenig oder gar nicht nützlich für die Bildmessung angesehen werden, sie einfach interpretierbar und enthalten Information über die Höhe der darin abgebildeten Merkmale.

[0011] WO 99/18732 A1 offenbart ein System und ein Verfahren zum Aufnehmen, Erdpositionsbestimmen und Messen schräger Bilder, umfassend eine Bildaufnahmevorrichtung, eine Erdpositionsbestimmungsvorrichtung, ein Computersystem und eine Bild- und Datenaufnahme-Software, welche die Bilddaten mit den Erdpositionsbestimmungs-Signaldaten verknüpft.

AUFGABE DER ERFINDUNG

[0012] Was daher auf diesem Gebiet benötigt wird, sind ein Verfahren und eine Vorrichtung zur Bildmessung, welche eine Erdpositionsbestimmung und genaue Messungen in schrägen Bildern ermöglichen.

[0013] Was darüber hinaus auf dem Gebiet benötigt wird, sind ein Verfahren und eine Vorrichtung zur Bildmessung, welche die Messung von Höhen und relativen Höhen von Objekten innerhalb eines Bildes ermöglichen.

[0014] Was ferner auf dem Gebiet benötigt wird, sind ein Verfahren und eine Vorrichtung zur Bildmessung, welche intuitivere und natürlichere Bilder verwenden.

ZUSAMMENFASSUNG DER ERFINDUNG

[0015] Die vorliegende Erfindung stellt ein System nach Anspruch 1 bereit.

KURZE BESCHREIBUNG DER ZEICHNUNGEN

[0016] Die oben erwähnten und andere Merkmale und Vorteile dieser Erfindung, und die Art, sie zu erlangen, werden durch Bezug auf die folgende Beschreibung einer Ausführungsform der Erfindung klar und genauer verstanden, wenn sie zusammen mit den beiliegenden Zeichnungen gelesen wird, worin:

[0017] Fig. 1 eine Ausführungsform einer Plattform oder eines Fahrzeuges darstellt, welches ein erfindungsgemäßes Bildaufnahmesystem trägt und damit aufgenommene beispielhafte orthogonale und schräge Bilder zeigt;

[0018] Fig. 2 eine diagrammatische Sicht des Bildaufnahmesystems aus Fig. 1 ist;

[0019] Fig. 3 ein Blockdiagramm des Bildaufnahmecomputersystems aus Fig. 2 ist;

[0020] Fig. 4 eine Darstellung einer beispielhaften Ausgabedatendatei des Bildaufnahmesystems aus Fig. 1 ist;

[0021] Fig. 5 ein Blockdiagramm einer Ausführungsform eines erfindungsgemäßen Bildanzeige- und Messcomputersystems zum Anzeigen und Aufnehmen von Messungen von und zwischen Objekten ist, welche in den durch das Bildaufnahmesystem aus Fig. 1 aufgenommenen Bildern dargestellt sind;

[0022] Fig. 6 ein beispielhaftes Abbild darstellt, welches auf dem System aus Fig. 5 angezeigt wird, und eine Ausführungsform des erfindungsgemäßen Verfahrens zur Messung von und zwischen in einem solchen Bild dargestellten Objekten darstellt;

[0023] Fig. 7 und Fig. 8 eine Ausführungsform eines erfindungsgemäßen Verfahrens zum Aufnehmen schräger Bilder darstellt;

[0024] Fig. 9 und Fig. 10 eine zweite Ausführungsform eines erfindungsgemäßen Verfahrens zum Aufnehmen schräger Bilder darstellt.

[0025] Entsprechende Bezugszeichen geben entsprechende Teile durch die unterschiedlichen Ansichten hindurch an. Die hierin dargestellten Beispiele stellen eine bevorzugte Ausführungsform der Erfin-

dung dar, und zwar in einer Form, und solche Beispiele sind nicht dazu aufgestellt worden, um den Umfang der Erfindung auf irgendeine Art zu beschränken.

BESCHREIBUNG DER BEVORZUGTEN AUSFÜHRUNGSFORMEN

[0026] Nun bezüglich der Zeichnungen, und insbesondere bezüglich Fig. 1, ist eine Ausführungsform einer Vorrichtung zum Aufnehmen und Erdpositionsbestimmen schräger Bilder nach der vorliegenden Erfindung gezeigt. Die Vorrichtung **10** umfasst eine Plattform oder ein Fahrzeug **20**, welches das Bildaufnahme- und Erdpositionsbestimmungssystem **30** trägt.

[0027] Die Plattform **20**, wie beispielsweise ein Flugzeug, ein Space Shuttle, eine Rakete, ein Satellit oder jedes andere geeignete Fahrzeug, trägt das Bildaufnahmesystem **30** über eine vordefinierte Fläche und auf einer oder mehreren vorbestimmten Höhenlagen über der Oberfläche **31**, wie beispielsweise die Erdoberfläche oder jede andere interessierende Oberfläche. Als solches ist die Plattform **20**, entweder bemannt oder unbemannt, zu einer gesteuerten Bewegung oder Flug in der Lage, und zwar entlang eines vorbestimmten Flugpfads oder -kurses durch beispielsweise die Erdatmosphäre oder den Weltraum. Die Bildaufnahmeplattform **20** umfasst ein System zum Erzeugen und Regeln von Leistung (nicht gezeigt), welches beispielsweise ein oder mehrere Generatoren, Brennstoffzellen, Solarzellen und/oder Batterien zum Antreiben des Bildaufnahmesystems **30** umfasst.

[0028] Das Bildaufnahme- und Erdpositionsbestimmungssystem **30**, wie es am besten in Fig. 2 gezeigt ist, umfasst Bildaufnahmevorrichtungen **32a** und **32b**, einen GPS ("global positioning system")-Empfänger **34**, eine Trägheitsnavigationseinheit ("inertial navigation unit"; INU) **36**, eine Uhr **38**, ein Gyroskop **40**, einen Kompass **42** und einen Höhenmesser **44**, von denen jedes mit einem Bildaufnahmecomputersystem **46** zusammengeschaltet ist.

[0029] Die Bildaufnahmevorrichtungen **32a** und **32b**, wie beispielsweise herkömmliche Kameras, Digitalkameras, digitale Sensoren, ladungsgekoppelte Vorrichtungen ("charge-coupled devices"; CCD) oder jegliche andere geeignete Bildaufnahmevorrichtungen sind in der Lage, Bilder fotografisch oder elektronisch aufzunehmen. Die Bildaufnahmevorrichtungen **32a** und **32b** weisen bekannte oder bestimmbare Eigenschaften auf, einschließlich einer Brennweite, einer Sensorgröße und einem Bildseitenverhältnis, radialen oder anderen Verzerrungstermen, einem Hauptversatzpunkt, einem Bildpunktabstand und eine Anpassung. Die Bildaufnahmevorrichtungen **32a** und **32b** nehmen Bilder auf und geben Bilddatensignale ("image data signals"; IDS) **48a** bzw. **48b** entsprechend den bestimmten aufgenommenen Bildern oder Fotografien aus, welche im Bildaufnahmecomputersystem **46** gespeichert werden, wie es genauer im Folgenden beschrieben wird.

[0030] Wie am besten in Fig. 1 gezeigt, weisen die Bildaufnahmevorrichtungen **32a** und **32b** entsprechende Mittelachsen A_1 und A_2 auf und sind auf der Plattform **20** so befestigt, dass die Achsen A_1 und A_2 jeweils unter einem Neigungswinkel θ relativ zu einer horizontalen Ebene P liegen. Der Neigungswinkel θ ist so gut wie jeder schräge Winkel, beträgt aber vorteilhafter Weise zwischen ca. 20° (zwanzig Grad) und ca. 60° (sechzig Grad) und liegt am meisten bevorzugt zwischen ca. 40° (vierzig Grad) und ca. 50° (fünfzig Grad).

[0031] Der GPS-Empfänger **34** empfängt GPS-Signale **52**, welche von einem oder mehreren GPS-Satelliten **54** ausgesandt werden. Die GPS-Signale **52** ermöglichen auf bekannte Weise die genaue Positionsbestimmung der Plattform **20** relativ zur zu bestimmenden Oberfläche **31**. Der GPS-Empfänger **34** dekodiert GPS-Signale **52** und gibt Positionssignale/-daten **56** aus, welche zumindest teilweise von den GPS-Signalen **52** abhängen und welche die genaue Position der Plattform **20** relativ zur Oberfläche **31** anzeigen. Die Positionssignale/-daten **56**, die zu jedem von den Bildaufnahmevorrichtung **32a** und **32b** aufgenommenen Bildern gehören, werden vom Bildaufnahmecomputersystem **46** empfangen und gespeichert.

[0032] Die INU **36** ist eine herkömmliche Trägheitsnavigationseinheit, welche mit Geschwindigkeitsänderungen der Bildaufnahmevorrichtungen **32a** und **32b** und/oder der Plattform **20** gekoppelt ist und diese erfasst, einschließlich einer Verschiebungs- und einer Drehgeschwindigkeit. Die INU **36** gibt Geschwindigkeitssignale/-daten **58**, die solche Geschwindigkeiten und/oder Änderungen daran anzeigen, an das Bildaufnahmecomputersystem **46** aus, welches die Geschwindigkeitssignale/-daten **58** speichert, welche zu jedem Bild gehören, das durch die Bildaufnahmevorrichtungen **32a** und **32b** aufgenommen wurde, und die durch das Bildaufnahmecomputersystem **46** empfangen und gespeichert werden.

[0033] Die Uhr **38** führt eine genaue Zeitmessung (Validierungszeit) durch, welche verwendet wird, um Ereignisse innerhalb des Bildaufnahme- und Erdpositionsbestimmungssystems **30** zu synchronisieren. Die Uhr **38** stellt ein Zeitdaten/Takt-Signal **62** bereit, welches die genaue Zeit angibt, zu der ein Bild durch die Bildaufnahmevorrichtungen **32a** und **32b** aufgenommen worden ist. Die Zeitdaten **62** werden auch dem Bildaufnahmecomputersystem **46** bereitgestellt und davon gespeichert. Alternativ ist die Uhr **38** im Bildaufnahmecomputersystem **46** integriert, wie bei-

spielsweise als ein Uhrsoftwareprogramm.

[0034] Das Gyroskop **40** ist ein herkömmliches Gyroskop, wie es üblicherweise in Flugzeugen und/oder in kommerziellen Navigationssystemen für Flugzeuge zu finden ist. Das Gyroskop **40** stellt Signale bereit, einschließlich eines Stampfsignals **64**, eines Rollsignals **66** und eines Giersignals **68**, welche entsprechend ein Stampfen, ein Rollen und ein Gieren der Plattform anzeigen. Das Stampfsignal **64**, das Rollsignal **66** und das Giersignal **68** sind jedem Bild zugehörig, welches von den Bildaufnahmevorrichtungen **32a** und **32b** aufgenommen worden ist, und werden vom Bildaufnahmecomputersystem **46** empfangen und gespeichert.

[0035] Der Kompass **42**, wie beispielsweise ein herkömmlicher elektronischer Kompass, gibt die Ausrichtung der Plattform **20** an. Der Kompass **42** gibt Ausrichtungssignale/-daten **72** aus, welche die Ausrichtung der Plattform anzeigen. Das Bildaufnahmecomputersystem **46** empfängt und speichert die Ausrichtungssignale/-daten **72**, welche jedem durch die Bildaufnahmevorrichtungen **32a** und **32b** aufgenommenen Bild entsprechen.

[0036] Der Höhenmesser **44** zeigt die Höhe der Plattform **20** an. Der Höhenmesser **44** gibt Höhenlagensignale/-Daten **74** aus, und das Bildaufnahmecomputersystem **46** empfängt und speichert die Höhenlagensignale/-Daten **74**, die zu jedem Bild gehören, das durch die Bildaufnahmevorrichtungen **32a** und **32b** aufgenommen worden ist.

[0037] Wie am besten in Fig. 3 gezeigt, umfasst das Bildaufnahmecomputersystem **46**, wie beispielsweise ein herkömmlicher Laptop-Personalcomputer, einen Speicher **82**, Eingabevorrichtungen **84a** und **84b**, eine Anzeigevorrichtung **86** und Eingabe/Ausgabe ("input/output"; I/O)-Anschlüsse **88**. Das Bildaufnahmecomputersystem **46** führt eine Bild- und Datenerfassungs-Software **90** aus, welche in dem Speicher **82** gespeichert ist. Der Speicher **82** speichert auch Daten, welche vom Bildaufnahmecomputersystem **46** während seines Betriebs verwendet und/oder berechnet worden sind, und umfasst beispielsweise einen nichtflüchtigen Nur-Lese-Speicher, einen Schreib/Lese-Speicher, einen Plattenspeicher, entfernbare Speicherkarten und/oder andere geeignete Speichervorrichtungen und/oder -medien. Die Eingabevorrichtungen **84a** und **84b**, wie beispielsweise eine Maus, eine Tastatur, ein Joystick oder andere solche Eingabevorrichtungen, ermöglichen die Eingabe von Daten und eine Wechselwirkung eines Nutzers mit der Software, die von dem Bildaufnahmecomputersystem **46** ausgeführt wird. Die Anzeigevorrichtung **86**, wie beispielsweise eine Flüssigkristallanzeige oder eine Kathodenröhre, zeigt dem Benutzer des Bildaufnahmecomputersystems **46** Information an. Eingabe/Ausgabe-Anschlüsse, **88**, wie beispielsweise serielle und parallele Dateneingabe- und -ausgabeanschlüsse, ermöglichen die Eingabe und/oder Ausgabe von Daten zum und vom Bildaufnahmecomputersystem **46**.

[0038] Jedes der oben beschriebenen Datensignale ist mit dem Bildaufnahmecomputersystem **46** verbunden. Insbesondere werden die Bilddatensignale **46**, Erdpositionssignale **56**, Geschwindigkeitssignale **58**, Zeitdatensignal **62**, Stampf-, Roll- und Gier-Signale **64**, **66** bzw. **68**, das Ausrichtungssignal **72** und das Höhenlagensignal **74** über Eingabe/Ausgabe-Anschlüsse **88** vom Bildaufnahmecomputersystem **46** empfangen und innerhalb des zugehörigen Speichers **82** gespeichert.

[0039] Im Gebrauch führt das Bildaufnahmecomputersystem **46** die Bild- und Datenerfassungs-Software **90** aus, welche allgemein das Lesen, das Behandeln und das Speichern der oben beschriebenen Datensignale steuert. Im Besonderen liest die Bild- und Datenerfassungs-Software **90** Datensignale **48a** und **48b** und speichert sie im Speicher **82**. Jedes der Erdpositionssignale **56**, Geschwindigkeitssignale **58**, Zeitdatensignal **62**, Stampf-, Roll- und Gier-Signale **64**, **66** bzw. **68**, das Ausrichtungssignal **72** und das Höhenlagensignal **74**, welche die Zustände darstellen, die zum Zeitpunkt eines Bildes herrschen, das durch die Bildaufnahmevorrichtungen **32a** und **32b** erfasst oder aufgenommen wird, und welche den bestimmten Bilddatensignalen **48a** und **48b** entsprechen, welche die aufgenommenen Bilder darstellen, werden vom Bildaufnahmecomputersystem **46** über Eingabe/Ausgabe-Anschlüsse **88** empfangen. Das Bildaufnahmecomputersystem **46**, welches die Bild- und Datenerfassungssoftware **90** ausführt, gibt ein Bildaufnahmesignal **92** an die Bildaufnahmevorrichtungen **32a** und **32b** aus, um dadurch diese Vorrichtungen zu veranlassen, ein Bild bei vorbestimmten Positionen und/oder zu vorbestimmten Intervallen zu erfassen oder aufzunehmen, welche zumindest teilweise von der Geschwindigkeit der Plattform **20** abhängen.

[0040] Die Bild- und Datenerfassungs-Software **90** dekodiert wie notwendig und speichert und oben genannten Signale im Speicher **82** und ordnet die Datensignale den zugehörigen Bildsignalen **48a** und **48b** zu. Daher sind die Höhe, Ausrichtung in Bezug auf Rollen, Stampfen und Gier und die Position der Bildaufnahmevorrichtungen **32a** und **32b** relativ zur Oberfläche **31**, d. h., der Längengrad und der Breitengrad, für jedes Bild bekannt, welches von den Bildaufnahmevorrichtungen **32a** und **32b** aufgenommen worden ist. Die Plattform **20** wird über einen Bildaufnahmepfad gelenkt oder auf andere Weise geführt, welcher über eine bestimmte Fläche der Oberfläche **31** führt, wie beispielsweise eine vorbestimmte Fläche der Erdoberfläche oder eines anderen Planeten. Vorzugsweise befindet sich der Bildaufnahme-

pfad der Plattform **20** rechtwinklig zu mindestens einer der Grenzen der Fläche von Interesse. Die Anzahl, wie oft die Plattform **20** und/oder die Bildaufnahmevorrichtungen **32a**, **32b** die interessierende Fläche überstreicht, ist zumindest teilweise abhängig von der Größe der Fläche und der in den aufgenommenen Bildern benötigten Detailgenauigkeit. Die bestimmten Details des Bildaufnahmepfads der Plattform **20** werden im Folgenden genauer beschrieben.

[0041] Wenn die Plattform **20** sich über die interessierende Fläche bewegt, wird eine Anzahl schräger Bilder durch die Bildaufnahmevorrichtungen **32a** und **32b** aufgenommen. Wie es vom Fachmann verstanden wird, werden die Bilder durch die Bildaufnahmevorrichtungen **32a** und **32b** zu vorbestimmten Bildaufnahmeintervallen aufgenommen oder erfasst, welche zumindest teilweise von der Geschwindigkeit der Plattform **20** abhängen.

[0042] Bilddatensignale **48a** und **48b**, welche jedem aufgenommenen Bild zugehörig sind, werden vom Bildaufnahmecomputersystem empfangen und in einem Speicher **82** davon gespeichert, und zwar über Eingabe/Ausgabe-Anschlüsse **88**. Auf ähnliche Weise werden die Datensignale (d. h., die Bilddatensignale **48**, die Erdpositionssignale **56**, die Geschwindigkeitssignale **58**, das Zeitdatensignal **62**, die Stampf-, Roll- und Giersignale **64**, **66** bzw. **68**, das Ausrichtungssignal **72** und das Höhenlagensignal **74**), welche jedem aufgenommenen Bild zugehörig sind, von dem Bildaufnahmecomputersystem **46** über Eingabe/Ausgabe-Anschlüsse **88** empfangen und innerhalb eines zugehörigen Speichers **82** gespeichert. Daher wird die Position der Bild-Aufnahmevorrichtungen **32a** und **32b** relativ zur Oberfläche **32** zu dem genauen Zeitpunkt, zu dem jedes Bild aufgenommen wird, im Speicher **82** empfangen und dem zugehörigen aufgenommenen Bild zugeordnet.

[0043] Wie man es am besten in Fig. 1 sieht, entspricht die Position der Bildaufnahmevorrichtungen **32a** und **32b** relativ zur Erde dem Fusspunkt N des orthogonalen Bildes **102**. Daher ist die genaue Erdpositionsbestimmung des Fusspunkts N des orthogonalen Bildes **102** durch Positionssignale **56**, Geschwindigkeitssignale **58**, Zeitdatensignal **62**, Stampf-, Roll- und Gier-Signale **64**, **66** bzw. **68**, das Ausrichtungssignal **72** und das Höhenlagensignal **74** angegeben. Sobald der Fusspunkt N des orthogonalen Bildes **102** bekannt ist, ist die Erdposition jedes anderen Bildpunkts oder Punkts innerhalb des Bildes **102** auf bekannte Weise bestimmbar.

[0044] Wenn die Bildaufnahmevorrichtung **32a** und **32b** schräge Bilder aufnehmen, wie beispielsweise schräge Bilder **104a** und **104b** (Fig. 1), wird die Position der Bildaufnahmevorrichtungen **32a** und **32b** relativ zur Oberfläche **31** ähnlich durch Positionssignale **56**, Geschwindigkeitssignale **58**, das Zeitdatensignal **62**, Stampf-, Roll- und Giersignale **64**, **66** bzw. **68**, das Ausrichtungssignal **72**, das Höhenlagensignal **74** und den bekannten Neigungswinkel θ der Hauptachsen A_1 und A_2 der Bildaufnahmevorrichtungen **32a** bzw. **32b** angegeben.

[0045] Es ist insbesondere anzumerken, dass ein Kalibrierungsprozess es der Bild- und Datenerfassungs-Software **90** ermöglicht, Korrekturfaktoren aufzunehmen und/oder jeden Fehler zu korrigieren, welcher der Bildaufnahmevorrichtung **32** zugehörig ist oder ihr zuzuschreiben ist, wie beispielsweise einen Fehler aufgrund der kalibrierten Brennweite, Sensorgröße, radialen Verzerrung, Hauptpunktversatz und Ausrichtung.

[0046] Die Bild- und Datenerfassungs-Software **90** erzeugt und speichert im Speicher **82** ein oder mehrere Ausgabebild- und -datendateien **120**. Im Besonderen wandelt die Bild- und Datenerfassungs-Software **90** Bilddatensignale **48a**, **48b** und die Orientierungsdatensignale (d. h., die Bilddatensignale **48**, die Erdpositionssignale **56**, die Geschwindigkeitssignale **58**, das Zeitdatensignal **62**, die Stampf-, Roll- und Giersignale **64**, **66** bzw. **68**, das Ausrichtungssignal **72** und das Höhenlagensignal **74**) in computerlesbare Ausgabebild- und -datendateien **120** um. Wie am besten in Fig. 4 gezeigt, umfasst die Ausgabebild- und -datendatei **120** eine Vielzahl von Dateien I_1, I_2, ..., I_n aufgenommener Bilder, welche aufgenommenen schrägen Bildern entsprechen, als auch die Positionsdaten C_{PD1}, C_{PD2}, ..., C_{PDn}, die dazu gehören.

[0047] Die Bilddateien I_1, I_2, ..., I_n der Bild- und Datendatei **120** werden in so gut wie jedem computerlesbaren Bild- oder Grafikdateiformat gespeichert, wie beispielsweise in JPEG-, TIFF-, GIF-, BMP- oder PDF-Datenformaten, und sind mit den Positionsdaten C_{PD1}, C_{PD2}, ..., C_{PDn} kreuzreferenziert, welche ebenfalls als computerlesbare Daten gespeichert werden. Alternativ sind die Positionsdaten C_{PD1}, C_{PD2}, ..., C_{PDn} in den zugehörigen Bilddateien I_1, I_2, ..., I_n in bekannter Weise eingebettet. Die Bilddatendateien **120** werden dann verarbeitet, entweder durch die Bild- und Datenerfassungs-Software **90** oder durch ein Nachverarbeiten, um Fehler zu korrigieren, wie beispielsweise Fehler aufgrund von Abweichungen vom Flugpfad und anderen dem Fachmann bekannten Fehlern. Danach sind die Bilddatendateien **120** fertig zur Verwendung zur Anzeige und zur Durchführung von Messungen von und zwischen den Objekten, die in den aufgenommenen Bildern dargestellt sind, einschließlich von Messungen der Höhen solcher Objekte.

[0048] Nun Bezug nehmend auf Fig. 5 umfasst das Bildanzeige- und -messungscomputersystem **130**, wie beispielsweise ein herkömmlicher Desktop-PC oder ein mobiles Computerendgerät in einem Polizeiwagen, einen Speicher **132**, Eingabevorrichtungen

134a und **134b**, eine Anzeigevorrichtung **136** und eine Netzwerkverbindung **138**. Das Bildaufnahmecomputersystem **130** führt die Bildanzeige- und -auswertesoftware **140** durch, welche im Speicher **132** gespeichert ist. Der Speicher **132** umfasst beispielsweise nichtflüchtigen Nur-Lese-Speicher, Schreib/Lese-Speicher, Plattenspeicher, entfernbare Speicherkarten und/oder andere geeignete Speichervorrichtungen und/oder -medien. Die Eingabevorrichtungen **134a** und **134b**, wie beispielsweise eine Maus, eine Tastatur, ein Joystick oder andere solche Vorrichtungen, ermöglichen die Eingabe von Daten und eine Interaktion eines Nutzers mit einer Bildanzeige- und -auswertesoftware **140**, welche von dem Bildanzeige- und -messungscomputersystem **130** ausgeführt wird. Die Anzeigevorrichtung **136**, wie beispielsweise eine Flüssigkristallanzeige oder eine Kathodenstrahlröhre, zeigt dem Nutzer des Bildanzeige- und -messungscomputersystems **130** Information an. Die Netzwerkverbindung **138** verbindet das Bildanzeige- und Messcomputersystem **130** mit einem Netzwerk (nicht gezeigt), wie beispielsweise einem lokalen Netzwerk ("local-area network"; LAN), einem Fernbereichsnetzwerk ("wide-area network"; WAN), dem Internet und/oder dem World Wide Web.

[0049] Im Gebrauch, und nun bezüglich Fig. 6, greift das Bildanzeige- und -messungscomputersystem **130**, welches die Bildanzeige- und -auswertesoftware **140** ausführt, auf ein oder mehrere Ausgabebild- und -datendateien **120** zu, welche in den Speicher **132** eingelesen worden sind, wie beispielsweise über eine Netzwerkverbindung **138**, eine Diskette, eine entfernbare Speicherkarte oder ein anderes geeignetes Mittel. Ein oder mehrere der aufgenommenen Bilder I_1, I_2, ..., I_n der Ausgabebild- und -datendateien **120** werden danach als angezeigte schräge Bilder **142** unter der Steuerung der Bildanzeige- und -auswertesoftware **140** angezeigt. Zu ungefähr der gleichen Zeit werden ein oder mehrere Datenabschnitte C_{PD1}, C_{PD2}, ..., C_{PDn}, die zu dem angezeigten schrägen Bild **142** gehören, in einen Schreib/Lese-Teil des Speichers **132** eingelesen.

[0050] Es sollte insbesondere bemerkt werden, dass das angezeigte schräge Bild **142** im wesentlichen wie aufgenommen dargestellt wird, d. h., dass das angezeigte Bild **142** nicht verformt oder irgendeinem Koordinatensystem angepasst ist, noch ist das angezeigte Bild **142** geradegezogen. Statt das angezeigte Bild **142** auf ein Koordinatensystem hin zu verformen, um ein Ausmessen von darin dargestellten Objekten zu ermöglichen, bestimmt die Bildanzeige- und -auswertesoftware **140** allgemein die Erdpositionen ausgewählter Bildpunkte nur wie benötigt, oder in Echtzeit, durch Referenzieren von Datenabschnitten C_{PD1}, C_{PD2}, ..., C_{PDn} der Ausgabebild- und Datendateien **120** und Berechnen der Position und/oder Erdposition solcher ausgewählten Bildpunkte unter Verwendung einer oder mehrerer Abbildungsgleichungen, wie es genauer weiter unten beschrieben ist.

[0051] Allgemein führt ein Nutzer des Anzeige- und Mess-Computersystems **130** Messungen von und zwischen Objekten, die in dem angezeigten schrägen Bild **142** dargestellt wird, mittels Auswählen eines von mehreren verfügbaren Messbetriebsarten durch, die in der Bildanzeige- und -auswertesoftware **140** vorgesehen sind. Der Nutzer wählt die gewünschte Messbetriebsart durch Zugreifen auf beispielsweise eine Folge von Pulldownmenüs oder Toolbars M oder durch Tastaturkommandos aus. Die Messbetriebsarten, die von der Bildanzeige- und -auswertesoftware **140** bereitgestellt werden, umfassen beispielsweise eine Abstandsbetriebsart, welche ein Messen des Abstands zwischen zwei oder mehr ausgewählten Punkten ermöglicht, eine Flächenbetriebsart, welche eine Messung der von mehreren ausgewählten und verbundenen Punkten umfassten Fläche ermöglicht, eine Höhenbetriebsart, welches eine Messung der Höhe zwischen zwei oder mehr ausgewählten Punkten ermöglicht, und eine Höhenlagenbetriebsart, welches die Messung der Änderung in der Höhenlage eines ausgewählten Punkts relativ zu einem oder mehreren anderen ausgewählten Punkten ermöglicht.

[0052] Nach Auswählen der gewünschten Messungsbetriebsart, wählt der Nutzer der Bildanzeige- und -auswertesoftware **140** mit einer der Eingabevorrichtungen **134a**, **134b** einen Anfangspunkt oder einen Anfangsbildpunkt **152** und einen Endpunkt oder Endbildpunkt **154** auf dem angezeigten Bild **142** aus, und die Bildanzeige- und -auswertesoftware **140** berechnet automatisch die gesuchte Größe und stellt diese dar, wie beispielsweise den Abstand zwischen dem Anfangsbildpunkt **152** und dem Endbildpunkt **154**.

[0053] Wenn der Nutzer den Anfangspunkt/-bildpunkt **152** auswählt, wird die Erdposition des dazu zugehörigen Punkts auf der Oberfläche **31** durch die Bildanzeige- und -auswertesoftware **140** berechnet, welche ein oder mehrere Abbildungsgleichungen unter Verwendung der Datenabschnitte C_{PD1}, C_{PD2}, ..., C_{PDn} der Ausgabebild- und -datendateien **120** ausführt, welche zu dem bestimmten angezeigten Bild gehören. Der Längengrad und der Breitengrad des Punkts an der Oberfläche **31**, welcher dem Bildpunkt **152** entspricht, werden dann durch die Bildanzeige- und -auswertesoftware **140** auf der Anzeige **136** angezeigt, wie beispielsweise durch Überlagern des Längengrads und des Breitengrads auf das angezeigte Bild **142** benachbart zum ausgewählten Endpunkt/-bildpunkt oder in einem aufklappbaren Anzeigekasten irgendwo auf der Anzeige **136**. Der gleiche Prozessschritt wird vom Nutzer zur Auswahl des Endbildpunkts/-punkts **154** wiederholt, als auch durch die Bildanzeige- und -auswertesoftware **140**

zum Auslesen und Anzeigen der Längengrad- und Breitengradinformation.

[0054] Die Berechnung des Abstands zwischen den Anfangs- und Endpunkten/-pixeln **152** bzw. **154** wird erreicht durch Bestimmen der Erdposition jedes ausgewählten Bildpunkts **152**, **154** in Echtzeit. Die Datenabschnitte C_{PD1}, C_{PD2}, ..., C_{PDn} der Ausgabebild- und -datendatei **120**, welche dem angezeigten Bild entspricht, werden ausgelesen, und die Erdposition des Punkts auf der Oberfläche **31**, welche jedem ausgewählten Bildpunkt entspricht, wird dann bestimmt. Der Unterschied zwischen den Erdpositionen, die zu den ausgewählten Bildpunkten gehören, bestimmt den Abstand zwischen den Bildpunkten.

[0055] Als ein Beispiel, wie die Erdposition eines gegebenen Punkts oder Bildpunkts innerhalb des angezeigten schrägen Bilds **142** bestimmt wird, nehmen wir an, dass das angezeigte Bild **142** dem angezeigten Bild **104a** (Fig. 1) entspricht. Der Nutzer der Bildanzeige- und -auswertesoftware **140** wählt den Bildpunkt **152** aus, welcher aus Gründen der Einfachheit der Mitte C (Fig. 1) des schrägen Bilds **104a** entspricht. Wie in Fig. 1 gezeigt, erstreckt sich die Linie **106** entlang der horizontalen Ebene G von einem Punkt **108** aus, welcher direkt unter der Bildaufnahmevorrichtung **32a** liegt, zur Mitte C der nächsten Grenze oder Kante **108** des schrägen Bilds **104a**. Eine Erweiterung der Hauptachse A_1 schneidet die Mitte C. Ein Winkel ⌀ ist der Winkel, welcher zwischen der Linie **106** der Erweiterung der Hauptachse A_1 gebildet wird. So wird ein Dreieck (nicht mit Bezugszeichen versehen) gebildet, welches Scheitelpunkte an der Bildaufnahmevorrichtung **32a**, dem Punkt **108** und der Mitte C bildet und Seiten **106**, die Verlängerung der Hauptachse A_1 und die vertikale (gestrichelte) Linie **110** zwischen Punkt **108** und der Bildaufnahmevorrichtung **32a** aufweist.

[0056] Die Grundebene G ist eine im Wesentlichen horizontale, ebene oder nicht-schräge Grundebene (und welche typischerweise eine Höhenlage aufweist, welche die durchschnittliche Höhenlage des Geländes widerspiegelt), und dadurch umfasst das oben beschriebene Dreieck einen rechten Winkel zwischen der Seite/Linie **110** und der Seite/Linie **106**. Da der Winkel ⌀ und die Höhenlage der Bildaufnahmevorrichtung **32** (d. h., die Länge der Seite **110**) bekannt sind, werden die Hypotenuse (d. h., die Länge der Verlängerung der Hauptachse A_1) und die übrige andere Seite des rechten Dreiecks durch einfache Geometrie berechnet. Da ferner die genaue Position der Bildaufnahmevorrichtung **32a** zu der Zeit bekannt ist, zu der das zum angezeigten Bild **142** entsprechende Bild aufgenommen wurde, sind auch der Breitengrad und der Längengrad von Punkt **108** bekannt. Die Kenntnis der Länge der Seite **106**, welche wie oben beschrieben berechnet wurde, ermöglicht die genaue Erdpositionsbestimmung von Bildpunkt **154**, welches der Mitte C des schrägen Bildes **104a** entspricht, durch die Bildanzeige- und -auswertesoftware **140**. Sobald die Erdposition des Punktes, welcher dem Bildpunkt **154** entspricht, bekannt ist, ist die Erdposition jedes anderen Bildpunkts im angezeigten schrägen Bild **142** unter Verwendung der bekannten Kameraeigenschaften bestimmbar, wie beispielsweise der Brennweite, der Sensorgröße und dem Bildseitenverhältnis, radialen und anderen Verzerrungstermen usw.

[0057] Der Abstand zwischen zwei und mehr Punkten, welche zwei oder mehr ausgewählten Bildpunkten innerhalb des angezeigten Bilds **142** entsprechen, wird von der Bildanzeige- und -auswertesoftware **140** durch Bestimmen des Unterschieds zwischen den Erdpositionen der ausgewählten Bildpunkte unter Verwendung bekannter Algorithmen berechnet, wie beispielsweise durch die Gauss'sche Formel und/oder die Fluchtpunktsformel, und zwar abhängig von der ausgewählten Messbetriebsart. Die Messung von Objekten, die in dem angezeigten Bild **142** dargestellt sind oder dort auftreten, wird mittels eines im Wesentlichen ähnlichen Ablaufs zu dem oben beschriebenen Ablauf zum Ausmessen von Abständen zwischen ausgewählten Bildpunkten durchgeführt. Beispielsweise werden die Längen, Breiten und Höhen von Objekten, wie beispielsweise von Gebäuden, Flüssen, Straßen und so gut wie jeder anderen geografischen oder menschengemachten Struktur, welche auf dem angezeigten Bild **142** auftauchen, durch Auswählen der geeigneten/gewünschten Messbetriebsart und durch Auswählen von Anfangs- und Endbildpunkten ausgemessen.

[0058] Es sollte insbesondere angemerkt werden, dass in der Abstandsmessungsbetriebsart der Bildanzeige- und -auswertesoftware **140** der Abstand zwischen den Anfangs- und Endpunkten/Bildpunkten **152** bzw. **154** entlang so gut wie jeden Pfads bestimmbar ist, wie beispielsweise entlang eines "geradlinigen" Pfads P1 oder eines Pfads P2, welcher die Auswahl von Zwischen-Punkten/Bildpunkten und einem oder mehreren "geradlinigen" Abschnitten, die darin verbunden sind, umfasst.

[0059] Es sollte insbesondere angemerkt werden, dass die Abstandsmessungsbetriebsart der Bildanzeige- und -auswertesoftware **140** den Abstand zwischen ausgewählten Bildpunkten gemäß dem "Fußgänger" ("walk the earth")-Verfahren bestimmt wird. Das "Fußgänger"-Verfahren erzeugt eine Folge zusammenhängender Linienabschnitte, welche gemeinsam durch die Pfade P1 und P2 dargestellt werden, die sich zwischen den ausgewählten Bildpunkten/Punkten erstrecken und welche auf den ebenen Flächen einer Folge zusammenhängender Facetten liegen, oder an diese angepasst sind, welche eine schachbrettartige bzw. mosaikartige Grundebene definieren. Die mosaikartige Grundebene folgt, wie ge-

nauer später beschrieben wird, dem Gelände der Oberfläche **31** eng oder erschafft es neu, und dadurch folgen auch die Pfade P1 und P2 dem Gelände der Oberfläche **31** eng. Durch Ausmessen des Abstands entlang des durch die mosaikartige Grundebene simulierten Geländes stellt das "Fußgänger"-Verfahren eine genauere und nützlichere Abstandsmessung zwischen ausgewählten Punkten bereit als der herkömmliche Ansatz, welcher das Bild auf eine flache Erdoberfläche oder auf ein Ebenensystem durchschnittlicher Höhenlage verformt und den Abstand zwischen ausgewählten Punkten entlang der flachen Erde oder Ebene ausmisst und im Wesentlichen Geländeschwankungen zwischen den Punkten ignoriert.

[0060] Beispielsweise kann ein Bauunternehmer, welcher sich darauf vorbereitet, für einen Vertrag zum Bahnen einer Fahrbahn über unebenes oder hügliges Gelände zu bieten, die ungefähre Größe oder Fläche der damit verbundenen Fahrbahn unter Verwendung der Bildanzeige- und -auswertesoftware **140** und des damit bereitgestellten "Fußgänger"-Ausmessverfahrens bestimmen. Der Bauunternehmer kann die ungefähre Größe oder Fläche der Fahrbahn von seinem oder ihrem Büro aus erlangen, ohne einen Landvermessungstrupp zum Bauplatz zu schicken, um die notwendigen Messungen zu erhalten.

[0061] Im Unterschied zu dem durch die vorliegende Erfindung bereitgestellten "Fußgänger"-Verfahren, beinhalten die "flache Erde"- oder Durchschnittshöhenabstands-Berechnungsansätze inhärente Ungenauigkeiten, wenn sie Abstände zwischen Punkten und/oder Objekten ausmessen, welche sich auf unebenem Gelände befinden, oder wenn sie die Größen und/oder Höhen der ähnlich angeordneten Objekte ausmessen. Sogar eine geringe Steigung oder Neigung in der Oberfläche, die aufgenommen wird, führt zu einem Unterschied in der Höhenlage des Fusspunkts relativ zu so gut wie jedem anderen interessierenden Punkt darauf. Daher mag, wieder in Bezug auf Fig. 1, das durch die Linie **106**, die Verlängerung der Hauptachse A_1 und die vertikale (gestrichelte) Linie **110** zwischen Punkt **108** und der Bildaufnahmevorrichtung **32a** gebildete Dreieck kein richtiges Dreieck sein. Falls dies der Fall ist, würden jegliche geometrische Berechnungen, welche annehmen, dass das Dreieck ein richtiges Dreieck ist, Fehler enthalten, und solche Berechnungen würden aufgrund sogar eines leichten Gradienten oder Steigung zwischen den interessierenden Punkten zu Abschätzungen verringert werden.

[0062] Falls sich beispielsweise die Oberfläche **31** zwischen dem Fusspunkt N und der Mitte C an der nahen oder unteren Kante **108** des schrägen Bilds **104** nach oben neigt, schneidet die zweite Linie **110** die Oberfläche **31** dann vor dem Punkt, an welchem eine solche Kreuzung auf einer ebenen oder sich nicht neigenden Oberfläche **31** auftreten würde. Falls die Mitte C 15 Fuß höher als der Fusspunkt N ist und einen Neigungswinkel θ gleich 40° (vierzig Grad) aufweist, würde die berechnete Position der Mitte C um ungefähr 17,8 Fuß versetzt sein ohne Korrektur der Änderung in der Höhenlage zwischen den Punkten.

[0063] Wie allgemein oben diskutiert, referenziert, um zumindest teilweise Änderungen in der Höhenlage und die sich ergebenden Ungenauigkeiten in der Ausmessung von und zwischen Objekten innerhalb des Bildes **142** zu kompensieren, die Bildanzeige- und -auswertesoftware **140**, wie notwendig, Punkte innerhalb des angezeigten Bilds **142** und auf der Oberfläche **31** auf eine vorberechnete mosaikförmige oder aus Facetten aufgebaute Grundebene, welche in Fig. 6 allgemein mit **160** bezeichnet ist. Die mosaikartige Grundebene **160** umfasst eine Vielzahl von einzelnen Facetten **162a**, **162b**, **162c** usw., wobei jede von diesen miteinander verbunden sind und durch vier Scheitelpunkte (nicht mit Bezugszeichen versehen, aber als Punkte eingezeichnet) mit entsprechenden Höhenlagen definiert sind. Benachbarte Paare von Facetten **162a**, **162b**, **162c** usw. teilen sich zwei Scheitelpunkte. Jede Facette **162a**, **162b**, **162c** usw. weist eine entsprechende Neigung und Steigung auf. Die mosaikartige Grundebene **160** wird auf der Grundlage verschiedener Daten und Ressourcen erzeugt, wie beispielsweise aus topografischen Karten und/oder digitalen Rastergrafiken, Landvermessungsdaten und verschiedenen anderen Quellen.

[0064] Allgemein wird die Erdposition eines interessierenden Punktes auf dem angezeigten Bild **142** berechnet durch Bestimmen, welche der Facetten **162a**, **162b**, **162** usw. zu diesem Punkt von Interesse gehört. Daher wird die Position des interessierenden Punktes auf der Grundlage der Eigenschaften, d. h., der Höhenlage, der Neigung und der Steigung der Facetten **162a**, **162b**, **162c** usw., statt auf der Grundlage einer flachen Grundebene oder einer solchen mit einer gemittelten Höhenlage berechnet. Ein Fehler wird nur in soweit eingeführt, als dass die Topografie der Oberfläche **31** und die Position des interessierenden Punktes darauf sich von der ebenen Oberfläche der Facette **162a**, **162b**, **162c** usw. unterscheidet, innerhalb welcher der interessierende Punkt liegt. Dieser Fehler ist durch eine bilineare Interpolation der Höhenlage des interessierenden Punktes mit einer bestimmten Facette **162a**, **162b**, **162c** usw. und Verwenden dieser interpolierten Höhenlage bei der Positionsberechnung, welche durch die Bildanzeige- und -auswertesoftware **140** durchgeführt wird, verringerbar.

[0065] Um die mosaikartige Grundebene **160** zu nutzen, verwendet die Bildanzeige- und -auswertesoftware **140** einen modifizierten Sehstrahl-Verfolgungsalgorithmus, um die Kreuzung des abgebilde-

ten Strahls von der Bildaufnahmevorrichtung **32a** oder **32b** in Richtung der Oberfläche **31** und der mosaikartigen Grundebene **160** zu finden. Der Algorithmus bestimmt nicht nur, welche der Facetten **162a**, **162b**, **162c** usw. von dem Sehstrahl geschnitten bzw. gekreuzt wird, sondern auch, wo innerhalb der Facette die Überschneidung auftritt. Durch Verwendung der bilinearen Interpolation kann eine angemessen genaue Bodenposition bestimmt werden. Für die umgekehrte Abbildung wird die mosaikartige Grundebene **160** verwendet, um den Grundhöhenlagenwert für die Eingabegrundposition zu finden, und zwar ebenfalls unter Verwendung einer bilinearen Interpolation. Die Höhenlage und die Position werden dann dazu verwendet, rückwärts durch ein Modell der Bildaufnahmevorrichtung **32a** oder **32b** abzubilden, um zu bestimmen, welcher der Bildpunkte innerhalb des angezeigten Bildes **142** mit der gegebenen Position übereinstimmt.

[0066] Im Besonderen, und als ein Beispiel, führt die Bildanzeige- und -auswertesoftware **140** die Erdpositionsbestimmung von Punkt **164** durch, oder berechnet sie, durch Überlagern und/oder Anpassen der mosaikartigen Grundebene **160** an mindestens einen Abschnitt **166**, wie beispielsweise einen Hügel, der Oberfläche **31**. Es sollte angemerkt werden, dass nur ein kleiner Bereich der mosaikartigen Grundebene **160** und der zugehörigen Facetten **162a**, **162b**, **162c** usw. entlang des Profils von Bereich **166** der Oberfläche **31** gezeigt ist. Wie oben diskutiert, wird jede der Facetten **162a**, **162b**, **162c** usw. durch vier Scheitelpunkte definiert, von denen jeder eine entsprechende Höhenlage aufweist und jeder der Facetten entsprechende Neigungen und Steigungen aufweist. Die bestimmte Position von Punkt **164** auf der Ebene/Oberfläche der Facette **162a**, **162b**, **162c** usw., innerhalb welcher Punkt **164** (oder seine Abbildung) liegt, wird wie oben beschrieben bestimmt.

[0067] Die mosaikartige Grundebene **160** wird vorzugsweise außerhalb des Betriebs des Bildanzeige- und -mess-Computersystems **130** und der Bildanzeige- und -auswertesoftware **140** erzeugt. Stattdessen nimmt die mosaikförmige Grundebene **160** die Form einer relativ einfachen Datentabelle oder Nachschlagetabelle **168** an, welche im Speicher **132** des Bildanzeige- und -messungscomputersystems **130** liegt, oder von diesem aus zugreifbar ist. Die Rechenkapazitäten, die benötigt werden, um die Positionen all der Scheitelpunkte der vielen Facetten einer typischen Grundebene zu berechnen, müssen nicht notwendiger Weise im Bildanzeige- und -messungscomputersystem **130** untergebracht sein. Daher ist das Bildanzeige- und -messungscomputersystem **130** kompatibel zur Verwendung mit und ausführbar durch einem herkömmlichen Personal Computer, ohne dass zusätzliche Rechenkapazitäten benötigt werden.

[0068] Das Berechnen der mosaikartigen Grundebene **160** außerhalb des Bildanzeige- und -messungscomputersystems **130** ermöglicht es, dass so gut wie jeden Detailgrad in die mosaikartige Grundebene **160** einzubeziehen, d. h., die Größe und/oder Fläche, welche von jeder der Facetten **162a**, **162b**, **162c** usw. abgedeckt wird, oder diesen entspricht, so groß oder so klein wie gewünscht sein kann, und zwar ohne die Berechnungszeit wesentlich zu erhöhen, den Betrieb davon zu verlangsamen oder die Ressourcen wesentlich zu erhöhen, welche von dem Bildanzeige- und -messungscomputersystem **130** und/oder der Bildanzeige- und -auswertesoftware **140** benötigt werden. Das Anzeige- und -messungscomputersystem **130** kann daher ein relativ grundsätzliches und unkompliziertes Computersystem sein.

[0069] Die Größe der Facetten **162a**, **162b**, **162c** usw. ist gleichförmig in ihrer Größe über ein bestimmtes angezeigtes Bild **142**. Falls beispielsweise das angezeigte Bild **142** einer Fläche entspricht, die im Vordergrund ungefähr 750 Fuß breit mal ungefähr 900 Fuß tief ist, kann das Bild in Facetten aufgebrochen werden, welche ungefähr 50 Quadratfuß messen, wodurch sich ca. 15 Facetten in der Breite und 18 Facetten in der Tiefe ergeben. Alternativ kann die Größe der Facetten **162a**, **162b**, **162c** usw, in Bezug auf die darin enthaltene Zahl von Bildpunkten gleichförmig sein, d. h., dass jede Facette die gleiche Zahl von Bildpunkten in der Breite und die gleiche Zahl von Bildpunkten in der Tiefe aufweist. Die Facetten im Vordergrund des angezeigten Bildes **142**, wo die Bildpunktdichte am größten ist, würden daher ausdehnungsmäßig kleiner sein als die Facetten im Hintergrund des angezeigten Bildes **142**, wo die Bildpunktdichte am niedrigsten ist. Da es wünschenswert ist, die meisten Messungen im Vordergrund eines angezeigten Bilds durchzuführen, wo die Bildpunktdichte am größten ist, weist ein Erzeugen von Facetten, welche in Bezug auf die Zahl der enthaltenen Bildpunkte gleichförmig sind, den Vorteil auf, genauere Messungen im Vordergrund des angezeigten Bilds **142** in Bezug auf die Facetten zu ermöglichen, welche ausdehnungsmäßig gleichförmig sind.

[0070] Ein weiterer Vorteil des Verwendens von Bildpunkten als einer Grundlage zum Definieren der Abmessungen der Facetten **162a**, **162b**, **162c** usw. ist es, dass die Positionsberechnung (Bildpunktposition zu Boden- bzw. Grundposition) relativ einfach ist. Ein Benutzer betreibt das Bildanzeige- und -messungscomputersystem **130**, um einen Bildpunkt innerhalb einer gegebenen Facette auszuwählen, und die Bildanzeige- und -auswertesoftware **140** schlägt die Daten für die dem ausgewählten Bildpunkt zugehörige Facette nach, die Höhenlage des ausgewählten Bildpunkts wird wie oben beschrieben berechnet, und diese Höhenlage wird bei der Positionsberechnung verwendet.

[0071] Allgemein teilt das erfindungsgemäße Verfahren zum Aufnehmen schräger Bilder eine interessierende Fläche, wie beispielsweise einen Landkreis, in Sektoren von allgemein gleichförmiger Größe auf, wie beispielsweise in Sektoren, welche annähernd eine Fläche von 1 Quadratmeile aufweisen. Dies wird getan, um die Erzeugung eines Flugplans zu vereinfachen, um schräge Bilder aufzunehmen, welche jeden Zentimeter der interessierenden Fläche abdecken, und um die Abschnitte und/oder deren Bilder zur einfachen Referenzierung, Speicherung und Wiedergewinnung zu organisieren und zu benamen (ein Ablauf, der im Stand der Technik als "Sektorisierung" bekannt ist). Weil die Kanten jeder geografischen interessierenden Fläche, wie beispielsweise eines Landkreises, selten auf gerade Quadratmeilengrenzen fallen, stellt das Verfahren zum Aufnehmen schräger Bilder nach der vorliegenden Erfindung mehr Abschnitte bzw. Sektoren bereit als Quadratmeilen in der interessierenden Fläche vorhanden sind – wie viele mehr, hängt zum großen Teil von der Länge der Landkreisgrenzen ab, als auch davon, wie gerade oder zackig sie sind. Typischerweise kann man einen zusätzlichen Abschnitt für alle zwei bis drei Meilen an Grenze erwarten. Falls ein solcher Landkreis oder eine andere interessierende Fläche grob 20 Meilen × 35 Meilen, oder 700 Quadratmeilen, groß ist, wird die Fläche in annähernd 740 bis 780 Sektoren aufgeteilt.

[0072] Das erfindungsgemäße Verfahren zum Aufnehmen schräger Bilder nimmt allgemein die schrägen Bilder von mindestens zwei Kompassrichtungen bzw. Marschzahlen aus auf und stellt eine volle Abdeckung der interessierenden Fläche aus zumindest diesen zwei Marschzahlen zur Verfügung. Nun Bezug nehmend auf die Fig. 7 und Fig. 8 wird eine erste Ausführungsform eines erfindungsgemäßen Verfahrens zum Aufnehmen schräger Bilder gezeigt. Aus Gründen der Klarheit basieren die Fig. 7 und Fig. 8 auf einem System, welches nur eine Bildaufnahmevorrichtung aufweist. Es ist jedoch so zu verstehen, dass zwei oder mehr Bildaufnahmevorrichtungen verwendet werden können.

[0073] Die Bildaufnahmevorrichtung nimmt ein oder mehrere schräge Bilder während jedes Überflugs bzw. Überfahrens von Fläche **200** auf. Die Bildaufnahmevorrichtung ist, wie oben diskutiert, unter einem Winkel auf die Fläche **200** ausgerichtet, um zugehörige schräge Bilder aufzunehmen. Fläche **200** wird durch die bildtragende Vorrichtung und/oder die Plattform in einem Vorwärts-Rückwärts-Muster durchquert, ähnlich dazu, wie ein Rasen gemäht wird, um eine doppelte Abdeckung der Fläche **200** sicherzustellen.

[0074] Im Besonderen wird die Fläche **200** dadurch überquert, dass die bildtragende Vorrichtung **32** und/oder Plattform **20** einen ersten Pfad **202** folgen, um dadurch schräge Bilder von Bereichen **202a**, **202b** und **202c** der Fläche **200** aufzunehmen. Die Fläche **200** wird dann dadurch überquert, dass die bildtragende Vorrichtung **32** und/oder Plattform **20** einem zweiten Pfad **204** folgt, welcher parallel zum und beabstandet vom, und in einer entgegengesetzten Richtung zu, d. h., 180° (einhundertundachtzig Grad) zum ersten Pfad **202** liegt, um dadurch schräge Bilder der Bereiche **204a**, **204b**, **204c** der Fläche **200** aufzunehmen. Durch Vergleichen der Fig. 7 und Fig. 8 kann man erkennen, dass ein Bereich **207** (Fig. 8) von Fläche **200** durch die Bilder **202a**–c abdeckt wird, welche aus einer ersten Richtung oder Perspektive aus aufgenommen worden sind, als auch durch Bilder **204a**–c, welche aus einer zweiten Richtung oder Perspektive aus aufgenommen worden sind. Als solches wird der Mittelteil der Fläche **200** 100%ig (einhundertprozentig) doppelt abgedeckt. Das oben beschriebene Muster des Überquerens bzw. Überfahrens der Fläche **200** entlang entgegengesetzter Pfade, welche parallel zu den Pfaden **202** und **204** liegen, wird wiederholt, bis die gesamte Fläche **200** vollständig von mindestens einem schrägen Bild abgedeckt ist, welches von den Pfaden, die zueinander parallel und voneinander beabstandet liegen, aus aufgenommen worden ist, wie durch die Größe der Fläche **200** bestimmt, als auch aus der gleichen Richtung wie die Pfade **202** und **204**, um dadurch eine 100%ige doppelte Abdeckungsfläche **200** aus diesen Perspektiven/Richtungen zu erhalten.

[0075] Falls gewünscht, und für eine verbesserte Detailgenauigkeit, wird die Fläche **200** durch zwei zusätzliche entgegengesetzte und parallele dritte und vierte Pfade **206** bzw. **208** abgedeckt, welche senkrecht zu den Pfaden **202** und **204** laufen, wie in den Fig. 9 und Fig. 10 gezeigt. Die Fläche **200** wird daher durch die bildtragende Vorrichtung **32** und/oder Plattform **20** einem dritten Pfad **206** folgend überquert, um schräge Bilder der Bereiche **206a**, **206b** und **206c** der Fläche **200** aufzunehmen, und wird dann entlang eines vierten Pfads **208** überquert, welcher parallel, beabstandet und entgegengesetzt dem dritten Pfad **206** ist, um schräge Bilder der Bereiche **208a**, **208b** und **208c** der Fläche **200** aufzunehmen. Dieses Muster des Durchquerens bzw. Überfliegens der Fläche **200** entlang entgegengesetzter Pfade, welche parallel zu den Pfaden **206** und **208** liegen, wird auf ähnliche Weise wiederholt, bis die gesamte Fläche **200** vollständig von mindestens einem schrägen Bild abgedeckt ist, welches von den Pfaden aufgenommen worden ist, die parallel und zueinander beabstandet liegen, wie durch die Größe der Fläche **200** vorgegeben, und in der gleichen Richtung liegen wie die Pfade **206** und **208**, um dadurch die Fläche **200** aus diesen Richtungen/Perspektiven 100%ig doppelt abzudecken.

[0076] Wie oben beschrieben, überquert die bildtragende Vorrichtung **32** und/oder Plattform **20** die Flä-

che **200** entlang eines vorbestimmten Pfads. Jedoch sollte es klar sein, dass die bildtragende Vorrichtung und/oder Plattform **20** nicht notwendigerweise die Fläche **200** direkt überfliegt oder durchquert, sondern stattdessen eine benachbarte Fläche überfliegen oder durchqueren kann, welche der Fläche **200** benachbart ist, oder sogar etwas davon entfernt ist, um sicherzustellen, dass der Bereich der Fläche **200**, welcher aufgenommen wird, in das Bildaufnahmefeld der Bildaufnahmevorrichtung fällt. Der Pfad **202**, wie in Fig. 7 gezeigt, ist ein solcher Pfad, als dass er nicht direkt die Fläche **200** überfliegt, und dennoch schräge Bilder davon aufnimmt.

[0077] Die vorliegende Erfindung ist in der Lage, Bilder bei verschiedenen Auflösungspegeln oder Grundabtastungsabständen aufzunehmen. Eine erste Detailebene, im Folgenden als eine Gebietsebene bezeichnet, weist einen Grundabtastabstand von beispielsweise ca. 2 Fuß pro Bildpunkt auf. Für orthogonale Gebietsebenenbilder bleibt der Grundabtastabstand im Wesentlichen über das Bild konstant. Orthogonale Gebietsebenenaufnahmen werden mit einem ausreichenden Überlapp aufgenommen, um eine Stereopaarabdeckung bereitzustellen. Für schräge Gebietsebenenbilder variiert der Grundabtastabstand von beispielsweise ungefähr 1 Fuß pro Bildpunkt im Vordergrund des Bildes bis ungefähr 2 Fuß pro Bildpunkt im Mittelbereich des Bildes und bis ungefähr 4 Fuß pro Bildpunkt im Hintergrund des Bildes. Schräge Gebietsebenenbilder werden mit ausreichendem Überlapp aufgenommen, so dass jede interessierende Fläche typischerweise von mindestens zwei schrägen Bildern aus jeder Kompassrichtung aufgenommen wird. Ungefähr 10 schräge Gebietsebenenbilder werden pro Sektor aufgenommen.

[0078] Eine zweite Detailebene, im Folgenden als Nachbarschaftsebene bezeichnet, ist erheblich detaillierter als die Gebietsebenenbilder. Die Nachbarschaftsebenenbilder weisen einen Grundabtastabstand von beispielsweise ungefähr 6 inch pro Bildpunkt auf. Für orthogonale Nachbarschaftsebenenbilder bleibt der Grundabtastabstand im Wesentlichen konstant. Schräge Nachbarschaftsebenenbilder weisen einen Grundabtastabstand von beispielsweise ungefähr 4 inch pro Bildpunkt im Vordergrund des Bildes bis zu ungefähr 6 inch pro Bildpunkt im Mittenbereich des Bildes und bis zu ungefähr 10 inch pro Bildpunkt im Hintergrund des Bildes auf. Schräge Nachbarschaftsebenenbilder werden mit ausreichend Überlapp aufgenommen, so dass jeder interessierende Bereich typischerweise von mindestens zwei schrägen Bildern aus jeder Marschzahl aufgenommen wird, und so, das entgegengesetzte Marschzahlen eine 100%ige Überlappung miteinander vorsehen. Ungefähr einhundert (100) schräge Flächenaufnahmen werden pro Sektor aufgenommen.

[0079] Es sollte insbesondere angemerkt werden, dass ein Aufnehmen schräger Bilder auf Gemeinde- und/oder Nachbarschaftsebene aus allen vier Kompassrichtungen sicherstellt, dass jeder Punkt im Bild im Vordergrund oder unteren Bereich mindestens eines der aufgenommenen schrägen Bilder auftaucht, wo der Grundabtastabstand am niedrigsten und die Bilddetailschärfe am größten ist.

[0080] In der gezeigten Ausführungsform umfasst das Bildaufnahme- und Erdpositionsbestimmungssystem **30** ein Gyroskop, einen Kompass und einen Höhenmesser. Es sollte jedoch klar sein, dass das erfindungsgemäße Bildaufnahme- und Erdpositionsbestimmungssystem alternativ eingerichtet sein kann, wie beispielsweise, um eine Höhe, ein Stampfen, Rollen und Gieren abzuleiten und/oder zu berechnen, als auch eine Kompassflugrichtung aus den GPS- und INU-Signalen/Daten, um ein oder mehrere von dem Gyroskop, Kompass oder Höhenmesser überflüssig zu machen.

[0081] In der gezeigten Ausführungsform liegen die Bildaufnahmevorrichtungen auf einem gleichen Neigungswinkel relativ zu einer horizontalen Ebene. Es sollte jedoch klar sein, dass die Neigungswinkel der Bildaufnahmevorrichtungen nicht gleich zu sein brauchen.

[0082] In der gezeigten Ausführungsform führt das Bildaufnahmecomputersystem die Bild- und Datenerfassungs-Software aus, welche ein gemeinsames oder ein einzelnes Bildaufnahmesignal an die Bildaufnahmevorrichtungen ausgibt, um dadurch zu bewirken, dass diese Vorrichtungen ein Bild erfassen oder aufnehmen. Es sollte jedoch klar sein, dass die vorliegende Erfindung alternativ so eingerichtet werden kann, dass sie die Bildaufnahmevorrichtungen separat dazu veranlasst, Bilder zu unterschiedlichen Zeitpunkten und/oder mit unterschiedlichen Zeitdauern aufzunehmen.

[0083] In der gezeigten Ausführungsform nimmt das erfindungsgemäße Verfahren schräge Bilder auf, um eine doppelte Abdeckung einer interessierenden Fläche von Pfaden/Perspektiven aus bereitzustellen, welche im Wesentlichen zueinander entgegengesetzt liegen, d. h., 180° (einhundertundachtzig Grad) relativ zueinander liegen. Jedoch sollte es klar sein, dass das erfindungsgemäße Verfahren alternativ so ausgestaltet werden kann, dass es eine doppelte Abdeckung von Pfaden/Perspektiven aus bereitstellen kann, welche allgemein und/oder im Wesentlichen senkrecht relativ zueinander liegen.

[0084] Während die vorliegende Erfindung als mit einer bevorzugten Ausführungsform versehen beschrieben worden ist, kann die Erfindung ferner innerhalb des Umfangs der Ansprüche modifiziert werden. Diese Offenbarung ist daher dazu gedacht, jeg-

liche Äquivalente bezüglich der hierin offenbarten Strukturen und Elemente zu umfassen. Ferner ist diese Offenbarung dazu gedacht, jegliche Änderungen, Verwendungen oder Anpassungen der vorliegenden Erfindung zu umfassen, welche die hierin offenbarten allgemeinen Grundlagen verwenden. Darüber hinaus ist diese Offenbarung dazu gedacht, jegliche Abweichungen vom offenbarten Gegenstand zu umfassen, welche innerhalb der bekannten oder üblichen Praxis des Standes der Technik liegen und welche in den Bereich der angehängten Ansprüche fallen.

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 Geländen 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 Bildaufnahmeereig-

nis 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, abzudecken;
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, abzudecken;
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.

Es folgen 10 Blatt Zeichnungen

Anhängende Zeichnungen

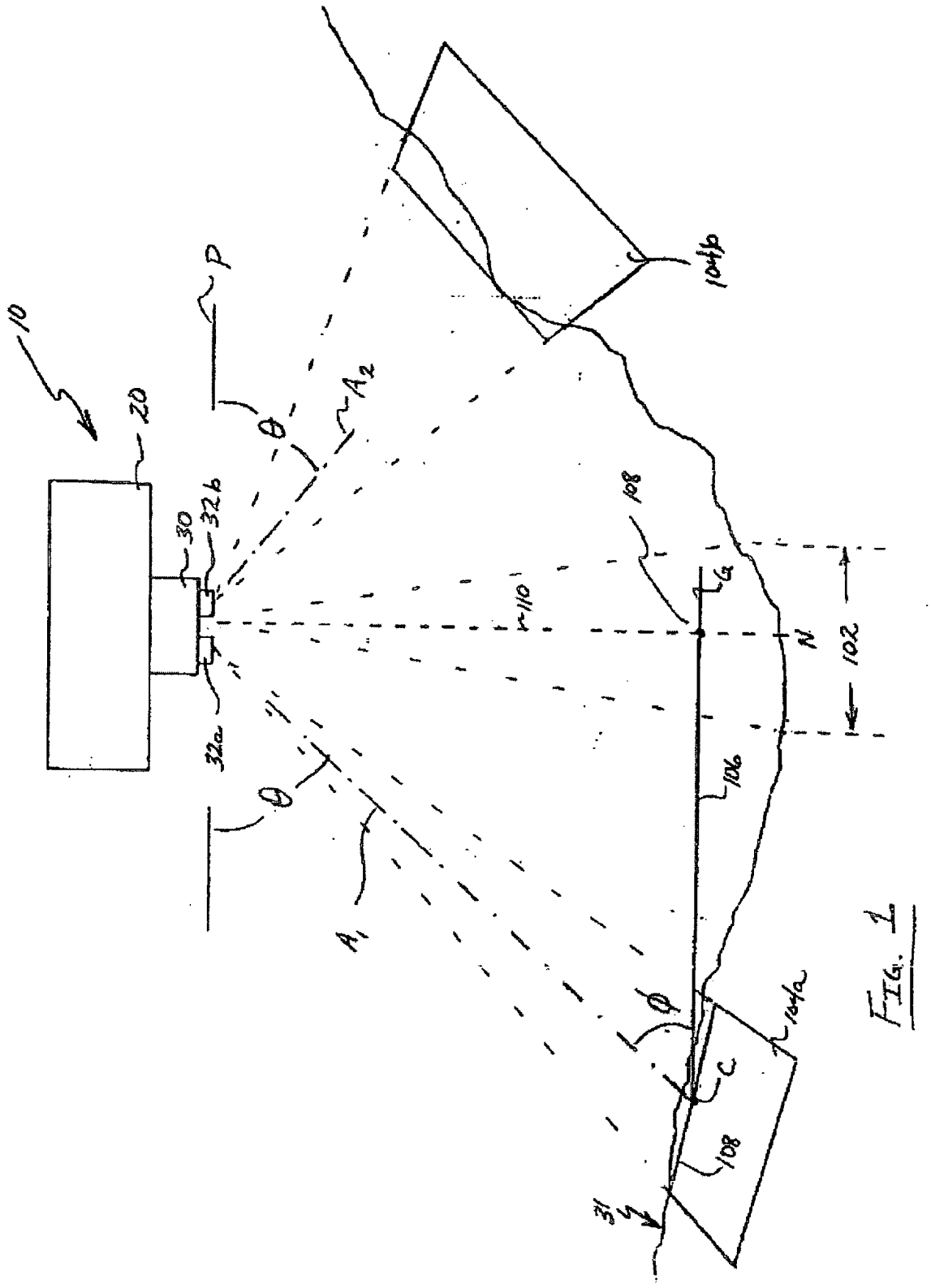


FIG. 1

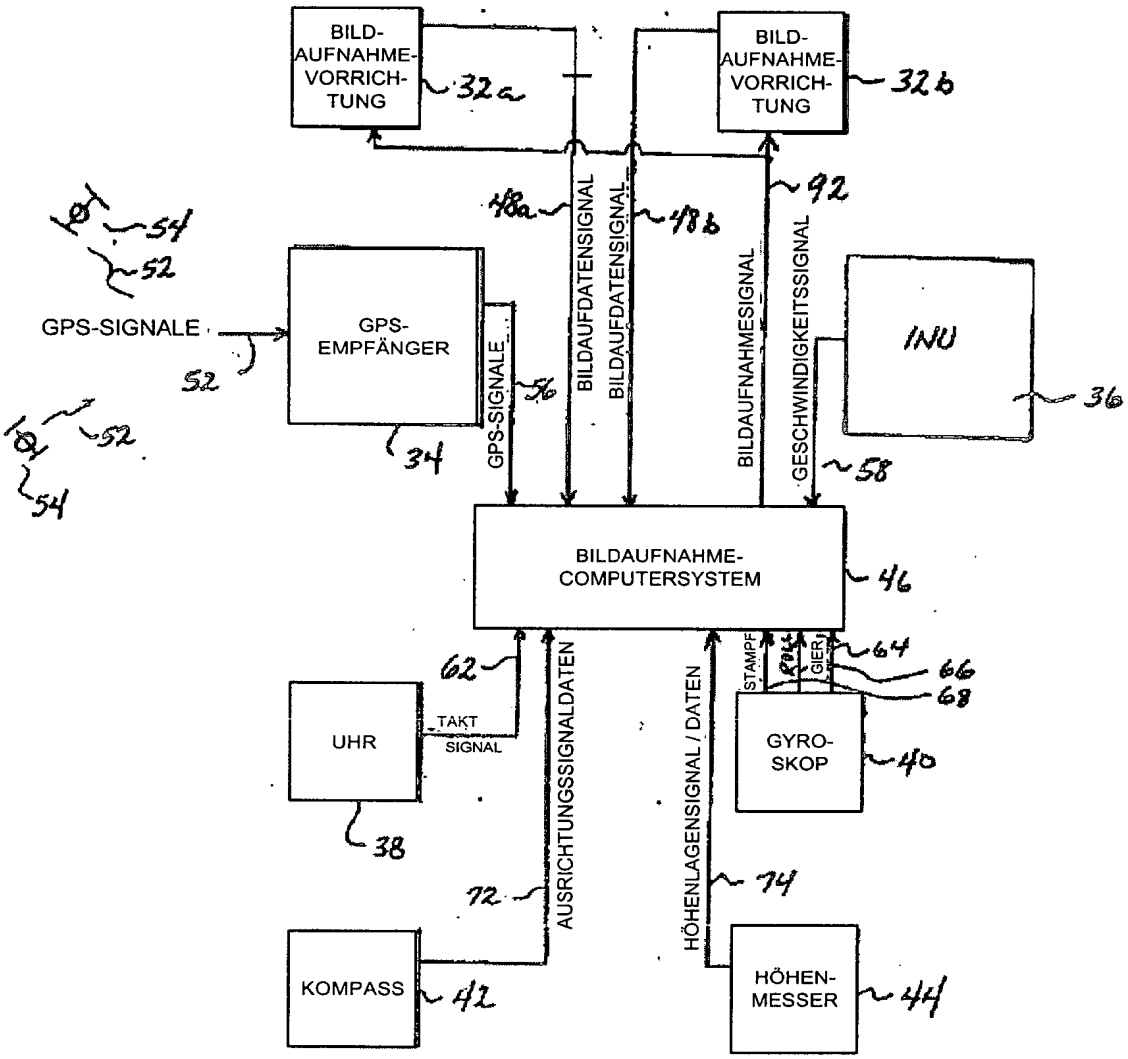

BILD-AUFNAHME-VORRICHTUNG
32a
BILD-AUFNAHME-VORRICHTUNG
32b
48a
BILDAUFDATENSIGNAL
48b
BILDAUFDATENSIGNAL
92
BILDAUFNAHMESIGNAL
GESCHWINDIGKEITSSIGNAL
INU
36
58
54
52
GPS-SIGNALE
52
GPS-EMPFÄNGER
34
GPS-SIGNALE
56
52
54
BILDAUFNAHME-COMPUTERSYSTEM
46
62
TAKT SIGNAL
UHR
38
AUSRICHTUNGSSIGNALDATEN
72
KOMPASS
42
STAMPF
ROLL
GIER
64
66
68
GYRO-SKOP
40
HÖHENLAGENSIGNAL / DATEN
74
HÖHEN-MESSER
44

FIG. 2

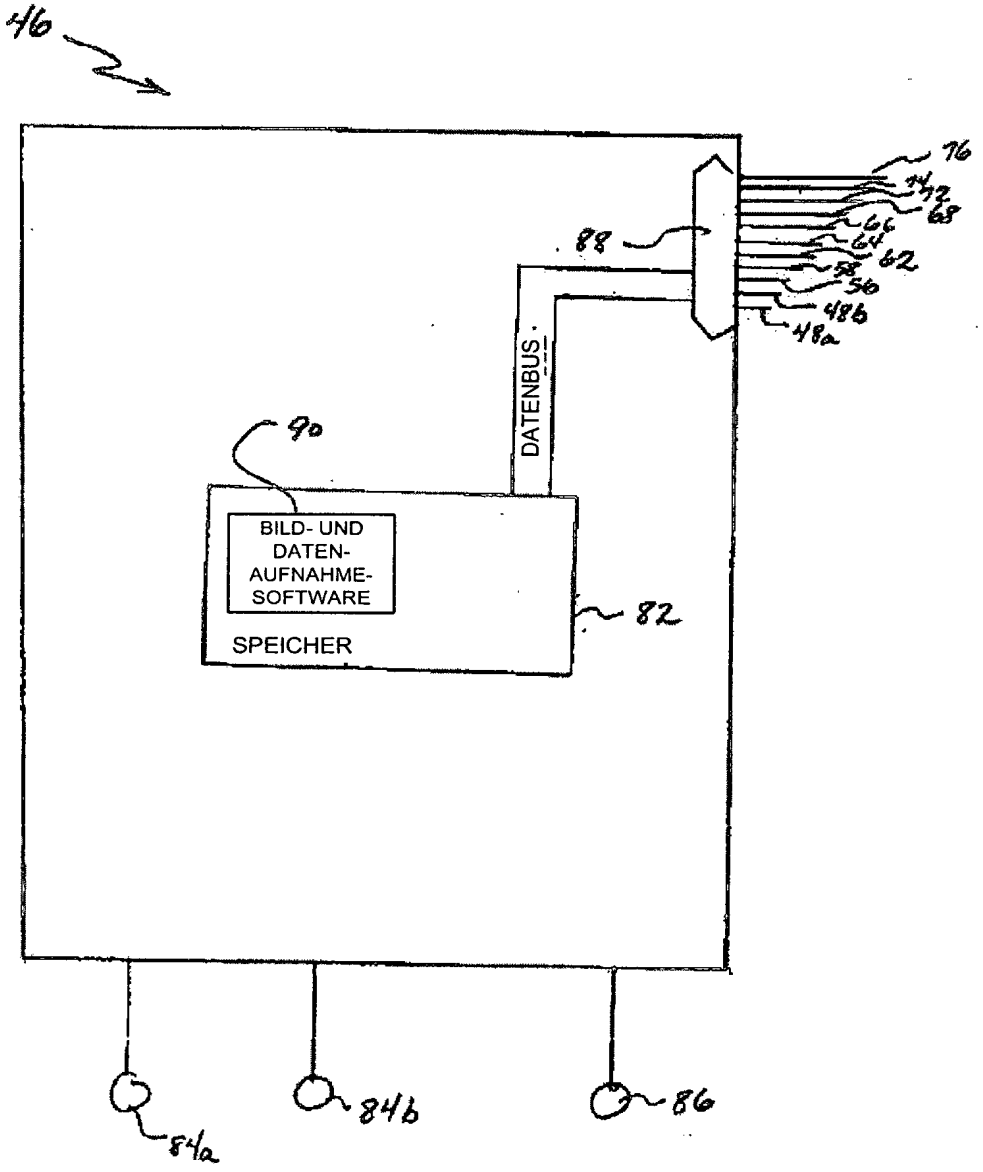

46
76
74
72
68
66
64
62
58
56
48b
48a
88
DATENBUS
90
BILD- UND
DATEN-
AUFNAHME-
SOFTWARE
SPEICHER
82
84a
84b
86

FIG. 3

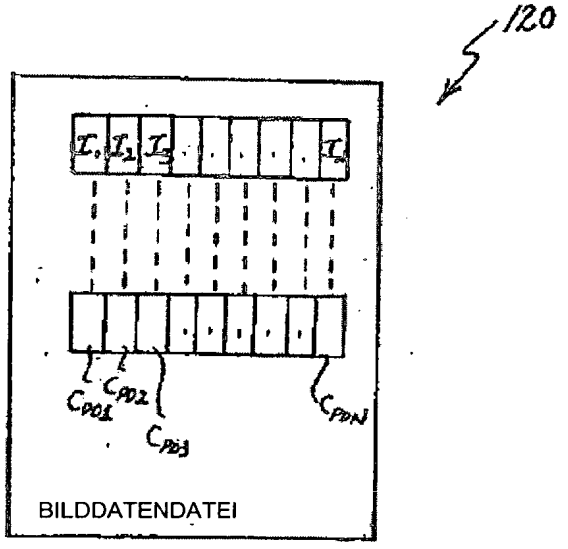


FIG. 4

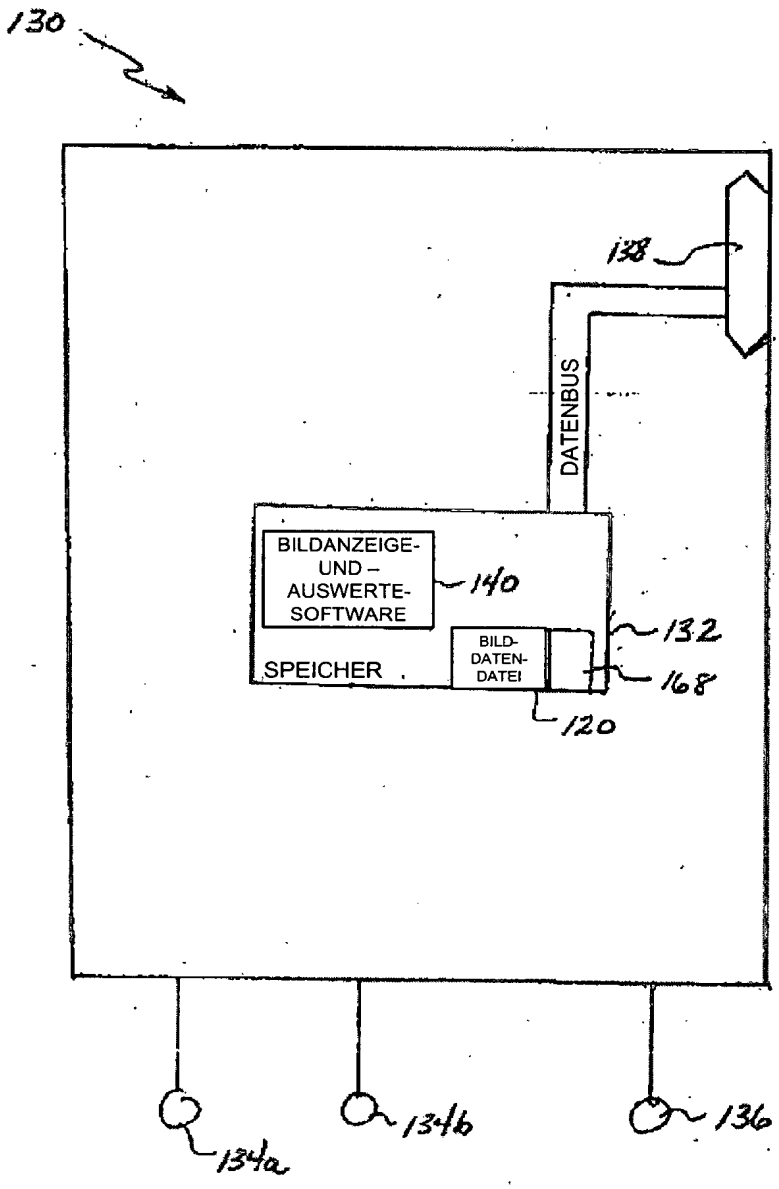

130
138
DATENBUS
BILDANZEIGE-
UND –
AUSWERTE-
SOFTWARE
140
SPEICHER
BILD-
DATEN-
DATEI
132
168
120
134a
134b
136

FIG. 5

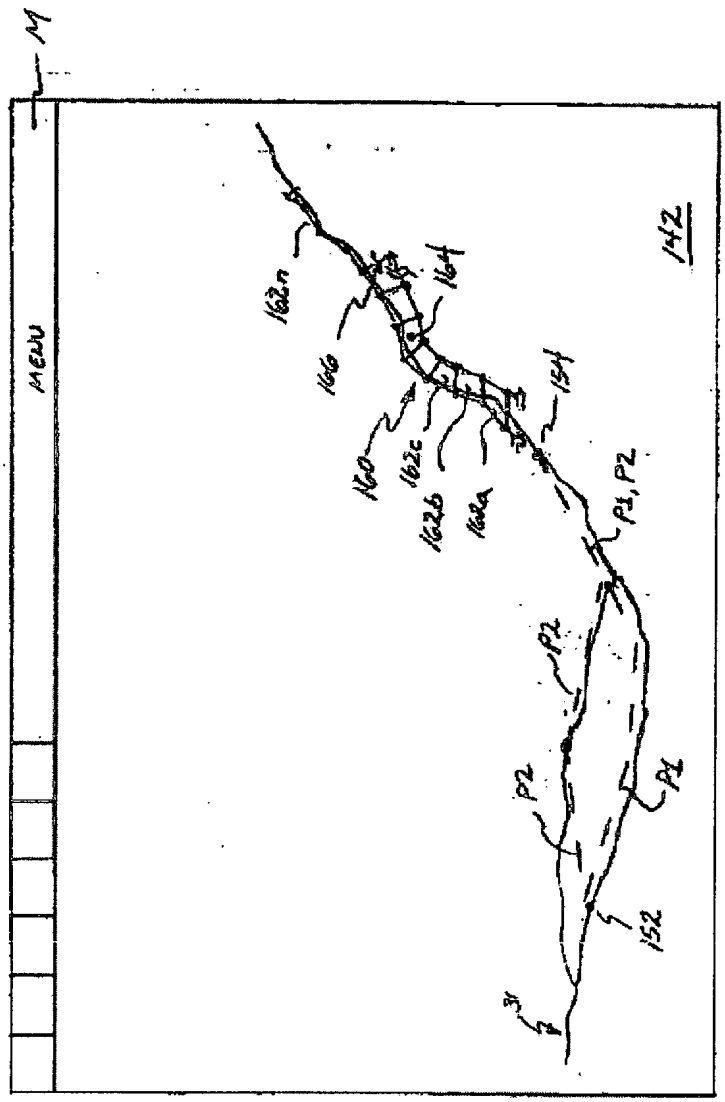

M
MENU
142
162n
164
166
160
162c
162b
162a
154
P1, P2
P2
P2
P1
152
3V

FIG. 6

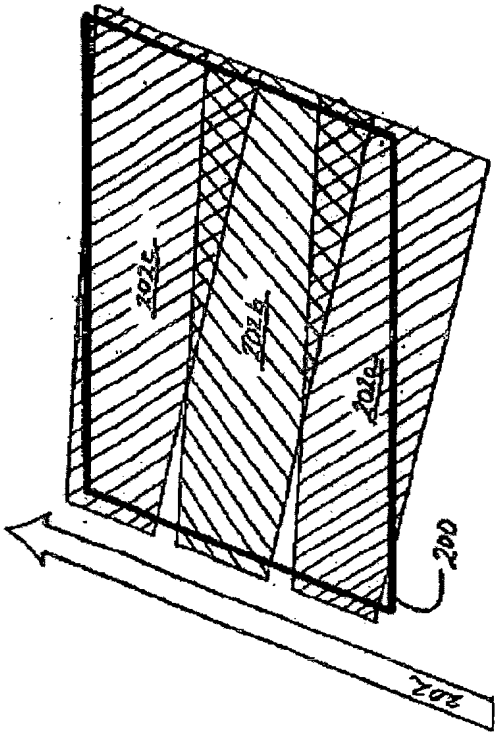


Fig. 1

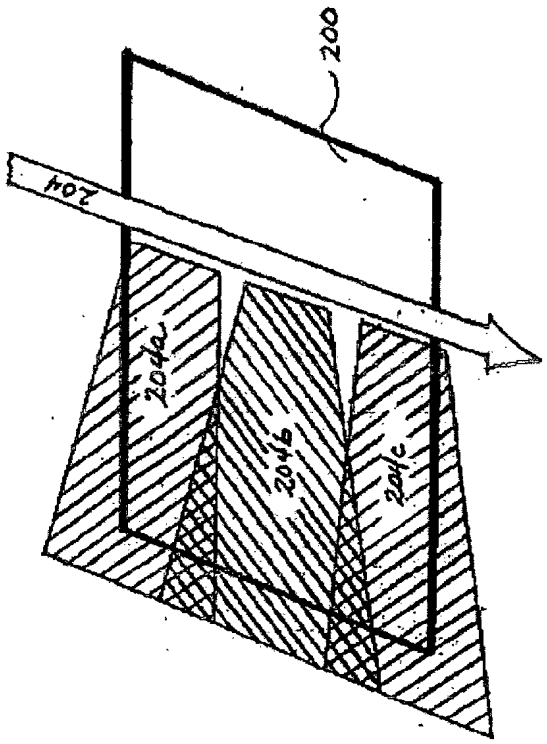


FIG. 8

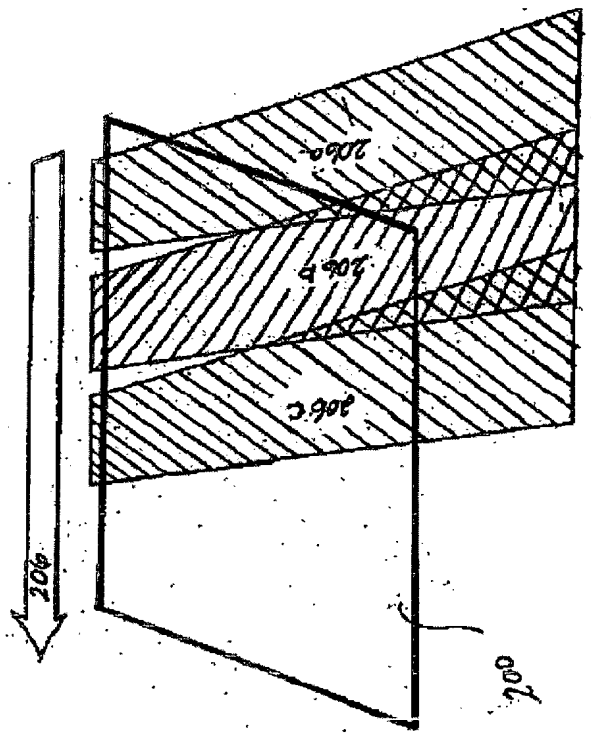


Fig. 9

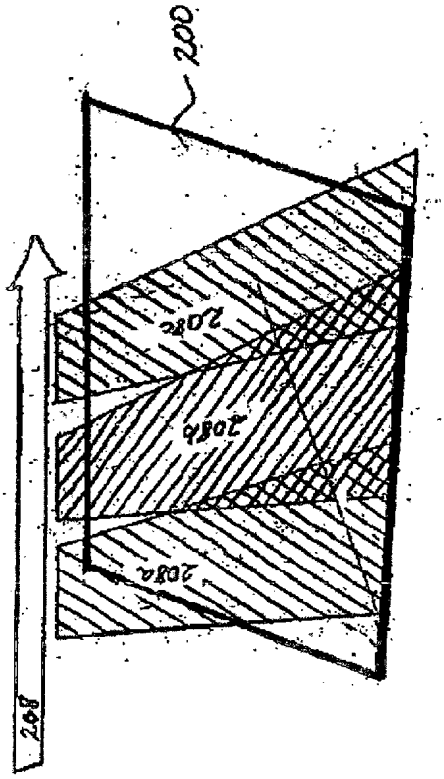


Fig. 10

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ES 2 266 704 T3

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DESCRIPCIÓN

Procedimiento y aparato para capturar, geolocalizar y medir imágenes oblicuas.

Referencias cruzadas a aplicaciones relacionadas

Esta solicitud reivindica el beneficio de la solicitud de patente provisional norteamericana número de serie 60/425.275, presentada el 8 de noviembre de 2002.

Campo técnico

La presente invención se refiere a la fotogrametría. Más en particular, la presente invención se refiere a un procedimiento y aparato para capturar imágenes oblicuas y para medir los objetos y las distancias entre los objetos que se muestran en las mismas.

Antecedentes

La fotogrametría es la ciencia de realizar mediciones de y entre objetos mostrados en fotografías, especialmente en fotografías aéreas. En general, la fotogrametría incluye tomar imágenes de características terrestres y obtener como resultado datos de las mismas, tales como, por ejemplo, datos indicativos de las distancias relativas entre los objetos y sus tamaños en las imágenes. La fotogrametría también puede incluir acoplar las fotografías a otros datos, tales como datos representativos de la latitud y de la longitud. En efecto, la imagen se superpone y se conforma a un sistema de coordenadas espaciales particular.

La fotogrametría convencional incluye la captura y/o la adquisición de imágenes ortogonales. El dispositivo de captura de imágenes, tal como una cámara o sensor, se transporta en un vehículo o plataforma, tal como un aeroplano o satélite, y se enfoca a un punto nadir que está directamente debajo y/o verticalmente hacia abajo desde esa plataforma. El punto o píxel en la imagen que se corresponde al punto nadir es el único punto/píxel que es verdaderamente ortogonal al dispositivo de captura de imágenes. Todos los otros puntos o píxeles en la imagen son, en realidad, oblicuos con relación al dispositivo de captura de imágenes. Cuando los puntos o píxeles se hacen crecientemente distantes del punto nadir, se hacen crecientemente oblicuos con relación al dispositivo de captura de imágenes y también se incrementa la distancia de la muestra de suelo (es decir, el área superficial que se corresponde o que está cubierta por cada píxel). Tal oblicuidad en una imagen ortogonal hace que las características en la imagen queden distorsionadas, especialmente imágenes relativamente distantes del punto nadir.

Una perturbación de este tipo se elimina, o se compensa, por el proceso de ortorectificación, en el cual, en esencia, elimina la oblicuidad de la imagen ortogonal ajustando o deformando cada píxel de una imagen ortogonal en una rejilla ortométrica o sistema coordenado. El procedimiento de la ortorectificación crea una imagen en la que todos los píxeles tienen la misma distancia de muestra de suelo y están orientados al norte. De esta manera, cualquier punto en una imagen ortorectificada puede ser localizado utilizando el sistema de coordenadas X, Y y, siempre que la escala de la imagen sea conocida, pueden ser calculadas la longitud y la anchura de las características terrestres así como la distancia relativa entre estas características.

Aunque el proceso de ortorectificación compensa hasta un cierto grado las distorsiones oblicuas en una imagen ortogonal, introduce otras distorsiones y/o inexactitudes indeseables en la imagen ortogonal ortorectificada. Los objetos mostrados en las imágenes ortogonales ortorectificadas pueden ser difíciles de reconocer y/o identificar puesto que la mayor parte de los observadores no están acostumbrados a visualizar objetos, particularmente características terrestres, desde arriba. Para un observador no entrenado, una imagen ortorectificada presente un número de distorsiones. Las carreteras que en realidad son rectas aparecen curvadas y los edificios parecen inclinarse. Además, las imágenes ortorectificadas no contienen sustancialmente ninguna información respecto a la altura de las características terrestres. La interpretación y el análisis de imágenes ortogonales y/o ortogonales ortorectificadas típicamente son efectuadas por analistas altamente cualificados que poseen años de entrenamiento especializado y experiencia para identificar objetos y características terrestres en tales imágenes.

De esta manera, aunque las imágenes ortogonales y ortorectificadas son útiles en la fotogrametría, les falta información referente a la altura de las características mostradas en ellas y requieren analistas altamente entrenados para interpretar los detalles a partir de lo que muestran las imágenes.

Las imágenes oblicuas son imágenes que han sido capturadas con un dispositivo de captura de imágenes enfocado o apuntado generalmente a un lado o hacia abajo de la plataforma que transporta el dispositivo de captura de imágenes. Las imágenes oblicuas, a diferencia de las imágenes ortogonales, muestran lados de las características terrestres, tales como casas, edificios y/o montañas, así como las partes superiores de las mismas. De esta manera, visualizar una imagen oblicua es más natural e intuitivo que visualizar una imagen ortogonal u ortorectificada, e incluso los observadores casuales pueden reconocer e interpretar características terrestres y otros objetos mostrados en las imágenes oblicuas. Cada píxel en el primer plano de una imagen oblicua se corresponde a un área relativamente pequeña de la superficie o del objeto mostrado (es decir, cada píxel de primer plano tiene una distancia de muestra de suelo relativamente pequeña) mientras que cada píxel en el plano de fondo se corresponde a un área relativamente grande de la superficie o del objeto mostrado (es decir, cada píxel de plano de fondo tiene una distancia de muestra de suelo relativamente grande). Las imágenes oblicuas capturan un área generalmente trapezoidal o una vista de la superficie del sujeto o un objeto, teniendo el primer plano del trapezoide una distancia de muestra de suelo sustancialmente menor (es decir, una resolución más elevada) que el plano de fondo del trapezoide.

Se considera que las imágenes oblicuas son de poca o ninguna utilidad en la fotogrametría. El enfoque convencional de forzar los píxeles de primer plano y de plano de fondo de distintos tamaño de una imagen oblicua en un tamaño uniforme para deformar de esta manera la imagen en un sistema de coordenadas distorsiona en gran medida la imagen oblicua y por lo tanto, impide la identificación de los objetos y la toma de medidas de los objetos mostrados y hace que esto sea una tarea laboriosa e inexacta. La corrección de los desplazamientos del terreno dentro de una imagen oblicua utilizando un modelo de elevación distorsiona adicionalmente las imágenes, con lo cual incrementa la dificultad con la que se pueden realizar las mediciones y reduce la precisión de tales mediciones.

Como consecuencia, aunque se considera que las

imágenes oblicuas tienen poca, o ninguna, utilidad en la fotogrametría, son fácilmente interpretadas y contienen información referente a la altura de las características mostradas en las mismas. El documento WO 99/18732 A1 muestra un sistema y procedimiento para capturar, geolocalizar y medir imágenes oblicuas, que comprende un dispositivo de captura de imágenes, un dispositivo de geolocalización, un sistema de ordenador y un software de adquisición de imágenes y datos, que asocia los datos de imágenes a los datos de la señal de geolocalización.

Objeto de la invención

Por lo tanto, lo que se precisa en la técnica es un procedimiento y aparato para la fotogrametría que permita la geolocalización y las mediciones precisas en imágenes oblicuas.

Además, lo que se necesita en la técnica es un procedimiento y aparato para la fotogrametría que permita la medición de alturas y de alturas relativas de los objetos dentro de una imagen.

Además, lo que se necesita en la técnica es un procedimiento y aparato para la fotogrametría que utilice imágenes más intuitivas y naturales.

Sumario de la invención

La presente invención proporciona un sistema de acuerdo con la reivindicación 1.

Breve descripción de los dibujos

Las características de esta invención que se han mencionado más arriba, así como otras, y la manera de conseguirlas, serán evidentes y más completamente comprensibles haciendo referencia a la descripción que sigue de una realización de la invención, cuando se lee en conjunto con los dibujos que se acompañan, en los cuales:

La figura 1 ilustra una realización de una plataforma o vehículo que transporta un sistema de captura de imágenes de la presente invención, y muestra imágenes ejemplares ortogonales y oblicuas tomadas por medio del mismo;

La figura 2 es una vista diagramática del sistema de captura de imágenes de la figura 1;

La figura 3 es un diagrama de bloques del sistema de ordenador de captura de imágenes de la figura 2;

La figura 4 es una representación de un archivo de datos de salida ejemplar del sistema de captura de imágenes de la figura 1;

La figura 5 es un diagrama de bloques de una realización de un sistema de una pantalla de imágenes y de ordenador de medición de la presente invención, para mostrar y tomar medidas de y entre los objetos mostrados en las imágenes capturadas por el sistema de captura de imágenes de la figura 1;

La figura 6 muestra una imagen ejemplar mostrada del sistema de la figura 5, e ilustra una realización del procedimiento de la presente invención para la medida de, y entre, objetos mostrados en una imagen de este tipo;

Las figuras 7 y 8 ilustran una realización de un procedimiento para capturar imágenes oblicuas de la presente invención;

Las figuras 9 y 10 ilustran una segunda realización de un procedimiento para capturar imágenes oblicuas de la presente invención.

Los caracteres de referencia correspondientes indican elementos correspondientes en las distintas vistas. Las ejemplarizaciones establecidas en la presente memoria descriptiva ilustran una realización preferente de la invención, en una forma, y tales ejemplarizaciones no deben considerarse como limitativas del alcance de la invención de ninguna manera.

Descripción de las realizaciones preferentes

Haciendo referencia a continuación a los dibujos, y en particular a la figura 1, se muestra una realización de un aparato para capturar y geolocalizar imágenes oblicuas de la presente invención. El aparato 10 incluye una plataforma o vehículo 20 que transporta un sistema 30 de captura de imágenes y de geolocalización.

La plataforma 20, tal como, por ejemplo, un aeroplano, trasbordador espacial, cohete, satélite o cualquier otro vehículo adecuado, transporta el sistema 30 de captura de imágenes sobre un área predefinida de una superficie 31 y a una o más altitudes predeterminadas sobre la misma, tal como, por ejemplo, la superficie de la tierra o cualquier otra superficie de interés. Como tal, la plataforma 20 puede controlar el movimiento o vuelo, ya sea tripulado o no tripulado, a lo largo de un trayecto o curso de vuelo predefinido, por ejemplo, la atmósfera de la tierra o el espacio exterior. La plataforma 20 de captura de imágenes incluye un sistema (no mostrado) para generar y regular la potencia que incluye, por ejemplo, uno o más generadores, células de combustible, paneles solares y/o baterías para energizar el sistema 30 de captura de imágenes.

El sistema 30 de captura de imágenes y de geolocalización, como mejor se muestra en la figura 2, incluye dispositivos 32a y 32b de captura de imágenes, un receptor 34 de un sistema de posicionado global (GPS), una unidad de navegación inercial (INU) 36, reloj 38, giroscopio 40, brújula 42 y altímetro 44, cada uno de los cuales está interconectado con el sistema 46 de ordenador de captura de imágenes.

Los dispositivos 32a y 32b de captura de imágenes tales como, por ejemplo, cámaras convencionales, cámaras digitales, sensores digitales, dispositivos acoplados en carga, u otros dispositivos adecuados de captura de imágenes, pueden capturar imágenes fotográfica o electrónicamente. Los dispositivos 32a y 32b de captura de imágenes tienen características conocidas o determinables que incluyen longitud focal, tamaño del sensor y relación de aspecto, términos radiales y de distorsión, punto principal de desplazamiento, paso de píxel, y alineación. Los dispositivos 32a y 32b de captura de imágenes adquieren imágenes y emiten señales de datos de imagen (IDS) 48a y 48b, respectivamente, que se corresponden a las imágenes particulares o fotografías tomadas y que se almacenan en el sistema 48 de ordenador de captura de imágenes, como será descrito más en particular en la presente memoria descriptiva posteriormente.

Como mejor se muestra en la figura 1, los dispositivos 32a y 32b de captura de imágenes tienen ejes centrales respectivos A_1 y A_2, y están montados en la plataforma 20 de manera que cada uno de los ejes A_1 y A_2 tenga un ángulo de declinación θ relativo al plano horizontal P. El ángulo de declinación θ es virtualmente cualquier ángulo oblicuo, pero preferiblemente es desde aproximadamente 20° (veinte grados) hasta aproximadamente 60° (sesenta grados) y más preferiblemente, desde aproximadamente 40° (cuarenta grados) a aproximadamente 50° (cincuenta grados).

El receptor GPS 34 recibe las señales 52 del sistema de posicionamiento global que son transmitidas por uno o más satélites 54 del sistema de posicionamiento global. Las señales GPS 52, de una manera conocida, permiten la localización precisa de la pla-

taforma 20 con relación a la superficie 31 que se determine. El receptor GPS 34 descodifica las señales GPS 52 y emite señales/datos 56 de localización, que dependen, al menos en parte, de las señales GPS 52 y que son indicativas de la localización precisa de la plataforma 20 con relación a la superficie 31. Las señales/datos de localización 56 que se corresponden a cada imagen capturada por los dispositivos 32a y 32b de captura de imágenes se reciben y se almacenan en el sistema 46 de ordenador de captura de imágenes.

La INU 36 es una unidad de navegación inercial convencional que está acoplada y detecta cambios en la velocidad, incluyendo velocidad de traslación y de rotación, de los dispositivos 32a y 32b de captura de imágenes y/o de la plataforma 20. La INU 36 emite señales/datos 58 de velocidad indicativas de tales velocidades y/o cambios del sistema 46 de ordenador de captura de imágenes, que almacena las señales/datos de velocidad 58 que se corresponden a cada imagen capturada por los dispositivos 32a y 32b de captura de imágenes y se reciben y almacenan en el sistema 46 de ordenador de captura de imágenes.

El reloj 38 mantiene una medida de tiempo precisa (tiempo de validez) que se utiliza para sincronizar los sucesos dentro del sistema 30 de captura de imágenes y de geolocalización. El reloj 38 proporciona la señal 62 de momento de datos/reloj que son indicativas del momento preciso en el que se tomó una imagen por medio de los dispositivos 32a y 32b de captura de imágenes. Los datos de momento 62 también se proporcionan y se almacenan en el sistema 46 de ordenador de captura de imágenes. Alternativamente, el reloj 38 es integral con el sistema 46 de ordenador de captura de imágenes, tal como, por ejemplo, un programa de software de reloj.

El giroscopio 40 es un giroscopio convencional, como se encuentra comúnmente en aeroplanos y/o en sistemas de navegación comercial para aeroplanos. El giroscopio 40 proporciona señales que incluyen la señal 64 de inclinación longitudinal, la señal 66 de balanceo y la señal 68 de guiñada, que respectivamente son indicativas de la inclinación longitudinal, balanceo y guiñada de la plataforma 20. La señal 64 de inclinación longitudinal, la señal 66 de balanceo y la señal 68 de guiñada que se corresponden a cada imagen capturada por los dispositivos 32a y 32b de captura de imágenes se reciben y almacenan en el sistema 46 de ordenador de captura de imágenes.

La brújula 42, tal como, por ejemplo, una brújula electrónica convencional, indica el rumbo de la plataforma 20. La brújula 42 emite señales/datos 72 de rumbo que son indicativos del rumbo de la plataforma 20. El sistema 46 de ordenador de captura de imágenes recibe y almacena las señales/datos 72 de rumbo que se corresponden a cada imagen capturada por los dispositivos 32a y 32b de captura de imágenes.

El altímetro 44 indica la altitud de la plataforma 20. El altímetro 44 emite señales/datos 74 de altitud y el sistema 46 de ordenador de captura de imágenes recibe y almacena las señales/datos de altitud 74 que se corresponden a cada imagen capturada por los dispositivos 32a y 32b de captura de imágenes.

Como mejor se muestra en la figura 3, el sistema 46 de ordenador de captura de imágenes, tal como, por ejemplo, un ordenador personal portátil convencional, incluye memoria 82, dispositivos de entrada 84a y 84b, dispositivo de pantalla 86, y puertos de entrada y salida 88 (I/O). El sistema 46 de ordenador de captura de imágenes ejecuta el software 90 de adquisición de imágenes y datos, que está almacenado en la memoria 82. La memoria 82 también almacena datos utilizados y/o calculados por el sistema 46 de ordenador de captura de imágenes durante la operación del mismo, e incluye, por ejemplo, memoria no volátil de solo lectura, memoria de acceso aleatorio, memoria de disco duro, tarjetas de memoria retirables y/o otros dispositivos y/o medios de almacenamiento de memoria adecuados. Los dispositivos 84a y 84b de entrada, tales como, por ejemplo, un ratón, tablero, palanca de control u otros dispositivos de entrada similares, permiten la introducción de datos y la interacción de un usuario con el software que está siendo ejecutado por el sistema 46 de ordenador de captura de imágenes. El dispositivo 86 de pantalla, tal como, por ejemplo, una pantalla de cristal líquido o un tubo de rayos catódicos, muestra información al usuario del sistema 46 de ordenador de captura de imágenes. Los puertos I/O 88, tales como, por ejemplo, puertos de entrada y salida de datos serie y paralelo, permiten la introducción y la salida de datos a y desde el sistema 46 de ordenador de captura de imágenes.

Cada una de las señales de datos que se han descrito más arriba se conecta al sistema 46 de ordenador de captura de imágenes. Más en particular, las señales 48 de datos de imágenes, las señales 56 de localización, las señales 58 de velocidad, la señal 62 de dato de tiempo, las señales 64, 66 y 68 de inclinación longitudinal, balanceo y guiñada respectivamente, la señal 72 de rumbo, y la señal 74 de altitud se reciben por medio de los puertos I/O 88 y se almacenan en la memoria 82 del sistema 46 de ordenador de captura de imágenes.

En uso, el sistema 46 de ordenador de captura de imágenes ejecuta el software 90 de adquisición de imágenes y datos que, en general, controla la lectura, manipulación y almacenamiento de las señales de datos que se ha descrito más arriba. Más en particular, el software 90 de adquisición de imágenes y datos lee las señales 48a y 48b de datos de imágenes y las almacena en la memoria 82. Cada una de las señales 56 de localización, señales 58 de velocidad, señales 62 de datos de tiempo, señales de inclinación longitudinal, balanceo y guiñada 64, 66 y 68, respectivamente, señal de rumbo 72 y señal de altitud 74, que representan las condiciones existentes en el momento en que se adquirió o capturó una imagen por los dispositivos 32a y 32b de captura de imágenes y que se corresponden a las señales 48a y 48b de datos de imágenes particulares que representan las imágenes capturadas, son recibidas por el sistema 46 de ordenador de captura de imágenes por medio de los puertos de I/O 88. El sistema 46 de ordenador de captura de imágenes que ejecuta software 90 de adquisición de imágenes y datos emite una señal 92 de captura de imágenes a los dispositivos 32a y 32b de captura de imágenes para hacer de esta manera que estos dispositivos adquieran o capturen una imagen en localizaciones predeterminadas y/o en intervalos predeterminados que dependen, al menos en parte, de la velocidad de la plataforma 20.

El software 90 de adquisición de imágenes y datos descodifica como sea necesario y almacena las señales que se han mencionado con anterioridad en la memoria 82, y asocia las señales de datos a las señales 48a y 48b de imágenes correspondientes. De esta manera, la altitud, rumbo en términos de inclinación

longitudinal, balanceo y guiñada, y la localización de los dispositivos 32a y 32b de captura de imágenes en relación con la superficie, es decir, longitud y latitud, de cada imagen capturada por los dispositivos 32a y 32b de captura de imágenes, es conocida.

La plataforma 20 es pilotada o guiada de otra manera a lo largo de un trayecto de captura de imágenes que pasa sobre un área particular de la superficie 31, tal como, por ejemplo, un área predefinida de la superficie de la tierra o de otro planeta. Preferiblemente, el trayecto de captura de imágenes de la plataforma 20 se encuentra en ángulo recto respecto, al menos, uno de los límites del área de interés. El número de veces que la plataforma 20 y/o los dispositivos 32a, 32b de captura de imágenes pasa sobre el área de interés depende de, al menos en parte, el tamaño del área y la cantidad de detalles deseados en las imágenes capturadas. Los detalles particulares del trayecto de captura de imágenes de la plataforma 20 se describen de manera más particular en la presente memoria y a continuación.

Cuando la plataforma 20 pasa sobre el área de interés, es capturado un número de imágenes oblicuas por los dispositivos 32a y 32b de captura de imágenes. Como podrán entender aquellos de conocimiento ordinario en la técnica, las imágenes son capturadas o adquiridas por los dispositivos 32a y 32b de captura de imágenes en intervalos de captura de imágenes predeterminados que dependen, al menos en parte, de la velocidad de la plataforma 20.

Las señales 48a y 48b de datos de imágenes que se corresponden a cada imagen adquirida son recibidas y/o almacenadas en la memoria 82 del sistema 46 de ordenador de captura de imágenes por los puertos I/O 88. De manera similar, las señales de datos (es decir, las señales 48 de datos de imágenes, las señales 56 de localización, las señales 58 de velocidad, las señales 62 de datos de momento, las señales 64, 66 y 68 de inclinación longitudinal, balanceo y guiñada, respectivamente, la señal de rumbo 72 y la señal altitud 74) que se corresponde a cada imagen capturada son recibidas y almacenadas en la memoria 82 del sistema 46 de ordenador de captura de imágenes por los puertos I/O 88. De esta manera, la localización del dispositivo 32a y 32b de captura de imágenes en relación con la superficie 32 en el momento de preciso en el que se capturó cada imagen se registra en la memoria 82 y se asocia a la imagen capturada correspondiente.

Como mejor se muestra en la figura 1, los dispositivos 32a y 32b de captura de imágenes relativos a la tierra se corresponden al punto nadir N de la imagen ortogonal 102. De esta manera, la geolocalización exacta del punto nadir N de la imagen ortogonal 102 está indicada por las señales de localización 56, señales de velocidad 58, señales 62 de datos de tiempo, señales 64, 66 y 68 de inclinación longitudinal, balanceo y guiñada, respectivamente, señal 72 de rumbo, y señal 74 de altitud. Una vez que el punto nadir N de la imagen ortogonal 102 sea conocido, el píxel de geolocalización o cualquier otro punto o píxel en la imagen 102 es determinable de una manera conocida.

Cuando los dispositivos 32a y 32b de captura de imágenes están capturando imágenes oblicuas, tales como imágenes oblicuas 104a y 104b (figura 1), la localización de los dispositivos 32a y 32b de captura de imágenes con relación a la superficie 31 está indicada de manera similar por las señales de localización 56, señales de velocidad 58, señales 62 de datos de tiempo, señales 64, 66 y 68 de inclinación longitudinal, balanceo y guiñada, respectivamente, señal 72 de rumbo, señal 74 de altitud y el ángulo conocido de declinación θ de los ejes primarios A_1 y A_2 de los dispositivos 32a y 32b de captura de imágenes, respectivamente.

Se debe hacer notar en particular que un proceso de calibración permite que el software 90 de adquisición de imágenes y datos incorpore factores de corrección y/o corrijan cualquier error inherente o debido al dispositivo 32 de captura de imágenes, tales como, por ejemplo, errores debidos a la longitud focal calibrada, tamaño del sensor, distorsión radial, punto principal de desplazamiento y alineación.

El software 90 de adquisición de imágenes y datos crea y almacena uno más archivos 120 de salida de imágenes y datos. Más en particular, el software 90 de adquisición de imágenes y datos convierte las señales 48a y 48b de datos de imágenes y las señales de datos de orientación (es decir, señales de datos de imágenes 48, señales de localización 56, señales de velocidad 58, señales 62 de datos de tiempo, señales 64, 66 y 68 de inclinación longitudinal, balanceo y guiñada, respectivamente, señal 72 de rumbo, y señal 74 de altitud) en los archivos 120 de salida de imágenes y datos legibles por el ordenador. Como mejor se muestra en la figura 4, el archivo 120 de imágenes y datos de salida contiene una pluralidad de archivos I_1, I_2, ... I_n de imágenes capturadas que se corresponden a las imágenes oblicuas capturadas, y los datos posicionales C_{PD1}, C_{PD2}, ..., C_{PDn} que se corresponden a los mismos.

Los archivos I_1, I_2, ... I_n de imágenes del archivo 120 de imágenes y datos se almacena virtualmente en cualquier formato de archivo de imágenes o gráficos legible por ordenador, tales como, por ejemplo, formatos de archivos JPEG, TIFF, GIF, BMP o PDF, y tienen una referencia cruzada con los datos C_{PD1}, C_{PD2}, ..., C_{PDn} que también están almacenados como datos legibles por el ordenador. Alternativamente, los datos posiciónales C_{PD1}, C_{PD2}, ..., C_{PDn} está incrustado en los archivos I_1, I_2, ... I_n de imágenes correspondientes de una manera conocida. A continuación, los archivos 120 de datos de imágenes son procesados, ya sea por el software 90 de adquisición de imágenes y datos o por postprocesamiento, para corregir errores, tales como, por ejemplo, errores debidos a desviaciones del trayecto de vuelo y otros errores conocidos a cualquiera de conocimiento ordinario en la técnica. A continuación, los archivos 120 de datos de imágenes están listos para utilizarse y mostrar y tomar mediciones de y entre los objetos mostrados en las imágenes capturadas, incluyendo mediciones de las alturas de tales objetos.

Haciendo referencia a continuación a la figura 5, el sistema 130 de ordenador de visualización y medida de imágenes, tal como, por ejemplo, un ordenador personal de sobremesa convencional o un terminal de ordenador móvil en un coche de policía, incluye una memoria 132, dispositivos de entrada 134a y 134b, dispositivo 136 de pantalla, y conexión de red 138. El sistema 130 de ordenador de captura de imágenes ejecuta el software 140 de visualización y análisis de imágenes que está almacenado en la memoria 132. La memoria 132 incluye, por ejemplo, memoria no volátil de solo lectura, memoria de acceso aleatorio, memoria de disco duro, tarjetas de memoria retirables y/o otros dispositivos y/o medios de almacenamiento

de memoria adecuados. Los dispositivos de entrada 134a y 134b, tales como por ejemplo, un ratón, tablero, palanca de control u otros dispositivos de entrada de este tipo, permiten la introducción de datos y la interacción de un usuario con el software 140 de visualización y análisis de imágenes que está siendo ejecutado por el sistema 130 de ordenador de visualización y medida de imágenes. El dispositivo 136 de pantalla, tal como, por ejemplo, una pantalla de cristal líquido o un tubo de rayos catódicos, muestra información al usuario del sistema 130 de ordenador de visualización y medida de imágenes. La conexión 138 de red conecta el sistema 130 de ordenador de visualización y medida de imágenes a una red (no mostrada) tal como, por ejemplo, una red de área local, una red de área amplia, Internet y/o la World Wide Web.

En uso, y haciendo referencia ahora a la figura 6, el sistema 130 de ordenador de visualización y medida de imágenes que ejecuta el software 140 de visualización y análisis de imágenes, accede a uno o más archivos 120 de salida de imágenes y datos que han sido leídos en la memoria 132, tal como, por ejemplo, por medio de la conexión 138 de red, controlador de disco floppy, tarjeta de memoria retirable y otros medios adecuados. A continuación, una o más de las imágenes capturadas I_1, I_2, ... I_n de los archivos 120 de salida de imágenes y datos se muestra como una imagen oblicua mostrada 142 bajo el control del software 140 de visualización y análisis de imágenes. Aproximadamente en el mismo momento, una o más porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} que se corresponden a la imagen oblicua mostrada 142 son leídos en la porción fácilmente accesible de la memoria 132.

Se debe hacer notar en particular que la imagen oblicua mostrada 142 se muestra sustancialmente como se captura, es decir, la imagen mostrada 142 no está deformada o ajustada en cualquier sistema coordenado, ni está ortorectificada la imagen 142. En lugar de deformar la imagen mostrada 142 en un sistema de coordenadas con el fin de permitir la medición de los objetos mostrados en la misma, el software 140 de visualización y análisis de imágenes, en general, determina la geolocalización de píxeles seleccionados solamente como se necesite, o "al vuelo", referenciando porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} de archivos 120 de salida de imágenes y datos, y calculando la posición y/o la geolocalización de estos píxeles seleccionados utilizando una o más ecuaciones de proyección, y se describe de manera más particular en la presente memoria descriptiva y a continuación.

En general, un usuario del sistema 130 de ordenador de visualización y medida toma medidas de y entre los objetos mostrados en la imagen oblicua mostrada 142 seleccionando uno o más de los distintos modos de medición disponibles provistos en el software 140 de visualización y análisis de imágenes. El usuario selecciona el modo de medición deseado accediendo, por ejemplo, a una serie de menús desplegables o barras de herramientas M, o por ordenes del teclado. Los modos de medición proporcionados por el software 140 de visualización y análisis de imágenes incluyen, por ejemplo, un modo de distancia que permite la medición de la distancia entre dos o más puntos seleccionados, un modo de área que permite la medición del área comprendida entre varios puntos seleccionados e interconectados, un modo de altura que permite la medición de la altura entre dos o más puntos seleccionados, y un modo de elevación que permite la medición del cambio en la elevación de un punto seleccionado con relación a uno o más otros puntos seleccionados.

Después de seleccionar el modo de medición deseado, el usuario del software 140 de visualización y análisis de imágenes selecciona con uno de los dispositivos 134a y 134b de entrada, un punto de inicio o píxel de inicio 152 y un punto o píxel de finalización 154 en la imagen mostrada 142, y el software 140 de visualización y análisis de imágenes calcula y muestra automáticamente la cantidad buscada, tal como, por ejemplo, la distancia entre el píxel de inicio 152 y el píxel de finalización 154.

Cuando el usuario selecciona el píxel/punto de inicio 152, la geolocalización del punto que se corresponde a la superficie 31 es calculada por el software 140 de visualización y análisis de imágenes, que ejecuta una o más ecuaciones de proyección utilizando las porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} de los archivos 120 de salida de imágenes y datos que se corresponde a la imagen particular que está siendo mostrada. La longitud y la latitud del punto en la superficie 31 que se corresponde al píxel 152 son entonces mostrados por el software 140 de visualización y análisis de imágenes en las pantallas 136, tal como, por ejemplo, superponiendo la longitud y la latitud en la imagen mostrada 142 adyacente al punto/píxel seleccionado o en una caja de visualización desplegable en cualquier punto en la pantalla 136. El mismo proceso es repetido por el usuario para seleccionar el píxel/punto 154 de finalización, y por el software 140 de visualización y análisis de imágenes para la retirada y la visualización de la información de longitud y latitud.

El cálculo de la distancia entre los puntos/píxeles de inicio y finalización 152, 154, respectivamente, se realiza determinando la geolocalización de cada píxel seleccionado 152, 154 "al vuelo". Las porciones de datos C_{PD1}, C_{PD2}, ..., C_{PDn} del archivo 120 de salida de imágenes y datos que se corresponde a la imagen mostrada se recuperan, y la geolocalización del punto sobre la superficie 31 que se corresponde a cada píxel seleccionado es entonces determinada. Las diferencias entre las geolocalizaciones correspondientes a los píxeles seleccionados determina la distancia entre los píxeles.

Como un ejemplo de cómo se determina la geolocalización de un punto o píxel dado en la imagen oblicua mostrada 142, se asumirá que la imagen mostrada 142 se corresponde a la imagen ortogonal 104a (figura 1). El usuario del software 140 de visualización y análisis de imágenes selecciona el píxel 152 que, por simplicidad, se corresponde al centro C (figura 1) de la imagen oblicua 104a. Como se muestra en la figura 1, la línea 106 se extiende a lo largo del plano horizontal G desde un punto 108 en el mismo que está directamente debajo del dispositivo 32a de captura de imágenes, al centro C del límite o borde cercano 108 de la imagen oblicua 104a. Una extensión del eje primario A_1 se cruza con el centro C. El ángulo Φ es el ángulo formado entre la línea 106 y la extensión del eje primario A_1. De esta manera, se forma un triángulo (no referenciado) que tiene vértices en el dispositivo 32a de captura de imágenes, el punto 108 y el centro C, y que tiene lados 106, la extensión del eje primario A_1 y la línea vertical (a trazos) 110 entre el punto 108 y el dispositivo 32a de captura de imágenes.

El plano de suelo G es un plano de suelo sustancialmente horizontal, llano o no inclinado (y que típicamente tendrá una elevación que refleja la elevación media del terreno) y por lo tanto el triángulo que se ha descrito más arriba incluye un ángulo recto entre el lado/línea 110 y el lado/línea 106. Puesto que el ángulo Φ y la altitud del dispositivo 32 de captura de imágenes (es decir, la longitud del lado 110) son conocidos, la hipotenusa (es decir, la longitud de la extensión del eje primario A_1) y el resto de los otros lados del triángulo rectángulo son calculados por geometría simple. Además, puesto que la posición exacta del dispositivo 32a de captura de imágenes es conocida en el momento en que se capturó la imagen correspondiente a la imagen mostrada 142, la latitud y la longitud del punto 108 también son conocidos. Conocer la longitud del lado 106, que se ha calculado como se ha descrito más arriba, permite la geolocalización exacta del píxel 154 que se corresponde al centro C de la imagen oblicua 104a que será determinada por el software 140 de visualización y análisis de imágenes. Una vez que la geolocalización del punto que se corresponde al píxel 154 sea conocida, la geolocalización de cualquier otro píxel en la imagen oblicua mostrada 142 se puede determinar utilizando las características de cámara conocidas, tales como, por ejemplo, longitud focal, tamaño de sensor y relación de aspecto, términos radiales y otros de distorsión, etc.

La distancia entre los dos o más puntos que se corresponden a dos o más píxeles seleccionados en la imagen mostrada 142 se calcula por el software 140 de visualización y análisis de imágenes determinando la diferencia entre las geolocalizaciones de los píxeles seleccionados utilizando algoritmos conocidos, tales como, por ejemplo, la formula de Gauss y/o la formula de punto de fuga que depende del modo de medición seleccionado. La medición de objetos mostrados o que aparecen en la imagen mostrada 142 es ejecutada por un procedimiento sustancialmente similar al procedimiento que se ha descrito más arriba para medir distancias entre píxeles seleccionados. Por ejemplo, las longitudes, anchuras y alturas de objetos tales como, por ejemplo, edificios, ríos, carreteras y virtualmente cualquier otra estructura geográfica o realizada por el hombre, que aparece en la imagen mostrada 142, son medidas seleccionando el modo de medición apropiado/deseado y seleccionando los píxeles de inicio y finalización.

Se debe hacer notar en particular que en el modo de medición de distancias del software 140 de visualización y análisis de imágenes, la distancia entre los puntos/píxeles de inicio y finalización 152, 154, respectivamente, se puede determinar a lo largo de virtualmente cualquier trayecto, tal como, por ejemplo, un trayecto P1 de "línea recta" o un trayecto P2 que incluye la selección de puntos/píxeles intermedios y uno o más segmentos de "línea recta" interconectados entre los mismos.

Se debe hacer notar en particular que en el modo de medición de distancias del software 140 de visualización y análisis de imágenes determina la distancia entre píxeles seleccionados de acuerdo con el procedimiento "caminar por la tierra". El procedimiento "caminar por la tierra" crea una serie de segmentos de línea interconectados, representados colectivamente por los trayectos P1 y P2, que se extienden entre los píxeles/puntos seleccionados y que se disponen o se conforman a las caras planas de una serie de facetas interconectadas que definen un plano de suelo teselado. El plano de suelo teselado, como será descrito más en particular en la presente memoria descriptiva y a continuación, sigue o recrea ajustadamente el terreno de la superficie 31, y por lo tanto los trayectos P1 y P2 también siguen ajustadamente el terreno de la superficie 31. Midiendo la distancia a lo largo del terreno simulado por el plano de terreno teselado, el procedimiento "caminar por la tierra" proporciona una medición más precisa y útil de la distancia entre puntos seleccionados que el enfoque convencional, que deforma la imagen sobre una tierra plana o sistema plano de elevación medio, y mide la distancia entre puntos seleccionados a lo largo de la tierra plana o plano y sustancialmente ignora las variaciones en el terreno entre los puntos.

Por ejemplo, un contratista que prepara una licitación de un contrato para pavimentar una carretera sobre terreno montañoso desigual, puede determinar la cantidad aproximada de área de la carretera incluida utilizando el software 140 de visualización y análisis de imágenes y el procedimiento de medición "caminar por la tierra" provisto de esta manera. El contratista puede obtener la cantidad o área aproximada de carretera en su propia oficina, sin tener que enviar un equipo de investigación al lugar para obtener las mediciones necesarias.

Como contraste al procedimiento "caminar por la tierra" proporcionado por la presente invención, los enfoques de cálculo de "tierra plana" o distancia de altura media incluyen imprecisiones inherentes cuando se miden distancias entre puntos y/o objetos dispuestos en un terreno desigual o cuando se miden los tamaños y/o alturas de objetos dispuestos de manera similar. Incluso una inclinación o cuesta modesta en la superficie que está siendo capturada produce una diferencia en la elevación del punto nadir relativa a virtualmente cualquier otro punto de interés en la misma. De esta manera, haciendo referencia de nuevo a la figura 1, el triángulo formado por la línea 106, la extensión del eje primario A_1 y la línea vertical (a trazos) 110 entre el punto 108 y el dispositivo 32a de captura de imágenes puede no ser un triángulo recto. En este caso, cualquier cálculo geométrico que asuma que el triángulo es un triángulo recto contendrá errores, y tales cálculos deben ser reducidos a aproximaciones, debido a incluso ligeros gradientes o pendientes entre los puntos de interés.

Por ejemplo, si la superficie 31 se inclina hacia arriba entre el punto nadir N y el centro C cerca o en el borde inferior 108 de la imagen oblicua 104, entonces la segunda línea 110 se cruza con la superficie 31 antes del punto en el cual se debería producir tal intersección en una superficie 31 a nivel o no inclinada. Si el centro C es 4,57 m más alto que el punto nadir N y con ángulo de declinación θ igual a 40º (cuarenta grados), la localización calculada del centro C estará desplazada aproximadamente 5,42 m sin corrección del cambio en elevación entre los puntos.

Como se ha discutido en general más arriba, con el fin de compensar, al menos en parte, los cambios en elevación y las imprecisiones resultantes en la medición de y entre los objetos en la imagen 142, el software 140 de visualización y análisis de imágenes referencia, cuando sea necesario, puntos en la imagen mostrada 142 y en la superficie 31 con un plano de suelo teselado o en facetas designado en general como 160 en la figura 6. El plano de suelo teselado 160

incluye una pluralidad de facetas individuales 162a, 162b, 162c, etc., cada una de las cuales está interconectada a las otras y están definidas por cuatro vértices (no referenciados, pero que se muestran como puntos) que tienen alturas respectivas. Las parejas adyacentes de facetas 162a, 162b, 162c, etc., comparten dos vértices. Cada faceta 162a, 162b, 162c, etc. tiene inclinación longitudinal y pendiente respectivas. El plano de suelo teselado 160 se crea sobre la base de varios datos y fuentes, tales como, por ejemplo, mapas topográficos y/o gráficos en tramas digitales, datos de reconocimiento y varias otras fuentes.

En general, la geolocalización de un punto de interés en una imagen mostrada 142 se calcula determinando cual de las facetas 162a, 162b, 162c, etc. se corresponde a ese punto de interés. De esta manera, la localización del punto de interés se calcula sobre la base de las características, es decir, elevación, inclinación longitudinal y pendiente de las facetas 162a, 162b, 162c, etc. en lugar de hacerlo sobre la base de un plano de suelo llano o de elevación media. El error se introduce solamente en lo que se refiere a la topografía de la superficie 31 y la localización del punto de interés en el mismo que se desvía de la superficie plana de la faceta 162a, 162b, 162c, etc. en la cual se encuentra dispuesto el punto de interés. Ese error se puede reducir por medio de una interpolación bilineal de la altura del punto de interés en una faceta particular de las facetas 162a, 162b, 162c, etc. y utilizando la altura interpolada en el cálculo de localización ejecutado por el software 140 de visualización y análisis de imágenes.

Para usar plano de suelo teselado 160, el software 140 de visualización y análisis de imágenes utiliza un algoritmo modificado de trazado de rayos para encontrar la intersección del rayo proyectado por el dispositivo 32a o 32b de captura de imágenes hacia la superficie 31 y el plano de suelo teselado 160. El algoritmo determina no solamente cual de las facetas 162a, 162b, 162c, etc. es intersectada por el rayo, sino también donde se produce la intersección dentro de la faceta. Utilizando la interpolación bilineal, se puede determinar una localización de suelo bastante precisa. Para la proyección inversa, se utiliza el plano de suelo teselado 160 para encontrar el valor de la altura del suelo para introducir la localización de suelo, usando también la interpolación bilineal. A continuación se utilizan la altura y la localización para proyectarse hacia atrás por un modelo del dispositivo 32a o 32b de captura de imágenes para determinar cual de los píxeles dentro de la imagen mostrada 142 se corresponde a una localización dada.

Más en particular, y como un ejemplo, el software 140 de visualización y análisis de imágenes ejecuta y/o calcula la geolocalización del punto 164 superponiendo y/o ajustando el plano 160 de suelo teselado al menos a una porción 166, tal como, por ejemplo, una colina, de la superficie 31. Se debe hacer notar que solamente una pequeña porción del plano 160 de suelo teselado y de las facetas 162a, 162b, 162c, etc. de la misma se muestra a lo largo del perfil de la porción 166 de la superficie 131. Como se ha discutido más arriba, cada una de las facetas 162a, 162b, 162c, etc. está definida por cuatro vértices, cada uno de los cuales tiene elevaciones respectivas, y cada una de las facetas tiene inclinaciones longitudinales y pendientes respectivas. La posición específica del punto 164 sobre el plano/superficie de la faceta 162a, 162b, 162c, etc. dentro del cual se mantiene el punto 164 (o su proyección) se determina como se ha descrito más arriba.

El plano 160 de suelo teselado preferiblemente se crea fuera de la operación del sistema 130 de ordenador de visualización y medida de imágenes y del software 140 de visualización y análisis de imágenes. Por el contrario, el plano 160 de suelo teselado toma la forma de una tabla de datos relativamente simple o tabla de visión 168 almacenada en la memoria 132 del sistema 130 de ordenador de visualización y medida de imágenes y/o es accesible al mismo. Los recursos de cálculo requeridos para calcular las localizaciones de todos los vértices y facetas de un plano de suelo típico, no necesariamente tienen que residir en el sistema 130 de ordenador de visualización y medida de imágenes. De esta manera, el sistema 130 de ordenador de visualización y medida de imágenes es compatible para utilizarse con, y es ejecutable por, un ordenador personal convencional sin requerir recursos de cálculo adicionales.

El cálculo de plano 160 de suelo teselado fuera del sistema 130 de ordenador de visualización y medida de imágenes permite virtualmente que cualquier nivel de detalle se incorpore en el plano 160 de suelo teselado, es decir, el tamaño y/o el área cubierta por, o que se corresponde a, cada una de las facetas 162a, 162b, 162c, etc. puede ser tan grande o pequeño como se desee, sin incrementar significativamente el tiempo de cálculo, sin hacer más lenta la operación, sin incrementar significativamente los recursos requeridos por el sistema 130 de ordenador de visualización y medida de imágenes y/o el software 140 de visualización y análisis de imágenes. Por lo tanto, el sistema 130 de ordenador de visualización y medida puede ser un sistema de ordenador relativamente básico y sencillo.

El tamaño de las facetas 162a, 162b, 162c, etc. es uniforme en tamaño en una imagen mostrada 142 en particular. Por ejemplo, si la imagen mostrada 142 se corresponde a un área que es aproximadamente de 228,6 m de anchura en el primer plano por aproximadamente 274,32 m de profundidad, la imagen se puede descomponer en facetas que son aproximadamente de 15,24 m de lado, proporcionando por lo tanto aproximadamente quince facetas de anchura y dieciocho facetas de profundidad. Alternativamente, el tamaño de las facetas 162a, 162b, 162c, etc. es uniforme en términos del número de píxeles que están contenidos en las mismas, es decir, cada faceta tiene el mismo número de píxeles de anchura y del mismo número de píxeles de profundidad. Por lo tanto, las facetas en el primer plano de la imagen mostrada 142, donde la densidad de píxeles es la mayor, serán dimensionalmente más pequeñas que las facetas en el fondo de la imagen mostrada 142, donde la densidad de píxeles es la más baja. Puesto que es deseable tomar la mayor parte de las medidas en el primer plano de una imagen mostrada en donde la densidad en píxeles es la mayor, la creación de facetas que son uniformes en términos del número de píxeles que contienen, tiene la ventaja de proporcionar mediciones más precisas en el primer plano de la imagen mostrada 142 en relación con las facetas que son dimensionalmente uniformes.

Otra ventaja de utilizar píxeles como base para definir las dimensiones de las facetas 162a, 162b, 162c, etc. es que el cálculo de la localización (localización de píxeles respecto a localización de suelo) es relativamente simple. Un usuario opera el sistema 130 de ordenador de visualización y medida de imágenes pa-

ra seleccionar un píxel dentro de una faceta dada, el software 140 de visualización y análisis de imágenes busca los datos de la faceta que se corresponde al píxel seleccionado, se calcula la elevación del píxel seleccionado como se ha discutido más arriba, y esa elevación se utiliza en el calculo de localización.

En general, el procedimiento de capturar imágenes oblicuas de la presente invención divide un área de interés, tal como, por ejemplo, una comarca, en sectores de tamaño generalmente uniforme, tales como, por ejemplo, sectores que son aproximadamente de 2,59 kilómetros cuadrados de área. Esto se realiza para facilitar la creación de un plan de vuelo para capturar imágenes oblicuas que cubran cada centímetro del área de interés, y organizar y nombrar los sectores y/o imágenes de la misma para una referencia, almacenamiento y recuperación fáciles (un proceso conocido en la técnica como "sectorización"). Debido a que los bordes de cualquier área geográfica de interés, tal como una comarca, raramente se encuentran en límites iguales de kilómetros cuadrados, el procedimiento de captura de imágenes oblicuas de la presente invención proporciona más sectores que kilómetros cuadrados en el área de interés, dependiendo en gran medida cuantos más de la longitud de los límites de la comarca así como de cómo son de rectos o dentado. Típicamente, se puede esperar un sector extra por cada dos o tres kilómetro de límite. De esta manera, si una comarca u otra área de interés es de aproximadamente 32,187 kilómetros por 56,327 kilómetros, o 1.813 kilómetros cuadrados, el área se medirá en, aproximadamente, 740 a 780 sectores.

El procedimiento de captura de imágenes oblicuas de la presente invención en general captura las imágenes oblicuas en, al menos, dos direcciones de brújula, y proporciona una cobertura total del área de interés en, al menos, esas dos direcciones de brújula. Haciendo referencia a continuación a las figuras 7 y 8, se muestra una primera realización de un procedimiento para capturar imágenes oblicuas de la presente invención. Con el fin de la claridad, las figuras 7 y 8 se basan en un sistema que tiene solamente un dispositivo de captura de imágenes. Sin embargo, se debe entender que se puede utilizar dos o más dispositivos de captura de imágenes.

El dispositivo de captura de imágenes captura una o más imágenes oblicuas durante cada paso sobre el área 200. El dispositivo de captura de imágenes, como se ha discutido más arriba, está apuntado con un cierto ángulo sobre el área 200 para capturar imágenes oblicuas de la misma. El área 200 es atravesada con un patrón hacia detrás y hacia delante, similar a la manera en que se corta el césped, por el dispositivo de transporte de imágenes y/o la plataforma, para asegurar doble cobertura del área 200.

Más en particular, el área 200 es atravesada por el dispositivo 32 de soporte de imágenes y/o la plataforma 20 siguiendo una primera trayectoria 202 para capturar de esta manera imágenes oblicuas de las porciones 202 a, 202b y 202c del área 200. A continuación, el área 200 es atravesada por el dispositivo 32 de transporte de imágenes y/o la plataforma 20 siguiendo una segunda trayectoria 204 que es paralela y está separada y en una dirección opuesta a la primera trayectoria 202, es decir 180° (ciento ochenta grados) para capturar de esta manera imágenes oblicuas de las porciones 204 a, 204b, 204c del área 200. Comparando las figuras 7 y 8, se ve que una porción 207 (figura 8) del área 200 está cubierta por las imágenes 202a-c capturadas desde una primera dirección o perspectiva, y por las imágenes 204a-c capturadas desde una segunda dirección o perspectiva. De esta manera, la porción media del área 200 es cubierta doblemente un 100% (cien por cien). El patrón que se ha descrito más arriba de atravesar o pasar sobre el área 200 a lo largo de trayectorias opuestas que son paralelas a las trayectorias 202 y 204 se repiten hasta que toda el área 200 sea completamente cubierta por al menos una imagen oblicua capturada desde las trayectorias que son paralelas, separadas una de las otras como sea obligado por el tamaño del área 200 en la misma dirección que las trayectorias 202 y 204, para de esta manera, cubrir doblemente un cien por cien el área 200 desde estas perspectivas/direcciones.

Si se desea, y para detalles mejorados, el área 200 es cubierta por dos trayectorias tercera y cuarta 206 y 208 adicionales opuestas y paralelas, respectivamente, que son perpendiculares a las trayectorias 202 y 204, como se muestra en las figuras 9 y 10. De esta manera, el área 200 es atravesada por el dispositivo de soporte de imágenes 32 y/o plataforma 20 siguiendo una tercera trayectoria 206 para capturar imágenes oblicuas de las porciones 206a, 206b y 206c del área 200, y a continuación es atravesada a lo largo por una cuarta trayectoria 208 que es paralela, separada y opuesta a la tercera trayectoria 206, para capturar imágenes oblicuas de las porciones 208a, 208b, 208c del área 200. Este patrón de atravesar o pasar sobre el área 200 a lo largo de trayectorias opuestas que son paralelas a las trayectorias 206 y 208 se repite de manera similar hasta que la totalidad del área 200 sea cubierta completamente por, al menos, una imagen oblicua capturada por trayectorias que son paralelas, y que están separadas por la manera obligada por el tamaño del área 200, y en la misma dirección que las trayectorias 206 y 208 para cubrir cien por cien el doble del área 200 desde estas direcciones/perspectivas.

Como se ha descrito más arriba, el dispositivo 32 de transporte de imágenes y/o la plataforma 20, atraviesa o pasa sobre el área 200 a lo largo de una trayectoria predeterminada. Sin embargo, se debe entender que el dispositivo y/o plataforma de transporte de imágenes y/o la plataforma 20 no necesariamente pasan o atraviesan directamente por encima del área 200, si no que, por el contrario, pueden pasar o atravesar un área adyacente, próxima, o incluso algo alejada del área 200 con el fin de asegurar que la porción del área 200 que está siendo capturada por imágenes cae dentro del campo de captura de imágenes del dispositivo de captura de imágenes. La trayectoria 202, como se muestra en la figura 7, es una trayectoria tal que no pasa directamente sobre el área 200 pero que todavía captura imágenes oblicuas de la misma.

La presente invención puede capturar imágenes con distintos varios niveles de resolución o distancias de las muestras de suelo. Un primer nivel de detalle, que en la presente memoria y a continuación se denominará nivel de comunidad, tiene una distancia de muestra de suelo de, por ejemplo, aproximadamente 0,61 metros por píxel. Para las imágenes ortogonales de nivel de comunidad, la distancia de muestra de suelo permanece sustancialmente constante en toda la imagen. Las imágenes ortogonales de nivel de comunidad se capturan con suficiente solapamiento para proporcionar una cobertura de pareja en estéreo. Para imágenes oblicuas de nivel de comunidad, la dis-

tancia de muestra de suelo varía desde, por ejemplo, aproximadamente 0,30 metros por píxel en el primer plano de la imagen hasta aproximadamente 0,61 metros por píxel en el nivel medio de la imagen, y hasta aproximadamente 1,22 metros por píxel en el fondo de la imagen. Las imágenes oblicuas de nivel de comunidad son capturadas con suficiente solapamiento de manera que cada área de interés sea cubierta típicamente por, al menos, dos imágenes oblicuas desde cada dirección de brújula capturada. Se capturan aproximadamente diez imágenes oblicuas de nivel de comunidad por sector.

Un segundo nivel de detalle, que en la presente memoria descriptiva y a continuación se denominará nivel de barrio, es significativamente más detallado que las imágenes de nivel de comunidad. Las imágenes de nivel de barrio tienen una distancia de muestra de suelo de, por ejemplo, aproximadamente 15,24 cm por píxel. Para las imágenes ortogonales de nivel de barrio, la distancia de muestra de suelo permanece sustancialmente constante. Las imágenes oblicuas de nivel de barrio tiene una distancia de muestra de suelo de, por ejemplo, desde aproximadamente 10,16 cm por píxel en el primer plano de la imagen hasta aproximadamente 15,24 cm por píxel en el plano medio de la imagen y hasta aproximadamente 25,4 cm por píxel en el fondo de la imagen. Las imágenes oblicuas de nivel de barrio se capturan con suficiente solapamiento de manera que cada área de interés sea cubierta típicamente por al menos dos imágenes oblicuas en cada dirección de compás capturada, y de manera que las direcciones de brújula opuestas proporcionen un solapamiento del 100% entre sí. Aproximadamente se capturan cien (100) imágenes de área oblicua por sector.

Se debe hacer notar en particular que la captura de imágenes oblicuas de nivel de comunidad y/o de barrio en todas las cuatro direcciones de brújula asegura que cada punto en la imagen aparecerá en el primer plano o en una porción inferior de al menos una de las imágenes oblicuas capturadas, en donde la distancia de muestra de suelo sea la más baja y el detalle de la imagen sea el mayor.

En la realización que se muestra, el sistema 30 de captura de imágenes y geolocalización incluye un giroscopio, brújula y altímetro. Sin embargo, se debe entender que el sistema de captura de imágenes y geolocalización de la presente invención alternativamente puede estar configurado tal como, por ejemplo, para derivar y/o calcular la altitud, inclinación longitudinal, balanceo y guiñada, y rumbo de brújula para las señales/datos de GPS y INU, con lo cual hace innecesario un elemento o más de entre el giroscopio, brújula y altímetro.

En la realización que se muestra, los dispositivos de captura de imágenes se encuentran con un ángulo igual de declinación en relación a un plano horizontal. Sin embargo, se debe entender que los ángulos de declinación de los dispositivos de captura de imágenes no tienen que ser iguales.

En la realización que se muestra, el sistema de ordenador de captura de imágenes ejecuta el software de adquisición de imágenes y datos que emite una señal de captura de imágenes común o única a los dispositivos de captura de imágenes para, de esta manera, hacer que estos dispositivos adquieran o capturen una imagen. Sin embargo, se debe entender que la presente invención alternativamente puede estar configurada para producir que los dispositivos de captura de imágenes capturen por separado imágenes en diferentes instantes y/o en diferentes intervalos.

En la realización que se muestra, el procedimiento de la presente invención captura imágenes oblicuas para proporcionar doble cobertura de un área de interés desde trayectorias/perspectivas que son sustancialmente opuestas una de la otra, es decir, que se encuentran a 180° (ciento ochenta grados) en relación de una con la otra. Sin embargo, se debe entender que el procedimiento de la presente invención alternativamente puede estar configurado para proporcionar doble cobertura de trayectorias/perspectivas que son generalmente y/o sustancialmente perpendiculares una en relación con la otra.

Aunque la presente invención se ha descrito teniendo un diseño preferente, la invención puede ser modificada adicionalmente en la amplitud y el alcance de las reivindicaciones. Por lo tanto, esta exposición pretende incluir cualquier equivalente a las estructuras y a los elementos que se muestran en la presente memoria descriptiva. Además, esta exposición pretende incluir cualquier variación, utilización o adaptación de la presente invención que utilicen los principios generales que se muestran en la presente memoria descriptiva. Además, esta exposición pretende incluir cualquier diferencia con el asunto del sujeto que se muestra que se encuentre dentro de la práctica conocida o normal en la técnica pertinente y que se encuentre dentro de los límites de las reivindicaciones adjuntas.

REIVINDICACIONES

1. Un sistema computerizado para mostrar, geolocalizar y realizar mediciones basadas en imágenes oblicuas capturadas, que comprende:

un sistema (130) de ordenador que tiene una memoria (132);

un archivo (120) de imágenes y datos accesible por el citado sistema (130) y que incluye una pluralidad de archivos de imágenes que se corresponden a una pluralidad de imágenes oblicuas capturadas, incluyendo adicionalmente el citado archivo (120) de imágenes y datos, datos de posición que se corresponden a la citada pluralidad de archivos de imágenes; y

software (140) de visualización y análisis de imágenes ejecutado por el citado sistema (130) para leer el citado archivo (120) de imágenes y datos y mostrar al menos una porción de las imágenes oblicuas capturadas como una imagen oblicua mostrada, calculando el citado software (140) de visualización y análisis de imágenes las geolocalizaciones de dos o más puntos localizados en la citada imagen oblicua mostrada, en base, al menos en parte, a los citados datos posicionales, calculando el citado software (140) de visualización y análisis de imágenes una distancia de separación entre dos o más puntos cualesquiera seleccionados en la imagen oblicua mostrada;

que se **caracteriza** por

un archivo de datos de plano de suelo que presenta un plano (160) de suelo teselado, proporcionando datos el citado archivo de datos de plano de suelo al citado software (140) de visualización y análisis de imágenes, representando el archivo de datos de plano de suelo un plano de suelo teselado que se aproxima ajustadamente, al menos, a una porción del terreno mostrado en las citadas imágenes oblicuas capturadas, comprendiendo además el citado plano de suelo teselado una pluralidad de imágenes interconectadas, comprendiendo además el citado plano de suelo teselado una pluralidad de facetas interconectadas (162a, 162b, 162c, ...) teniendo cada una de la citada pluralidad de facetas una inclinación longitudinal y una pendiente respectivas, comprendiendo el citado archivo de datos de plano de suelo una pluralidad de vértices, teniendo cada uno de la citada pluralidad de vértices elevaciones respectivas y definiendo esquinas de la citada pluralidad de facetas interconectadas (162a, 162b, 162c, ...) estando compartidos dos de la citada pluralidad de vértices por cada una de las citadas facetas interconectadas; e

identificando el citado software (140) de visualización y análisis de imágenes cual de la citada pluralidad de facetas se corresponde a un punto seleccionado en la citada imagen oblicua mostrada, y calculando una elevación del citado punto seleccionado que depende, al menos en parte, de la elevación de los vértices de la faceta que se corresponde al punto seleccionado, utilizando el citado software (140) de visualización y análisis de imágenes la citada elevación calculada para calcular la citada distancia de separación entre el citado punto seleccionado y uno o más puntos seleccionados adicionales.

2. El sistema de la reivindicación 1, en el que

el citado software (140) de visualización y análisis de imágenes calcula las citadas geolocalizaciones solamente como se precise.

3. El sistema de las reivindicaciones 1 ó 2, en el que el citado software (140) de visualización y análisis de imágenes calcula una altura de un objeto dentro de la citada imagen oblicua mostrada calculando la distancia de separación entre dos o más puntos seleccionados.

4. El sistema de una de las reivindicaciones 1 a 3, en el que el citado plano de suelo teselado (160) se encuentra superimpuesto sobre la citada imagen oblicua mostrada y que se ajusta a la misma.

5. El sistema de una de las reivindicaciones 1 a 4, en el que el citado software (140) de visualización y análisis de imágenes incluye modos de medida seleccionables por el usuario que son accesibles por medio de al menos un menú desplegable, barras de herramientas y órdenes de teclado.

6. El sistema de una de las reivindicaciones 1 a 5, en el que cada una de las citadas imágenes fue capturada por un dispositivo (32a, 32b) de captura de imágenes y en un suceso de captura de imágenes respectivo, incluyendo el citado archivo de datos posicionales de la citada imágenes y datos:

datos de tiempo que representan el momento de cada suceso de captura de imágenes;

datos de localización que representan la localización del dispositivo (32a, 32b) de captura de imágenes en cada suceso de captura de imágenes;

datos de rumbo que representan el rumbo del dispositivo (32a, 32b) de captura de imágenes de cada suceso de captura de imágenes;

datos de corrección que representan factores de corrección del dispositivo (32a, 32b) de captura de imágenes; y

datos de elevación que representan una elevación media de la superficie capturada por el dispositivo (32a,32b) de captura de imágenes.

7. El sistema de la reivindicación 6, en el que los citados datos de localización incluyen la latitud, longitud y altitud del aparato (32a, 32b) de captura de imágenes en cada suceso de captura de imágenes.

8. El sistema de la reivindicación 6 ó 7, en el que los citados datos de rumbo incluyen inclinación longitudinal, balanceo, guiñada y rumbo del citado dispositivo (32a, 32b) de captura de imágenes en cada suceso de captura de imágenes.

9. El sistema de una de las reivindicaciones 6 a 8, en el que el citado dispositivo (32a, 32b) de captura de imágenes es una cámara y los citados datos de conexión incluyen, al menos, un dato de longitud focal, de tamaño de sensor, de relación de aspecto, de punto principal de desviación, distorsión, e inclinación longitudinal del píxel.

10. El sistema de una de las reivindicaciones 6 a 9, que comprende:

un dispositivo de entrada (134a, 134b) para seleccionar un punto de inicio y un punto de finalización en la imagen oblicua mostrada; y

el citado software (140) de visualización y análisis de imágenes para recuperar los datos posicionales que se corresponden al citado punto de inicio y al citado punto de finalización del citado archivo de datos; para referenciar el citado archivo de datos de plano de suelo que se corresponden al citado plano de suelo teselado que tiene una pluralidad de facetas, teniendo cada una de las citadas facetas una inclinación longitudinal y pendiente respectivas, correspondiéndose ajustadamente el citado plano de suelo teselado a un terreno de la citada imagen oblicua mostrada; para conectar los citados puntos de inicio y finalización con segmentos de línea, conformando los citados segmentos de

línea al citado inclinación longitudinal y pendiente de las citadas facetas para seguir de esta manera el citado terreno; y para calcular la distancia lineal a lo largo de los citados segmentos de línea entre los citados puntos de inicio y finalización, con lo cual se toma en consideración la citada inclinación longitudinal y la citada pendiente de las citadas facetas.

11. El sistema de una de las reivindicaciones 1 a 10, en el que el citado software (140) de visualización y análisis de imágenes se superpone al citado plano de suelo teselado sobre la citada imagen oblicua mostrada.

12. El sistema de la reivindicación 10 u 11, que comprende:

el citado dispositivo de entrada (134a, 134b) para seleccionar uno o más puntos intermedios en la citada imagen oblicua mostrada; y

el citado software (140) de visualización y análisis de imágenes para recuperar los datos posicionales que se corresponden al citado uno o más puntos intermedio desde el citado archivo de datos; para conectar los puntos intermedios adyacentes entres sí, y conectar los citados puntos de inicio y finalización a los puntos intermedios adyacentes con segmentos de línea, conformándose los citados segmentos de línea a la citada inclinación longitudinal y pendiente en las citadas facetas para seguir de esta manera el citado terreno; y para calcular la distancia a lo largo de los citados segmentos de línea entre los citados puntos de inicio y finalización.

13. El sistema de una de las reivindicaciones 1 a 12, en el que la citada pluralidad de facetas (162a, 162b, 162c, ...) se corresponde, cada una de ellas, a áreas iguales de la citada imagen oblicua mostrada.

14. El sistema de una de las reivindicaciones 1 a 13, en el que la citada pluralidad de facetas (162a, 162b, 162c, ...) incluyen cada una de ellas un número igual de píxeles de la citada imagen oblicua mostrada.

15. El sistema de una de las reivindicaciones 1 a 14, que comprende un dispositivo de entrada (134a, 134b) para seleccionar uno o más puntos intermedios en la citada imagen oblicua mostrada; y el citado software (140) de visualización y análisis de imágenes para recuperar los datos posicionales que se corresponden a los citados puntos intermedios.

16. El sistema de una de las reivindicaciones 1 a 15, en el que la citada distancia de separación comprende una distancia entre dos o más puntos seleccionados, una altura diferente entre uno o más puntos diferentes, una diferencia en elevación de dos o más puntos seleccionados y un área abarcada por al menos tres puntos.

17. El sistema de una de las reivindicaciones 1 a 16, que comprende:

un dispositivo (32a, 32b) de captura de imágenes, capturando el citado dispositivo (32a, 32b) de captura de imágenes, imágenes oblicuas en sucesos de captura de imágenes, emitiendo el citado dispositivo (32a, 32b) de captura de imágenes señales de imágenes/datos que se corresponden a las imágenes capturadas;

al menos un dispositivo de geolocalización (34,..., 44), emitiendo cada uno de los citados al menos un dispositivo de geolocalización (34, ...,44) al menos una señal de geolocalización siendo indicativa, al menos en parte, de una geolocalización del citado dispositivo (32a, 32b) de captura de imágenes durante cada suceso de captura de imágenes; y

un sistema (46) de ordenador que recibe y almacena las citadas señales de datos de imágenes y la citada al menos una señal de geolocalización; y

software (90) de adquisición de imágenes y datos que lee las citadas imágenes - datos y la citada al menos una señal de geolocalización, asociando el citado software (90) cada una de las citadas señales de imágenes - datos a la correspondiente citada al menos una señal de geolocalización de cada suceso de captura de imágenes.

18. El sistema de la reivindicación 17, en la que el citado al menos un dispositivo de geolocalización y la citada al menos una señal de geolocalización respectivamente, comprende, al menos, uno de entre los siguientes elementos:

un reloj (38) que emite al citado sistema (46) de ordenador de captura de imágenes señales de datos de los momento indicadores de un momento de cada citado suceso de captura de imágenes;

un receptor (34) de sistema global de posicionamiento (GPS) que recibe señales GPS y emite al citado sistema (46) de ordenador de captura de imágenes señales de datos de localización indicativas de una longitud y latitud del citado dispositivo (32a, 32b) de captura de imágenes, en cada uno de los citados sucesos de captura de imágenes;

una unidad (36) de navegación inercial que proporciona al citado sistema (46) de ordenador de captura de imágenes, señales de datos de velocidad indicativas de la velocidad del citado dispositivo (32a, 32b) de captura de imágenes en cada uno de los citados sucesos de captura de imágenes;

un giroscopio (40) que proporciona al citado sistema (46) de ordenador de captura de imágenes una señal de inclinación longitudinal, una señal de balanceo y una señal de guiñada que son indicativas, respectivamente, de la inclinación longitudinal, balanceo y guiñada del citado dispositivo (32a, 32b) de captura de imágenes en cada uno de los citados sucesos de captura de imágenes;

una brújula (42) que proporciona al citado sistema (46) de ordenador de captura de imágenes señales de datos de rumbo indicativas del rumbo del citado dispositivo (32a, 32b) de captura de imágenes en cada uno de los citados eventos de captura de imágenes; y

un altímetro (44) que proporciona al citado sistema (46) de ordenador de captura de imágenes señales de datos de altitud indicativas de la altitud del citado dispositivo (32a, 32b) de captura de imágenes en cada uno de los citados sucesos de captura de imágenes.

19. El sistema de la reivindicación 17 ó 18, que comprende, además, datos de corrección indicativas de las características del citado dispositivo (32a, 32b) de captura de imágenes, incluyendo longitud focal, tamaño del sensor, distorsión radial, punto principal de desviación y alineación, utilizando el citado software (90) de adquisición de imágenes y datos los citados datos de corrección para corregir las imágenes capturadas.

20. El sistema de una de las reivindicaciones 17 a 19, que comprende, además, un archivo de datos de salida creado por el citado software (90) de adquisición de imágenes y datos, incluyendo el citado archivo de datos de salida una pluralidad de archivos de imagen y de datos posicionales que se corresponden a cada una de la citada pluralidad de archivo de imagen.

21. El sistema de una de las reivindicaciones 17 a 20, que comprende, además, una plataforma (20) que

transporta el citado dispositivo (32a, 32b) de captura de imágenes una distancia predeterminada por encima de una superficie de interés.

22. El sistema de la reivindicación 21, en el que el citado dispositivo (32a, 32b) de captura de imágenes captura imágenes oblicuas de un área de interés como las citadas imágenes oblicuas por medio de:

subdividir el área (200) de interés en una pluralidad de sectores (202a, 202b, 202c);

guiar la citada plataforma (20) a lo largo de una primera trayectoria (202) para que apunte de esta manera a uno o más sectores objetivos con el citado dispositivo (32a, 32b) de captura de imágenes;

capturar con el citado dispositivo (32a, 32b) de captura de imágenes una o más imágenes oblicuas para cubrir de esta manera la totalidad de cada uno de los citados sectores objetivos con imágenes oblicuas capturados desde una primera perspectiva;

guiar la citada plataforma (20) a lo largo de una segunda trayectoria (204) para apuntar de esta manera a los citados sectores objetivos;

capturar con el citado dispositivo (32a, 32b) de captura de imágenes una o más imágenes oblicuas para cubrir de esta manera la totalidad de cada uno de los citados sectores objetivos con imágenes oblicuas capturadas desde una segunda perspectiva;

repetir las citadas etapas de guiado y captura a lo largo de trayectorias sustancialmente paralelas y separadas de las citadas trayectorias primera y segunda (202, 204) y capturar una o más imágenes oblicuas para cubrir de esta manera la totalidad de cada una de la citada pluralidad de sectores en imágenes oblicuas capturadas desde cada una de las citadas perspectivas primera y segunda;

registrar los datos posicionales indicadores de una geolocalización en el citado dispositivo (32a, 32b) de captura de imágenes en cada suceso de captura de imágenes.

23. El sistema de la reivindicación 22, en el que la citada trayectoria (204) es sustancialmente paralela en relación y a 180° (ciento ochenta grados) respecto a la citada primera trayectoria (202).

24. El sistema de la reivindicación 23, en el que la citada segunda trayectoria (204) también está separada de la citada primera trayectoria (202).

25. El sistema de una de las reivindicaciones 22 a 24 en el que:

la citada plataforma (20) está guiada a lo largo de una tercera trayectoria (206) para apuntar de esta manera a uno o más sectores objetivos con el citado dispositivo (32a, 32b) de captura de imágenes, siendo sustancialmente perpendicular la citada tercera trayectoria (206) a las citadas primera y segundas trayectorias (202, 204);

el citado dispositivo (32a, 32b) de captura de imágenes captura una o más imágenes oblicuas para capturar de esta manera la totalidad de cada uno de los citados sectores objetivos en imágenes oblicuas capturadas desde una tercera perspectiva; en el que

la citada plataforma (20) es guiada y el citado dispositivo (32a, 32b) de captura de imágenes captura las citadas imágenes oblicuas a lo largo de trayectorias sustancialmente paralelas y separadas de la citada tercera trayectoria (306); y

el citado dispositivo (32a, 32b) de captura de imágenes captura una o más imágenes oblicuas para cubrir de esta manera la totalidad de cada una de la citada unidad de sectores en imágenes oblicuas capturadas desde la citada tercera perspectiva.

26. El sistema de la reivindicación 25, en el que

la citada plataforma (20) es guiada a lo largo de una cuarta trayectoria (208) para apuntar de esta manera a uno o más sectores objetivos con el citado dispositivo (32a, 32b) de captura de imágenes, siendo sustancialmente paralela la citada cuarta trayectoria (208) a la citada tercera trayectoria (206) y a 180° (ciento ochenta grados) respecto a la citada tercera trayectoria (206);

el citado dispositivo (32a, 32b) de captura de imágenes captura una o más imágenes oblicuas para capturar de esta manera la totalidad de cada citado sector objetivo en imágenes oblicuas capturadas desde una cuarta perspectiva; y

las citadas etapas de guiado y captura se repiten a lo largo de trayectorias sustancialmente paralelas y separadas de la citada cuarta trayectoria (208), y capturar una o más imágenes oblicuas para cubrir de esta manera la totalidad de cada uno de la citada pluralidad de sectores en imágenes oblicuas capturadas desde la citada cuarta perspectiva.

27. El sistema de la reivindicación 26, en el que la citada cuarta trayectoria (208) también está separada de la citada tercera trayectoria (206).

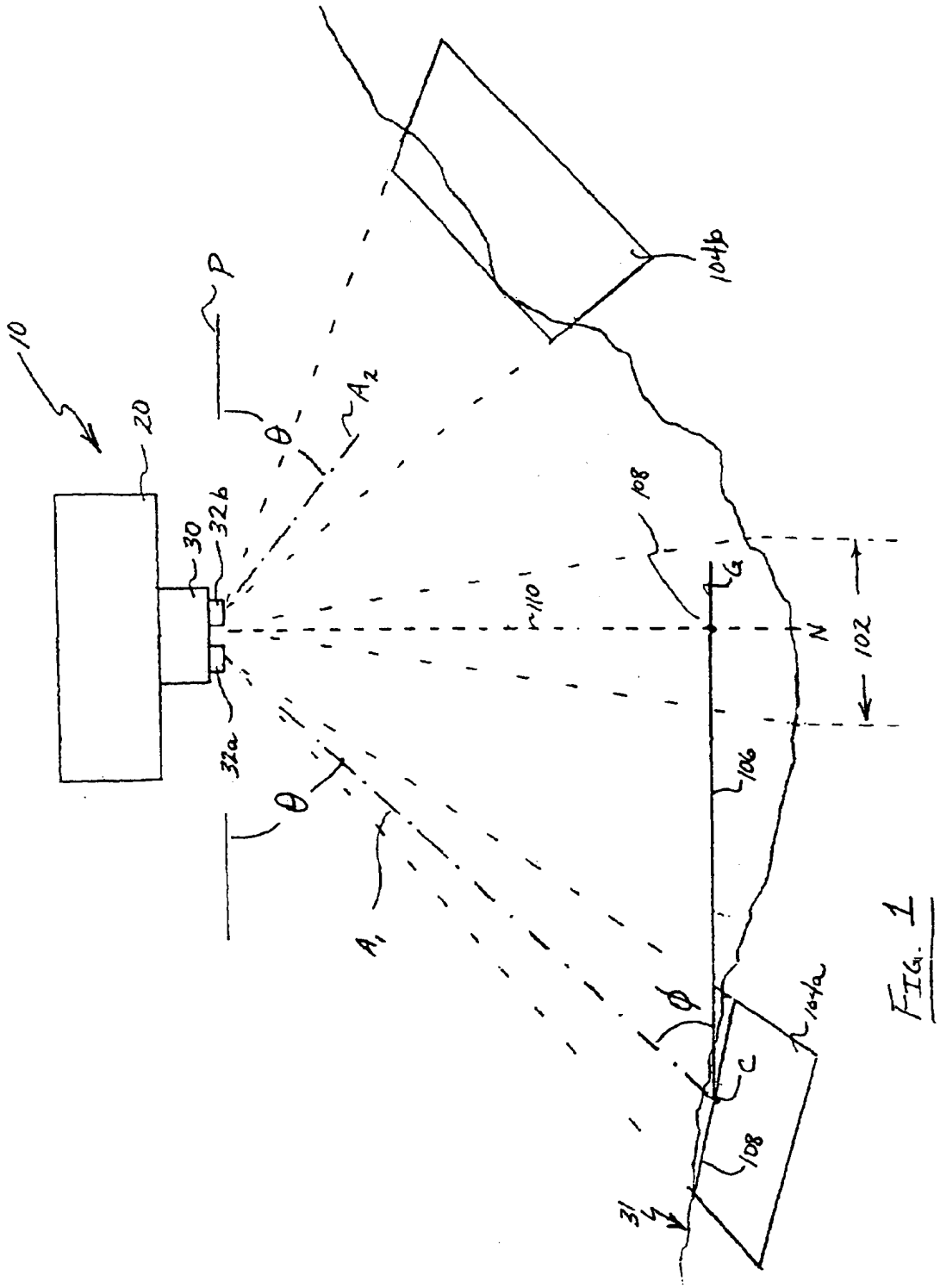


FIG. 1

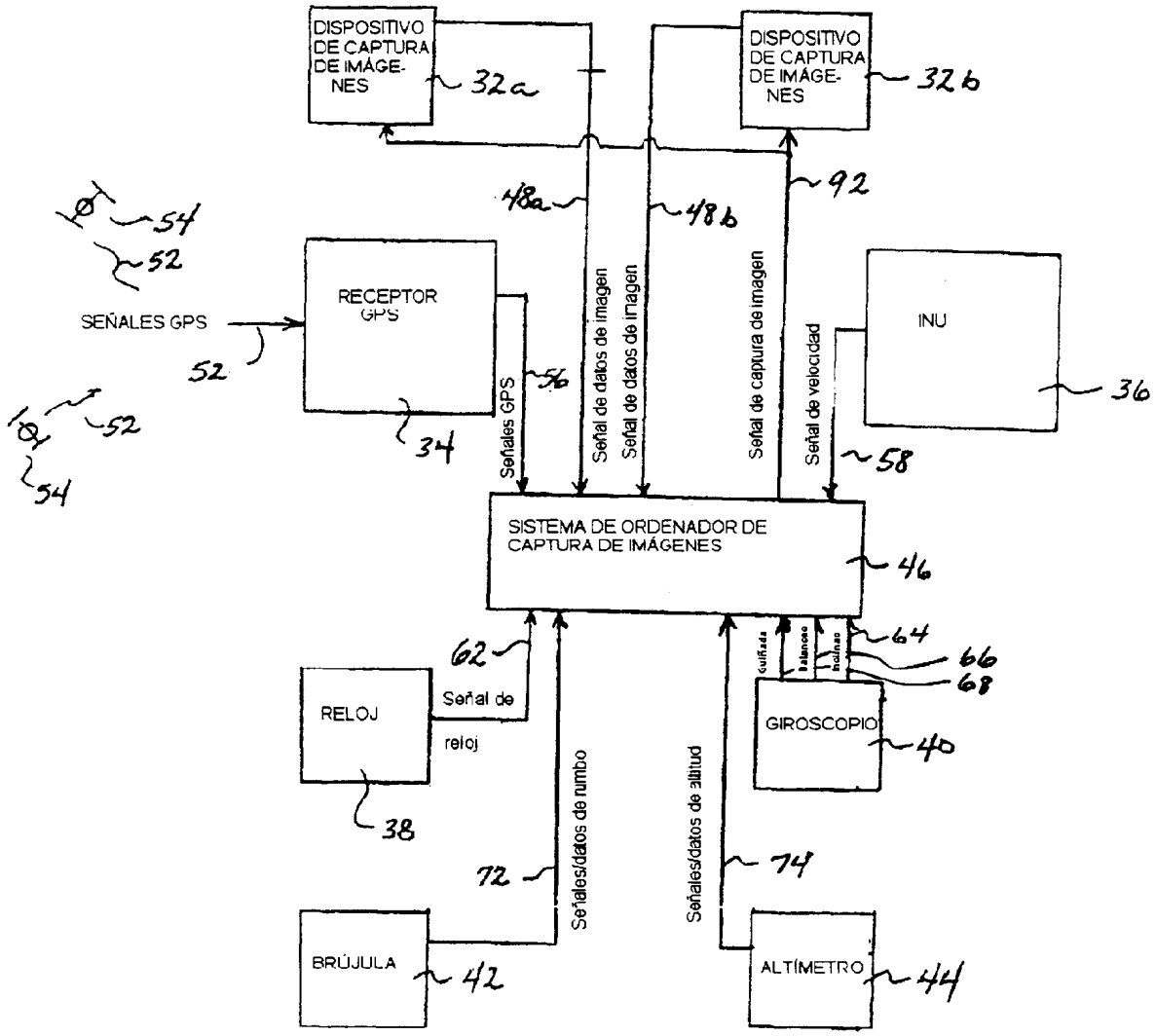

DISPOSITIVO DE CAPTURA DE IMÁGE-NES
32a
DISPOSITIVO DE CAPTURA DE IMÁGE-NES
32b
54
52
SEÑALES GPS
52
RECEPTOR GPS
34
Señales GPS
56
48a
Señal de datos de imagen
48b
Señal de datos de imagen
92
Señal de captura de imagen
Señal de velocidad
58
INU
36
SISTEMA DE ORDENADOR DE CAPTURA DE IMÁGENES
46
62
RELOJ
Señal de reloj
38
Señales/datos de rumbo
72
Señales/datos de altitud
74
64
66
68
GIROSCOPIO
40
BRÚJULA
42
ALTÍMETRO
44

FIG. 2

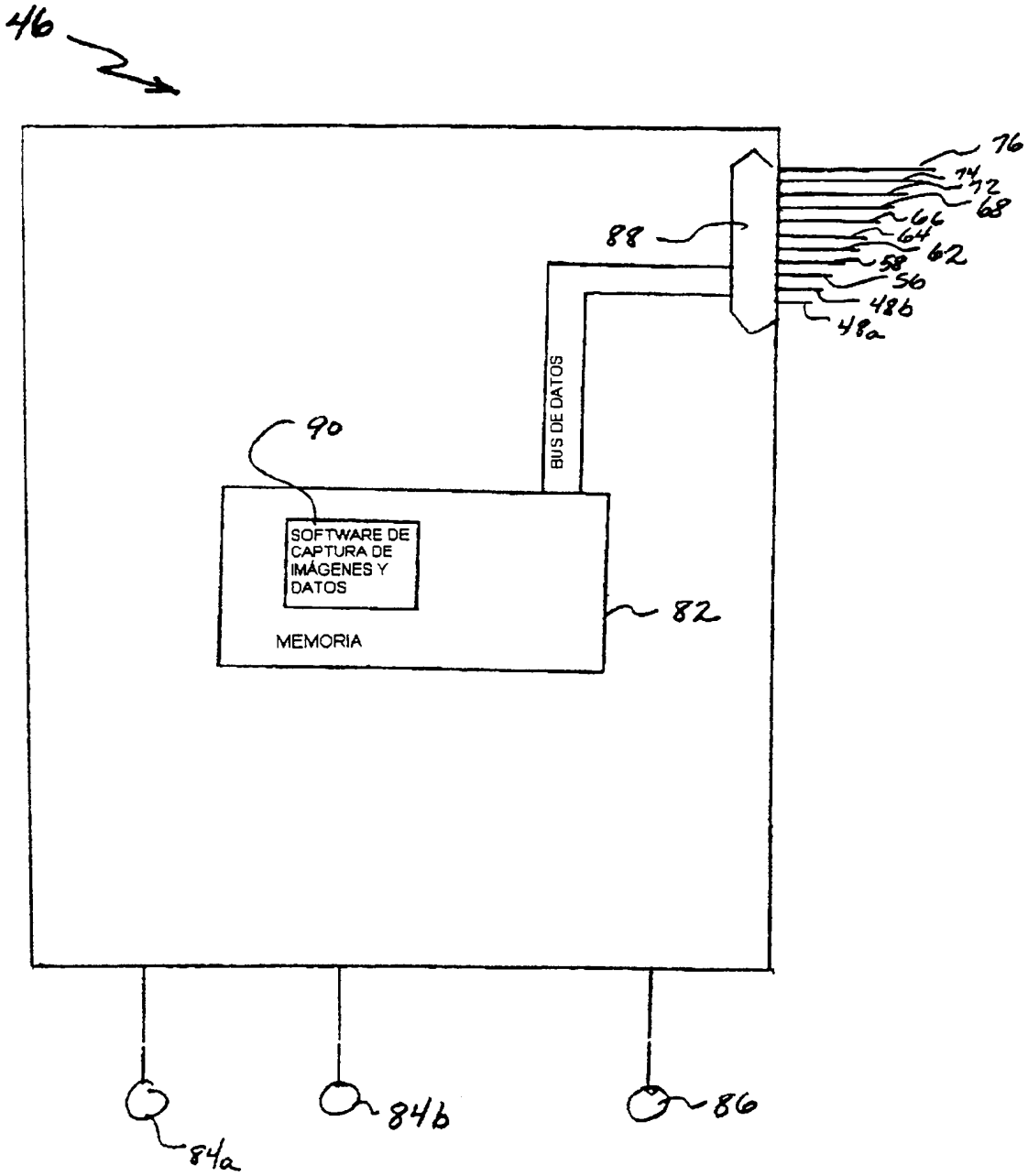

46
76
74
72
68
66
64
62
58
56
48b
48a
88
BUS DE DATOS
90
SOFTWARE DE CAPTURA DE IMÁGENES Y DATOS
MEMORIA
82
84a
84b
86

FIG. 3

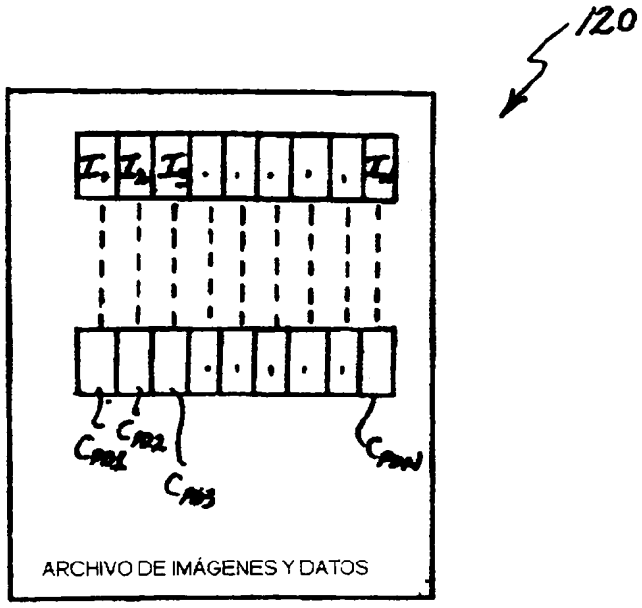


FIG. 4

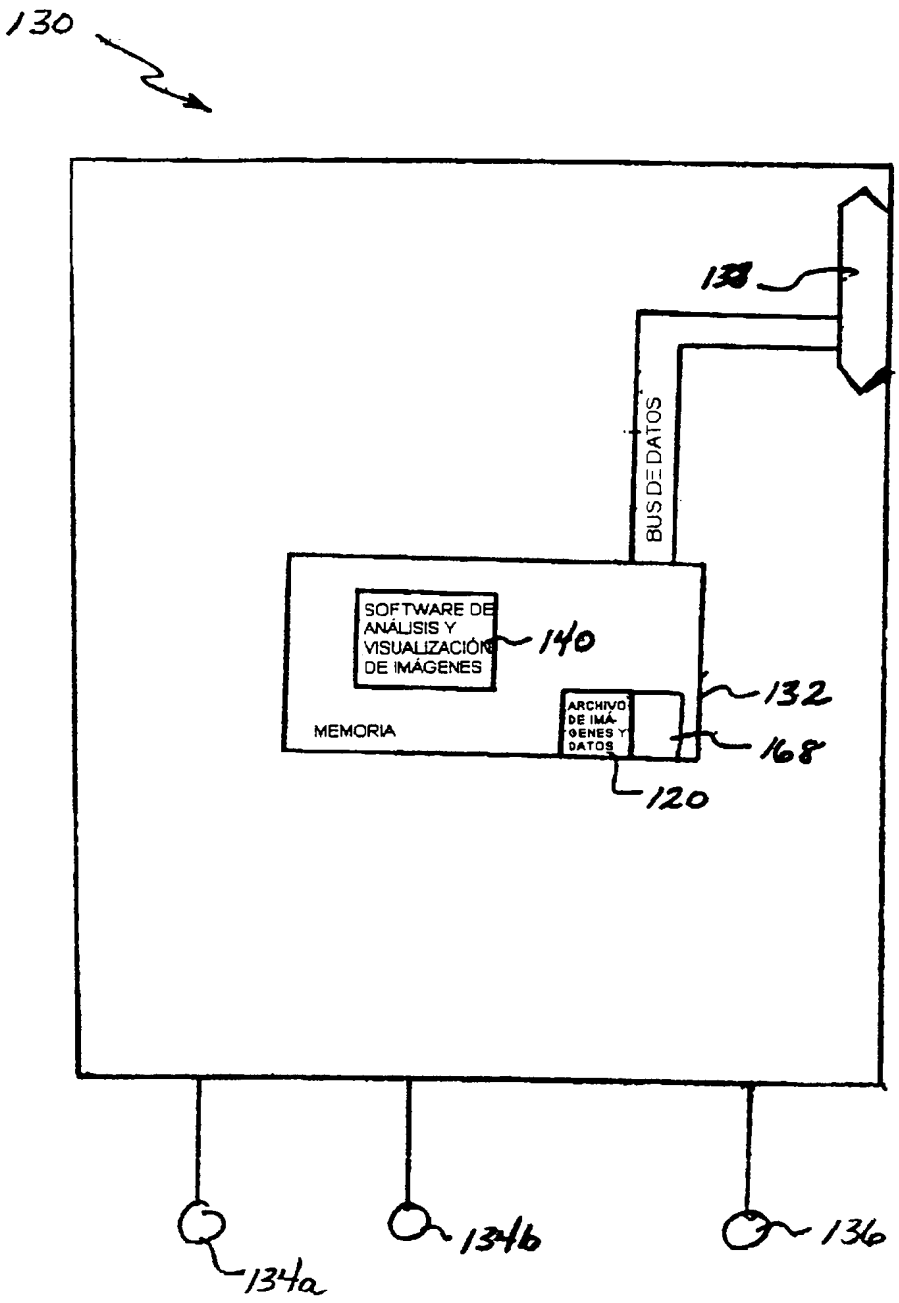

130
138
BUS DE DATOS
SOFTWARE DE ANÁLISIS Y VISUALIZACIÓN DE IMÁGENES
140
MEMORIA
ARCHIVO DE IMÁGENES Y DATOS
132
168
120
134a
134b
136

FIG. 5

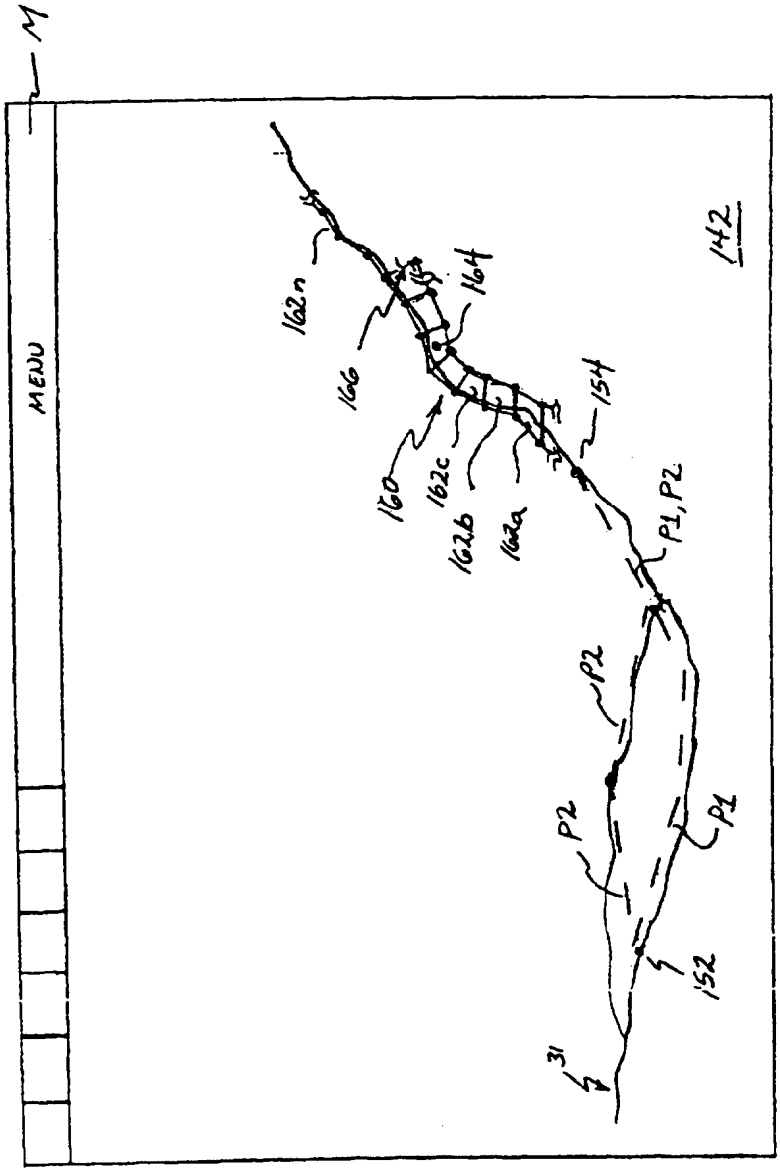

M
MENU
142
162n
164
166
160
162c
162b
162a
154
P1, P2
P2
P2
P1
152
31

FIG. 6

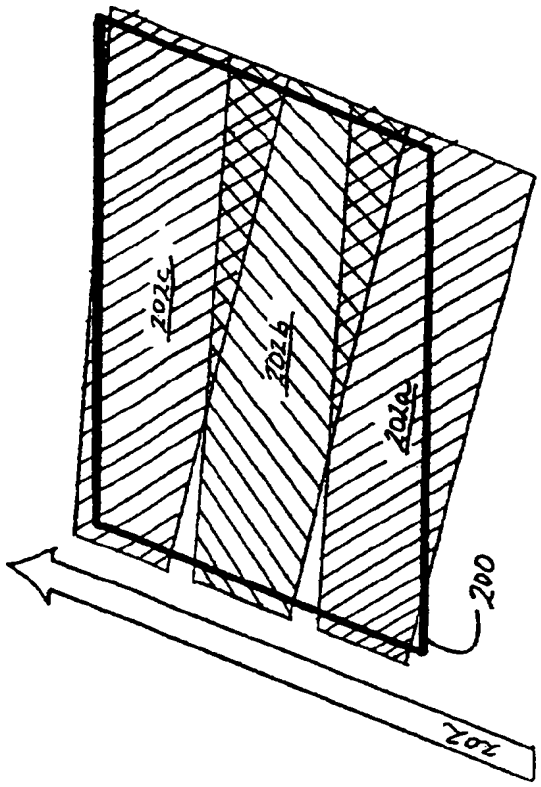


FIG. 1

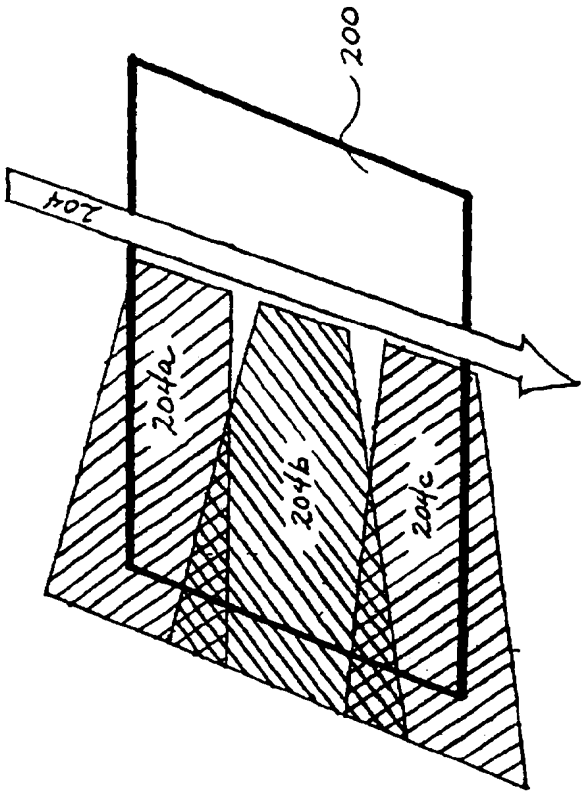


FIG. 8

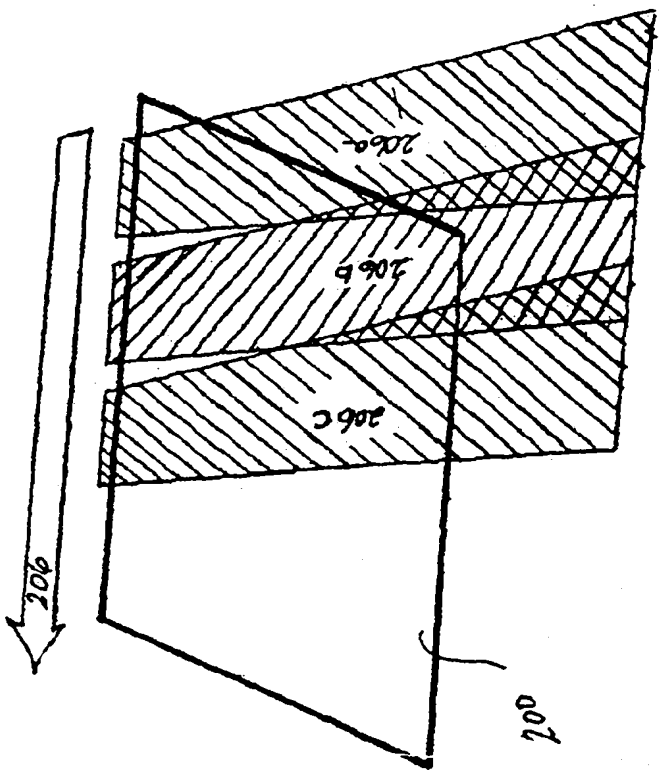


Fig 9

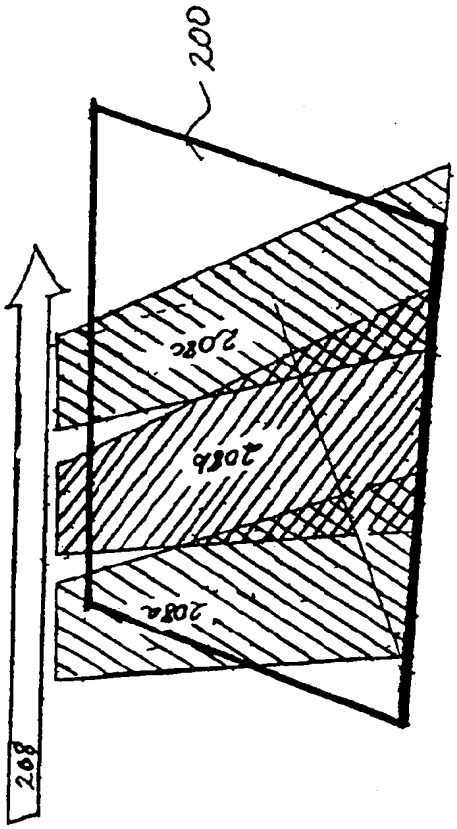


FIG. 10

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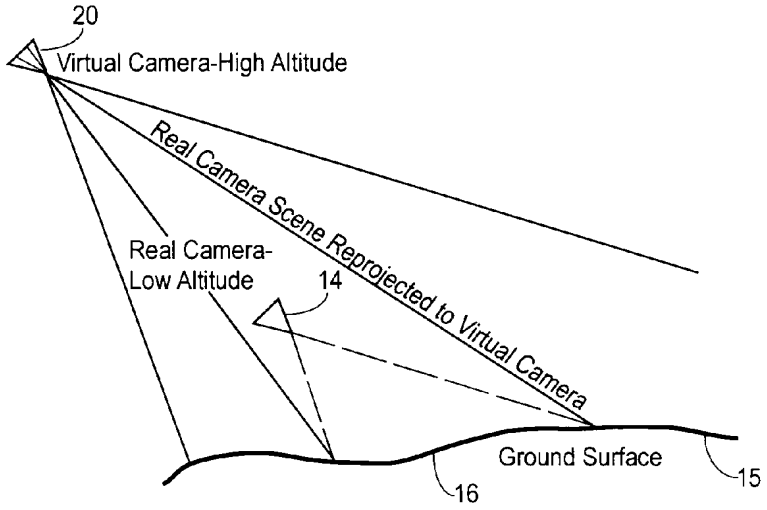
(74) Agent: **BROCKHAUS, Marc, A.**; Dunlap, Codding & Rogers, P.C., P.O. Box 16370, Oklahoma City, OK 73113-2370 (US).

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(54) Title: MOSAIC OBLIQUE IMAGES AND METHODS OF MAKING AND USING SAME



(57) Abstract: A method for creating an oblique-mosaic image from a plurality of source images is disclosed. Initially, a desired area to be imaged and collected into an oblique-mosaic image is identified and then a mathematical model of a sensor of a virtual camera is created, where the virtual camera has an elevation greater than an elevation of the area to be imaged. The mathematical model has an oblique-mosaic pixel map for the sensor of the desired area. A surface location is determined for each pixel included in the oblique mosaic pixel map, and at least one source oblique image pixel of the area to be imaged is reprojected for each pixel included in the oblique-mosaic pixel map to thereby create an oblique-mosaic image of the desired geographical area. The at least one single oblique-mosaic image is visually pleasing and geographically accurate. Further, techniques for compensating for building lean in oblique-mosaic images are disclosed.

WO 2008/028040 A2

MOSAIC OBLIQUE IMAGES AND METHODS OF MAKING AND USING SAME

Cross-Reference to Related Applications

[0001] The present patent application claims priority to the provisional patent application identified by U.S. Serial No. 60/840,992, the entire content of which is hereby incorporated herein by reference.

Statement Regarding Federally Sponsored Research or Development

[0002] Not Applicable.

The Names of the Parties to a Joint Research Agreement

[0003] Not Applicable.

Reference To A "Sequence Listing," A Table, Or A Computer Program Listing Appendix Submitted On A Compact Disc And An Incorporation-By-Reference Of The Material On The Compact Disc (See § 1.52(E)(5)). The Total Number Of Compact Discs Including Duplicates And The Files On Each Compact Disc Shall Be Specified

[0004] Not Applicable.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0005] The presently claimed and disclosed invention(s) relate to mosaicked oblique images and methods for making and using same. More particularly, the presently claimed and disclosed invention(s) use a methodology whereby separate obliquely captured aerial images are combined into at least one single oblique mosaic image.

The at least one single oblique-mosaic image is visually pleasing and geographically accurate.

2. Background of the Art

[0006] In the remote sensing/aerial imaging industry, imagery is used to capture views of a geographic area and be able to measure objects and structures within the images as well as to be able to determine geographic locations of points within the image. These are generally referred to as "geo-referenced images" and come in two basic categories:

1. Captured Imagery – these images have the appearance they were captured by the camera or sensor employed.

2. Projected Imagery – these images have been processed and converted such that they conform to a mathematical projection.

[0007] All imagery starts as captured imagery, but as most software cannot geo-reference captured imagery, that imagery is then reprocessed to create the projected imagery. The most common form of projected imagery is the ortho-rectified image. This process aligns the image to an orthogonal or rectilinear grid (composed of rectangles). The input image used to create an ortho-rectified image is a nadir image – that is, an image captured with the camera pointing straight down.

[0008] It is often quite desirable to combine multiple images into a larger composite image such that the image covers a larger geographic area on the ground. The most common form of this composite image is the "ortho-mosaic image" which is an image created from a series of overlapping or adjacent nadir images that are mathematically combined into a single ortho-rectified image.

[0009] Each input nadir image, as well as the output ortho-mosaic image, is composed of discrete pixels (individual picture elements) of information or data. As part of the process for creating an ortho-rectified image, and hence an ortho-mosaic image, an attempt is made to reproject (move within a mathematical model) each pixel within the image such that the resulting image appears as if every pixel in the image were a nadir pixel – that is, that the camera is directly above each pixel in the image.

[0010] The reason this ortho-rectification process is needed is it is not currently possible to capture an image where every pixel is nadir to (directly below) the camera

unless: (1) the camera used is as large as the area of capture, or (2) the camera is placed at an infinite distance above the area of capture such that the angle from the camera to the pixel is so close to straight down that it can be considered nadir. The ortho-rectification process creates an image that approximates the appearance of being captured with a camera where the area on the ground each pixel captures is considered nadir to that pixel, i.e. directly below that pixel. This process is done by creating a mathematical model of the ground, generally in a rectilinear grid (a grid formed of rectangles), and reprojecting from the individual captured camera image into this rectilinear grid. This process moves the pixels from their relative non-nadir location within the individual images to their nadir positions within the rectilinear grid, i.e. the image is warped to line up with the grid.

[0011] When creating an ortho-mosaic, this same ortho-rectification process is used, however, instead of using only a single input nadir image, a collection of overlapping or adjacent nadir images are used and they are combined to form a single composite ortho-rectified image known as an ortho-mosaic. In general, the ortho-mosaic process entails the following steps:

- A rectilinear grid is created, which results in an ortho-mosaic image where every grid pixel covers the same amount of area on the ground.

- The location of each grid pixel is determined from the mathematical definition of the grid. Generally, this means the grid is given an X and Y starting or origin location and an X and Y size for the grid pixels. Thus, the location of any pixel is simply the origin location plus the number of pixels times the size of each pixel. In mathematical terms: $X_{pixel} = X_{origin} + X_{size} \times Column_{pixel}$ and $Y_{pixel} = Y_{origin} + Y_{size} \times Row_{pixel}$.

- The available nadir images are checked to see if they cover the same point on the ground as the grid pixel being filled. If so, a mathematical formula is used to determine where that point on the ground projects up onto the camera's pixel image map and that resulting pixel value is then transferred to the grid pixel. During this selection process, two important steps are taken:

    - When selecting the image to use to provide the pixel value, a mathematical formula is used to select an image that minimizes building lean – the effect where buildings appear to lean away from the camera.

This is accomplished in a number of ways, but the most common is to pick the image where the grid pixel reprojects as close to the camera center, and hence as close to that camera's nadir point, as possible.

- When determining the source pixel value to use, the ground elevation is taken into account to ensure the correct pixel value is selected. Changes in elevation cause the apparent location of the pixel to shift when captured by the camera. A point on the ground that is higher up will appear farther from the center of the image than a point on the ground in the same location that is lower down. For instance, the top of a building will appear farther from the center of an image than the bottom of a building. By taking the ground elevation into account when determining the source pixel value, the net effect is to "flatten" the image out such that changes in pixel location due to ground elevation are removed.

[0012] Because the rectilinear grids used for the ortho-mosaic are generally the same grids used for creating maps, the ortho-mosaic images bear a striking similarity to maps and as such, are generally very easy to use from a direction and orientation standpoint. However, since they have an appearance dictated by mathematical projections instead of the normal appearance that a single camera captures and because they are captured looking straight down, this creates a view of the world to which we are not accustomed. As a result, many people have difficulty determining what it is they are looking at in the image. For instance, they might see a yellow rectangle in the image and not realize what they are looking at is the top of a school bus. Or they might have difficulty distinguishing between two commercial properties since the only thing they can see of the properties in the ortho-mosaic is their roof tops, where as most of the distinguishing properties are on the sides of the buildings. An entire profession, the photo interpreter, has arisen to address these difficulties as these individuals have years of training and experience specifically in interpreting what they are seeing in nadir or ortho-mosaic imagery.

[0013] Since an oblique image, by definition, is captured at an angle, it presents a more natural appearance because it shows the sides of objects and structures – what we are most accustomed to seeing. In addition, because oblique images are not generally ortho-rectified, they are still in the natural appearance that the camera captures as opposed to the mathematical construction of the ortho-mosaic image. This combination makes it very easy for people to look at something in an oblique

image and realize what that object is. Photo interpretation skills are not required when working with oblique images.

[0014] Oblique images, however, present another issue. Because people have learned navigation skills on maps, the fact that oblique images are not aligned to a map grid, like ortho-mosaic images, makes them much less intuitive when attempting to navigate or determine direction on an image. When an ortho-mosaic is created, because it is created to a rectilinear grid that is generally a map grid, the top of the ortho-mosaic image is north, the right side is east, the bottom is south, and the left side is west. This is how people are generally accustomed to orienting and navigating on a map. But an oblique image can be captured from any direction and the top of the image is generally "up and back," meaning that vertical structures point towards the top of the image, but that the top of the image is also closer to the horizon. However, because the image can be captured from any direction, the horizon can be in any direction, north, south, east, west, or any point in between. If the image is captured such that the camera is pointing north, then the right side of the image is east and the left side of the image is west. However, if the image is captured such that the camera is pointing south, then the right side of the image is west and the left side of the image is east. This can cause confusion for someone trying to navigate within the image.

[0015] Additionally, because the ortho-mosaic grid is generally a rectilinear grid, by mathematical definition, the four cardinal compass directions meet at right angles (90-degrees). But with an oblique image, because it is still in the original form the camera captured and has not been reprojected into a mathematical model, it is not necessarily true that the compass directions meet at right angles within the image. Because in the oblique perspective, you are moving towards the horizon as you move up in the image, the image covers a wider area on the ground near the top of the image as compared to the area on the ground covered near the bottom of the image. If you were to paint a rectangular grid on the ground and capture it with an oblique image, the lines along the direction the camera is pointing would appear to converge in the distance and the lines across the direction of the camera is pointing would appear to be more widely spaced in the front of the image than they do in the back of the image. This is the perspective view we are all used to seeing – things are smaller in the distance than close up and parallel lines, such as railroad tracks, appear to converge in the distance. By contrast, if an ortho-mosaic image was created over this same painted rectangular grid, it would appear as a rectangular grid in the ortho-mosaic image since all perspective is removed as an incidental part of the ortho-mosaic process.

[0016] Because of these fundamental differences in perspective and appearance, the creation of an ortho-mosaic image by the process described above does not work well for oblique images. Because the camera's optical axis (an imaginary line through the center of the lens or optics that follows the aim of the camera) is typically pointed at an angle of 45-degrees or more from nadir (pointed 45-degrees or more up from straight down), the effects of building lean, elevation differences, and non-square pixels are all exaggerated – effects that are considered negative qualities in an ortho-mosaic image. In the ortho-mosaic industry, requirements are generally placed on the image capture process such that they limit the amount of obliqueness to as little as 5-degrees from nadir so as to minimize each of these negative effects.

[0017] In addition, if the admirable properties of an oblique image are to be maintained, namely seeing the sides of structures and the natural appearance of the images, then clearly a process that attempts to remove vertical displacements, and hence the sides of the buildings, and one that warps the image to fit a rectilinear grid is not a viable choice. A new process is needed, one which meets the following desirable qualities in an effort to preserve the admirable properties of the oblique image:

- If the oblique perspective is to be maintained, the pixels cannot be aligned to a rectilinear grid, or even a trapezoidal grid. Instead, the pixels are preferably aligned to the natural perspective that a camera captures.

- As part of the oblique perspective, the pixels in the image cannot all measure the same size on the ground, as pixels in the foreground of the image cover a much smaller area on the ground than pixels in the background of the image – that is by definition part of the natural perspective of a camera.

- Because the pixels are so far from nadir, the effects of building lean become extreme and the standard solutions employed in the ortho-mosaic process do not do an adequate enough job compensating for this effect – new techniques must be developed to better compensate for this effect.

- If the effects of changes in elevation are backed out, the resulting image has a very unnatural appearance – the vertical sides of buildings can warp and twist, which is something we are not accustomed to seeing and therefore, when looking at such an image, we have a tendency to "reject" it. Thus, to

keep the buildings, structures, and objects within an image looking natural, it is preferable to leave the effects of elevation in the perspective of the image and instead account for it in another manner.

[0018] Because of these issues, the common practice in the industry is to provide oblique imagery as a series of individual images. However, some of the same benefits of the ortho-mosaic also apply to an oblique-mosaic (an image created from a collection of overlapping or adjacent oblique images), namely the fact that the mosaic covers a larger geographic area than each or any of the individual images that were used to create it. This invention details a means by which a quality oblique-mosaic can be created, overcoming the above limitations.

SUMMARY OF THE INVENTION

[0019] This invention allows for the creation of an oblique-mosaic image that has both a natural appearance and is preferably geo-referenced to maintain the ability to measure and determine geographic coordinates. While the preferred embodiment applies this invention to aerial oblique imagery, the invention will also work with non-aerial oblique imagery captured in a variety of ways, including but not limited to cameras mounted obliquely on a vertical pole, hand-held cameras aimed obliquely, and cameras mounted at oblique angles on an underwater probe.

[0020] In one embodiment, the present invention is directed to a method for creating an oblique-mosaic image from a plurality of source oblique images of a geographical area. The source oblique images are preferably captured oblique images. In this method, a desired area to be imaged and collected into an oblique-mosaic image is identified, and a mathematical model of a sensor of a virtual camera is created. The virtual camera has an elevation greater than an elevation of the area to be imaged. The mathematical model has an oblique-mosaic pixel map for the sensor of the desired area. A surface location for each pixel included in the oblique mosaic pixel map is determined and/or assigned. Then, at least one source oblique image pixel of the area to be imaged is reprojected for each pixel included in the oblique-mosaic pixel map to thereby create an oblique-mosaic image of the desired geographical area. Thus, the oblique-mosaic image is a composite image formed from pixels reprojected from multiple source oblique images.

[0021] In one version of the invention, multiple source oblique images represent the same surface location. In this embodiment, the method can further comprise steps for selecting which pixels and/or source oblique images to utilize in forming the oblique-mosaic image. For example, the method can further comprise the step of selecting source oblique images of the surface location captured at an oblique angle and compass direction similar to the oblique angle and compass direction of the virtual camera. In yet another version, the pixels of each source oblique image that represent the same surface location are compared to determine which source pixel is most representative of the surface location, the more representative pixel to be included in the oblique-mosaic image.

[0022] In one version of the invention, the step of assigning is further defined by as projecting each pixel through the perspective of the virtual camera to determine a corresponding surface location for each pixel in the oblique-mosaic pixel map.

[0023] In another version of the invention, the step of reprojecting is further defined by reprojecting the pixel to match the size and shape of the represented surface location as taken from the elevation, compass direction, and oblique angle of the virtual camera.

[0024] In yet another version of the invention, the step of reprojecting is further defined by removing the effects of elevation from the source oblique images prior to reprojection and then adding the effects of elevation to the oblique-mosaic image after reprojection.

[0025] In yet another version of the invention, the method includes the step of minimizing lean of vertical structures within the oblique mosaic image. This can be accomplished in a variety of manners, such as creating an elevation model from the source oblique images taking into account the vertical structures, and reprojecting at least one source oblique image pixel of the area to be imaged utilizing the elevation model. Alternatively, lean of vertical structures can be minimized by matching vertical structures in multiple source oblique images and shifting pixels apparent location in at least one of the source oblique images by a relative height above a ground model.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0026] Fig. 1 is a schematic view of a real camera captured scene reprojected to a "virtual camera", i.e., a mathematical model that describes a camera larger than the real camera and higher in elevation than the real camera.

[0027] Fig. 2 is an illustration of an exemplary software/function flow chart of a method for making an oblique-mosaic image using a methodology whereby separate obliquely captured aerial images are combined into the oblique-mosaic image.

[0028] Fig. 3a is a pictorial representation of a prior art oblique-mosaic image.

[0029] Fig. 3b is an enlarged view of the pictorial representation of the prior art oblique-mosaic image of Fig. 3a.

[0030] Fig. 4a is a pictorial representation of an exemplary oblique-mosaic image created in accordance with the present invention.

[0031] Fig. 4b is an enlarged view of the pictorial representation of the exemplary oblique-mosaic image created in accordance with the present invention of Fig. 4a.

DETAILED DESCRIPTION OF THE PRESENTLY DISCLOSED AND CLAIMED INVENTION

[0032] Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction, experiments, exemplary data, and/or the arrangement of the components set forth in the following description or illustrated in the drawings. The invention 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 purpose of description and should not be regarded as limiting.

[0033] The presently claimed and disclosed invention(s) relate to oblique-mosaic images and methods for making and using the same. More particularly, the presently claimed and disclosed invention(s) use a methodology whereby separate obliquely captured aerial images are combined into at least one single oblique-mosaic image. The at least one single oblique-mosaic image is visually pleasing and geographically accurate.

[0034] Referring now to the Figures and in particular to Figs. 1 and 2, shown in Fig. 1 and designated by a reference numeral 10 is a schematic view of a method for creating an oblique mosaic image 12 (See Figures 4A and 4B). Fig. 2 is an illustration of an exemplary software/function flow chart 14 of a method for making the oblique-mosaic image 12 using a methodology whereby separate obliquely captured aerial images are combined into the oblique-mosaic image 12. Fig. 4a is a pictorial representation of an exemplary oblique-mosaic image 12 created in accordance with the present invention. Fig. 4b is an enlarged view of the pictorial representation of the exemplary oblique-mosaic image 12 created in accordance with the present invention.

[0035] In general, the method identifies a desired area 15 to be imaged and collected into the oblique-mosaic image 12. Source images are obtained utilizing a real camera 14 capturing a scene 16 as indicated by a block 18 in Fig. 2. Then, a virtual camera 20 is created as indicated by a block 22 in Fig. 2. The virtual camera 20 is a mathematical model that describes a camera larger than the real camera 14 and higher in elevation than the real camera 14 as shown in Fig. 1. The mathematical model has an oblique-mosaic pixel map for the sensor of the desired area. A surface location is assigned to each pixel included in the oblique pixel map, and then as indicated by a block 24, source oblique images are selected for the ground locations and then at least one source oblique image pixel of the area to be

imaged for each pixel included in the oblique-mosaic pixel map is reprojected to thereby create the oblique-mosaic image of the desired geographical area (as indicated by a block 26). Optionally, the method further includes one or more steps to minimize the effect of vertical structure lean as indicated by a block 28.

[0036] As described hereinabove, the use of a grid reprojection methodology to create oblique-mosaic images is fraught with problems and is unlikely to provide a useable image. Therefore, in order to produce the quality oblique-mosaic image 12, an improved process must be performed. Such an improved and unique process is described and claimed herein and preferably uses, generally, the following considerations:

- First, rather than projecting onto a rectilinear grid, the input image pixels are projected onto the "virtual camera" 20. The virtual camera 20 is a mathematical model that describes a very large camera, high up in the sky. Since it is a mathematical creation, this camera 20 is not bound by the current limitations of camera manufacturing.

- Second, the pixels are not then reprojected to be square or even the same size in the output image, as is the case in the standard ortho-rectification process used when creating an ortho-mosaic. Instead, they are reprojected to match the size they would project onto the ground from this virtual camera 20 – i.e. the natural perspective that a camera captures.

- Third, in order to best align the combined imagery, the effects of changes in elevation are first backed out of the input imagery during the projection from the original input image's camera location to the ground, and then the effects of elevation are reintroduced during the projection from the ground up to the virtual camera's location. The result is a natural looking image that properly shows the contours of the land as seen from a natural oblique perspective.

- Finally, the effects of building lean are desirably minimized. There are a number of different ways in which building lean can be minimized:

- By "steering" the cut-lines between input images down streets such that the cut-lines do not run through a building, which can cause conflicting building lean to greatly distort the appearance of a building.

- The angle of building lean can be calculated and the images warped in order to compensate for the building lean.

- The buildings can be matched in adjacent images and aligned to each other.

[0037] In practice, the methodology disclosed and claimed herein, consists of multiple steps and data transformations that can be accomplished by one of ordinary skill in the art given the present specification. There are a number of algorithms already known in the art that steer cut-lines for ortho-mosaics and could be readily adapted for use with oblique images. In addition, follow-on work could create new algorithms specifically designed to deal with the complexities of oblique images.

[0038] The first step to creating the oblique-mosaic image 12 according to the presently disclosed and claimed invention requires the selection of an area to be imaged. Generally, the area to be imaged would be a specific geographical location. However, other areas can also be selected to be imaged into the oblique-mosaic image 12 such as building sides, walls, landscapes, mountain sides and the like.

creation of a "virtual camera" 20 that is capable of covering the entire landscape or area of interest to be imaged.

[0039] Once a desired area to be imaged and collected into the oblique-mosaic image 12 has been determined, the user or operator creates the "virtual camera" 20 i.e. a mathematical construct that is capable of covering or capturing a portion of, or the entirety of the desired area. The virtual camera 20 is a mathematical model of a camera with the necessary camera geometry parameters (the mathematical values that define the camera model, for instance the number of rows and columns of the sensor plane, size of the sensor plane in millimeters, focal length in millimeters, height above ground, yaw, pitch, and roll of the optical axis) that enable it to preferably "capture" the desired scene. For instance, a virtual camera can be devised having a very large sensor (e.g. 20,000 pixel columns and 10,000 pixel rows), a standard field of view (36 mm by 24 mm sensor plane and a 60 mm focal length), and be "placed" at a relatively high altitude (e.g. 30,000 feet) looking down at

an oblique angle to the north (yaw and roll of 0 and pitch of –40 degrees). In a preferred embodiment, a sensor model from a real camera is used and the user simply modifies the parameters such that it meets the requirements in order to "capture" the desired area.

[0040] The second step creates the resulting oblique pixel map for the virtual camera 20. The pixel map corresponds to the virtual camera's sensor and thus typically, but not necessarily, has the same number of rows and columns as the virtual camera's sensor. Then, for each pixel in the pixel map image, the projective equations for the virtual camera 20 are used to project each pixel downward and away from the virtual camera 20 and onto the ground, taking elevation into account when doing so (generally through the use of a mathematical elevation model of the ground surface). This results in a corresponding ground location for that virtual camera's pixel.

[0041] Once the corresponding ground location has been found, it can be used to select which previously captured images contain image data for that ground location. This is generally done by checking to see if the ground location lies within the image boundaries of a previously captured image.

[0042] When selecting source oblique images, e.g., input captured images, in order to achieve a desirable output image, it is important to use source oblique images that were captured in the same, or nearly the same, relative orientation of the virtual camera 20, in terms of oblique downward angle and compass direction of the optical axis. While it is generally not an issue to use input imagery from a camera whose model is different than the virtual camera's model, if that model is radically different (for instance, a line scanner versus a full frame capture device), it may result in an undesirable resulting image.

[0043] While this invention discusses using captured images as input to the oblique mosaic 12, it is not actually required. It is possible to use a projected image as input to this process or even to use another oblique mosaic as input to this process. However, since this process reprojects the input images, it is desirable to use non-projected input images, i.e. captured images. The reason is that reprojecting already projected data can often lead to artifacts, sort of like rounding errors in mathematical calculations. These artifacts can create an undesirable resulting oblique-mosaic.

[0044] It is generally desirable to create the continuous oblique-mosaic 12. In order to do so, there must be captured image data for the entire area being "captured" by the virtual camera 20. This means that if multiple captured images are being combined to create the oblique-mosaic 12, those input images must be adjacent or more commonly, overlapping. As a result of this overlap, it is common for there to be multiple captured images covering the same area on the ground. If multiple captured

images are available for selection, a preferred captured image is chosen according to the selection criteria described below.

[0045] When multiple images from real cameras 14 cover the same point on the ground, a selection process can be used to determine which real camera image should be used as input for the creation of the virtual camera's pixel map image. This selection process can be done by assigning weights (assigned numerical values) to the following input criteria, multiplying those weights by the normalized criterion (a value that has been scaled between 0 and 1), and then selecting the image with the greatest sum of these weight/criterion products. While any number of criteria can be used, the following three criteria have been used in the development of this invention:

Selection Criterion: Distance to Optical Axis

[0046] The distance between the point on the ground being selected and the point where the input camera's optical axis intersects the ground. This value can be normalized by dividing the distance by the maximum distance able to be measured in the scene.

Selection Criterion: Angular Difference to Optical Axis

[0047] The difference between the following two angles: the angle of the input camera's optical axis (generally measured relative to the perpendicular) and the angle of the ray being cast from the virtual camera to the point on the ground being selected (again, generally measured relative to the perpendicular). This value can be normalized by dividing by 180-degrees.

Selection Criterion: Distance to Nearest Street Centerline

[0048] The distance between the point on the ground being selected and the nearest street centerline. The street centerlines can be obtained from vector data files such as TIGER files or other Geographic Information System files. This value can be normalized by dividing by the maximum distance able to be measured in the scene.

[0049] Once the preferred captured image has been selected, the projective equations for the captured image's camera are used to project from the ground up to the camera, taking the ground elevation into account when doing so. This projection through the focal point and onto the camera's sensor plane will find a pixel row and

column corresponding to the point on the ground. As this typically does not fall on an integer row or column, bilinear interpolation (an industry standard mathematical formula for finding a single value from the proportionate proximity to the four surrounding pixels) is used to find the pixel value for the corresponding point on the camera's sensor plane.

[0050] This pixel value is then used to fill the pixel in the image that corresponds to the virtual camera's sensor plane from which the original ray was projected outward onto the ground. This process is repeated for some or all of the remaining pixels in the virtual camera's sensor plane, resulting in an image that covers some area or the entire area on the ground that the virtual camera 20 can "see." Preferably, this process is repeated for all of the remaining pixels in the virtual camera's sensor plane, resulting in a complete image that covers the entire area on the ground that the virtual camera 20 can "see."

[0051] The resulting image and its corresponding projective equations are then stored. The resulting image can be stored in any format, including one of many industry standard image formats such as TIFF, JFIF, TARGA, Windows Bitmap File, PNG or any other industry standard format. For the corresponding projective equations, the following data should, in a preferred embodiment, be stored as metadata with the resulting image, either appended to the same file or in another file readily accessible (an industry standard practice is to use the same filename but with a different file extension):

1. The location of the camera – generally, the location of the camera is specified by a geographic location and altitude (or height over ground).

2. The orientation of the camera – generally specified by three angles: yaw, pitch and roll (or omega, phi, and kappa).

3. The size of the sensor – generally specified as an overall sensor size in millimeters (or by the size of an individual sensor element).

4. The focal length of the lens – generally specified in millimeters.

5. Optionally, lens distortion information – generally specified as a principal point offset (offset between the optical axis and the middle of the sensor) and as radial distortion terms (polynomial coefficients that describe the amount of distortion that occurs radially out from the optical axis).

6. Optionally, a ground elevation model – generally specified as a grid of elevation values.

[0052] As discussed above, the relative perspective of the camera causes an effect known as "building lean." While building lean is most commonly applied to, and thus discussed as, buildings, it also applies to any vertical structure in the object, such as electrical towers, trees, cars, phone booths, mailboxes, street signs, and so on. Building lean is an effect that makes it appear as if buildings that are not along the optical axis of the camera "lean" away from the optical axis – the farther away from the optical axis, the greater the lean. This lean is the result of perspective, which causes objects that are raised off the ground to appear farther "back" into the image, away from the camera. Thus, the top of a building appears farther back than the bottom of a building. When this lean corresponds to the camera's perspective, it looks normal. However, as part of the oblique-mosaic process, captured images, each with their own perspective, are combined into a single virtual camera's perspective.

[0053] This combination of different perspectives becomes problematic, especially when two different captured images from different vantage points contribute pixel values to adjacent areas in the virtual camera's pixel map image. For example: If a camera to the left of a building provides the left side of a building, then that portion of the building will appear to be leaning to the right (away from the camera). If a camera that is located to the right of the building provides the right side of the building, then that portion of the building will appear to be leaning to the left. Since the two halves of the building "lean into" each other, the resulting combined image has a building that has a triangular, rather than a rectangular, appearance.

[0054] Because building lean only affects surfaces above the surface of the ground, it is generally fairly difficult to account for or correct these effects because in order to do so, the user must have knowledge of the presence of the building or structure. Features that are on the ground do not experience this building lean because the change in relative perspective is backed out when ground elevation is taken into account in the projective equations. The mathematical model used to define the ground surface during the projective process ensures the correct ground location is selected. However, for objects that rise above the ground surface, and are not represented in the mathematical model used to define the ground surface, this relative perspective change causes the virtual camera to "see" the building top in the wrong place – i.e. too far back from the camera.

[0055] A method for minimizing the effects of building lean, as contemplated herein, is to transition between one input camera image and the next input camera image over an area where there are no structures above or below the ground elevation model. In one embodiment, this is accomplished by placing the transition down the middle of a street. Thus, by having a properly weighted selection criterion for distance to street centerline, if there is a street in the area where two captured images overlap, then the transition from contributing pixels from the one captured image to contributing pixels from the second captured image will occur along this street, thus minimizing the effects of building lean.

[0056] A method for removing building lean entirely, as contemplated herein, is to provide an accurate ground elevation model taking into account buildings and other vertical structures. Thus, every pixel that comprises the image of the building is represented in the mathematical model of the ground elevation model and therefore the change in relative perspective is accounted for in the projective process. However, for this to work well, the elevation model must be highly correlated to the input imagery. If there is any shift in location between the imagery and the elevation model, then the buildings will not be projected properly when creating the oblique-mosaic image 12.

[0057] To overcome this limitation, the preferred methodology is to create the elevation model from the imagery itself. This can be done by using an industry standard process known as aero-triangulation, which finds the elevation of a point on the ground by comparing its location in two overlapping captured images and using the projective equations of their corresponding cameras to triangulate its location and elevation. Repeating this process over the entire overlap area can produce an accurate mathematical model of the surface of not only the ground, but also of the surface of structures and objects within the images. More importantly, because this model is derived from the imagery itself, it is by definition, highly correlated to the input image.

[0058] Another method for removing building lean, contemplated for use herein, is to attempt to identify vertical structures by using an edge matching process between the oblique and the corresponding nadir imagery. Vertical structures do not appear in a truly nadir image, and they barely appear in a slightly off-nadir image. Thus, when comparing an oblique image with its corresponding nadir image, the primary difference between the structures that appear in the two images will be the vertical structures. By using one or more edge detection algorithms (such as an industry standard Laplacian Filter), it is possible to identify the various structures within the two images and then isolate the vertical edges in the oblique image by subtracting

out the non-vertical structures that also appear in the nadir image. Once these vertical structures have been found, the pixels for those vertical structures can be shifted to remove the effects of the change in relative perspective. By shifting the pixel's apparent location in the captured oblique image by the relative height above the ground model found through the measuring of the vertical edges, its proper ground location can be determined, thus negating the effects of building lean.

[0059] It should be understood that the processes described above can be performed with the aid of a computer system running image processing software adapted to perform the functions described above, and the resulting images and data are stored on one or more computer readable mediums. Examples of a computer readable medium include an optical storage device, a magnetic storage device, an electronic storage device or the like. The term "Computer System" as used herein means 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, or a general purpose computer system, or distributed processing computer system, all of which are well understood in the art, and a detailed description of how to make or use such computers is not deemed necessary herein. When the computer system is used to execute the logic of the processes described herein, such computer(s) and/or execution can be conducted at a same geographic location or multiple different geographic locations. Furthermore, the execution of the logic can be conducted continuously or at multiple discrete times. Further, such logic can be performed about simultaneously with the capture of the images, or thereafter or combinations thereof.

[0060] Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be obvious to those skilled in the art that certain changes and modifications may be practiced without departing from the spirit and scope thereof, as described in this specification and as defined in the appended claims below.

What is claimed is:

1. A method for creating an oblique-mosaic image from a plurality of source oblique images, comprising the steps of:

identifying a desired area to be imaged and collected into an oblique-mosaic image;

creating a mathematical model of a sensor of a virtual camera, where the virtual camera has an elevation greater than an elevation of the area to be imaged, the mathematical model having an oblique-mosaic pixel map for the sensor of the desired area;

assigning a surface location to each pixel included in the oblique mosaic pixel map; and

reprojecting at least one source oblique image pixel of the area to be imaged for each pixel included in the oblique-mosaic pixel map to thereby create an oblique-mosaic image of the desired geographical area.

2. The method of claim 1, wherein the step of assigning is further defined by projecting each pixel through the perspective of the virtual camera to determine a corresponding surface location for each pixel in the oblique-mosaic pixel map.

3. The method of claim 1, wherein multiple source oblique images represent the same surface location.

4. The method of claim 1, wherein the method further comprises the step of selecting source oblique images of the surface location captured at an oblique angle and compass direction similar to the oblique angle and compass direction of the virtual camera.

5. The method of claim 3, wherein the pixels of each source oblique image that represent the same surface location are compared to determine which source pixel is most representative of the surface location, the more representative pixel to be included in the oblique-mosaic image.

6. The method of claim 1, wherein the step of reprojecting is further defined by reprojecting the pixel to match the size and shape of the represented surface location as taken from the elevation, compass direction, and oblique angle of the virtual camera.

7. The method of claim 1, wherein the step of reprojecting is further defined by removing the effects of elevation from the source oblique images prior to reprojection and then adding the effects of elevation to the oblique-mosaic image after reprojection.

8. The method of claim 1, further comprising the step of minimizing lean of vertical structures within the oblique mosaic image.

9. The method of claim 8, wherein the step of minimizing lean of vertical structures within the oblique mosaic image is defined further as the steps of creating an elevation model from the source oblique images taking into account the vertical structures, and reprojecting at least one source oblique image pixel of the area to be imaged.

10. The method of claim 8, wherein the step of minimizing lean of vertical structures is defined further as matching vertical structures in multiple source oblique images and shifting pixels apparent location in at least one of the source oblique images by a relative height above a ground model.

11. The method of claim 1, wherein metadata is stored with the oblique-mosaic image.

12. The method of claim 1, wherein the oblique-mosaic image is geo-referenced.

13. The method of claim 1, wherein the desired area to be imaged represents a geographical area.

14. A method for creating an oblique-mosaic image from a plurality of source oblique images, comprising the steps of:

identifying a desired area to be imaged and collected into an oblique-mosaic image;

creating a mathematical model of a sensor of a virtual camera, where the virtual camera has an elevation greater than an elevation of the area to be imaged, the mathematical model having an oblique-mosaic pixel map for the sensor of the desired area;

determining a surface location for each pixel included in the oblique mosaic pixel map; and

reprojecting at least one source oblique image pixel of the area to be imaged for each pixel included in the oblique-mosaic pixel map to thereby create an oblique-mosaic image of the desired geographical area.

15. The method of claim 14, wherein the step of determining is further defined by projecting each pixel through the perspective of the virtual camera to determine a corresponding surface location for each pixel in the oblique-mosaic pixel map.

16. The method of claim 14, wherein multiple source oblique images represent the same surface location.

17. The method of claim 14, wherein the method further comprises the step of selecting source oblique images of the surface location captured at an oblique angle and compass direction similar to the oblique angle and compass direction of the virtual camera.

18. The method of claim 16, wherein the pixels of each source oblique image that represent the same surface location are compared to determine which source pixel is most representative of the surface location, the more representative pixel to be included in the oblique-mosaic image.

19. The method of claim 14, wherein the step of reprojecting is further defined by reprojecting the pixel to match the size and shape of the represented surface location as taken from the elevation, compass direction, and oblique angle of the virtual camera.

20. The method of claim 14, wherein the step of reprojecting is further defined by removing the effects of elevation from the source oblique images prior to reprojection and then adding the effects of elevation to the oblique-mosaic image after reprojection.

21. The method of claim 14, further comprising the step of minimizing lean of vertical structures within the oblique mosaic image.

22. The method of claim 21, wherein the step of minimizing lean of vertical structures within the oblique mosaic image is defined further as the steps of creating an elevation model from the source oblique images taking into account the vertical structures, and reprojecting at least one source oblique image pixel of the area to be imaged.

23. The method of claim 21, wherein the step of minimizing lean of vertical structures is defined further as matching vertical structures in multiple source oblique images and shifting pixels apparent location in at least one of the source oblique images by a relative height above a ground model.

24. The method of claim 14, wherein metadata is stored with the oblique-mosaic image.

25. The method of claim 14, wherein the oblique-mosaic image is geo-referenced.

26. The method of claim 14, wherein the desired area to be imaged represents a geographical area.

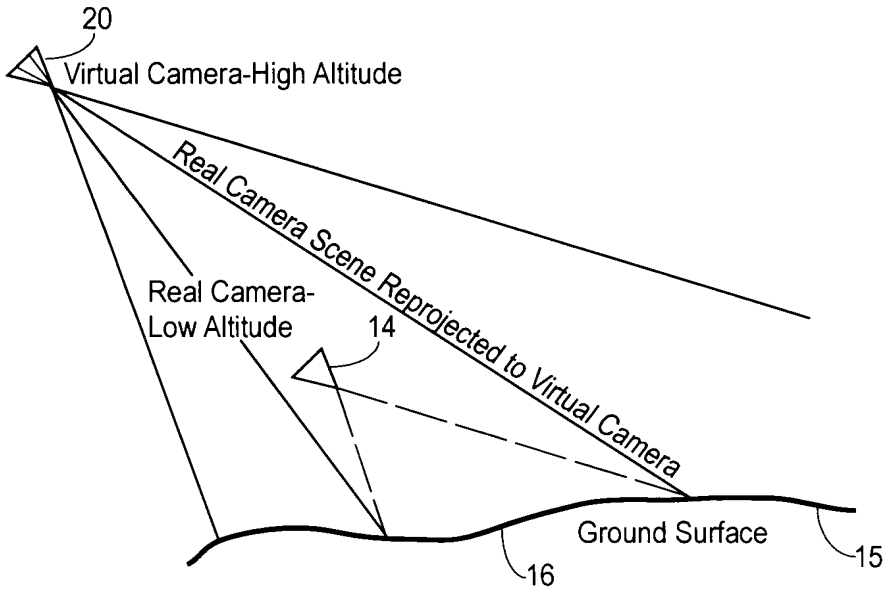

20
Virtual Camera-High Altitude
Real Camera Scene Reprojected to Virtual Camera
Real Camera-
Low Altitude
14
Ground Surface
16
15

Fig. 1

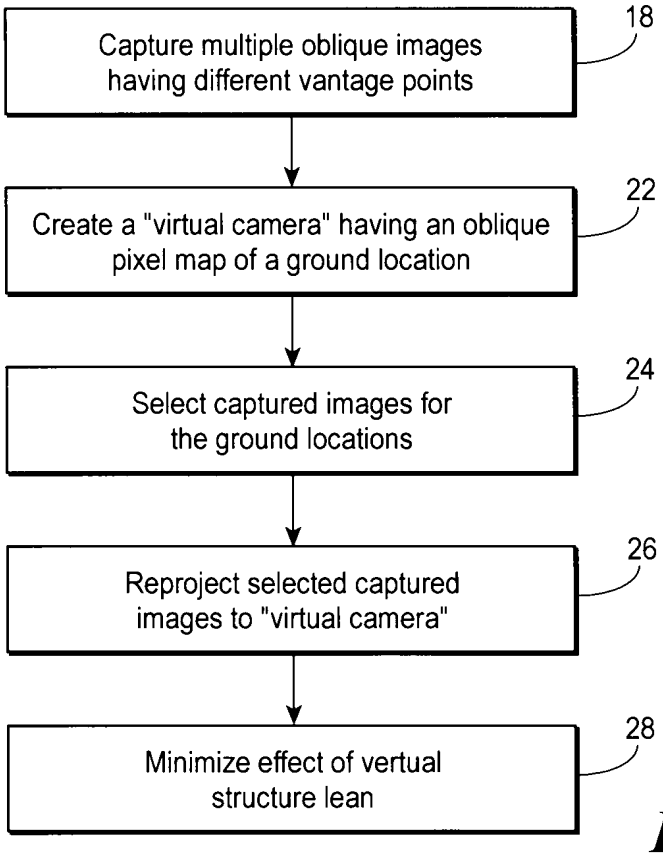
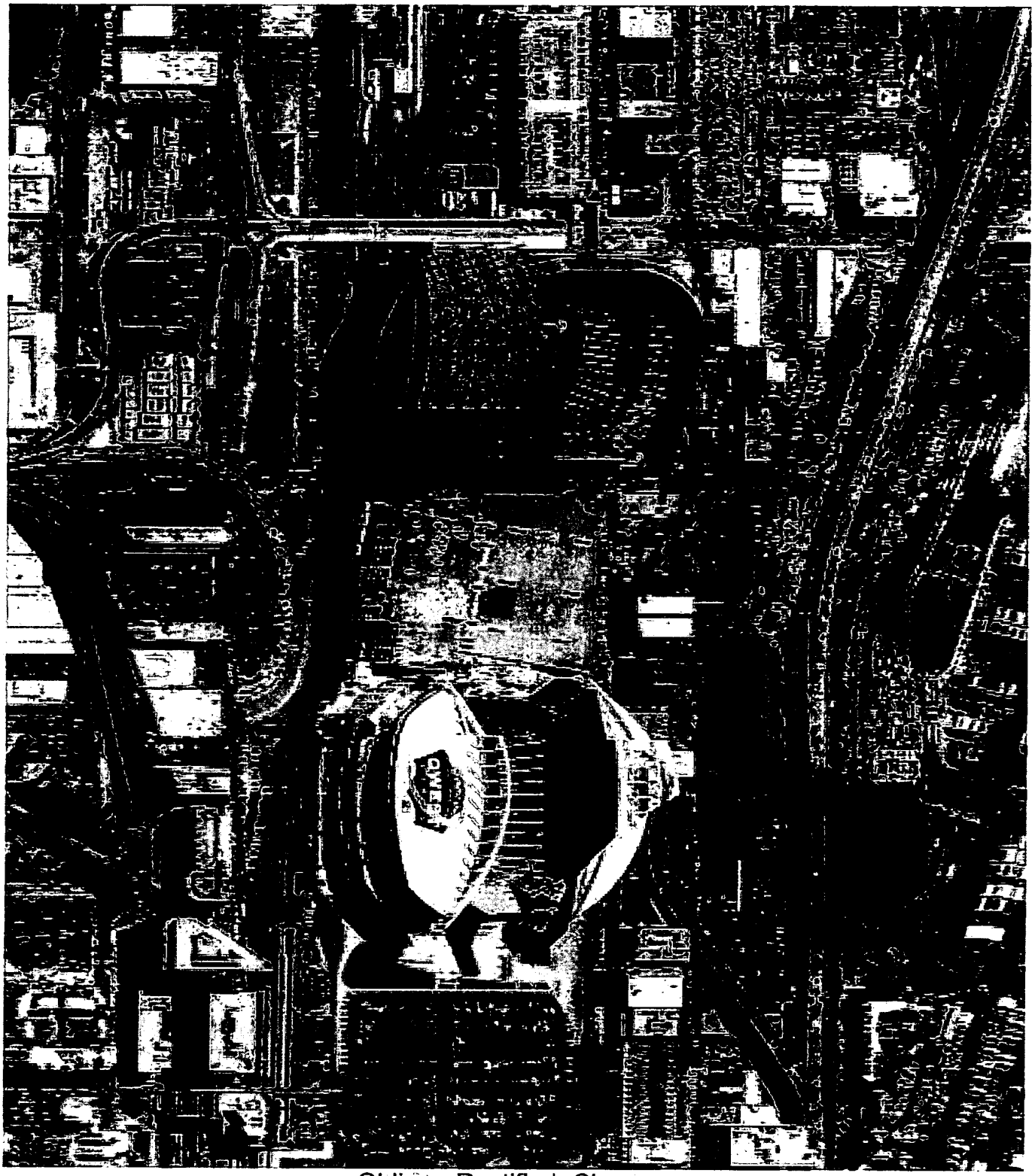

Capture multiple oblique images having different vantage points
18
Create a "virtual camera" having an oblique pixel map of a ground location
22
Select captured images for the ground locations
24
Reproject selected captured images to "virtual camera"
26
Minimize effect of vertual structure lean
28

Fig. 2



FIG. 3A



Oblique-Rectified_Closeup

FIG. 3B

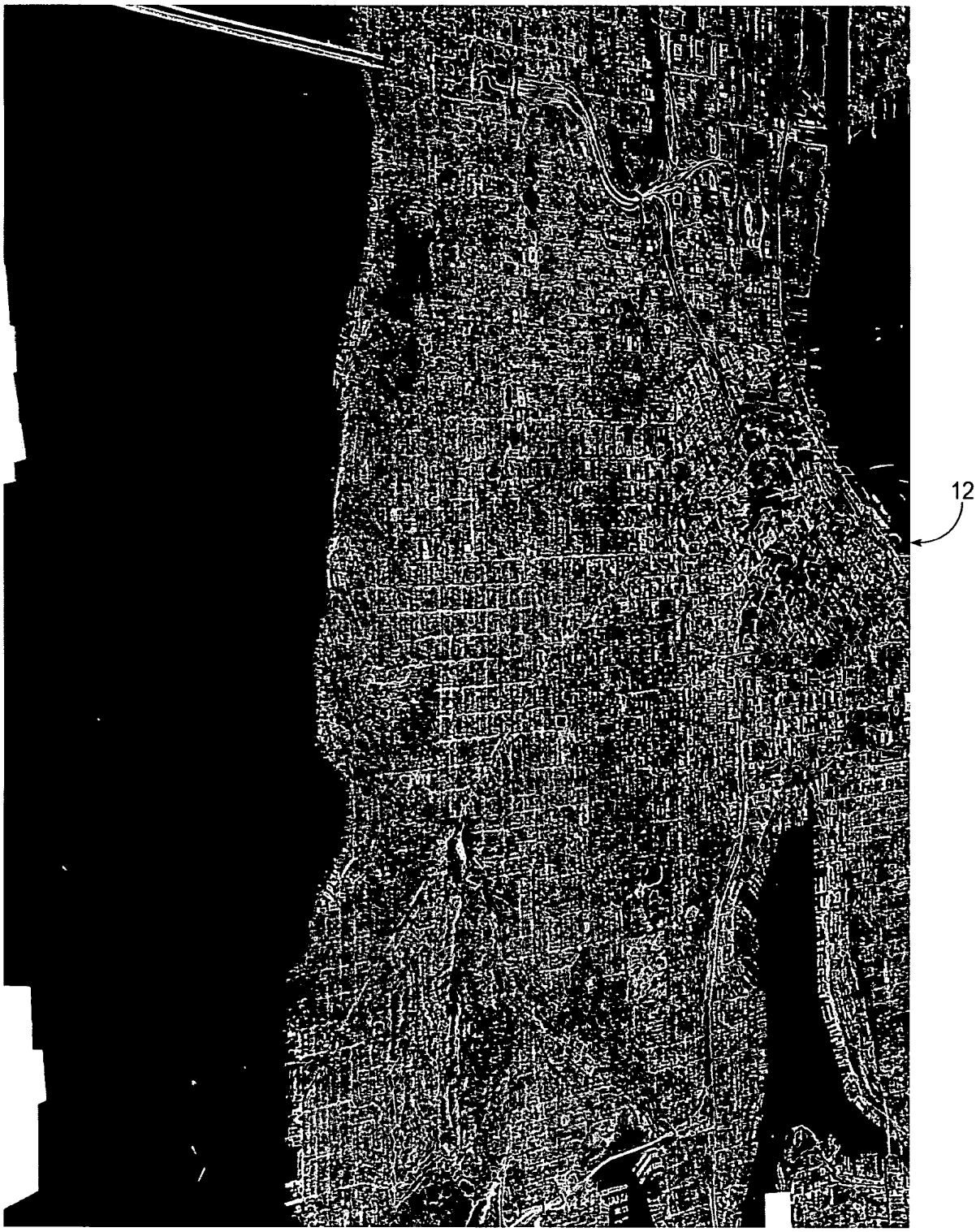


Fig. 4A

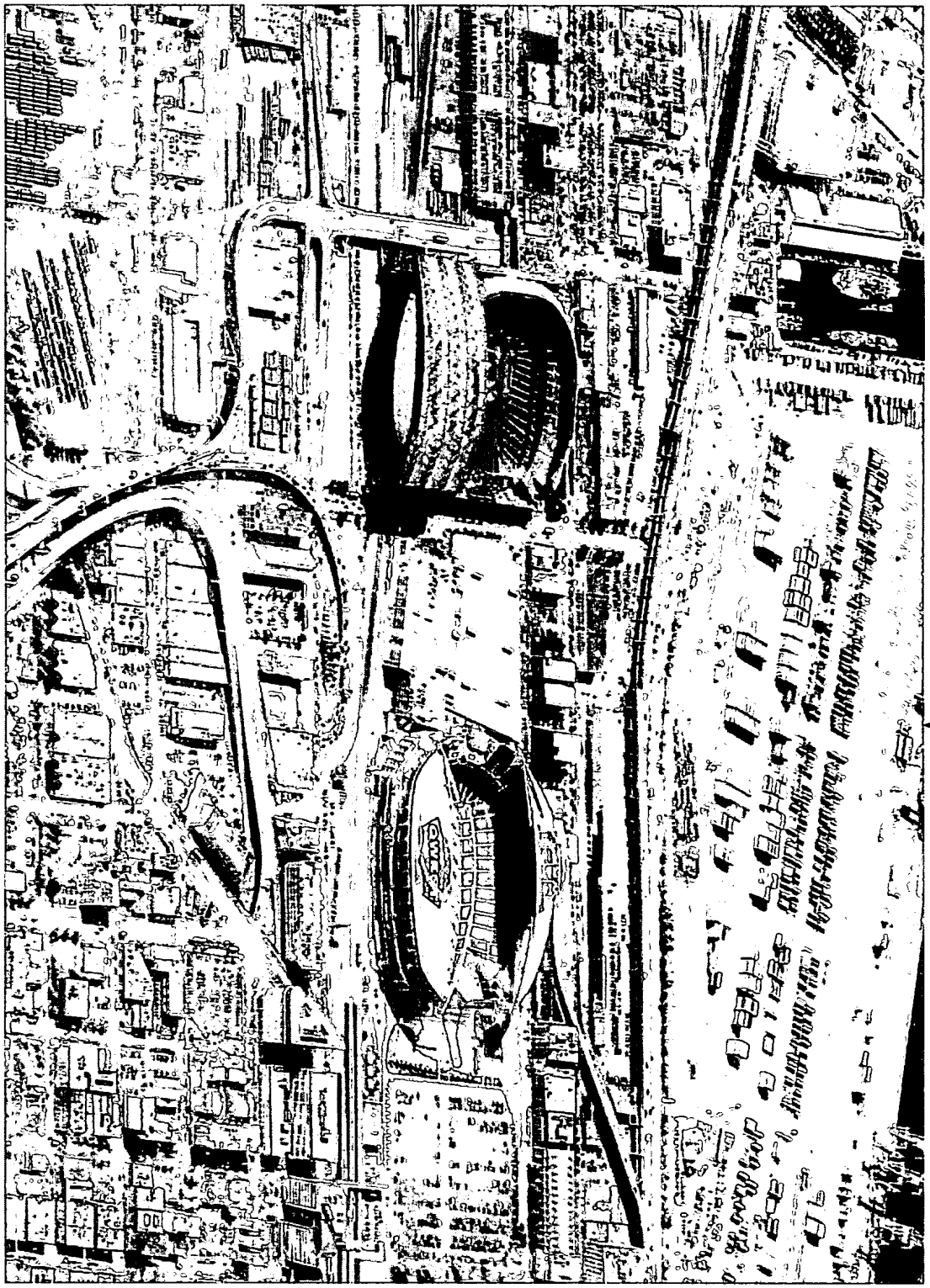


Fig. 4B

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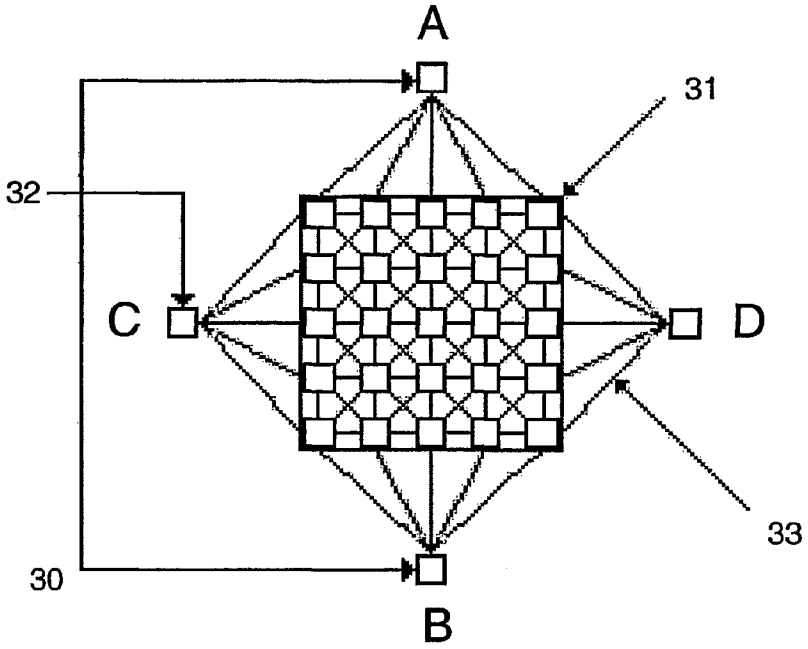
(74) Agents: **SUNSTEIN, Bruce, D.** et al.; Bromberg & Sunstein LLP, 125 Summer Street, Boston, MA 02110-1618 (US).

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[Continued on next page]

(54) Title: FORMING A SINGLE IMAGE FROM OVERLAPPING IMAGES



(57) Abstract: Forming a single image from multiple images is described. A first image and a second image partially overlap to define a common overlap region, and each image has multiple pixels. A boundary between the first image and the second image is automatically calculated based on processed pixel values in the common overlap region. Then the first and second image may be integrated along the boundary to form a single image.

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Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Attorney Docket: 2686/112WO

Forming A Single Image From Overlapping Images

Field of the Invention

[0001] The invention generally relates to image processing and, more particularly, the invention relates to forming a single image from multiple images.

Background Art

[0002] Photogrammetry seeks to obtain reliable measurements or information from photographs, images, or other sensing systems. This field is currently being challenged to transition to currently available digital and computer processing technology with fewer file size and memory limitations, faster hardware, and improved software algorithms. Generally, aerial/satellite photographs, survey points of the ground, and other information are first transformed into digital elevation models called "DEMs" (also known as a digital terrain model "DTM"), which are then further processed to produce ortho-rectified photo image files called "orthos".

[0003] Images of large geographical regions commonly are produced from multiple aerially shot pictures integrated into a single picture. For example, many overlapping, individual pictures may be integrated into a single mosaic that forms the final picture of a relevant region. It thus is important to ensure that the boundary between two contiguous pictures in a larger picture is accurately determined to ensure that the two images merge smoothly. When they merge smoothly, the overall image should have the appearance of a single picture.

[0004] Individual images taken of a single region typically have overlapping regions with immediately adjacent images. Accordingly, to determine the boundaries of two adjacent images, for example, the overlapping regions commonly first are roughly aligned. After they are aligned, a seam line is drawn somewhere in the middle of that region (on each of the adjacent pictures) to represent the boundary. This process is prone to error, however, due to its imprecise processes.

[0005] An example of a current commercial photogrammetry product is ImageStation OrthoPro by Z/I Imaging of Intergraph Corporation, which is an ortho production tool that addresses the complete ortho production workflow. Figure 1 shows the Main User Interface for OrthoPro. The "Project Planning" button allows the operator to select the data for a given job, which may include photographs, elevation models, and geo-referenced orthos in various horizontal and vertical datum, projections, and units. This robust functionality avoids the need for the operator to use an external utility to convert the input data to the desired ortho coordinate system. Furthermore, multiple elevation files can be selected, all in different coordinate systems, and prioritized for the automated software to automatically choose which to use during the ortho-rectification process. This avoids the need for the operator to merge DEM files before ortho-rectification. The operator can also select the images of interest, the desired deliverable ortho area(s), and the size of a pixel in ground units. The "Preferences" button allows the operator to turn on or off operator preferences of visual feedback of progress for the job in production. The "Orthorectification", "Dodge", "True Ortho", and "Mosaic" buttons allow for automated processing of orthos, but these buttons are disabled on the user interface until processing of the prior step is complete. If these buttons were enabled, the operator could choose the desired file format and processing options after "Project Planning," but before any processing begins.

[0006] In ortho production programs such as OrthoPro, repetitive human operator intensive processes can create bottlenecks in the production workflow. For example, OrthoPro requires the operator to continuously check the progress of the current step to see if it is complete before the next step can be started. In theory, each step could be automated to start the next step instead of making the operator wait for completion of that step before pushing the button to start the processing of the next step. Then, when processing starts there would be no need to stop until the job is complete. The main issue that prevents the workflow from being automated from beginning images to desired ortho area(s) of interest is the need to acceptably define the seam needed to mosaic the adjacent orthos together. A great deal of operator time can be needed to draw seam lines.

[0007] The need for seam lines arises from limitations associated with file format/size and data collection techniques, which cause images to be separated into partially overlapping

areas. The union of these overlapping areas forms one single large area on the ground referred to as the "project area". The goal is to produce one or more area(s) of interest found within the project area called "product areas". In some cases, the desired product area can be found within a single image, but often the desired product area must be extracted from the union of a combination of more than one of these overlapping areas; i.e. it must be extracted from a mosaic of the originals. A mosaic is the joining images together along seam lines.

[0008] Various algorithms presently exist to determine where to join or fuse the data together to form a seam line. Most algorithms require the operator to do a time-consuming visual quality check to ensure that there are smooth transitions where the data joins along a seam. Ideally, a seam joining the adjacent data should appear undetectable. Realistically, the seam will only be undetectable if the adjacent data has minimal or gradual changes along each side of the seam's edge.

[0009] Many prior automated seam line algorithms are based the Digital Elevation Models (DEMs), but such algorithms cannot predict the radiometric balancing and possible cloud cover in satellite projects without the using the orthos. Furthermore, DEM files must be created and/or maintained to recognize the new buildings or features found along seam lines. Therefore, visual inspection and manual editing is not always avoided using these algorithms.

[0010] OrthoPro provides an automated method to create seam lines, and also provides an option for the operator to edit, save, and import seam lines. But when images overlap more than fifty percent, it becomes confusing where to draw the seam lines. The "Generate Seamlines" button in Fig. 1 avoids such confusion and creates seam lines so that the camera position of the image is more perpendicular to the ground it covers than any other available image camera position. In other words, any point inside the seam lines generated is closer to the position of the camera of that image than any other image; it creates seam lines relative to the most "nadir" camera position. Such a partitioning is generally referred to as Voronoi diagram. This approach helps to increase visibility of the ground and avoids hidden areas due to anything tall obstructing the view of the camera.

[0011] But this automatic method is not perfect. While the algorithm does minimize hidden areas, it does not create substantially undetectable seam lines, and the operator usually will need to adjust the automatically generated seam line. An operator manually adjusting the seam line may find that a lack of survey points near the seam line and less than perfect DEMs will cause two overlapping orthos to have a ground shift relative to each other. In addition, building and tree lean with respect to the camera perspective is also a problem without the time consuming true ortho capabilities. The operator typically must shift back and forth between orthos trying to modify seam lines within the overlap region between the orthos so that there is minimal difference on each side of the seam lines. After the mosaic process is completed, the operator may do a visual quality check of the mosaic to ensure a smooth transition along the seam line. If the seam line was not adequate, the mosaic process must be reperformed. This operator intensive manual seam line editing and the visual quality check of the mosaic is very time consuming.

Summary of the Invention

[0012] A single image is formed from multiple images which partially overlap to define a common overlap region, and each image has multiple pixels. A boundary between the first image and the second image is automatically calculated based on processed pixel values in the common overlap region. Then the first and second image may be integrated along the boundary to form a single image.

[0013] In further embodiments, calculating a boundary includes minimizing a difference between intensity values of pixels adjacent to the boundary. The pixel intensity values may be used as weights which represent short line segments in a shortest path algorithm. Embodiments may further reduce a digital seam associated with the boundary by eliminating redundant segment vertices.

[0014] The boundary calculations may be based on a Voronoi diagram of the first and second images with respect to a camera center point of each image. The first and second images may be ortho-rectified images, aerial images, and/or satellite images of a geographic region.

[0015] Embodiments also include an imaging system adapted to use any of the above methods, and computer software adapted to perform any of the above methods.

Brief Description of the Drawings

[0016] Figure 1 shows the Main User Interface of one commercial ortho production product.

[0017] Figure 2 shows multiple overlapping images which need to be combined into a single image.

[0018] Figure 3 shows a pixel weight grid according to one specific embodiment of the present invention.

[0019] Figure 4 shows potential shortest path grid vectors according to one specific embodiment of the present invention.

[0020] Figure 5 shows reduction of redundant vertex points according to one specific embodiment of the present invention.

Detailed Description of Specific Embodiments

[0021] Various embodiments of the present invention are directed to techniques for automatically processing image pixel data to form a substantially contiguous boundary between a pair of overlapping images. For example, the difference values between corresponding pixel values within overlapping regions of both images may be analyzed to form the boundary. After the boundary is determined, the two images may be integrated together along the boundary to form a substantially unitary single image. Various embodiments of the invention create substantially undetectable seam lines and minimize hidden areas in ortho-image mosaics. This avoids the need for the operator to manually draw, edit, or quality check seam lines since the operator is assured that no better seam line can be created. Details of illustrative embodiments are discussed below. Of course, it should be noted that specific details mentioned below are not necessarily limiting of all embodiments. Many of the discussed embodiments thus are exemplary.

[0022] The seam joining the adjacent orthos should appear undetectable, and this requires that adjacent orthos have minimal or gradual changes along both sides of the seam edge. Various embodiments of the present invention use the difference between the adjacent ortho pixel intensity values as weights digitally representing short line segments in a shortest path algorithm to generate the direction for the least contrast difference between adjacent ortho files.

[0023] The overlap region of the adjacent ortho files is read and the pixels in the overlap region are analyzed to find the differences between the orthos. The algorithm then automatically adjusts where to place the seam lines between the adjacent orthos based upon where the least changes are found. The seam lines are represented digitally as very short fixed magnitude vectors that are created to calculate the refined direction across the overlap region. The digital seam lines can further be reduced by eliminating redundant segment vertices. The approach is somewhat like pouring water down a hill and plotting its course until it reaches the bottom of the hill. Just like the water will find the path of least resistance down the hill, embodiments of the present invention find the best possible seam line to connect adjacent orthos together to form one single large quilt/mosaic of orthos.

[0024] An arbitrarily defined magnitude for the grid size is chosen based upon the size of a pixel relative to the ground coordinate system. Then a grid of points called "grid posts" is calculated in ground coordinates covering the adjacent ortho overlap regions using the grid size to space the grid posts apart. Pixel coordinates are read from the adjacent ortho-rectified files at the ground coordinates of the grid posts. These pixel coordinates are subtracted from their corresponding adjacent ortho pixel coordinates as described in detail below. An adjacency list data structure is used to store the results of the analyzed data thereby minimizing system memory requirements.

[0025] Initial seams are created according to a Voronoi diagram from the ortho-image with the closest camera position. The camera position for each image is used to calculate which image is closer to perpendicular relative to any given ground position within the product area. If the camera position is not readily available, the center of the footprint of each ortho can serve as a good approximation for the camera positions. Given these

ground points, the Voronoi diagram can be calculated which makes an excellent initial and approximate solution to the seam line problem from which the rest of the algorithm refines the seam line. The adjacency list is loaded using the Voronoi diagram to control the order of the loading of the adjacency list. This sets up application of a shortest path calculation which will choose the best path as close to the Voronoi seam lines as possible while creating the path of minimum change across the ortho overlap.

[0026] A weighted graph shortest path algorithm positions the initial seam lines within the overlap regions. The adjacency list holds the pixel weights used as inputs into the shortest path calculation. One purpose of the adjacency list is to track which pixels are adjacent and their weighted connection to each other. The minimum weight path across the adjacent overlap region is then determined.

[0027] Figure 2 shows an example of four separate images, A, B, C, and D, which overlap in the respective shaded regions. For the weight grid calculation for a given overlap region, the ground coordinates within the overlap region are transformed into pixel coordinates, and the pixel intensity values at the calculated (x, y) pixel coordinates are read from the corresponding ortho-image file. The differences between the permutations of these ortho-image pixel intensities for each band are summed and the result is a weight grid for the region.

[0028] Furthermore, all four of the images in Fig. 2 also commonly overlap in the small central square. This region common to all four images will be referred to as the "overlap intersection." The grid posts of the overlap intersection must account for all the adjacent ortho-images in its weighted solution, not just two images. Therefore, the shortest path calculation for the overlap intersection may be processed separately from the other ortho-image overlap regions. The weight grid for this area is computed as:

abs(A-B)+abs(A-C)+abs(A-D)+abs(B-C)+abs(B-D)+abs(C-D)

where abs stands for the absolute value of the difference in the pixel intensity values.

[0029] Figure 3 shows a pixel weighted grid **31** representing the ABCD overlap intersection **30**. An artificial grid post **32** with zero weight is generated to represent each intersecting ortho-image in the overlap intersection **30**. These are shown in Fig. 3 as grid

posts A, B, C, and D representing their respective overlap region border. This artificial grid post **32** is used as a single entry/exit point within the adjacency list to enter/exit the weighted grid **31**. Any grid post along its respective overlap border will be connected to the artificial grid post **32** in the adjacency list and therefore an entry/exit point to the computed solution. The minimum weighted path from A to B is calculated, and then the minimum weighted path from C to D is calculated. After the minimum weight (shortest) path across the grid to connect the artificial pixels has been determined, the artificial pixels will be discarded. The first shortest path pixel connected to each artificial pixel will be the connection point between the overlap region and its corresponding area in the overlap intersection **30**.

[0030] Based on the foregoing description of how to handle overlap intersection areas, handling of the basic two image overlap regions is similar. The weight grid calculation is the same as before, but there are only two ortho-image files to find the weight difference. For example, ortho-images A and B intersect in a common overlap region. The weight grid for the overlap region is computed as abs(A-B). Any known pre-computed grid points from an overlap intersection are utilized and artificial grid posts points are used elsewhere when loading the adjacency list. This algorithm will then determine the minimum weight (shortest) paths across the overlap intersection area. The results will give a seam line across the overlap region to join the overlapping orthos together with minimal contrast difference.

[0031] Using the shortest path algorithm puts the seam lines in digital form. The seam line vertices are created dense in an effort to calculate the correct direction; i.e., the path of least intensity difference. These short vectors will have a possibility of only eight directions and have a constant magnitude equivalent to the size of one grid spacing as shown in Figure 4. The vertex seam line can move one grid post in any direction, but each segment's magnitude is limited by the grid spacing. This connectivity is set up in the adjacency list. The shortest path algorithm will calculate the direction, but not the magnitude of the vectors.

[0032] Once the optimal seam line is determined, redundant vertex points may be removed to reduce processing time. In one specific embodiment, this process may be based on an

algorithm of slope comparison such that points that fall in line without change in grid direction may be removed. For example, the seam line shown in Figure 5A will be reduced to the seam line shown in Figure 5B. By looping through the seam line vertex points looking at the previous and next vertex points to determine if they contain the same direction, the vertex in the center can be quickly removed giving the prior vertex a larger magnitude.

[0033] The final result is an automated process that saves operator time. Embodiments of the present invention make sure that there is no better location to smoothly join the orthos together by analyzing the pixels within the overlap region. Seams are generated that avoid building lean, cloud cover, and areas on the ground that has changed. And operator time is saved since manually drawing mosaic seam lines and/or quality-checking seams no longer needed.

[0034] Embodiments of the invention may be implemented in any conventional computer programming language. For example, preferred embodiments may be implemented in a procedural programming language (*e.g.*, "C") or an object oriented programming language (*e.g.*, "C++"). Alternative embodiments of the invention may be implemented as pre-programmed hardware elements, other related components, or as a combination of hardware and software components.

[0035] Embodiments can be implemented as a computer program product for use with a computer system. Such implementation may include a series of computer instructions fixed either on a tangible medium, such as a computer readable medium (*e.g.*, a diskette, CD-ROM, ROM, or fixed disk) or transmittable to a computer system, via a modem or other interface device, such as a communications adapter connected to a network over a medium. The medium may be either a tangible medium (*e.g.*, optical or analog communications lines) or a medium implemented with wireless techniques (*e.g.*, microwave, infrared or other transmission techniques). The series of computer instructions embodies all or part of the functionality previously described herein with respect to the system. Those skilled in the art should appreciate that such computer instructions can be written in a number of programming languages for use with many computer architectures or operating systems. Furthermore, such instructions may be

stored in any memory device, such as semiconductor, magnetic, optical or other memory devices, and may be transmitted using any communications technology, such as optical, infrared, microwave, or other transmission technologies. It is expected that such a computer program product may be distributed as a removable medium with accompanying printed or electronic documentation (*e.g.*, shrink wrapped software), preloaded with a computer system (*e.g.*, on system ROM or fixed disk), or distributed from a server or electronic bulletin board over the network (*e.g.*, the Internet or World Wide Web). Of course, some embodiments of the invention may be implemented as a combination of both software (*e.g.*, a computer program product) and hardware. Still other embodiments of the invention are implemented as entirely hardware, or entirely software (*e.g.*, a computer program product).

[0036] Although various exemplary embodiments of the invention have been disclosed, it should be apparent to those skilled in the art that various changes and modifications can be made which will achieve some of the advantages of the invention without departing from the true scope of the invention.

What is claimed is:

1. A method of forming a single image from a plurality of images, the method comprising:

for a first image and a second image which partially overlap to define a common overlap region, each image having a plurality of pixels, automatically calculating a boundary between the first image and the second image based on processed pixel values in the common overlap region; and

integrating the first and second image along the boundary to form a single image.

2. A method according to claim 1, wherein calculating a boundary includes minimizing a difference between intensity values of pixels adjacent to the boundary.

3. A method according to claim 2, wherein the pixel intensity values are used as weights which represent short line segments in a shortest path algorithm.

4. A method according to claim 3, further comprising:

reducing a digital seam associated with the boundary by eliminating redundant segment vertices.

5. A method according to claim 1, wherein calculating a boundary is based on a Voronoi diagram of the first and second images with respect to a camera center point of each image.

6. A method according to claim 1, wherein the first and second images are ortho-rectified images.

7. A method according to claim 1, wherein the first and second images are aerial images of a geographic region.

8. A method according to claim 1, wherein the first and second images are satellite images of a geographic region.

9. An imaging system adapted to use the method according to any of claims 1-8.

10. Computer software adapted to perform the method according to any of claims 1-8.

7/12/2008, EAST Version: 2.2.1.0
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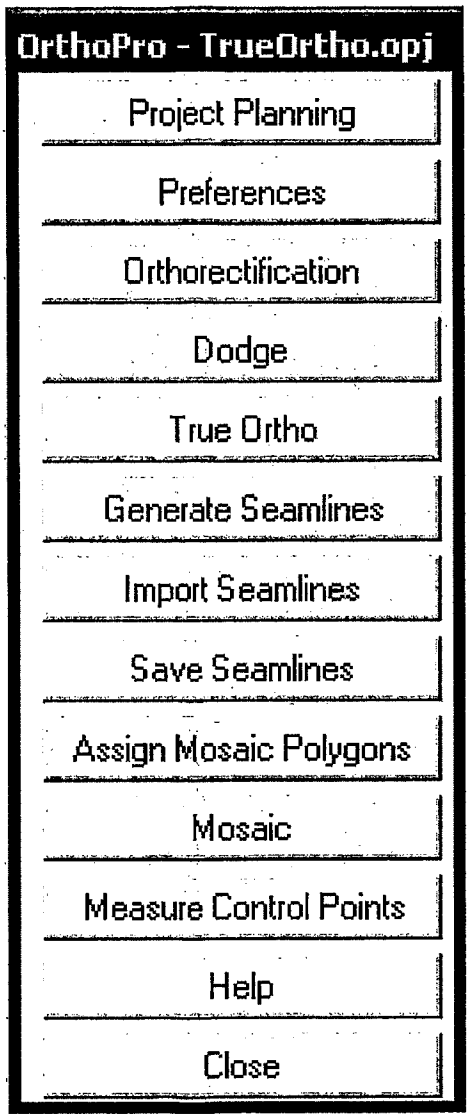

OrthoPro - TrueOrtho.opj
Project Planning
Preferences
Orthorectification
Dodge
True Ortho
Generate Seamlines
Import Seamlines
Save Seamlines
Assign Mosaic Polygons
Mosaic
Measure Control Points
Help
Close

Figure 1

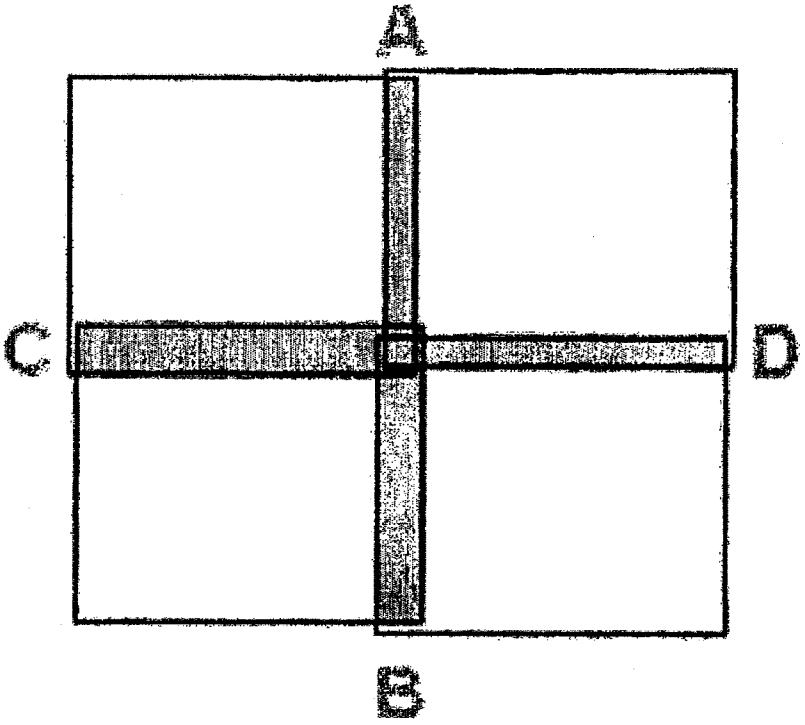


Figure 2

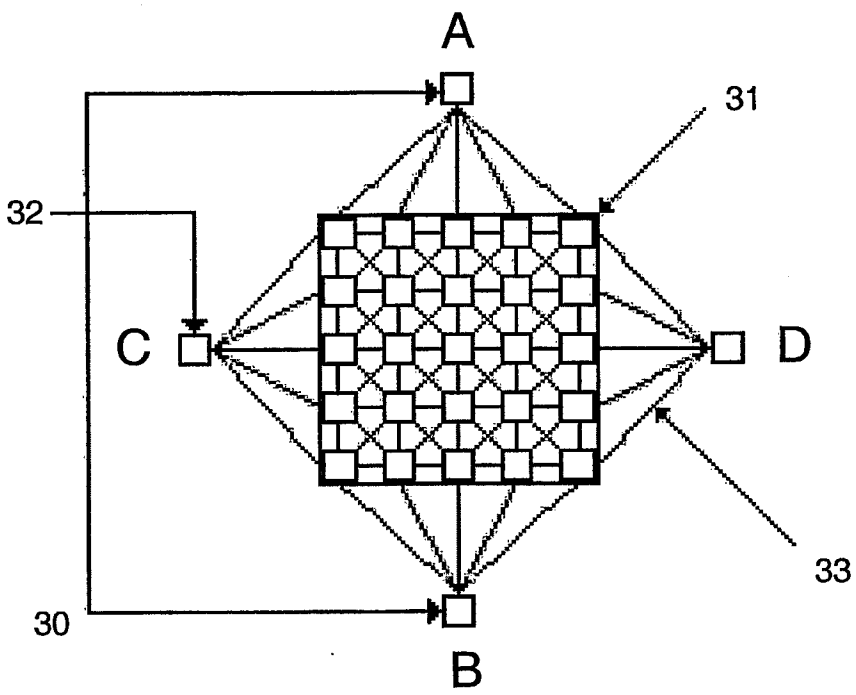


Figure 3

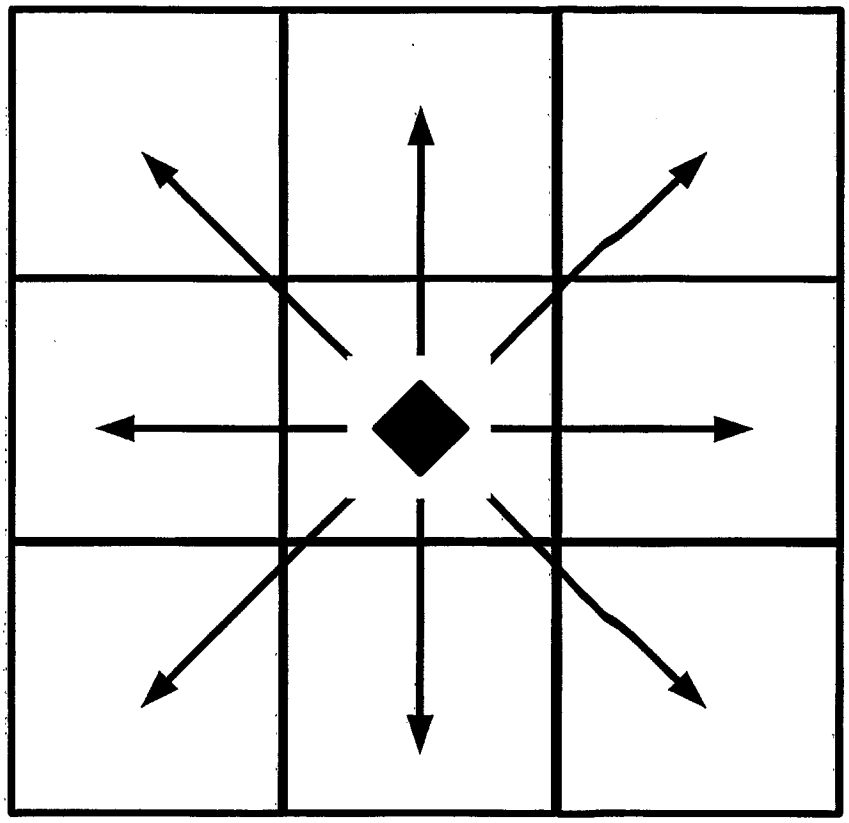


Figure 4

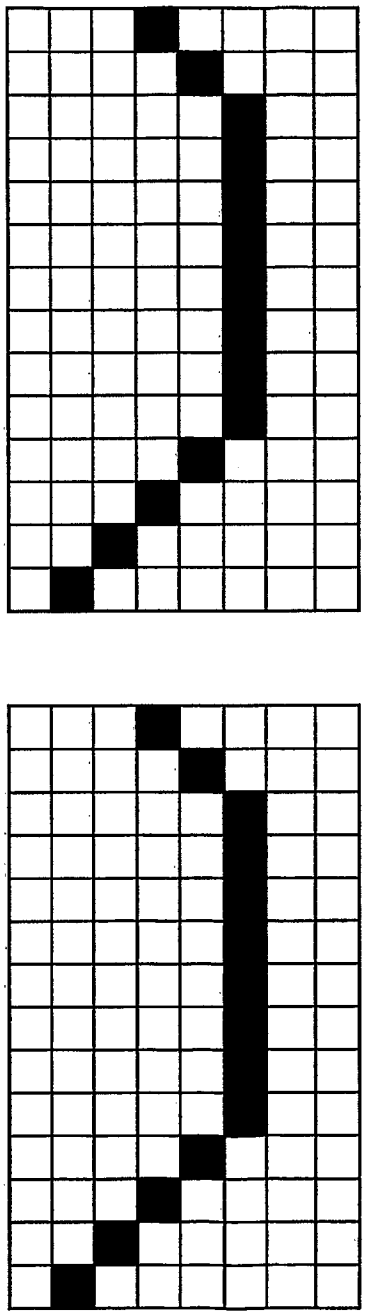


Figure 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/005689

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01C11/00 H04N1/387

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)
IPC 7 G01C H04N

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 12, 5 December 2003 (2003-12-05) -& JP 2003 317089 A (DAINIPPON PRINTING CO LTD), 7 November 2003 (2003-11-07)	1-3,9,10
Y	abstract paragraphs '0016! - '0023!	4-8
Y	Orthovista (TM) Software Manual Version 3.3, Release Date 14-01-2002 XP002329753 paragraph '5.2.5!	4-8

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"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
27 May 2005	10/06/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Hoekstra, F

2

Form PCT/ISA/210 (second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

Inte[redacted]onal Application No
PCT/US2005/005689

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2003317089 A	07-11-2003	NONE	

Form PCT/ISA/210 (patent family annex) (January 2004)

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PUBLICATION NUMBER EP1010966

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DECLARATION

I, Janet Elizabeth Llewellyn, B.A. (Hons.), Diploma in Technical and Specialised Translation, MITI, Technical Translator of D. Young & Co., Briton House, Briton Street, Southampton SO14 3EB, England, do hereby declare that I am conversant with the German and English languages and I certify that the following translation made by me is to the best of my knowledge and belief a true and correct translation of the authentic text for grant of European Patent No. 1010966 prepared in pursuance of The Patents Rules 1995.

Janet Llewellyn

(Janet Llewellyn)

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The present invention relates to a method of producing a three-dimensional object description of a located spatial object – in particular a building – from stereoscopic pairs of aerial pictures, in which

- from the pairs of aerial pictures two-dimensional image data and stereoscopic parameter data are stored digitised as three-dimensional raw data in a data processing installation,

- two-dimensional orthophoto-data and three-dimensional object data are calculated from the raw data, and

- external object-specific factual data are associated with the three-dimensional object data to form a three-dimensional object description.

The object of this method of measuring is to give a three-dimensional description by way of aerial pictures of spatial objects found on the earth's surface, particularly sites and constructions with spatial boundaries, such as roads, residential housing and industrial buildings, or other buildings. By virtue of the fact that a pair of stereoscopic aerial pictures is recorded for each of the objects, i.e. two aerial pictures in stereoscopic overlap, sets of two-dimensional geometric image data as well as parameter data are obtained which contain highly accurate information about the relative camera angle of the pairs of aerial pictures, absolute shooting co-ordinates and other shooting parameters. This data forms the raw data for calculating oriented representations of the earth's surface which are true to reality. By scanning the individual aerial pictures into an electronic data processing installation digital two-dimensional image data is obtained. In consideration of the stereoscopic parameter data aerial pictures with altitude information are calculated on the basis of them by way of aerotriangulation. In this way, three-dimensional object data is obtained from the original raw data and forms the three-dimensional object description.

The three-dimensional object data has been stored hitherto in data processing installations and has been available for additional evaluation. Topographical maps, traffic route plans, digital models of the ground including three-dimensional accurate point determination are prepared on the basis of the entire store of three-dimensional object data which accrues for getting to know a town or quarter by way of aerial pictures. The accuracy of measurement which can be

achieved makes it quite easy for buildings and parts of buildings to be detected and represented with sufficient accuracy to give angle-related data for constructional and architectural purposes. For example, for the reconstruction of a roof, all relevant information such as roof shape, roof area, roof inclination including any possible peculiarities are detected with sufficient accuracy for that information to be used to prepare an overmeasure.

In the prior art, a method of the kind mentioned in the introduction for detecting and evaluating aerial picture data is described in DE 44 19 359 A1. That method provides that by using the afore-mentioned method steps pairs of aerial pictures are used to prepare three-dimensional models of the earth's surface alongside orthophotographic projections thereof. In that specification, reference is also made to the already known possibility of associating the three-dimensional object data produced from the aerial picture data with external object-specific factual data e.g. land register lines present.

The afore-mentioned prior art does indeed make reference to combining a three-dimensional object data base which is obtained by way of aerial picture assisted measurements with external factual data and making it available to potential users in stored form on data carriers. However, a significant problem with this method which has long since been used in its basic form in photogrammetry for map construction is that extraordinarily extensive object data bases are created which are not without their problems in view of the technical work involved. The work involved in preparing all of the raw data in order to produce a complete three-dimensional object data base is considerable and data processing installations of corresponding efficiency are required. Although the data acquired can basically be stored on high capacity data carriers, e.g. CD-ROMs, transmitting the data using currently available data lines of customary capacity e.g. telephone lines, is extremely tedious and in practice it is virtually unconvertible. Finally, the production of extensive structured data sets is sometimes undesirable in view of data-protection legislation.

DE 197 19 620 A1 relates to a process for the computer-assisted production, processing and use of aerial picture data. The process according to this publication does not, however, essentially transcend that already taught in the afore-mentioned DE 44 19 359 A1. From DE 197 19 620 A1 it can be seen that in the same way analog aerial picture recordings are initially input into a computer system by scanning. Therein, GPS-position data is assigned to the image data which permit the identification of individual objects within the range under

detection. The computer system then uses the scanned aerial pictures to draw up and store three-dimensional model data. The German A-document refers to "object data" since that data, unlike that with the process according to DE 44 19 359 A1, is assigned to individual image objects, such as buildings, villages, open fields etc. By way of this assignment the data for individual three-dimensional object data sets is restricted, thereby making it easier for it to be made available, and also making possible interactive use over the Internet. Over the Internet, the user has access to the aerial picture data : from the network of data he can download onto his PC the object data of the object of interest to him and evaluate it there in an interactive way.

However, with that previously known process as well, a further problem is that the preparation of the object data is extremely consuming and intensive in terms of memory space. Fast workstations with memory capacities of more than 100 GB are needed. A further problem is that the interactive use of the object data requires special software for the user's PC. That software is proprietary and first of all has to be made available to the potential users, which, in turn, involves a certain expenditure.

The aim of the invention is therefore to avoid the afore-mentioned problems and to reduce the necessary computational expenditure for the production of three-dimensional object descriptions, and to reduce the total amount of data produced therein to such an extent that user-friendly data transmission is possible using relatively low capacity remote data lines. In particular, this involves handling aerial picture data using telephone lines on the World-Wide-Web (Internet). Finally, a general overview of the object descriptions should be possible from the point of view of data-protection legislation.

To solve the problem outlined hereinabove, on the basis of the prior art, the invention proposes a method with the following method steps:

- associating external object-specific factual data with the two-dimensional orthophoto-data for forming object-specific orthophoto-hybrid data sets,

- storing the orthophoto-hybrid sets on a host computer of a networked data processing installation, which host computer is connected to client computers by way of data transmission lines,

- transmitting the orthophoto-hybrid data sets to a client computer by way of the data transmission lines,
- selecting an object-specific orthophoto-hybrid data set at the client computer by inputting the object-specific factual data,
- transmitting the selected object-specific data to the host computer by way of the data transmission lines,
- calculating an object-specific three-dimensional object data set from the three-dimensional raw data which are stored in the host computer and which form the basis for the selected object-specific orthophoto-hybrid data set,
- transmitting the three-dimensional object data set with the object-specific factual data as a three-dimensional object description to the client computer by way of the data transmission lines.

A particular advantage of the method according to the invention results from the fact that rather than a complete three-dimensional object data base being produced, as has been customary hitherto, first of all only a two-dimensional orthophoto-data base is produced, i.e. a two-dimensional projection true to the surface area. The expenditure in terms of data technology in producing, handling and storing this two-dimensional image data is significantly less then if the raw data accruing were to be prepared immediately and completely in three-dimensional manner.

In the next step of the method, the orthophoto-data is structured by adding external factual data. This results in object-specific orthophoto-hybrid data sets. The factual data involved here may be land register-, road- and/or other building data. In this way, a clear association of an address ID with street name and house number is produced for a specific building. The two-dimensional orthophoto-data is stored together with this external factual data in an orthophoto-hybrid data set which is assigned to the specific object.

The afore-mentioned orthophoto-hybrid data sets are stored in the following method step on a host computer i.e. a server. This latter is connected by way of data transmission lines to a data processing installation with a network. This can be both a local network in a business as well as a decentralised extended network, e.g. the Internet of global structure. A number of client-computers are connected to the data transmission lines, and, by way of the data transmission lines, they have access to the data bases of the host computer(s).

In the next step, the orthophoto-hybrid data sets are transmitted by request to any client computer connected to the network. The amount of data which can be overviewed for the two-dimensional image data makes it possible for details from large surface-area aerial pictures to be transmitted even across remote data lines of limited transmission capacity. By way of example, it is possible to envisage the transmission of a picture representation of a village or town sector over the Internet, i.e. via telephone line, by request, to the customer.

The next method step relates to the selection of an object-specific orthophoto-hybrid data set at the client computer. Therein, the user of the client computer, i.e. the customer, can select a specific building e.g. by inputting the address. A particular advantage of the method according to the invention is that now no longer – as hitherto – does a building need to be identified tediously in an aerial picture, but instead for the purposes of selection only the object-specific factual data are input, e.g. the street name and house number. This is quite sufficient for the purpose of selecting an object-specific orthophoto-hybrid data set.

The object-specific factual data selected in the previous method step is now transmitted by data transmission lines from the client computer to the host computer. There, all of the original three-dimensional raw data is available in stored form.

With the aid of the command which has been sent from the client computer by inputting the object-specific factual data, the three-dimensional raw data forming the basis of the object-specific orthophoto-hybrid data set selected on the host computer is then first of all identified in the host computer. This is the aerial picture data and the parameter data, e.g. of a building, or of a house roof. On the basis of the three-dimensional raw data a three-dimensional model computation is then performed in the host computer for the selected object. As a result, a three-dimensional object data set is produced, which, together with the object-specific factual data, forms a complete three-dimensional object description from aerial perspective. In concrete terms, a three-dimensional object description of this kind can contain accurate information about the shape and surface of a house roof, including data about the inclination of the roof, arrangement and size of windows and chimneys, and the like. The clear association with the factual data, such as street and house number, ensures simple and unequivocal access.

Finally, the object data which is prepared in this way, including the associated factual data, is transmitted in the form of a three-dimensional object description to the client by way of data transmission lines. At this point, the three-dimensional data is transmitted across data transmission lines which can in some circumstances have a low transmission capacity. However, the actual amount of data sent is relatively small because the description relates merely to a specific object. Therefore, the technical expenditure here is also substantially less than in the prior art.

Expediently, the external factual data contain the afore-mentioned street- or land register data. However, for a given application, any external data connected in any form to the respective object can in theory be added to the factual data. By way of example, for specific agricultural uses climatic or meteorological data is pertinent, whereas for the development of residential areas or holiday areas local immission data is of importance. The adding of further external factual data can be meaningful depending on the application.

The object description can be represented graphically and/or alphanumerically on the client computer. Expediently, the measurement data which is prepared in the host computer goes so far as to make further processing by the client unnecessary. By way of example, the customer is given extensive measured data relating to a house roof in respect of calculating materials and cost for reconstruction work on a roof by a roofer.

By way of the method according to the invention the possibility is given firstly to a wide circle of users of using aerial picture data for the spatial measurement and description of specific objects. This is done on the principal whereby the raw data which is produced first of all by measurement undergoes two-dimensional preparation. In so doing, following structuring by the integration of external factual data, the restricted amount of data yielded is optimum for processing in a decentralised data processing installation with a network, in particular with transmission lines of small transmission capacity, e.g. the Internet.

A particularly advantageous application of the method according to the invention is in the planning of roof reconstruction work. In this case, the roof of the building forms the object for which a spatial object description is prepared in the way according to the invention. Expediently, the factual data in this case contains street data relating to the building, i.e. street

names, and, additionally, house number. Clearly, land register data or co-ordinates can also be contained as well.

Therein, the roof shape and/or roof surface area is defined in the host computer by partial or fully automated picture analysis methods. Therefore, time-consuming manual processing is abandoned.

Preferably, the orthophoto-data is displayed graphically on the client computer. That display is particularly user-friendly, if, additionally, the factual data of the orthophoto-hybrid data sets is displayed graphically, i.e. mixed in with the orthophoto-data. In the application proposed hereinabove, it is conceivable, for example, for the outline of the roof surface areas which form the objects to be marked graphically, e.g. to be emphasised in colour. This display is particularly user-friendly.

With a preferred further development of the graphic display of the orthophoto-hybrid data sets it is not only the orthophoto-hybrid data and the factual data which are displayed jointly on the client computer, but a graphic user interface is also formed by them, wherein specific orthophoto-hybrid data sets are selectable graphically in an interactive way. This permits user guidance, such as that known within the domain of modern graphic user interfaces. In concrete terms, a marker such as a mouse is moved by way of appropriate input devices across the graphics displayed on the screen, and the desired roof surface area is marked by clicking, for example. In this way, a command is already given to prepare an object description.

Expedient further embodiments of the method according to the invention make provision for data compression before the data is transmitted via the data transmission lines, in order to reduce the amount of data to be transmitted.

Preferably, prior to calculation and transmission of the object-specific three-dimensional object data a security enquiry is installed in order to prevent unauthorised access. Therefore, over and above this, a service for overmeasurement of house roofs can be offered and calculated across the public data network. Therein, sufficient consideration is taken of data protection regulations.

The method according to the invention is described in greater detail hereinafter with the aid of the drawings, wherein:

Figure 1: is a two-dimensional orthophoto display of the roofs of buildings;

Figure 2: is a graphically prepared orthophoto-hybrid data set according to Figure 1;

Figure 3 is a graphic display of a roof evaluation;

Figure 4 is a spatial display of a three-dimensional object description of the building according to Figure 3.

Figure 1 shows the orthophotographic display, produced from a corresponding pair of aerial pictures, of a number of house roofs. According to the method of the invention, this picture is stored in the form of two-dimensional orthophoto-data in a host computer which may be connected to the Internet, for example.

The part of the picture shown is merely selected for the sake of clarity. The display of individual buildings, a street, or an entire town sector can be called up on the client computer which is connected by data lines to the afore-mentioned host computer.

The orthophoto-data is structured in accordance with extreme factual data, e.g. street details, and, in addition, house numbers. In Figure 2, the orthophoto-data set shown graphically in Figure 1 is prepared into an ortho-photo-hybrid data set by the addition of external factual data. For example, a street is emphasised graphically by the light line. Additionally, one individual building is marked graphically by a circle. With a user interface of this kind, the customer, i.e. the end user on the client computer is able, by interactive graphic data input, to select the building marked with the circle, for example.

After selecting the building, a command is sent to the host computer via the data lines. On the basis of the three-dimensional raw data present there a stereoscopic model description of the roof is formulated. Using image analysis processes, it is therein possible to detect the information relating to the roof description which is necessary for the reconstruction work –

roof surface area, roof shape, ridge lines, eave lines, chimneys, windows, roof tops, with sufficient accuracy.

The orthophoto-hybrid data set can be further processed to form technical graphics giving dimensions, as shown in Figure 3.

The three-dimensional object description worked out on the basis of this is, alternatively, emitted in a planar, two-dimensional graphic display, as in Figure 3, and/or in a perspective, spatial display, as in Figure 4, and transmitted to the client computer. At the same time, the factual data is prepared and added alphanumerically to the image data transmitted. Thus, for example, the roof surface area is given in m^2 in order to give a first impression of the extent of the roof reconstruction work needed.

The data for transmission may possibly be compressed in order to limit expenditure. Expediently, security enquiries are executed for the purpose of preventing unauthorised use and for the purpose of making payments for services rendered.

CLAIMS

1. A method of producing a three-dimensional object description of a located spatial object - in particular a building - from stereoscopic pairs of aerial pictures, in which

- from the pairs of aerial pictures two-dimensional image data and stereoscopic parameter data are stored digitised as three-dimensional raw data in a data processing installation,

- two-dimensional orthophoto-data and three-dimensional object data are calculated from the raw data, and

- external object-specific factual data are associated with the three-dimensional object data to form a three-dimensional object description,

characterised by the method steps:

- associating external object-specific factual data with the two-dimensional orthophoto-data for forming object-specific orthophoto-hybrid data sets,

- storing the orthophoto-hybrid data sets on a host computer of a networked data processing installation, which host computer is connected to client computers by way of data transmission lines,

- transmitting the orthophoto-hybrid data sets to a client computer by way of the data transmission lines,

- selecting an object-specific orthophoto-hybrid data set at the client computer by inputting the object-specific factual data,

- transmitting the selected object-specific factual data to the host computer by way of the data transmission lines,

- calculating an object-specific three-dimensional object data set from the three-dimensional raw data which are stored in the host computer and which form the basis for the selected object-specific orthophoto-hybrid data set, and

- transmitting the three-dimensional object data set with the object-specific factual data as a three-dimensional object description to the client computer by way of the data transmission lines.

2. A method according to claim 1 characterised in that the object is the roof of a building.

3. A method according to claim 2 characterised in that the factual data include street data of the building.

4. A method according to claim 1 characterised in that the factual data include land register data.

5. A method according to claim 1 characterised in that the orthophoto-data are graphically represented at least on a client computer.

6. A method according to claim 1 characterised in that the factual data of the orthophoto-hybrid data sets are graphically represented.

7. A method according to claim 1 characterised in that the orthophoto-hybrid data and the factual data are graphically represented on a client computer jointly in the form of a graphical user interface, wherein a specific orthophoto-hybrid data set can be interactively graphically selected.

8. A method according to claim 1 characterised in that the host computer is an Internet server.

9. A method according to claim 1 characterised in that the data network is the World Wide Web.

10. A method according to claim 2 characterised in that determination of the roof shape and/or the roof area is effected in the host computer by at least partially automated image analysis processes.

11. A method according to claim 1 characterised in that data compression is effected in each case prior to a transmission of data by way of data transmission lines.

12. A method according to claim 1 characterised in that a security enquiry is executed prior to calculation of the object-specific three-dimensional object data set.

13. A method according to claim 1 characterised in that further external factual data are added to the object-specific three-dimensional object data set.

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02. Dez. 1999

Fig.1



Fig.2



Fig.3

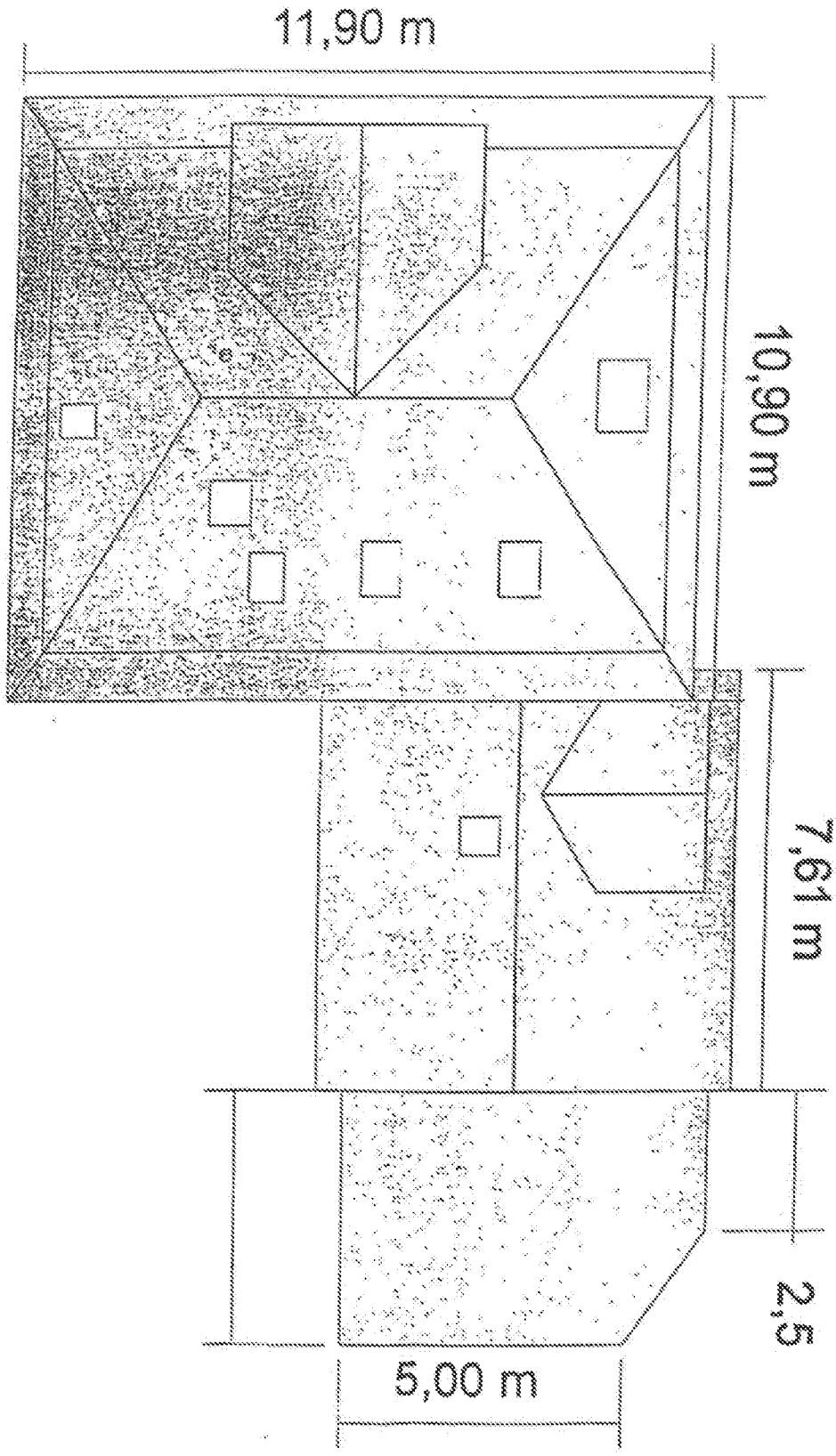
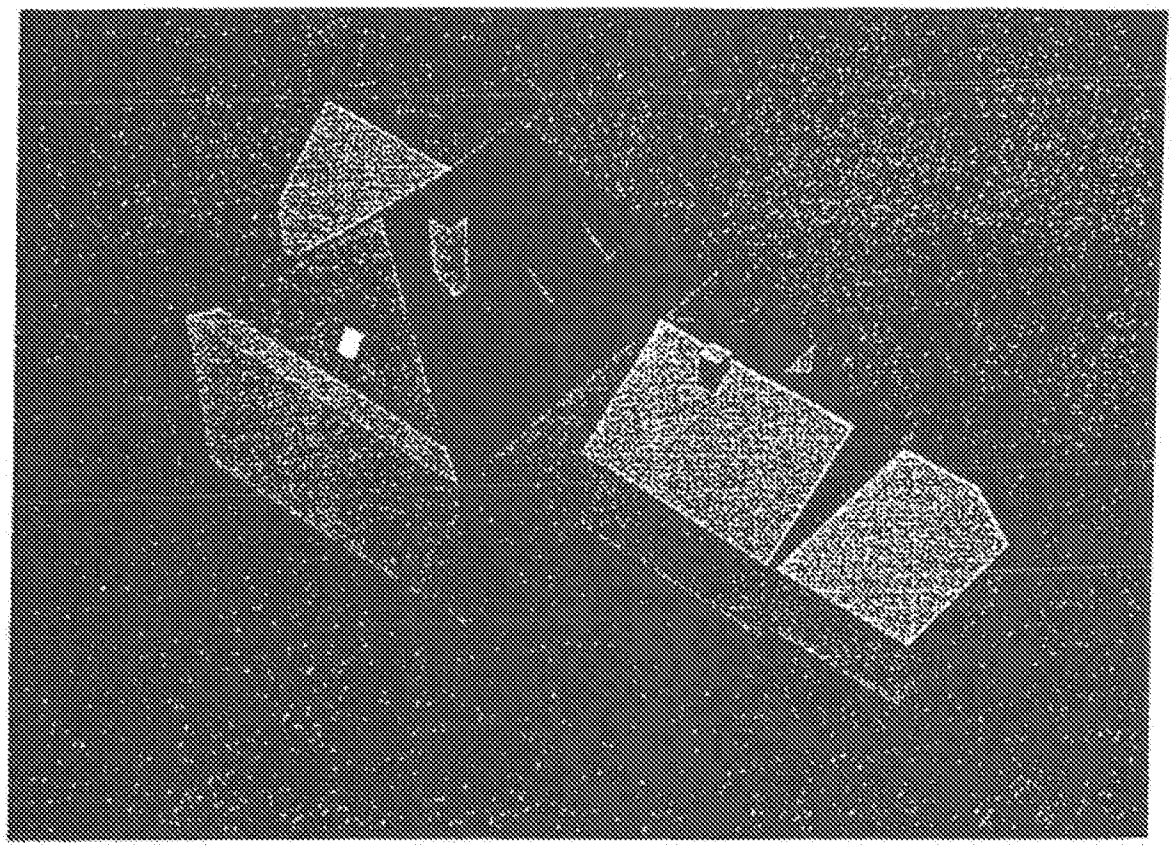


Fig.4



Prospects of kinematic GPS for aerial triangulation

Fritz Ackermann[1]

ABSTRACT

The principle of high-precision camera positioning by relative kinematic GPS phase observations is laid out, and its application to aerial triangulation by combined adjustment is reviewed. After discussion of some practical problems, the most favourable accuracy performance of GPS blocks is investigated theoretically. Particular attention is paid to the occurrence and compensation of signal interruptions and the resulting drift errors. Empirical investigations have confirmed the high accuracy potential of GPS positioning. Its application to aerial triangulation is highly economical by considerably reducing ground control. The system is ready for practical application.

This article is dedicated to Hans Jerie on the occasion of his retirement. It celebrates and recalls for the author years of happy personal cooperation with him and of intense and successful development of photogrammetry at ITC.

Aerial triangulation has been a major topic for Hans Jerie for a considerable part of his scientific and professional career. The breakthrough in 1958 with his analogue computers into the first sound concepts of block adjustment marks one of the outstanding milestones in the evolution of aerial triangulation. Another topic of similar scope has been auxiliary data for aerial triangulation. In his PhD thesis of 1953, he already anticipated later developments by the design of an analytical method for using statoscope data in aerial triangulation. Later he strongly advocated the use of various auxiliary data by laying out their accuracy effects and by designing methods for combined block adjustment (see bibliography).

It is a most appropriate opportunity to present hereafter some views on GPS and its application in aerial triangulation. It is, in historical context, the latest and most successful step of development concerning the old topic of auxiliary camera orientation data. It is remarkable that today's concepts relate directly to the ideas which were formulated more than 25 years ago by Hans Jerie, although today's system's performance and processing tools were not even conceivable at the time.

GPS RANGING

THE NAVSTAR GLOBAL POSITIONING SYSTEM (GPS)

GPS is a satellite-based system which is intended for direct positioning practically anywhere on Earth and at any time. The system was initiated by the U.S. Department of Defense, primarily for navigation purposes, *ie*, positioning in realtime. The system is still in a pre-operational phase, but it can already be used for many purposes. Completion of phase II is scheduled for 1994.

GPS for navigation of moving vehicles has to have realtime capability, the design of which had priority over accuracy considerations at the beginning. It was soon realized, however, that—in combination with post-processing methods—GPS has a very high accuracy potential for positioning, which makes it highly interesting for geodetic applications.

Also photogrammetry is recognizing the great potential which GPS has for applications in aerial surveys. We distinguish here three photogrammetric applications:

(1) GPS for photo-flight navigation and pin-point photography

(2) camera positioning for use in aerial triangulation (and perhaps for direct exterior photo-orientation)

(3) sensor positioning (for multispectral scanners, radar/laser profilers or scanners, video cameras, or other airborne sensors for geophysics, meteorology, etc).

We are not concerned here with survey flight navigation or with non-imaging sensor orientation, but will concentrate on GPS positioning of aerial survey cameras in connection with aerial triangulation.

PRINCIPLES OF GPS

Let us briefly recall the principles of GPS (see [5, 6, 8]). When it is complete, GPS will consist of 24 satellites orbiting at an altitude of 20,000 km. Each satellite makes two revolutions per day, its apparent movement through the sky being relatively slow. Eventually, there should be five to 10 GPS satellites visible at any time from practically anywhere on Earth.

All satellites emit continuous signals for ranging. The signals consist of two electromagnetic carrier waves (L1 and L2) at frequencies of 1575.42 MHz and 1227.60 MHz, which correspond to wavelengths of $\lambda_1 = 19$ cm and $\lambda_2 = 24$ cm, respectively. Both carrier waves are modulated by pseudo-noise (PN) sequences. There are two codes used: the (precision) P code and the (coarse acquisition) C/A code. The P code will be accessible only to specially entitled (military) users, although it is free at present. The C/A code is generally accessible, but is expected to be "deteriorated" in order to reduce the accuracy for the general user. The intentional degradation is euphemistically called "selective availability" (SA). At present, it has been on or off at irregular times. Further details will not be discussed here. It suffices to state that the P code signals have an equivalent (signal) wavelength of 30 m, the C/A code of 300 m (without SA). In general, a signal can be expected to be measured to about ≤ 1 percent of its wavelength, which is the basis of the potential accuracy of GPS for high-precision positioning.

There is an additional modulation of the carrier waves, transferring general information about the satellite identification numbers, orbit data (broadcast ephemeries), clock errors, atmospheric parameters, state

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of health of the satellite, etc. The result is that no external information is required to process the signals.

PSEUDO-RANGES

It is the basic principle of GPS, as far as positioning is concerned, to allow simultaneous distance measurements (ranging) to all visible satellites from one or several receivers which may be stationary on the Earth or in moving vehicles. The principle is one-way ranging, *ie*, the time difference between emission and reception of a signal is measured. This implies very high synchronization and time accuracy of the respective clocks. While the satellites carry atomic clocks of the highest possible accuracy, the quartz clocks in the receivers are less accurate. Synchronization errors can be in the order of msec; thus ranging errors may be as large as hundreds of km. The measured distances are therefore called pseudo-ranges, not claiming direct ranging accuracy. Apart from the clock error, the pseudo-range measurements give distances directly, the internal precision (standard errors) being respectively in the order of 0.3 m (P code), 3 m (C/A code without SA), or ≥ 30 m (C/A code with SA). The essential point is that pseudo-ranges have realtime capability.

There is a second type of range measurement, based on interferometric phase measurement of the incoming carrier waves, which operates essentially code-free. Because of the short wavelengths of the carrier waves, the expected precision of 1 percent of λ is about 2 mm. Phase measurements, however, refer only to the last incoming cycle of a sine wave. The total number of integer cycles the signal has travelled through are not known. The ambiguity of phase measurement is therefore treated as unknown. It amounts to approximately 10^6 cycles. It is only the initial phase ambiguity, at the beginning of a series of phase measurements, which has to be determined and solved for by an additional unknown (per satellite carrier wave). Thereafter the receiver would lock on the signal and trace the counts until an interruption occurs.

GPS POSITIONING

THE NAVIGATION SOLUTION

The principle of GPS positioning based on distance (range) measurements is very simple (see [5, 6, 8]). If a GPS receiver measures distances simultaneously to at least three satellites, its position can be calculated (by distance intersection/trilateration) provided that the positions of the satellites are known. As we have seen, however, the clock error of the receiver can be large (and may not be constant). It is therefore treated as an additional unknown in each solution. Hence simultaneous pseudo-ranges to at least four satellites are required for determining the position of the receiver (and its momentary clock error). This is the standard configuration for what is known as the navigation solution. It is also valid for phase measurements if the initial phase ambiguity has been solved separately (see below).

The navigation solution, based on one receiver, stationary or moving, is basically very simple. Navigation receivers have been in use for quite some time to process the positioning measurements and calculations in realtime. The inherent precision is determined by the ranging precision σ_s of P code and C/A code pseudo-ranging and of phase observations, respectively. In terms of least-squares adjustments, σ_s represents the standard error of unit weight σ_0. The precision (point error) of the derived position is expressed as PDOP x σ_s, with PDOP (point dilution of precision) = $\sqrt{Q_x + Q_y + Q_z}$. It depends on the number and the geometric configuration of the satellites, expressing the geometrical strength of the solution. Good or acceptable PDOP values are in the order of 3 to 6.

SYSTEMATIC ERRORS, ERROR MODELLING

Positioning by redundant or non-redundant ranging is only too familiar to the surveyor. He also knows that the real problems are the systematic errors. This is particularly true for GPS positioning. The systematic errors in the system can be very large. They concern the orbits and the satellite positions, the clock errors and other signal errors of the satellite, the refraction effects in the ionosphere and troposphere, and possible error effects of the antenna and receiver. The errors are very large compared with the measuring precision σ_s. They can reach tens or hundreds of meters, although a worldwide tracking system monitors the satellites continuously and updates the system parameters at short intervals. Fine corrections can be obtained subsequently for refined post-processing.

It is evident that precise positioning is concerned with the elimination or modelling of all relevant systematic errors. There are a number of possibilities that cannot be discussed here in any detail. The main strategy for modelling practically all systematic errors, orbit corrections included, is a combination of two principles: (1) stationary observations of fixed points over extended periods of time (up to hours), and (2) switching from absolute to relative positioning by using simultaneously two or more receivers. By using single or double differences of simultaneous observations, common errors can evidently be eliminated.

Such modelling of systematic errors relies on post-processing, in combination with adjustment methods. Realtime solutions, as required for navigation purposes, are less capable of complete error modelling.

In the geodetic application for GPS networks, methods for sophisticated error modelling have been elaborated and very much refined. Observations (pseudo-range and phase observations) are done with four to six (or more) receivers, some stationary and recording continuously, others moving around in vehicles (kinematic mode) and also occupying slave stations for some time. Accuracies in the order of 1 cm for networks are obtained. Research is still being carried out on how extended the networks can be and over what periods of time observations are required. Performance in the mm range of accuracy is envisaged for applications in engineering surveys and in geophysics (*eg*, for plate tectonics).

The situation is less favourable in aerial photogrammetry. The receiver in the flying aircraft is continuously moving. Also, for the time being, only

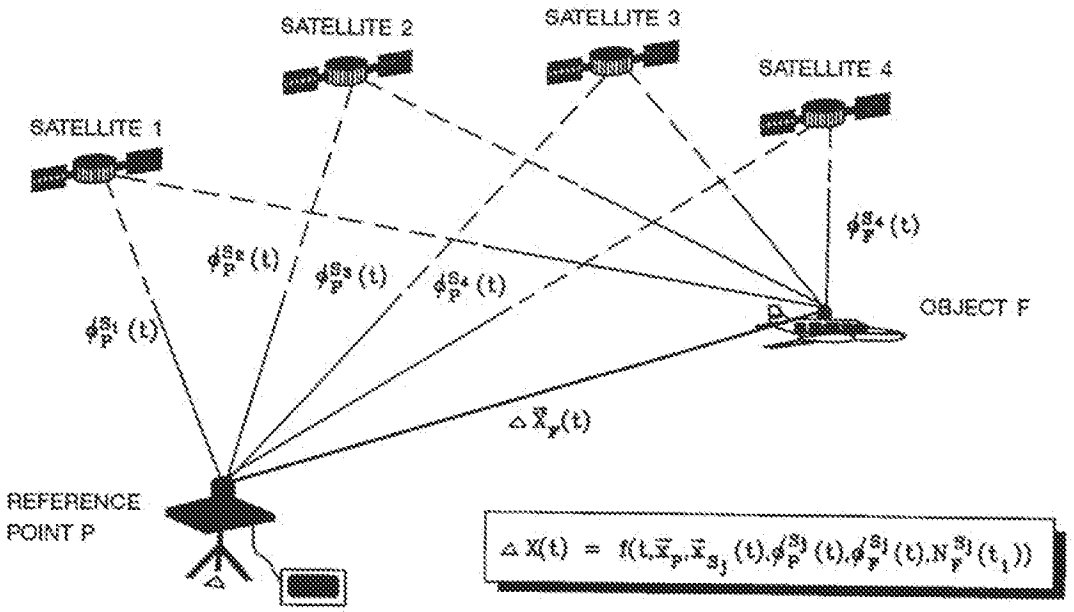


FIGURE 1 Relative kinematic positioning

one stationary receiver on the ground is considered, for operational reasons. Thus we are concerned with relative kinematic positioning, restricted to two receivers, as depicted in Figure 1. That special constellation of receivers limits the potential elimination of systematic errors (by single or double differencing). However, the method is still considered highly effective, although the distance between the two receivers, which may be several hundred km, and the duration of the flight of up to several hours may leave some systematic errors not compensated. On the other hand, the photogrammetric accuracy requirements for GPS camera positioning are often not very demanding. Accuracies in the order of several decimeters or meters are sufficient in many cases, as will be shown.

SOME SPECIFIC PROBLEMS

Relative kinematic positioning of a camera in an airplane is concerned with some specific problems which are briefly summarized.

GPS ANTENNA OFFSET

GPS positioning refers to the GPS antenna mounted on the upper side of the airplane. It has to be reduced to the perspective center of the aerial survey camera. The offset is described by Δx, Δy, Δz components which are to be measured directly at the airplane on the ground and subsequently transformed into the object coordinate system. For that purpose, the airplane (camera) attitude has to be approximately known, either by measuring tilts directly (by INS) or by deriving tilts after preliminary block adjustment. Caution has to be observed concerning resetting the camera during the flight (crab angle in particular).

TIME OFFSET

Normally, the GPS receivers take recordings at regular short time intervals. We want, however, the position of the camera at the moment of image exposure. Hence the camera has to give a signal, at each exposure, to be recorded on the GPS time-scale. Then the GPS position at those instants can be interpolated between the two nearest neighbours. For that reason the rate of GPS measurements has to be correspondingly high. Current receivers allow measurements at rates of 1 sec to 0.3 sec. The airplane moves in 1 sec approximately 50 m to 100 m.

Recently, some receivers allow GPS observations which coincide close enough with the camera exposures. In such cases interpolation errors do not occur.

DATA FLOW

The high recording rate for kinematic positioning implies a considerable volume of data to be recorded onboard and at the stationary receiver, unlike geodetic operations. During a photo flight mission, the GPS data recorded and stored may amount to about 20 or more Mbytes.

INITIAL PHASE AMBIGUITY

Precise positioning makes use of phase observations. There is the problem of the initial phase ambiguity which has to be solved before the kinematic positioning can start. In our case of one stationary receiver and one receiver in the airplane, the problem can be solved by stationary recordings of both receivers before take-off (and after landing). There are two versions: either start from a known baseline (both receivers at known GPS points) or determine an initial baseline by having the ground receiver antenna on a known point and the other fixed on the stationary airplane. The simultaneous stationary observations have to continue for about one hour in order to obtain a precise baseline determination. In case of too short recording time, the baseline, and hence the ambiguity solution, will still have some error, which will cause drift effects in the subsequent relative kinematic positioning (see [5]). Whether, and

how far, drifts can be accepted will be considered below. Great efforts are being made to bring down the stationary observations to several minutes by fast ambiguity solutions.

REFERENCE COORDINATE SYSTEM, DATUM PROBLEM

GPS positioning refers to the GPS coordinate system WGS 84. It is a Cartesian coordinate system, centered at the mass center of the Earth. If all control points and all GPS camera positions are determined in that system, there is no datum problem in combined aerial triangulation. The results will refer to WGS 84.

Photogrammetric results are, however, normally wanted with reference to a national geodetic system. The easiest way to obtain such results with GPS-supported aerial triangulation will be to ask for some control points to be geodetically given in both WGS 84 and the national coordinate system (such as UTM), in order to subsequently carry out the datum transformation or to include it in the combined block adjustment. There may still be problems concerning the vertical datum, for which the geoid, or an approximation to it, has to be given.

CYCLE SLIPS, DISCONTINUITIES

Phase observations have to be continuous throughout the flight (including the stationary recordings before take-off and after landing) in order to calculate the trajectory of a flight. Unfortunately, there are several kinds of interruption to be dealt with, known as (1) interruption of signals, (2) cycle slips and (3) constellation changes.

(1) Signal interruptions. It can happen that the signal from a satellite is interrupted, for example being cut off by the wings and fuselage of an airplane while turning. Especially during a 180° turn with a large banking angle, one signal after the other may be interrupted.

(2) Cycle slips. It happens, sometimes without apparent cause, during phase observations that the full cycle counts may slip in the receiver by a few up to possibly thousands of cycles, although the phase observations still seem to be continuous on first sight. The results of cycle slips are jumps in the trajectory. Genuine cycle slips are a matter of receiver design and may also be caused by multiple path effects, or by discontinuities in the ionosphere. They should normally not happen any more, but apparently they still do. We have observed cycle slips even at stationary receivers.

(3) Constellation changes. During observation periods of up to several hours, some satellites move out of sight and others come up. Hence the number and the constellations of observed satellites are changing. Normally, several such changes may happen during a flight mission. Unfortunately, because of receiver problems, examples of up to hundreds of constellation changes have been observed, with signals from satellites jumping in and out almost at random.

GPS software has to handle such disturbances. The problem is not too severe if at least four or five satellites remain undisturbed and thus allow relocking of interrupted signals. The main problem is always that the phase ambiguities have to be reassessed. There are a number of concepts to solve the problem, depending on the remaining information. If only two or three satellites—or none at all—remain undisturbed, the problem is more severe. It may happen that the phase ambiguity cannot be exactly locked on after an interruption. We have experienced several instances in which the receiver firmware was not able to overcome the discontinuities. It shows that the problem is serious, asking for more sophisticated software, especially in connection with kinematic camera positioning and the determination of precise airplane trajectories. We are preparing, in Stuttgart, robust software capable of handling practically all disturbances that might occur. One tries, generally, to obtain almost instantaneous ambiguity solutions during the flight, after any interruption.

EMPIRICAL ACCURACY OF RELATIVE KINEMATIC GPS POSITIONING

FLEVOLAND GPS TEST, 1987

We described the high accuracy potential of GPS positioning, especially on the basis of the code-free phase observations of the carrier waves. It remains to determine experimentally what accuracy performance relative kinematic GPS positioning really reaches in practical applications. In the following, some empirical results are presented which confirm the high accuracy of post-processed relative kinematic positioning of a survey camera in-flight. We refer here to the controlled "Flevoland" test, which still seems to be one of very few thoroughly investigated tests available (see [5, 7]). Other tests partly confirmed the Flevoland results, but did not succeed completely because it is very critical to provide sufficiently precise check values for the true camera positions.

The photogrammetric GPS Flevoland test was arranged by Rijkswaterstaat in The Netherlands in 1987. It was flown by KLM Aerocarto and was independently processed and investigated at the Institute of Photogrammetry at Stuttgart University. Two five-channel Sercel receivers were used, the stationary one positioned on a control point in the test area. Forty-eight control and check points were determined by geodetic GPS. All data refer to WGS 84 (except for a local transformation). Thus no datum transformation was required. The test area, covering about 2 x 4 km, was flown in 10 strips (photo scale 1:3800, Wild RC10 camera, f = 210 mm, flying altitude h = 800 m). All control points and some tie points were signalized. The photo overlap was somewhat irregular, with p = 60 to 70 percent forward overlap and q = 50 to 60 percent side overlap. The block, consisting of 184 photographs, was aerial triangulated by monocomparator measurements and bundle adjustment with additional parameters. Its sole purpose was to obtain independent coordinates for all camera positions (perspective centers of all photographs) which were subsequently used as check points to be compared with the GPS camera positions. The least-squares block adjustment gave for the (unit weight) accuracy of the image coordinates σ_0 = 5 µm and, by propagation of errors, for the accuracy in object space of the camera station coordinates $\sigma_{x,y}$ = 4.0cm and σ_z = 2.8 cm, respectively.

The recordings were processed by first differences to GPS antenna coordinates. Then the respective distance S to each "true" camera station was calculated and compared with the true distance S between GPS antenna and camera, as measured directly in the airplane. In this way tilt effects did not disturb the comparison.

RANGING PRECISION

The analysis of the internal accuracy of the GPS data gave a standard deviation for ranging of σ_ϕ = 1.4 mm (phase observations) and of σ_ρ = 1.14 m for C/A code pseudo-ranges (without SA). The values correspond to 0.7 percent λ and 0.4 percent λ_c respectively, which is even better than the initial expectation of 1 percent λ. Then, with PDOP = 5, the internal precision of position should be about 7 mm and 5.7 m, respectively. The empirical noise analysis gave actually 1 cm and 3 to 5 m, respectively. Thus the empirical values are—if not in total agreement with theoretical expectation—at least quite close. Anyway, random errors of camera positions in the order of 1 cm are too far below the level of photogrammetric concern to warrant any closer investigation.

ABSOLUTE POSITIONING ACCURACY, DRIFT ERRORS

The truly interesting question concerns the external accuracy of kinematic GPS positioning of the camera. In the Flevoland test, the absolute accuracy was assessed, as explained, by comparing the GPS results with the "true" camera stations as obtained from the photogrammetric block adjustment, or rather by comparing the directly measured true distance S between camera and GPS antenna with the distance S as computed from the respective WGS 84 coordinates.

Before results of the Flevoland test are presented, some additional facts must be mentioned. It was not possible to have continuous recording of all GPS data. The flights took place on two days. Also, there were some additional interruptions, resulting in altogether five separate sets of continuously recorded data, extending over one-half to four strips. The PDOP was 5, except for two very poor constellations with four satellites only at strip 2 (PDOP = 30) and strip 3.1 (PDOP = 57). Such strips would normally have to be excluded. It also was not known then that the initial ambiguity solution would require one hour of stationary recordings. Thus the ambiguity solutions were only approximations, and some remaining drift errors had to be expected, despite working with first differences. (It was shown that double differencing gave exactly the same results as first differences in the cases at hand.)

The main results of the accuracy investigation are summarized in Figures 2 to 4. The errors dS resulting from the direct comparison of GPS antenna coordinates and "true" camera stations are shown in Figure 2. Here the errors dS are equivalent to Z errors, because the GPS antenna happened to be mounted directly above the camera. The direct results are not very conclusive. Some datasets show directly GPS accuracy of several cm. Others seem to display linearly increasing errors. The poor satellite constellation of strips 2 and 3.1 are reflected in quite large

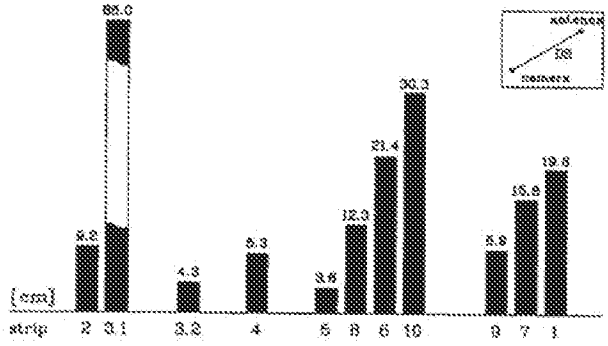


FIGURE 2 RMS DS with respect to the "true value"

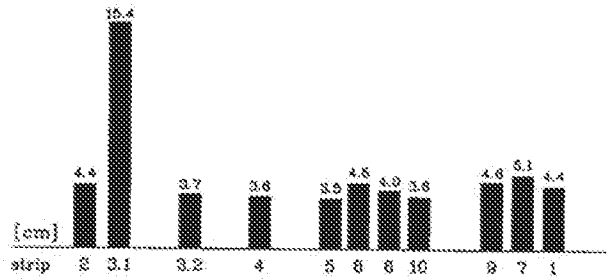


FIGURE 3 RMS DS with respect to the mean values per strip

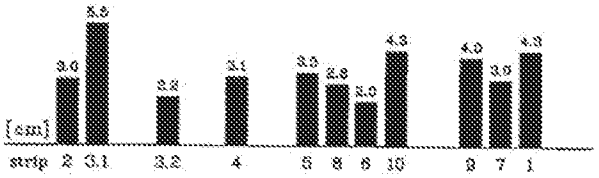


FIGURE 4 RMS DS with respect to linear regression

rms errors of as much as 86 cm.

The closer analysis confirmed that all GPS datasets contain systematic errors, *ie*, errors increasing linearly with time. In other words, GPS positioning is subject to residual systematic errors or drift errors, which seem to be linear in first approximation. The validity of that conclusion was fully confirmed by applying supplementary corrections for systematic errors. If the systematic errors are removed, first by applying constant shifts and second by applying linear corrections, the results obtained are quite remarkable, as Figures 3 and 4 show. The rms differences go down to 3.5 cm. Even the strips with poor geometry fit very well into that picture. The poor geometry seemingly did not affect the internal precision, but caused considerable drift errors instead. It should be noted here that the post-correction of linear drift errors will be possible in connection with combined block adjustments, as will be shown below.

The resulting rms accuracy of 3.5 cm for dS can be further broken down, because it still contains the errors of the "true" camera stations as derived from the aerial triangulation of the block, apart from the GPS interpolation errors which are still included. If the rms Z-errors of the camera stations, amounting to 2.8 cm, are subtracted, and if GPS positioning with

only five satellites is taken into account, the remaining rms accuracy of GPS camera positioning (in Z), after linear corrections for systematic errors, is 1.5 cm.

The main results of the Flevoland test can be summarized as follows:

(1) If systematic errors are suppressed or eliminated, the accuracy of relative kinematic GPS positioning of airborne sensors is in the order of a few cm. Considering that the Flevoland results refer to only five or four satellites and that they still contain the interpolation errors and other minor errors which are effective in the cm order of magnitude, it can be stated that the experimental results are very close to the theoretical expectation, although only limited error modelling took place. In terms of aerial photogrammetry, it should be observed that most applications for mapping will not require most precise camera positioning. Thus the internal precision of GPS camera positioning meets the immediate photogrammetric requirements amply enough.

(2) The second result is that all GPS-positioned camera trajectories show drift errors which, within periods of up to 15 minutes, are linear in first approximation (see Figure 5). This is a point of considerable controversy among geodesists. They claim that complete error modelling is possible to the extent that no drift errors remain. While this is not in doubt, the questions remain of whether complete error modelling is possible under the restricted operational conditions of photogrammetric flight missions and whether it is necessary at all. A mission may take up to five or six hours, the mission area may cover many thousands of km^2 or may combine several smaller projects quite some distance apart, and the stationary GPS receiver may be placed several hundred km away. Also, only one stationary receiver is used, and some types of receiver record only the L1 frequency. The practical circumstances of field operations can impose additional restrictions. Only four or five satellites may be visible, and the window of visibility may be short. Accordingly, the initial baseline determinations and phase ambiguity solutions may not be accurate enough. And, finally, partial or complete signal interruptions may occur. In addition, there is the completely independent consideration that many aerial survey applications do not require high accuracy of GPS camera positioning. Also, operational and economic considerations may warrant keeping the GPS field operations as simple and as robust as possible, at the acceptable expense of some accuracy. Thus it is certainly a valid conclusion to assume that drift errors may happen, by exception or regularly. Whether, and to which extent, drift errors are acceptable depends on the intended use of GPS data and on the possibility of subsequent correction. It is important to note, in this context, that linear GPS drift errors can be corrected in combination with aerial triangulation.

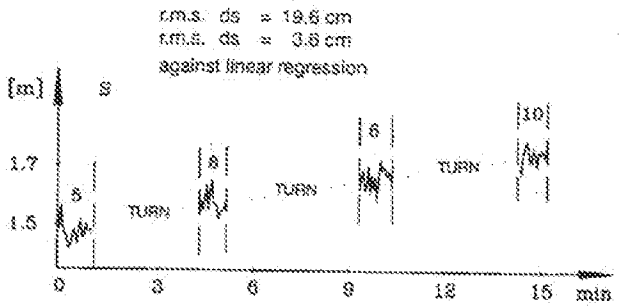


FIGURE 5 Flevoland test, strips 5, 8, 6, 10: linear drift error

COMBINED BLOCK ADJUSTMENT

GPS DATA AS ADDITIONAL OBSERVATIONS

We now turn to the utilization of GPS-determined camera air stations in aerial triangulation. The GPS position data, after reduction for antenna and time offsets, refer to the coordinates of the respective perspective centers of the aerial photographs. They represent observations of the position parameters of the exterior camera orientation elements. It is therefore an expedient approach to treat GPS camera positioning data as additional observations, and merge them, properly weighted, with photogrammetric aerial triangulation data into combined block adjustments. It is essentially the same approach that was formerly referred to as block adjustment with auxiliary (camera orientation) data. The photogrammetric aerial triangulation observations are assumed to be the same as in conventional aerial triangulation, with standard tie point distribution. The anticipated advantageous effects concern accuracy and reliability of adjusted blocks, as well as very much reduced ground control, as will be shown.

Treating GPS camera position data as additional observations raises the problem of their relation to the photogrammetric reference coordinate system, *ie*, whether drift or datum corrections are to be considered. In view of the above discussion, it is suggested to take linear GPS corrections into account, the parameters of which are treated as unknowns and solved for in the combined block adjustment. Linear corrections can be interpreted as drift errors or as datum corrections. The formulation should be such that three possible cases can be distinguished: (1) corrections not used at all, (2) one set of corrections for the whole block, (3) several separate sets of corrections for several subunits of a block; in the extreme case, each strip is treated separately, as the data may require. It is understood that this approach is intended as a safeguard measure to be used only if necessary, *ie*, not to lose flights if GPS data interruptions occur.

GPS OBSERVATION EQUATIONS WITH UNKNOWN DRIFT PARAMETERS

The observation equations for the reduced GPS camera station observations therefore read as follows:

$$\begin{aligned} X_j^{GPS} + V_{xj} &= X_{oj} + (a_o + a_1 t_j)_k \\ Y_j^{GPS} + V_{yj} &= Y_{oj} + (b_o + b_1 t_j)_k \\ Z_j^{GPS} + V_{zj} &= Z_{oj} + (c_o + c_1 t_j)_k \end{aligned} \qquad [1]$$

The prime unknowns are the X_o, Y_o, Z_o coordinates of the perspective centers j; they link the GPS data via the same unknowns to the bundle block adjustment or to the block adjustment by independent models. The terms (a_o, a_1, b_o, b_1, c_o, c_1)$_k$ represent

the unknown linear drift or datum parameters, assumed to be constant for any desired set k of data. The cases to be distinguished for k refer to: a zero set (no parameters at all), one set for the whole block, sets for groups of strips, or for strips individually. It is convenient to express the corrections as functions of GPS time t, starting for each set k at instant t_0 (in time), to which the shifts a_0, b_0, c_0 will refer.

The programming and execution of the block adjustment do not present any special problems. The normal equations can be partitioned into the various groups of unknowns, leading to the well-known banded-bordered reduced normal equations. Hence existing solution techniques can be applied. The case of combined block adjustment with GPS data has been treated in literature (see [1, 2, 3]). It is therefore not dealt with here further.

GROUND CONTROL

It is only the unknown drift parameters which require some additional consideration. They might not be determinable in general, because of singularities (rank deficiencies) in the combined block adjustment, unless certain precautions are taken. The most convenient and the safest way of taking care of rank deficiencies in photogrammetric blocks is the use of ground control points.

It is possible, in principle, to adjust GPS blocks without any ground control points at all. The slogan of "aerial triangulation without ground control" has raised considerable attention and seems to be highly attractive. However, the block adjustment results refer in that case to the WGS 84, leaving a subsequent datum transformation into a national geodetic coordinate system still to be done.

It is standard practice in photogrammetry to integrate the datum transformation into the block adjustment by making use of ground control points. It seems expedient, for practical reasons, to apply the same principle also with GPS blocks. Some few control points are sufficient to provide for the datum transformation. Placing control more or less at the corners of a block is suggested as the standard scheme for that purpose. In that case, one set of linear correction parameters according to equations *[1]* can be applied and determined, provided that the GPS recordings are not interrupted.

Four ground control points are not sufficient, however, for a block with standard (20 percent) side overlap, to solve for all drift parameters if each strip is given a separate set of parameters. Either two chains of additional vertical control points or two cross strips must be applied, as sketched in Figure 6. It is suggested, for the time being, always to use in practice one of the two options (a, b in Figure 6) for safety reasons. The GPS block can then be safely adjusted, even if GPS signal interruptions or discontinuities occur—which unfortunately cannot be ruled out in advance.

ACCURACY OF ADJUSTED GPS BLOCKS

GENERAL FEATURES

The general effects of GPS-positioned camera stations on the results of combined block adjustment are most favourable, as can easily be anticipated. Disregarding GPS drift and datum errors for the moment, it can be stated that GPS positioning of camera air stations is very precise, more precise than photogrammetric mapping requires. That statement is valid over the full range of large-scale to small-scale mapping. The result is equivalent to having a control point at each air station, or to having the three position parameters of the six elements of exterior orientation of each photograph directly and precisely measured. Thus, effectively, the blocks are extremely well controlled. It can therefore be expected that GPS blocks will have almost no error propagation in the orientation elements, the resulting block accuracy staying close to the mere intersection accuracy of the rays. It can also be concluded that the accuracy will be very little dependent on block size. And, most important, conventional ground control points are not required anymore for accuracy reasons, *ie*, to ensure or stabilize the accuracy of adjusted blocks, a function which is effectively taken over by GPS camera positioning. The function of ground control points will be restricted to datum transformation and, possibly, correction of additional rank deficiencies.

Those general considerations alone make aerial triangulation in combination with GPS camera positioning extremely interesting, with great economic prospects. The details need to be studied, as described below. The prime questions are the effects of GPS camera station data on block adjustment, and how much the additional GPS drift parameters will weaken the geometric stability of a block and reduce the generally most favourable accuracy features of GPS blocks.

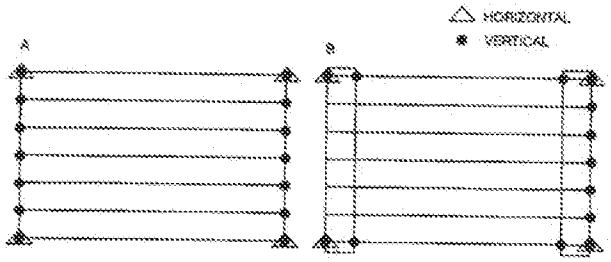


FIGURE 6 Standard ground control for GPS blocks

THEORETICAL ACCURACY EXPECTATIONS

There exist, to date, scarcely any real GPS blocks that would be suited for thorough investigation into the various accuracy features of GPS blocks after combined block adjustment. Their accuracy behaviour has been studied mainly by computer simulation and theoretical propagation of errors. Such studies are somewhat schematic. Nevertheless, they give insight into the effects of variation of project parameters. Only theoretical accuracy studies will be discussed here. It can be mentioned, however, that the Flevoland test block (actually a selection of seven strips, forming a block of standard overlap) was adjusted on the basis of ground control according to Figure 6(a) and with linear parameters applied per strip. The rms accuracy results of the combined block adjustment, derived from 41 horizontal and 35 vertical checkpoints, were $\mu_{x,y}$ = 2.1 cm, μ_z = 4.1 cm. Such

empirical values at least confirm independently that adjusted GPS blocks with minimum control actually do reach the expected high accuracy level. (Note: Since the submission of this paper in mid-1991, a number of GPS test blocks have been analyzed. Also practical application of GPS blocks has begun. The results, to be published elsewhere, confirm in general the high accuracy performance of combined block adjustment and demonstrate that an operational level of practical application has been reached.)

Preliminary simulation studies in 1986 exhibited the general high accuracy level of adjusted GPS blocks (see [4]). It was shown then that the resulting block accuracy is in the order of the photogrammetric measuring magnitude (σ_o, transformed into ground units) if the GPS accuracy is of the same order. It was also shown that block size has little effect, and that block adjustment is possible without any ground control as long as the relative kinematic GPS measurements are not interrupted.

In the following, some more recent theoretical investigation results are presented, based on the inversion of normal equations coefficient matrices of combined least-squares block adjustment (see [3]). The investigations took realistic conditions into account and concentrated on the effects of linear modelling of GPS drift or datum errors. The theoretical investigations actually refer to photo scale 1:30,000, block size 6 x 21 = 126 photos (6 x 20 stereo models), control according to Figure 6; the precision of measured image coordinates, which represent the weight unit, was assumed to be σ_o = 10 µm. The accuracy parameters taken into account were:

(1) the standard deviation of ground control coordinates (σ_{CP})

(2) the photogrammetric measuring precision (in the photo) of ground control points ($\sigma_{CP'}$)

(3) the accuracy of GPS camera station coordinates (σ_{GPS}).

It is recalled that the actual magnitudes of the standard errors are not essential because only the weight relations act in least-squares adjustment. The results can therefore be transferred to other cases. The combined block adjustment is based on the bundle method and takes the options of error modelling by linear drift parameters according to equations *[1]* into account.

Let us first consider the case of combined block adjustment without drift parameters. Figure 7 shows that the variation of ground control standard deviations (σ_{CP} and $\sigma_{CP'}$) has little effect on the accuracy of the adjusted blocks, almost independent of whether the accuracy of GPS camera positioning (σ_{GPS}) is very high, as referred to in Figure 7, or not. Figure 8 shows also that the accuracy of adjusted blocks is almost independent of block size, with or without the use of additional drift parameters. It can be concluded that the accuracy results of the subsequent investigations, which all refer to a block of 6 x 20 stereopairs, can be taken as representative for other blocks within ± 10 percent, the signs referring to smaller and larger blocks respectively.

The weak influence of the standard deviations of ground control points according to Figure 6 justifies the introduction of some generalizing assumptions which are in no way restrictive. We specify that the photogrammetric measuring accuracy of all image points (tie points and control points) is the same. In addition, the standard errors of the terrain coordinates, reduced to photo scale, are to be not larger than the standard errors of image coordinates—an assumption that is quite realistic and in agreement with standard practice. Thus with $\sigma_o = \sigma_{CP'} = \sigma_{CP/S}$ (s = scale number of photo scale), the accuracy investigations can be restricted to consider only the accuracy of GPS camera positioning (σ_{GPS}) and the various options for drift or datum corrections as main parameters, in combination with the two standard cases of ground control according to Figure 6. The results are summarized in Figure 9 (horizontal accuracy) and Figure 10 (vertical accuracy).

Figures 9 and 10 show the theoretical accuracy of adjusted GPS blocks (covering 6 x 20 stereopairs) as a function of the accuracy (σ_{GPS}) of the GPS camera positioning. The resulting accuracy after combined block adjustment is expressed as rms values $\mu_{x,y}$ and μ_z of the horizontal and vertical standard coordinate errors, respectively, of all adjusted tie points. The accuracy figures are given in cm, referring to a photo scale of 1:30,000. They are also converted to multiples of σ_o, which makes the results valid for

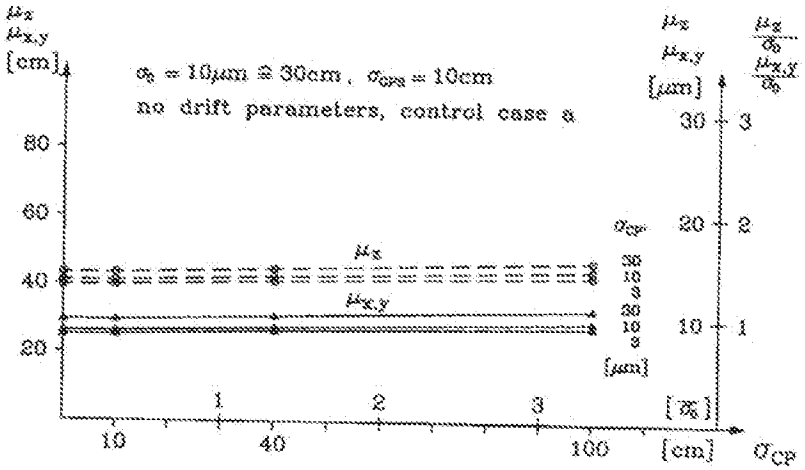


FIGURE 7 Effects of ground control errors (σ_{CP}, $\sigma_{CP'}$) on GPS blocks

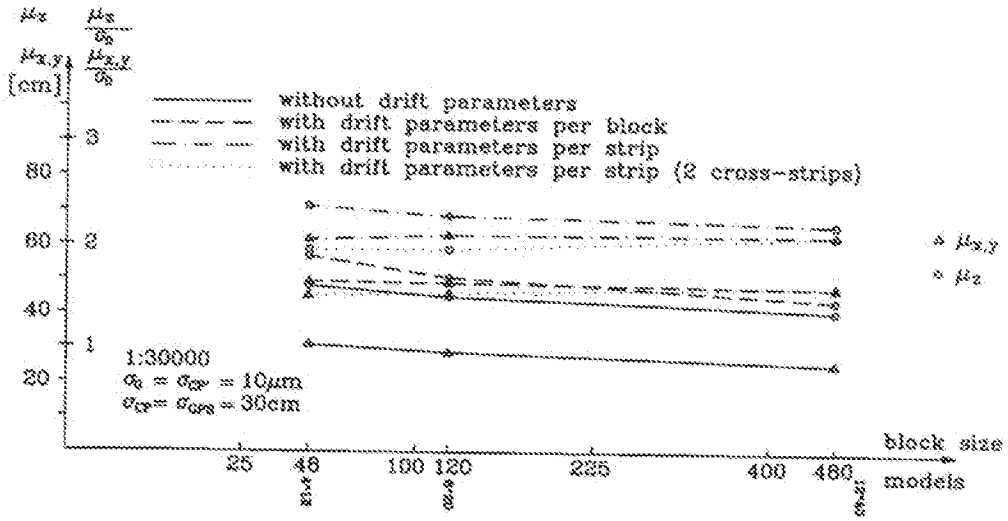


FIGURE 8 Influence of block size on GPS blocks

any other photo scale. The graphs show three different cases of drift corrections by block adjustment, in combination with the two suggested standard cases of ground control (Figure 6). They are:

(1) no drift parameters
(2) one set of drift parameters for the complete block
(3) an independent set of drift parameters for each strip separately (control case Figure 6a)
(4) drift parameters per strip (control case Figure 6b)

A discussion and interpretation of the results may distinguish between the cases of precise and less precise GPS camera positioning. Let us look first at the lower parts of the functions in Figures 9 and 10, representing block adjustment with precise GPS camera positioning, as specified by $\sigma_{GPS} \leq \sigma_0$. If GPS data are absolute, without drift errors, the camera stations have the absolute accuracy as determined by GPS. There is practically no propagation of errors in the block, and the resulting accuracy is determined only by the mere intersection errors of the perspective rays, amounting to $\leq 1.0\sigma_0 \times s$ and $\leq 1.5\sigma_0 \times s$ in X, Y and Z coordinates, respectively. That ideal result cannot be maintained if drift parameters are applied in the block adjustment, *ie*, if systematic GPS errors are to be taken into account and compensated by the combined adjustment. The additional parameters weaken the geometry of the system to a considerable degree. The rms horizontal coordinate

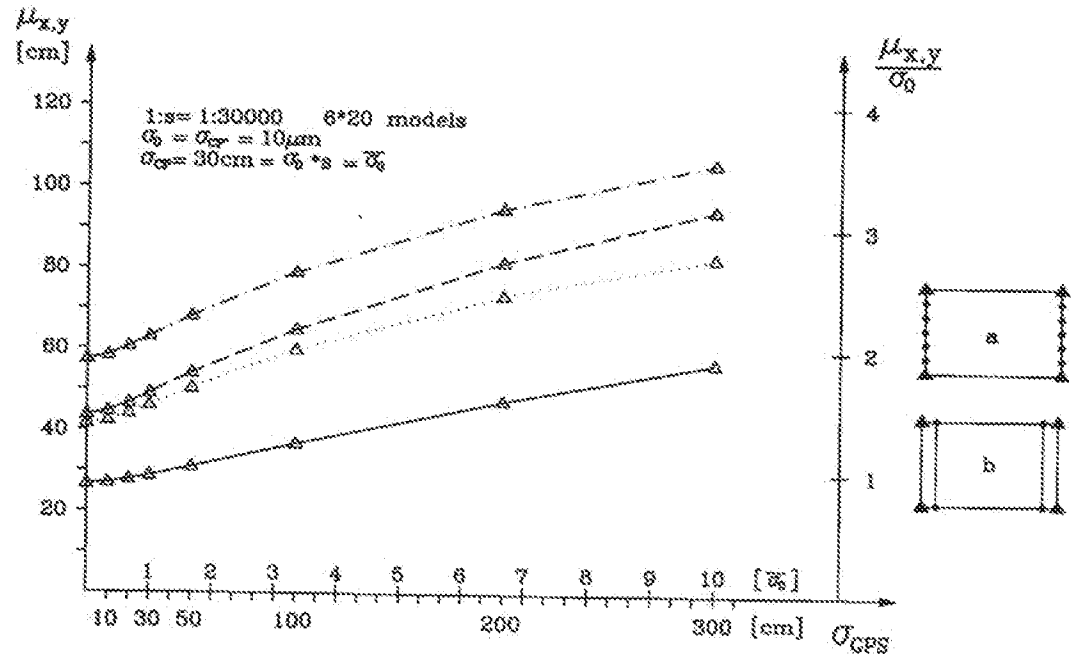


FIGURE 9 Influence of GPS camera positioning accuracy (σ_{GPS}) and drift parameters on horizontal accuracy ($\mu_{x,y}$) of adjusted blocks

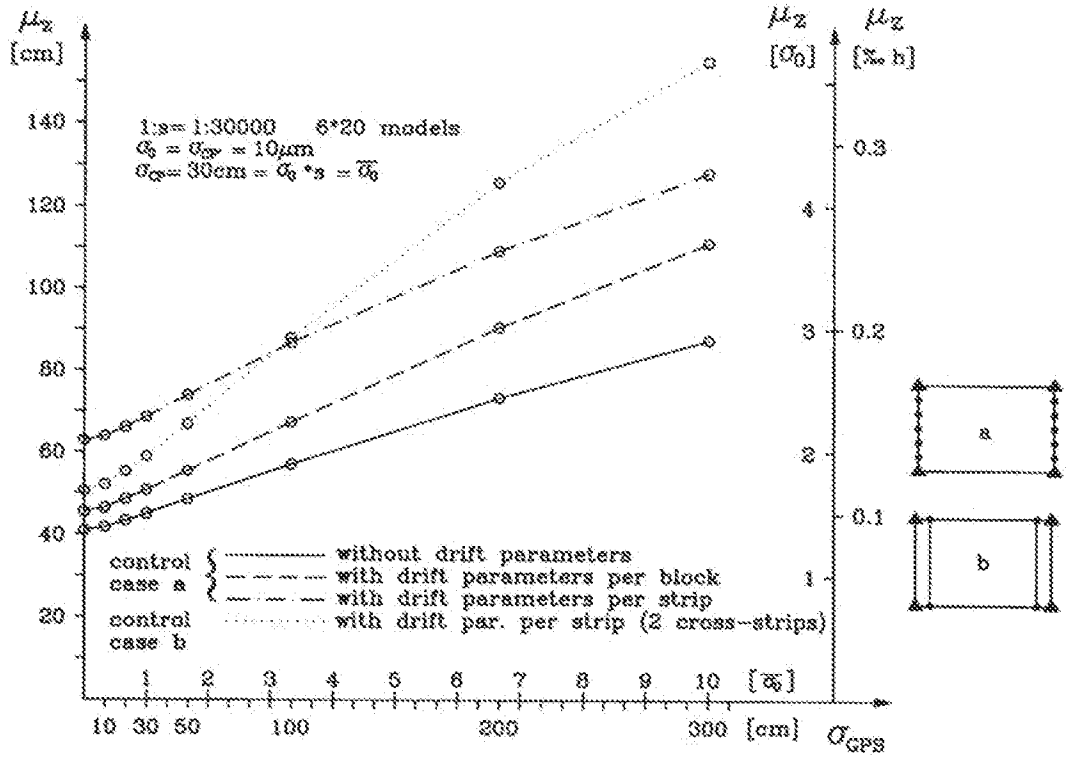


FIGURE 10 Influence of GPS camera positioning accuracy (σ_{GPS}) and drift parameters on vertical accuracy (μ_z) of adjusted blocks

errors $\mu_{x,y}$ are increased to $1.7\sigma_o$ x s and $2.1\sigma_o$ x s if blockwise or stripwise correction of drift errors is applied (respectively), compared with $1.0\sigma_o$ x s without drift errors. The respective values for μ_z are $1.7\sigma_o$ x s and $2.3\sigma_o$ x s, compared with $1.5\sigma_o$ x s. The blocks with cross strips (control according to Figure 6b) and stripwise drift corrections fit very favourably into the picture and can be compared with the blockwise drift correction of the standard control pattern A. The results are summarized in Table 1.

We now look at the accuracy funtions in Figures 9 and 10, and how they react to larger values of σ_{GPS}, *ie*, to poorer accuracy of GPS camera positioning. All relations increase monotonously with σ_{GPS}, at roughly similar rates (except for μ_z, case b). The most important feature is, however, that the rms coordinate errors increase rather slowly, at a much slower rate than σ_{GPS} itself. Even if the GPS camera positioning accuracy goes to $\sigma_{GPS} = 10\sigma_o$ x s, the magnitudes for $\mu_{x,y}$ and μ_z increase only by about a factor of two (except for μ_z in case of cross strips). The explanation relates to the well-known averaging effect if a block has many control points. We thus have the quite favourable relation that rather large GPS errors can be tolerated if the required block accuracy is only $2\sigma_o$ x s to $3\sigma_o$ x s in X, Y or 0.2 to 0.3 permille of h in Z.

APPLICATION TO MAPPING

This consideration is of considerable practical importance with regard to the application of GPS aerial triangulation for mapping at medium and small scales. In those cases there is a considerable margin between the actual photogrammetric measuring accuracy and the

TABLE 1 Accuracy of adjusted GPS blocks, standardized assumptions (control cases a and b)

If

$\sigma_{cp} = \sigma_o$, $\sigma_{cp} \leq \sigma_o$ x s, $\quad \sigma_{GPS} \leq \sigma_o$ x s (s = photo scale number)

Then

$\mu_{x,y} \leq 1.0\ \sigma_o$ x s	$\mu_z \leq 1.5\ \sigma_o$ x s	(a, no drift parameters)
$1.7\ \sigma_o$ x s	$1.7\ \sigma_o$ x s	(a, drift parameters per block)
$2.1\ \sigma_o$ x s	$2.3\ \sigma_o$ x s	(a, drift parameters per strip)
$1.5\ \sigma_o$ x s	$2.0\ \sigma_o$ x s	(b, drift parameters per strip)

blocksize: 6 x 20 models
smaller blocks: + 10% larger blocks: - 10%

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accuracy required for mapping. The acceptable rms errors $\mu_{x,y}$ and μ_z of adjusted blocks can be larger than $\sigma_o \times s$. It can therefore be concluded that the acceptable standard errors (σ_{GPS}) of GPS camera positioning can be even considerably larger than $\sigma_o \times s$.

This can be verified by inverting the relationships of Figures 9 and 10. We ask now which σ_{GPS} is required in order to meet given specifications for $\mu_{x,y}$ and μ_z. For that purpose, the relations of Figures 9 and 10 can be tranferred to different photo scales, taking the weight relations into account while maintaining the geometry of the blocks.

The results are summarized in Table 2. The required accuracies $\mu_{x,y}$ and μ_z of adjusted blocks have been schematically specified by referring to the conventional ratios between photo and map scales, as applied in practice and as expressed in the well-known von Gruber rule ($\mu_{x,y} = c/s_{map}$), and by assuming standard accuracy specifications of the maps (see first five columns of Table 2). The corresponding required accuracies (σ_{GPS}) of GPS camera positioning are also given in Table 2 for the four different cases of drift parameters and ground control.

The results show clearly that the accuracy requirements for GPS camera positioning are not critical at all for medium- and small-scale mapping. Even utilization of P code or C/A code pseudo-range observations could be sufficient in some cases. Even the poorest case, drift parameters per strip (3), meets the requirements for topographic mapping up to 1:25,000 map scale without requiring precise values for σ_{GPS}, the magnitudes of which can be 1 m or larger. In general, the requirements for the vertical accuracy of GPS positioning are somewhat more tight than for horizontal accuracy.

The specifications for large-scale mapping get more demanding as the map scales increase. Nevertheless, the GPS results can still meet the demands, especially as the project areas are usually small and flying times brief. GPS positioning accuracy with relative phase observations can realistically be expected to be in the order of 10 cm in those cases.

Summarizing the contents of Table 2, it can generally be concluded that GPS camera positioning and combined block adjustment can meet all accuracy demands for photogrammetric mapping. In particular, also minimum ground control specifications and the drift corrections are acceptable, although the latter weaken the geometric stability, especially if applied per strip. It is only the blocks for very large-scale mapping (1:1000) and the photogrammetric point determination (1:1) by combined block adjustment which require more specific investigations than presented here. It is expected, in any case, that also high-precision photogrammetric block adjustment will greatly benefit from the use of GPS camera positioning.

SUMMARY AND CONCLUSIONS

There is no doubt that GPS camera positioning is of the greatest interest and economic importance for aerial triangulation. It is applicable and highly effective over the full scale range of photogrammetric mapping. Its main effect is, in all cases, that the conventional number of ground control points can be greatly reduced, down to a very few points.

The method is ready for practical application as far as the GPS system is concerned. It is also ready for application as far as hardware is concerned. A number of high-quality receivers are on the market, and software development is quite well on its way. The originally simple programs for GPS data processing and kinematic GPS positioning have to be made more sophisticated in order to handle all possible disturbances, such as cycle slips, interruptions, phase ambiguities, inaccurate baselines, etc. Our group of experts in Stuttgart has such computer programs ready for application, as well as software for combined block adjustment, including drift correction capabilities.

There are a number of research topics that warrant further investigation. Additional experimentation is especially required concerning the behaviour of systematic GPS errors over long distances, up to several hundred km, and long periods of time, up to several hours. Also, operational use of GPS blocks has to be demonstrated by practical examples. At present (1991), a number of test blocks and pilot

TABLE 2 GPS blocks for mapping, required accuracy of GPS camera positioning

Map scale 1:	Photo scale 1:	Required AT accuracy $\mu_{x,y}$ (m)	Required AT accuracy μ_z (m)	Contour interval ΔH (m)	Required σ_{GPS} (1) x,y (m)	(1) z (m)	(2) x,y (m)	(2) z (m)	(3) x,y (m)	(3) z (m)	(4) x,y (m)	(4) z (m)
100000	100000	5	4	20	39	16	21	11	19	8.5	27	6.2
50000	65000	2.5	2	10	18	6.9	9.2	4.5	7.5	2.8	11	2.4
25000	40000	1.5	1.0	5	11	2.8	5.4	1.8	4.4	0.7	6.8	0.9
10000	25000	0.6	0.6	2.5	3.6	1.6	1.3	1.0	0.6	0.4	1.7	0.5
5000	12000 SWA(1)	0.3	0.25	1	1.9	0.3	1.0	0.2	0.3	-	0.9	0.05

σ_o = 10 µm
(1) σ_o = 12 µm for z

(1) control case a, no drift parameters
(2) control case a, drift parameters per block
(3) control case a, drift parameters per strip
(4) control case b, drift parameters per strip (2 cross strips)

applications are under study in several countries. Results will be available in the near future. The datum problem also needs additional attention. GPS-supported aerial triangulation requires, in principle, good knowledge of the local geoid, although approximations will do in most mapping applications. With regard to national geodetic coordinate systems (such as UTM), the anticipated ideal solution would be that absolute transformation formulae could directly transform WGS 84 coordinates into the national grid within 10 cm accuracy, without relying on common control points in the project area. Finally, large-scale high-precision applications of photogrammetry, which require GPS accuracy of a few cm, will have to be given a closer look.

In view of the moderate GPS accuracy required for mapping (according to Table 2), none of these research items is particularly critical. Hence the practical applications of GPS will not have to wait until additional research results are available.

The relative kinematic camera positioning has its first application in aerial triangulation. There are also several extensions and additional applications in sight, just mentioned here without further elaboration.

(1) GPS can be used also for attitude determination. The idea is to place three GPS antennae on the wings and body of the airplane to form a triangle as large as possible. By interferometry, coordinate differences between the three antennae can be established to an accuracy of about 1 mm. Thus attitude values can be derived in the accuracy order of 10^{-4} radians, or 6 mgon. Hardware developments and investigations into the accuracy and the potential use of GPS attitude determination have recently been initiated.

(2) With or without GPS attitude data it will be possible, for a number of applications, to simplify aerial triangulation to some extent and still get results sufficient to meet mapping specifications. Still, precise and direct measurement of all six parameters of exterior orientation by GPS is far ahead. Nevertheless, some applications are conceivable where orientation by GPS might be used directly, avoiding the process of aerial triangulation completely.

(3) GPS sensor positioning (other than cameras) is gaining in importance. Examples include positioning of multispectral scanners, laser or radar profilers or scanners and digital linear array cameras (of MOMS type). Most encouraging results have already been obtained. It can be expected that the use of relative kinematic GPS positioning will develop very much beyond the presently scheduled applications.

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RÉSUMÉ

Le principe de positionnement de caméra de haute précision par des observations relatives de phases GPS cinématiques est posé et son application à la triangulation aérienne par ajustement combiné est passée en revue. Après la discussion de certains problèmes pratiques, les possibilités de précision des blocs GPS sont étudiées du point de vue théorique. Une attention particulière est portée à l'occurrence et à la compensation d'interruption de signaux et des erreurs de dérive qui en résultent. Des recherches empiriques ont confirmé le potentiel élevé du positionnement GPS. Son application à la triangulation aérienne est très économique, car les contrôles au sol peuvent être considérablement réduits. Le système est prêt pour l'application pratique.

RESUMEN

Se explica el principio de posicionamiento topográfico mediante el uso de cámaras GPS de alta precisión que permiten lecturas seriales en base al movimiento relativo de la tierra, y se revisan sus aplicaciones a la triangulación aérea por ajustes combinados. Después de discutir algunos problemas prácticos, se realiza un estudio teórico del mejor rendimiento de precisión alcanzable en bloques de GPS. Se le da atención particular a la ocurrencia y compensación de interrupciones de señales y a los consecuentes errores por desplazamiento. Investigaciones empíricas han confirmado el potencial de alta precisión, que puede esperarse del posicionamiento mediante GPS. Su aplicación a la triangulación aérea es altamente económica por reducir considerablemente el control en tierra. El sistema está listo para aplicación práctica.

Pictometry digital video mapping

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ABSTRACT

Pictometry is a proprietary digital imaging process which computationally maps each pixel of a digital land image to actual geographic coordinates, so that features in a mosaic of land images may be located and or measured.

1. Background

Up to now images and maps have occupied totally distinct realms because the image which depicts space could not be expected to be scaled to georeferences and maps which model space with georeferences could not be expected to contain photographic detail. Pictometry brings the image and map together into a new compound form.

For some years computers have played a role in mapping land use. Geographic Information Systems (GIS) are now well known to planners and engineers, and other public and private agencies. Also well known to all GIS users are its two greatest problems which have to do, one with input and the other with output.

On the input side manual vectorization of paper or raster images of maps is time consuming and fraught with error. Even with computer assisted automation schemes the time and expense of assembling data has left many GIS systems incomplete.

On the output side the GIS uses its newfound interactive electronic potential to allow zooms in and out of standard two dimensional, bird's- eye- view maps. Two dimensional maps are an important tool of the pre-information age in that they were able to compress representations of space for the limited capacity afforded by paper delivery systems; that limited capacity had to leave out a third dimension on which human brains rely for orientation. The orthogonal (straight down) perspective is disorienting, in that it does not map to cognitive visual memories of space to which the brain has become accustomed by reason of the eye's movement in real space . Electronic image

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disorienting, in that it does not map to cognitive visual memories of space to which the brain has become accustomed by reason of the eye's movement in real space . Electronic image delivery systems now afford the capacity to deliver the third dimensional perspective and also, with interactive windowing, can contain much more detail. Up to now, oblique perspectives and zooms in and out have not been applied to photogrametry because of their lack of predictable scale and registration.

For more than a decade I and my associates have worked to provide oblique aerial and ground images to depict land and buildings. Using laser and optical disks, which afford both enormous storage and random frame access, spaces such as the Kremlin and entire cities such as Rochester NY and more than fifty other American cities and towns have been captured using this patented technology known as Landisc™. (Methods and devices used to capture and present these land images on laser disc are the subjects of a US Patent which I hold NO 4,635,136). The Landisc technology has won several public technology awards including the 1986 Innovations in State and Local Government, award, where the Rochester Landisc project was selected from 1,350 nominations by a panel of national leaders and the Harvard Kennedy School of Government for a Ford Foundation Award, which resulted in the production of Skydisc.

In Skydisc, oblique aerial images of the entire City of Rochester NY, on three levels, are presented in a moving window so that the user can quickly become oriented in the photographic (rather than two dimensional graphic) representation of space. In addition to orientation the angle and focus of the images provides the heretofore unseen lateral features of land and buildings which would otherwise be available only by time consuming and expensive field surveys. For example the user can actually see the condition of the bridge or highway, or the quality of a neighborhood or can count the cracks, flooding or other effects on a single lot or in an entire region.

The millions of laser disc images already stored on Landisc™ systems and the experimental Skydisc™, while they provide better orientation and a closer look at real features of the land and buildings are not automatically georeferenced, and therefore have to be coordinated with separately compiled spatial data such as addresses or coordinates "wiped" onto the video in production or overlaid in post production.

On September 21, 1993 a new US patent No. 5247356 was issued to me for pictometric video mapping, a method and device for automated georeferencing of oblique aerial video images. The new software attached to this method maps each pixel in the digital image to associated ground coordinates.

Thanks to the developments in digital image processing and computer mathematics this process can be wholly automated.

Pictometry's hardware and software allows hand held simultaneous image and data capture and instant image/map production. The fact that objects or subjects can be accurately located within digital images seconds after the image is captured represents a timely breakthrough. The fact that the pictometric images can be acquired on foot or from any size vehicle, manned or unmanned aircraft, fixed wing or helicopter at any angle, from any location, and most importantly, by anyone who can point and shoot adds a new perspective to visual information. The ease and cost efficiency of acquiring image/maps will be welcomed by the ever growing need to survey and monitor objects and subjects.

Scanned digital images or images captured with digital cameras such as those of the Kodak line can be instantly processed in a Pentium ™ lap top or work station computer running current versions of Windows™. Proprietary code and friendly graphical user interfaces locates miniature copies of the images or tiles by geographic coordinates in a mosaic of the project area which may be perused and zoomed at any level of detail. Within each image any point can be located in terms of geographic coordinates and sets of points can be measured.

Should different angles of the same area be required the mosaic reflects this in its tile placement affording easy access to different angles of the same area or transition to adjoining areas. Multiple angles would be useful for a more detailed inspection of three dimensional objects such as buildings.

National and international publicity surrounding the announcement of the patent and proof of concept projects have added many new potential users in both the private and public sector, such things as ecological surveys, mineral prospecting, surveillance, routing and personal navigation systems. Potential customers for the technology have unanimously come to the conclusion that decisions based on this "coordinated", recognizable visual data, with or without GIS will be more informed and more efficient.

The methods and devices described below are wholly owned by John A. Ciampa and are protected by copyright, US Patent No. 5247356, mentioned above and by a pending patent application filed on June 1, 1995

2. METHODOLOGY

The method involves four phases Preproduction, Production, Postproduction and Display:

2.1 Pre Production

In a simple graphical user interface, the user inputs project area, viewing requirements, storage constraints, camera and image details whereupon production estimates for the number of images, storage capacity and altitude are recommended.

Input Project Area

For example the user may describe an entire State, or a particular construction site in square miles, meters or feet.

Input Minimum Object Area

The user then enters in the appropriate box the size of the minimum viewed object. It may be a house, car, tree, leaf, etc. This object area may be roughly estimated, e.g. 5 square centimeters, 10 square meters, etc.

Input Lens and Image Plane Area

The user enters the focal length of the lens which will be used and or the image or film plane area. Should this be unknown the software will have look up tables for standard formats. Should the user leave out focal length, the preproduction software will recommend a focal length, in light of the other entered variables.

Output Production Requirements

Based on user inputs, the preproduction software will now suggest an altitude to be flown, the number of images, speed over ground, allowing sufficient time for each shot and overlap system requirements; in addition the storage requirements for the total project images will be estimated. The user may change any of the input variables so as to accommodate requirements to existing circumstances or facilities. For instance the altitude suggested may be too low or too high. By tweaking the altitude the other production requirements will change accordingly.

2.2 Production

Any camera and lens as specified in the Preproduction routine joined to the palm sized shot data instrument box may be hand held on land, sea or up in an aircraft Sufficient field storage will have been estimated in the Preproduction phase so that the correct amount of memory cards, or other storage systems will be on board.

Two cameras one on each side of the vehicle or aircraft would sweep double swatches which would theoretically double the production efficiency for a given region.
Should the application require multiple angles or perspectives of the same ground features with different points of view, assembly of crossing shot paths is made simple by the software.
In the field, pictometric coordinates may trigger prerecorded label data which may be superimposed on the image , such as street addresses as described in the Ciampa, Landisc Patent 4,635,136

2.3 Post Production

Upon the completion of field production the stored images and shot data may be reprocessed for greater accuracy by means of reconciliation, justification or reckoning.

Reconciliation

Pre-fix or known points or linear distances may be entered in any or all of the images. As the user browses through the mosaic of images and identifies a monument such as a telephone cell, street intersection, or other pre-established fix, the system will display

its calculated fix and/or linear distance; the variables may be automatically fine tuned by inserting a corrected fix or distance.

Justification

Pictometric coordinates may also be fine tuned with proprietary optimization algorithms, making use of databases of known ground truth.

Reckoning

Where greater accuracy is required and the project circumstances make "justification" and/or "reconciliation" impossible, an additional software system may be employed which passes verification along from frame to frame beginning with a single known point. "Pictometric reckoning" provides a new level of efficiency and accuracy where continuous reconciliation is impossible. Images processed by this method calculate adjustments to geographic coordinates based on changes in the relative position of recognized, discrete, stationary, digital image elements in the successive scenes of a shooting path. Georeferenced corner coordinates of a first frame are deduced from a single given fix and then passed on from segment to segment. The inside picture control for the movement of the imaging device is a pre-established earmark in the first image and subsequent earmarks or discrete image elements in succeeding images. After the first registered earmark passes out of the picture, and after corner coordinates are passed on to the next image, a discrete image element is selected from the next scene and its location is fixed according to the verified corner coordinates of the previous scene. The corner coordinates of the current scene are now accordingly updated and the process is repeated through all successive scenes or images. In addition to the induced shot data, each image file now has "pictometrically deduced" coordinates. These "pictometrically deduced" coordinates are reconciled with the trigonometric coordinates induced from the shot data with intelligent error adjustment algorithms. The combination of these divergent variables lock stitches a new level of accuracy into each image file.

2.4 Display

Access

Digital images are accessed by simple cursor moves. Should the cursor move outside the border of the current image file, the next contiguous image is seamlessly moved onto the screen. Image file management is done by geographic header data and therefore the screen acts as a moving window on the entire project area. Each digital image automatically becomes an appropriately placed tile in a mosaic. If shots are taken at several different angles, a different viewing angle may be selected for the same area.

Orientation

The entire project area is graphically represented in a corner of the display screen, while any level of zoom is being displayed in the larger main window. The mosaic may be moved to the larger window and the tiles may be set at any level of zoom.

Image Browsing

During installation, the user may configure the display software according to hardware limitations. For instance, if memory constraints are present, the user may select image reduction which allows the user to browse a mosaic of shots at lower resolution until greater detail is required and then the shot which contains the detail will be swapped into high resolution.

3. APPLICATIONS

Surveys, mineral prospecting, surveillance, routing , vehicular and personal navigation systems and geographic information systems (GIS)can all benefit from Pictometric image/maps.

The international market for the Pictometry image/maps must be estimated in the multi billions, if we take into account only the obvious government needs for surveillance, security, legal descriptions and geographic information systems.

Pictometry is useful for any visual inventory of persons places or things where simultaneous geo-location and time are required. In this latter use, since the pictometric image knows where it is in space and time, pre-established accompanying data can be retrieved using pictometry coordinates, which data can suggest what is expected to be in the particular place (for example a building address; or a particular numbered utility, vehicle or missile); the suggested label can be instantly affirmed or updated, eliminating the time and error potential of field data entry. Images of subjects and objects can be amassed and linked to data bases for purposes of appraisal and inventory control of such items as real estate, weapons, vehicles, general stock, etc..

3.1 Geographic Information System Enhancement

Place features such as hydrology, river banks, flood planes, railways and other utilities can be identified in the pictometric image and then exported to GIS system for planning purposes.

3.2 Monitoring

Precious or dangerous persons or objects can be plotted and tracked in the pictometric image . Persons or objects can be fitted with existing emitters which send coordinates, so that present location is instantaneously plotted in pictometric images. With a Pictometric image map a single monitor can track thousands of subjects and objects, plotting the subjects movements within a meaningful visual scene. Subject location signals in the context of Pictometric image/maps can trigger required reactions almost

instantly.The coordinates alone would not be as helpful as the plotted image. A single monitor can set corridors in pictometric images, schools , banks, etc.. so that when the object or subject enters the corridor the entry is signaled and noted.

Probationers in several jurisdictions have been fitted with leg bracelets which use microwave and cellular phone technology to transmit location variables of the wearer. The plotting of these paths on pictometric images makes such a system more intelligent. Soaring prison costs could be eroded by such a system. National borders and other peace keeping and ecological perimeters could be monitored from the comfort of a desk top.

Remote sensing for rural development planning in Africa

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ABSTRACT

Multi-level remote sensing techniques were combined to provide land resource and land use information for rural development planning in Arusha Region, Tanzania. Enhanced Landsat imagery, supplemented by low-level aerial survey data, slope angle data from topographic sheets, and existing reports on vegetation and soil conditions, was used jointly by image analysts and district level land management officials to divide the region's six districts into land planning units. District planning officials selected a number of these land planning units for priority planning and development activities. For the priority areas, natural colour aerial photographs provided detailed information for land use planning discussions between district officials and villagers. Consideration of the efficiency of this remote sensing approach leads to general recommendations for similar applications. The technology and timing of data collection and interpretation activities should allow maximum participation by intended users of the information.

Human and natural resource data are often unavailable in the format, quality and quantity required for planning rural development; new data acquisition is therefore usually an important part of the planning process. It is a challenge to planners to collect efficiently the information they need without being overwhelmed by the costs of data collection and analysis. Remote sensing is being increasingly used to reduce the time and cost of data acquisition. Remotely sensed information in itself, however, has limited value unless its collection and analysis are carefully integrated with the planning process.

The Tanzanian government assigned us the task of collecting and interpreting land resource information for village development planning in Arusha Region, one of 22 regions of Tanzania. It covers an area of 82 400 km^2, including the Rift Valley of northern Tanzania and the surrounding highlands and plains. The region is bounded by, but does not include, Mount Kilimanjaro on the east and Serengeti National Park on the west. It comprises Arusha Town and six rural districts, including 133 wards composed of 463 villages. The 1978 population was 928 475 (88 200 in Arusha Town). Agricultural land occupies approximately 5 percent of the total land area; grazing land occupies approximately 85 percent. The remainder is montane forest, wildlife reserves and lakes [2].

Intensive village planning depends on the ability to group similar villages into larger planning units--which allows typically overworked planning staff to concentrate on a few villages that are representative of the others in the same unit. Further elaboration of this strategy and its rationale can be found in recent publications on farming systems research and development [6, 14, 19, 21]. In brief, the principal underlying assumption is that solutions developed for problems in the representative villages can be successfully extended to other villages in the same planning unit. The planning staff can establish their work priorities by selecting planning units which have the greatest need or potential for development. They can then concentrate initially on villages representative of the priority units. Planners give such choices political legitimacy by applying acceptable decision criteria to an objective data base.

The criteria used to group villages necessarily vary, depending on the type of development activity being planned. In Arusha Region, the dominant economic activity is subsistence herding and rainfed agriculture. The regional planners therefore decided that villages should be grouped into *land planning units* based on topography, natural vegetation, soils and current land use.

The planners decided on a two-step procedure for collecting the land resource information. Step one was a rapid reconnaissance to provide enough objective data to divide the region into a manageable number of land planning units and to determine legitimately which units should have priority for development planning. In step two, the high-priority units were surveyed in detail to provide adequate data for selecting the representative villages. The survey also provided sufficient information about these villages (including the whole area used by villagers) to start the intensive planning process in collaboration with the villagers themselves.

We attempted to minimize the time, money and personnel needed for data collection and interpretation by using a combination of remote sensing techniques. The objectives of this article are to illustrate our use of remote sensing techniques and to discuss the efficiency of our combination of techniques in meeting the planning needs of government officials and villagers.

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