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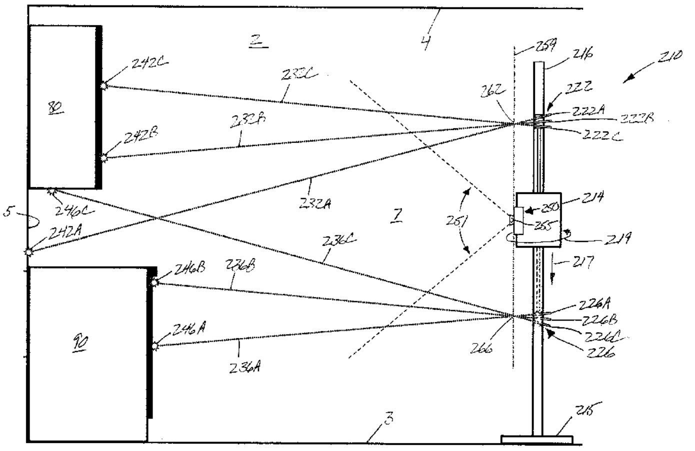


FIG. 10B

(57) **Abstract**: An apparatus for measuring an enclosed space. The apparatus is comprised of a support pole; a fixture engaged with the support pole; a driving device engaged with the fixture to rotate the fixture around the support pole and translate the fixture along the support pole; a camera mounted on the fixture and positioned facing outwardly from the fixture and having an image pupil and a field of view containing a portion of the surfaces of the enclosed space; a plurality of lasers joined to the fixture, the lasers directing laser beams outwardly from the fixture to the portion of the surfaces of the enclosed space that are contained within the field of view of the camera; and a processor in signal communication with the camera, the processor containing an algorithm to process images of the surfaces and calculate distances from the image pupil to the laser spots on the surfaces.

APPARATUS AND METHOD FOR MEASURING ROOM DIMENSIONS

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] This application claims priority from U.S. Provisional Patent Application No. 61/549,718 filed October 20, 2011, the disclosure(s) of which is/are incorporated herein by reference.

TECHNICAL FIELD

[0002] Apparatus and methods for measuring rooms and other three-dimensional spaces having boundaries.

BACKGROUND ART

[0003] Computer aided design (CAD) and manufacturing (CAM) has been widely adopted across a range of industries, including the construction industry. Residential and commercial buildings are now routinely designed in complete detail using these tools. The designs may include not only the structural walls and infrastructure (plumbing, wiring, heating/cooling, etc.), but also all of the decorative trim, lighting, cabinetry, and furnishings. These various items to be installed or placed in a given room can be specified and even custom manufactured to fit within the room, based upon the design as provided in a three-dimensional model of the facility in a CAD file. This is simple to achieve, because in a “clean sheet” design of a facility, all of the dimensions of the respective rooms are known, and exist as data within the 3D CAD file.

[0004] However, a significant portion of construction work in the overall economy involves remodeling, in which an existing room may be updated to more current construction standards, or refurnished with newer furnishings, or simply refurbished with more aesthetically appealing décor. In order to execute any of these sorts of projects, computer aided design can be a significant productivity tool. However, in order to effectively use CAD in a substantial remodeling project in a room, the first step is to obtain a 3D model of the room, from which the various steps of the CAD design of the remodeled room can proceed, which may include modifications to the structural walls, floors, and ceiling, the infrastructure, and/or the decorative trim, lighting, cabinetry, and furnishings. For most residential and commercial buildings more than 15 years old, no such useable 3D model files exist, or at the very least, no files that are compatible with present computers and 3D modeling software exist.

[0005] Accordingly, a 3D model of the room must be created from scratch. This involves a painstaking and labor intensive procedure in which all dimensions of all surfaces and structures in the room are measured and recorded. A CAD design technician then creates a 3D model of the room using a 3D CAD program such as SOLIDWORKS® by the SolidWorks Corporation, INVENTOR® by Autodesk Inc., or CREO™ by PTC. This measurement, transcription, and model building process has many opportunities for errors to occur, human or otherwise, or may lack completeness of detail or overlook imperfections in construction.

[0006] Certain three-dimensional scanning technologies and systems are available commercially today. However, these systems typically rely on measuring the "time of flight" for laser light to be projected from a laser, be reflected from a surface, and return to a sensor system on the device. By measuring the time taken for light to travel to the surface and back to the sensor, a distance can be determined due to the known and consistent speed of light.

[0007] However, due to the extremely high speed of light, sophisticated and expensive sensor and electronic systems are required to ensure a useful level of accuracy. Accordingly, commercially available systems sold for the purpose of creating accurate three-dimensional computer models are quite expensive and not suitable for many day-to-day applications due to the cost. What is needed is a three-dimensional room measurement system that is low in cost, highly accurate, and easy to use.

SUMMARY

[0008] In a broad, general aspect of the invention, there is provided an apparatus and method for measuring the distance from a known point to various surfaces in a three-dimensional space, such as a room. By measuring the distance from that known reference point to many surfaces in the space, enough data can be acquired to create an accurate three-dimensional computer model of that space. The apparatus is capable of self-controlled rotation and movement in at least one other axis in order to gather more measurement information than is attainable from a single perspective. The other axis of motion of the apparatus may be vertical, but is not limited only to vertical motion.

[0009] In a first aspect of the invention, an apparatus for measuring and imaging a room is provided. The apparatus is comprised of a distance meter joined to a fixture that is engaged with a supporting structure, and a plurality of light sources joined to the fixture, the light sources directing light beams outwardly from the fixture.

The fixture is operable so as to scan the light beams over the room surfaces while measuring distances from the fixture to the room surfaces with the distance meter. The apparatus may be further comprised of a camera for acquiring images of the room surfaces. The apparatus may include a processor that receives and stores distance data from the distance meter and/or images acquired by the camera. The processor may include an algorithm to analyze the distance data and/or images and calculate the dimensions of the surfaces of the room. Alternatively, the image processing to produce the 3D model may be performed entirely by a processor (not shown) that is external to the apparatus. In such circumstances, the digital images and the correlated apparatus positional data may be communicated to the external processor, or to an external memory or other data storage device such as a hard disk drive or memory card via wireless communication means, or a hard-wired network connection (not shown) that may be connected to the processor. The communication to the external processor may be in real time during the measuring and imaging, or the communication may be after completion of measuring and imaging the room.

[0010] The apparatus may include a Global Positioning System (GPS) device to identify and record the particular location at which the measurements and/or images are being taken. The apparatus may include means for wireless communication of input data to the processor and/or room measurement data and images from the processor. The apparatus may include a motion controller that controls the motion of the fixture to scan the light sources and the camera over the surfaces of the room. The apparatus may include an electronic level for defining a horizontal plane as a datum during the room measuring.

[0011] In a related aspect of the invention, a method for measuring and imaging a room is provided comprising directing light beams from a plurality of light sources outwardly from a fixture while operating the fixture to scan the light beams over the surfaces of the room, measuring distances from the fixture to the room surfaces, analyzing the fixture-to-surfaces distance data, and calculating the dimensions of the room.

[0012] In a second aspect of the invention, an alternative apparatus for measuring and imaging an enclosed space containing surfaces is provided. The enclosed space may be a room. The room may contain objects in contact with the walls of the room, or free standing within the room. The apparatus is comprised of a support pole; a fixture engaged with the support pole; a driving device engaged with the fixture so as to rotate the fixture around the support pole and translate the fixture along the support pole; a camera configured to acquire images of the enclosed space, the camera mounted on the fixture and positioned facing outwardly from the fixture and having an image pupil and a field of view containing a portion of the surfaces of the enclosed space; a motion control module in signal communication with the first driving device and obtaining linear position data and angular position data of the camera; a plurality of lasers joined to the fixture, the lasers directing laser beams outwardly from the fixture to the portion of the surfaces of the enclosed space that are contained within the field of view of the camera; and a first processor in signal communication with the camera, and with the motion control module, the first processor containing a program to correlate each image of the surfaces of the enclosed space acquired by the camera with the linear and angular position of the camera when the image was acquired.

[0013] In certain embodiments, the program may include steps to process the images of the surfaces of the enclosed space, and for each acquired image, to identify laser spots on the surfaces of the enclosed space, and calculate distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired. The program may further include a calculation of the dimensions of the enclosed space based upon the calculated distances from the image pupil to the laser spots on the surfaces and the linear and angular position data obtained when images of the surfaces of the enclosed space are captured by the camera. The program may include instructions for calibrating the field of view of the camera to account for the effect of distortion by the camera on an acquired image.

[0014] The enclosed space may include surfaces of walls bounding the enclosed space, and surfaces of objects contained within the wall surfaces, and the program may include a calculation of the dimensions of the wall surfaces and the object surfaces. The program may further include characterization of textures and/or colors of the surfaces of the enclosed volume.

[0015] The apparatus may be further comprised of a second driving device engaged with the support pole of the apparatus and configured to move the support pole and the fixture within the enclosed space. The apparatus may be further comprised of a second processor located external to the fixture and in signal communication with the first processor. The second processor may include program instructions to process the images of the surfaces of the enclosed space, and for each acquired image, to identify laser spots on the surfaces of the enclosed space, and calculate distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired.

[0016] In certain embodiments, a first laser is mounted on a first support extending outwardly from the fixture, and a second laser is mounted on a second support extending outwardly from the fixture in a direction opposite to the first support. In other embodiments, a first laser is mounted on a first support extending vertically upwardly from the fixture, a second laser is mounted on a second support extending vertically downwardly from the fixture, a third laser is mounted on a third support extending horizontally from the fixture, and a fourth laser is mounted on a fourth support extending horizontally from the fixture in a direction opposite of the third support.

[0017] In certain embodiments, the apparatus may be further comprised of four laser sets, wherein a first laser set is mounted on a first support extending vertically upwardly from the fixture, a second laser set is mounted on a second support extending vertically downwardly from the fixture, a third laser set is mounted on a third support extending horizontally from the fixture, and a fourth laser set is mounted on a fourth support extending horizontally from the fixture in a direction opposite of the third support. The first, second, third, and fourth laser sets may be comprised of at least two lasers. The first, second, third, and fourth laser sets may be comprised of three lasers. The three lasers may be a red laser, a blue laser, and a green laser.

[0018] As noted previously, the image processing to produce the 3D model may be performed entirely by a processor (not shown) that is external to the apparatus. In such circumstances, the digital images and the correlated apparatus positional data may be communicated to the external processor, or to an external memory or other data storage device such as a hard disk drive or memory card via wireless communication means, or a hard-wired network connection (not shown) that may be connected to the processor. The communication to the external processor may be in real time during a scan of an enclosed space, or after completion of the scan.

[0019] In a third aspect of the invention, there is provided a method for measuring the dimensions of an enclosed space bounded by surfaces. The method comprises moving a fixture supporting a camera and at least two lasers in rotational and linear motion so as to scan the laser beams of the at least two lasers along the surfaces of the enclosed space to produce laser spots on the surfaces, the laser spots being within the field of view of the camera; capturing images of the surfaces of the enclosed space with the camera while acquiring rotational and linear position data of the camera; identifying the rotational and linear position of the camera for each acquired image; and identifying within each acquired image the laser spots on the surfaces of the enclosed space, and calculating distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired. The step of calculating distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired may be performed by an algorithm using parallax triangulation.

[0020] The method may further include calculating the dimensions of the enclosed space based upon the calculated distances from the image pupil to the laser spots on the surfaces and the linear and angular position data obtained when images of the surfaces of the enclosed space are captured by the camera.

[0021] The method may further include calibrating the field of view of the camera to identify the amount of distortion by the camera on the captured images, and calculating the dimensions of the enclosed space based also upon the amount of distortion by the camera on the captured images. The method may further include creating a three-dimensional model of the enclosed space. The three dimensional model may include textures and/or colors of the surfaces of the enclosed space. The three dimensional model may include wall surfaces of the enclosed space, and objects contained within the wall surfaces.

[0022] In a fourth aspect of the invention, there is provided a computer-implemented method of measuring the dimensions of an enclosed space bounded by surfaces comprising moving a fixture supporting a camera and at least two lasers in rotational and linear motion so as to scan the laser beams of the at least two lasers along the surfaces of the enclosed space to produce laser spots on the surfaces, the laser spots being within the field of view of the camera; capturing digital images of the surfaces of the enclosed space with the camera while acquiring rotational and linear position data of the camera, and communicating the digital images and the corresponding rotational and linear position of the camera when each digital image was acquired to a processor; processing the digital images with the processor to identify within each acquired image the laser spots on the surfaces of the enclosed space; with the processor, calculating distances from the image pupil of the camera to the laser spots on the surfaces; and with the processor, calculating the dimensions of the enclosed space based upon the calculated distances from the image pupil to the laser spots on the surfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The present disclosure will be provided with reference to the following drawings, in which like numerals refer to like elements, and in which:

[0024] FIG. 1A is a side elevation view of the Applicants' room measurement apparatus;

[0025] FIG. 1B is a detailed side elevation view of the portion of the apparatus of FIG. 1A denoted within the bracket 1B in FIG. 1A;

[0026] FIG. 2 is a schematic diagram of a portion of one embodiment of the Applicants' room measurement apparatus;

[0027] FIG. 3 is a perspective view of the room measurement apparatus of FIGS. 1A – 2 in the process of measuring a room;

[0028] FIG. 4 is a perspective view of another embodiment of the instant room measurement apparatus in the process of measuring a room;

[0029] FIG. 5 is a perspective view of the instant room measurement apparatus measuring a room from different locations within the room;

[0030] FIG. 6 is a flowchart depicting a method of measuring a room using the Applicants' apparatus;

[0031] FIG. 7 is a schematic front perspective view of another embodiment of the instant room measurement apparatus;

[0032] FIG. 8 is a top view of the apparatus of FIG. 7, taken along line 8 – 8 of FIG. 7;

[0033] FIG. 9 is a side elevation view of the apparatus of FIG. 7, taken along line 9 – 9 of FIG. 7 and shown disposed in a simple rectangular shaped room;

[0034] FIGS. 10A-10C are side elevation views depicting the apparatus of FIGS. 7-9 during the operation of making measurements of a room;

[0035] FIG. 11 is a schematic diagram of a portion of the embodiment of the room measurement apparatus of FIGS. 7-9;

[0036] FIG. 12A is a schematic illustration of the measurement of a room dimension using the principles of parallax triangulation;

[0037] FIG. 12B is a further illustration of the measurement of a room dimension when the camera of the room measurement apparatus has been rotated relative to its angular position at the start of a scan of a room; and

[0038] FIG 13 is a control target that may be used for calibrating the angle of view of a camera system used in the room measurement apparatus of FIGS. 7-9.

[0039] The present invention will be described in connection with a preferred embodiment. However, it is to be understood that there is no intent to limit the invention to the embodiment described. On the contrary, the intent is to cover all alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

[0040] For a general understanding of the present invention, reference is made to the drawings. In the drawings, like reference numerals have been used throughout to designate identical elements. In the following disclosure, the present invention is described in the context of its use as an apparatus for measuring the dimensions of a room. However, it is not to be construed as being limited only to use in room measurement. The invention is adaptable to any use in which dimensional measurements of any volume bounded by surfaces is desired. Accordingly, as used herein, the term, “room” is meant to indicate any volume of space surrounded or partially surrounded by surfaces. Additionally, the description identifies certain components with the adjectives “top,” “upper,” “bottom,” “lower,” “left,” “right,” etc. These adjectives are provided in the context of use of the apparatus in measuring room dimensions and in the context of the orientation of the drawings. The description is not to be construed as limiting the apparatus to use in a particular spatial orientation. The instant apparatus may be used in orientations other than those shown and described herein.

[0041] In a first aspect of the invention, an apparatus for measuring and imaging a room is provided. Referring first to FIGS. 1A and 1B, the apparatus 10 is comprised of a fixture 12 upon which are mounted the various components for measuring and imaging a room 2. The fixture 12 may include a mounting plate or framework (not shown) for the mounting of various components. The fixture 12 may include a housing 14, which encloses the various components shown in FIG. 2.

[0042] In certain embodiments (not shown), the fixture 12 and/or housing 14 may be provided with a flat bottom surface to enable the fixture to be placed on a flat surface such as a table top or a floor of a room, and acquire dimensional data and/or images of the room from that position. In other embodiments (not shown), the fixture 12 may include releasable fastening means for clamping the fixture to a rod, bracket, countertop edge, or other available structure to position it for acquiring dimensional data and/or images of the room 2.

[0043] In the embodiment depicted in FIGS. 1A and 1B, the fixture 12 is engaged with a rod 16. The housing 14 is provided with an open bore therethrough to accommodate the rod 16 and its engagement with the fixture 12. The rod 16 may be in a horizontal position, a vertical position as shown, or another position. The rod 16 may be provided with threads 18 or teeth, which engage with corresponding threads (not shown) or gears of the fixture 12. Threads 18 or teeth serve as a means to traverse the fixture 12 vertically as indicated by arrow 17 along the rod 16, and rotationally as indicated by arrow 19 around the rod 16. During such linear and rotational motion of the fixture 12, dimensional data and images of the room 2 are obtained, as will be explained subsequently herein. The rod 16 may be mounted on a tripod 15 as shown in FIG. 1A, and may extend vertically from near the floor 3 to the ceiling 4 of the room 2.

[0044] Referring now to FIG. 2, the schematic diagram depicted therein shows a portion of one embodiment of the apparatus 10. Various components of the apparatus 10 are mounted on a fixture 12, and may be enclosed within a housing 14. The apparatus 10 is comprised of a distance meter 20. The distance meter 20 may be an optical distance meter 20, wherein a beam of light is projected from a source outwardly to a surface of the room, and the optical distance meter 20 receives light reflected back from the surface and determines the distance from the projection point of the light and the surface. The light source may be a laser 22 as shown in FIG. 2. The laser 22 may operate in the visible spectrum, such as at a wavelength of about 660 nanometers, which is typical of a red laser diode. Alternatively, the laser may operate in the infrared region of the spectrum.

[0045] A plurality of lasers 22 may be used as the light source. The beam(s) from the laser(s) 22 may be divided by an optical multiplexer 24 or other beam splitting means so that multiple beams 26 may be directed outwardly from the fixture at different angles. The light beams may be routed within the housing 14 using optical fibers 28 and 29.

[0046] The apparatus may also include a camera 30 for capturing images of the room 2. The lens (not shown) of the camera 30 may be aligned with a dedicated port (not shown) in the housing 14, or the lens may be in optical communication with multiple ports. The camera 30 may capture images through an optical fiber or fiber bundle 32. The camera 10 may share some or all of the same optical fibers 29 and optical ports with the laser 22.

[0047] Referring now to FIGS. 1A and 1B, as well as FIG. 2, the housing 14 may be provided with a plurality of ports through which the outwardly directed laser beam passes. In the embodiment depicted in FIG. 2, the housing is ellipsoid in shape, and provided with upper ports 34A middle ports 34B, and lower ports 34C. Housing shapes other than ellipsoid are contemplated. Multiple lasers 22 may be provided, with each one dedicated to a single port, or dedicated to several ports; or a single laser 22 may be provided as shown in FIG. 2, with its beam split among the various ports 34A – 34C. The optical ports 34A – 34C may simply be openings in the housing, or they may be small transparent windows of glass or plastic.

[0048] In the embodiment depicted in FIG. 2, twelve ports are provided, distributed at 90 degree intervals around the housing, and at three levels and directions: horizontal (34B), and about 45 degrees upward and downward (34A and 34C, respectively). Other arrangements are contemplated, such as port spacing at 120 degree intervals. In general, having a greater number of ports reduces the number of rotations or the angle of rotation of the housing 14 to perform a full scan of the room, but increases the rate of generation of dimensional data which must be processed by the distance meter 20, and images captured by the camera 30. A processor 36, such as an application specific integrated circuit (ASIC) may be provided, and placed in signal communication with the camera 30, the laser 22, and the laser distance meter 20 to receive dimensional data from the meter 20 and digital images from the camera 30, and also to control these devices during a measurement operation. A plurality of laser distance meters may be provided for acquiring room dimensional data. In the embodiment depicted in FIG. 2, three laser distance meters 20A, 20B, and 20C may be provided, with the respective ports they are dedicated to being aligned along three orthogonal axes. The laser distance meters (also known as laser range finders) may be e.g., as disclosed in United States patents 7,409,312, 7,516,039, and/or 7,127,378; and/or United States Patent Application Publications 2007/0182950 and/or 2003/0218736, the disclosures of which are incorporated herein by reference.

[0049] The apparatus 10 may include a GPS receiver 38 to provide data on the exact location of the room or other volume being measured, with the data being recorded by the processor 36. The GPS location can then be used for various subsequent purposes, such as when routing construction materials and/or furnishings to a remodeling site.

[0050] The apparatus 10 may include an electronic level or levels 38. The levels 38 serve to establish a horizontal datum or plane, to which the room dimensional data is referenced. This is particularly important when measuring rooms having a floor or other surface that is not level, or rooms or other volumes having an irregular shape, possibly with no horizontal floor or other base surface.

[0051] The apparatus 10 may include wireless communication means 40 in the processor 36, or in the camera 30 and/or distance meter 20 and/or GPS 38 for wirelessly communicating input and output data to and from the apparatus 10. The apparatus 10 may also include a user interface 42, which may be located on the exterior of the housing 14. The user interface 42 may include lights such as LEDs indicating power on, apparatus in standby mode, apparatus in scanning mode, and scan complete. The user interface may also include an on-off switch, and a run scan switch. Alternatively, the apparatus 10 may be controlled remotely, such as with a hand-held remote controller.

[0052] The apparatus 10 may include a motion controller 44 that controls the motion of the fixture 12 during a room measuring and imaging scan. The motion controller 44 may include a motor (not shown) that starts and stops motion of the fixture 12 along and around the rod 16. Alternatively, in embodiments wherein room scans are performed by the action of gravity causing the fixture 12 to descend along and around the rod 16, the motion controller 44 may be comprised of braking means, such as a solenoid actuating a brake pad to apply friction to the rod 16, thereby slowing or stopping the motion of the fixture along and around the rod 16.

[0053] The apparatus may include a power supply 46, such as one or more compact batteries, which provide electrical power to the various components 20, 22, 30, 36, 38, 40, and 44.

[0054] Referring again to FIGS. 1A and 1B, and in one embodiment depicted therein, the rod 16 may be provided with steeply pitched coarse threads 18, such that the fixture 12 may be released from an uppermost position, and traverse the rod 16 axially and rotationally as indicated by respective arrows 17 and 19. The threads 18 of the rod 16 may be sufficiently coarse so as to result in only a single rotation of the fixture 12 around the rod 16, or only a few rotations, while acquiring room dimensional data and room images. This configuration is beneficial in that no drive motor is needed to cause the motion of the fixture 12 along and around the rod 16. A braking device may be provided for motion control as described above. The motion of the fixture 12 may be continuous along and around the rod 16 during dimensional data and image acquisition. Alternatively, the motion may be intermittent, as depicted in FIG. 3. The fixture 12 is stationary at a first vertical location 45, where it acquires dimensional data and images of the left wall 5, right wall 6, rear wall 7, front wall (not shown), floor 3 and ceiling (not shown). The fixture 12 is then traversed to a second location 47 where it acquires dimensional data and images, and it is then traversed to a third location 49 where it acquires dimensional data and images. The number of incremental locations needed for precise room measurement and imaging will depend upon the number of ports and light beams provided in the fixture 12 and the placement and orientation of objects and surfaces within the room. It is noted that it is not necessary that the apparatus 10 be located in the center of the room 2 to make measurements and acquire images; instead it can be off-center as shown in FIG. 2.

[0055] FIG. 4 is a perspective view of another embodiment of the instant room measurement apparatus in the process of measuring a room. The apparatus 11 may include a fixture 12 containing the components as described previously disposed upon a horizontal stand 50, which in turn may be supported by a tripod 52 or other support. The horizontal stand 50 may include a turntable (not shown) for rotating the fixture 12 in a horizontal plane through 360 degrees, or ±180 degrees. During a scan, the fixture emits at least one laser beam, which is traversed along the left wall 5, the right wall 6, the rear wall 7, and the front wall (not shown). The laser beam is reflected back and detected by the laser distance meter 20 (FIG. 2). Laser beams 56 and 58 are directed vertically to the floor 3 and ceiling (not shown), and are reflected back and detected by the laser distance meter 20 so that the horizontal location of the particular scan can be recorded. Subsequently, the horizontal location of the stand 50 is repositioned, and another scan of the side walls of the room is performed. The stand 50 may be raised or lowered by a linear actuator (not shown) or by an operator (not shown) of the apparatus 11. The stand 50 may include orthogonal levels (not shown) and adjustment means (not shown) to establish the operation of the scan in a true horizontal plane.

[0056] FIG. 5 is a perspective view of the instant room measurement apparatus 10 or 11 measuring a room from different locations within the room 2. A full set of room measurements may be obtained by moving the apparatus 10 or 11 to different locations within the room (e.g., locations 55, 56, 57, 58, and 59), and performing the room scans vertically as previously described. This may be beneficial in situations where the room has a complex shape, and there is no one location from which there is a direct line of sight to all surfaces of the room 2. It is noted that the room apparatus 10 and 11 are capable of measuring rooms of irregular shape (e.g., not rectangular and/or with curved walls) from a single location, as long as there is a direct line of sight to all surfaces of the room. Additionally, the apparatus 10 and 11 are capable of detecting and dimensioning irregular shapes present on or in the walls of a room, such as windows, doors, pictures, and other wall hangings, fixtures, or features, as well as defects and surface irregularities of surfaces.

[0057] In another aspect of the invention related to the aforementioned first aspect, there is also provided a method for measuring and imaging a room. Referring to FIG. 6, the method may comprise setup 110 of the apparatus, and initializing 120 the apparatus, i.e. establishing a “zero” position from which to begin a scan. The scan is then initiated 130. The room is scanned 140 by the apparatus, and dimensional data and images of the room are acquired. The data and/or images may be analyzed 160 within the apparatus 10 by the processor 36, or the data and/or images may be transmitted 150 externally for such analysis. Once transmitted externally, the dimensional data may be uploaded into a computer containing three dimensional modeling software, by which a three dimensional model of the room may be created for subsequent use in remodeling and/or interior decorating. The images acquired by the camera may be stitched together to produce a 360 degree panoramic view image file for viewing by a user, thereby facilitating further remodeling and decorating decisions. During scanning, the images may be acquired by the camera simultaneously with the room dimensional data, so that room dimensional markings may be added to images of the room by the software, and so that the color of each surface point detected may be added to the 3-dimensional model being created.

[0058] Further aspects of the invention will now be described. However, certain terms relating to these aspects will first be defined as follows:

[0059] Entrance pupil: The point defining the center of the vertex of an angle of view of a camera system. In a pinhole lens system, this point is the center of the pinhole itself. (See, for example, http://en.wikipedia.org/wiki/Entrance_pupil

[0060] Origin (in reference to a laser light source of the apparatus): The point where a laser light source crosses a plane which is parallel to the image plane of a camera system and which also passes through the entrance pupil of the camera system. (Although it is possible to make the calculations described in this disclosure using an origin at a different known point in relation to the camera entrance pupil, for the sake of simplicity and clarity, the origin point as defined above is used in the instant room measurement device and methods.)

[0061] Laser dot or laser spot: Reference to the point on a surface within a space being measured by the instant apparatus where the light from a laser source of the apparatus first intersects with a surface, thereby illuminating that surface so that it may be detected by the camera system of the apparatus.

[0062] Pointing direction: the center of the axis along which light from a laser of the apparatus is traveling, or the center of the axis of the angle of view of the camera system of the apparatus.

[0063] Image axis (in reference to a camera system of the apparatus): the axis along the center of the angle of view of the camera system.

[0064] With regard to these further aspects of the invention, in certain embodiments of the room measurement apparatus and methods, a different method of distance detection is used. In certain embodiments, an optical camera system and one or more laser light sources with known, measured, or calibrated origin points and pointing direction may be used. The position of each laser spot within an image captured by the camera system may be used to calculate the distance between the center of the camera system entrance pupil and the surface point where the detected laser spot is reflected in the space being measured.

[0065] The mathematical model for calculating such distance is based on parallax triangulation measurement, as will be described subsequently in this disclosure. In certain embodiments, if the camera system does not have a theoretically "perfect" and non-distorted image, any distortions may be corrected for if the distortion properties are known, or through a distortion calibration process, in order to increase the accuracy of measurements. By combining the known distance between the camera system's entrance pupil and the laser spot's origin, the pointing direction of the laser illuminating the laser spot, the azimuth and elevation angle at which the point was detected within the image, as well as the known current position and rotation of the entrance pupil of the camera system at the time of the image capture, it is possible to calculate the precise position of the surface at the point of the laser dot in relation to a fixed reference point. By taking multiple images with the camera system as the system rotates and/or moves along one or more axes, a high enough number of individual surface distance measurements can be gathered to generate a three-dimensional (“3D”) model of the space being measured.

[0066] In certain embodiments, multiple laser light sources may be used simultaneously to increase the number of measurement points detected and/or to provide multiple illumination perspectives in images acquired by the camera system, in order to enable better detection of surfaces at various angles and orientations in relation to the apparatus. In certain embodiments, the apparatus may include "line laser" systems to measure a much higher number of points per image captured. This aspect of the invention is described subsequently in more detail.

[0067] When multiple laser light sources are used simultaneously, the apparatus must be able to determine which laser source created each detected laser spot within a captured image, and therefore determine the origin point of that laser source. This can be done through several means, including one or more of the following possibly combined with other methods:

[0068] – using different color (i.e. wavelength) lasers, along with a camera system which is capable of distinguishing between these colors or wavelengths

[0069] – matching detected laser spots in an image against a list or formula of known-possible points within the image at which each known laser source could possibly appear to determine which laser is the most likely source for that point. (It is noted that while this method of distinguishing laser sources is very useful for distinguishing individual laser dots and reducing false-detections from reflections and other light sources, it may not be as effective with "line laser" sources due to the significantly larger area potentially covered by a line laser in each image.)

[0070] Additionally, by use of a color camera system within the sensing device of the instant apparatus, it is possible to not only measure the distance to each measured point, but also to detect the natural color and/or visual texture at each measured point. This allows the final 3D model of the measured space that is created to contain both the position of each surface detected and the original color and/or visual texture of that surface, resulting in a more complete and natural-appearing model.

[0071] At the time of measurement, because the measured point is illuminated by a bright, colored laser source, the color and texture sampling mentioned above must be performed in previous or subsequent images that are captured where that point is illuminated by a more natural light, or the laser source be periodically turned on and off, so that both distance measurement and color/texture measurement can be performed separately. This can be accomplished by knowledge of the change in position and/or rotation of the sensing device between images captured, and sampling the color and visual texture of the previously-detected and located points in the subsequent or previous images.

[0072] It is noted that other commercially available 3D scanning systems are capable of self-controlled rotation to perform a 360-degree scan from a fixed location, but do not move in other axes by themselves. This results in the device having only a single perspective on a scene being scanned. By having a fixed perspective, the device cannot gather measurement data for surfaces that may be behind an object or other surface in the scene. The un-seeable area (or "shadow") results in blind spots and incomplete 3D models. Some systems on the market today address this problem by allowing measurement data from multiple separate scans from different fixed positions to be combined into a single set of scan data. In such a case, alignment of the data collected from each position must be done to ensure accuracy - either manually, or automatically by detecting common points within the measurement data from each individual scan via software, or via other positional data such as GPS location of the scanning device during each scanning process.

[0073] The present invention addresses this problem by moving in one or more axis (other than just rotation) automatically during the scanning process. By tracking the precise position and pointing direction of the camera system from which each measurement is taken, that information can be combined with the distance and angular direction data for each measured point to accurately locate the detected surface in relation to a fixed reference point. This allows the apparatus to gather measurement data of a scene from multiple perspectives along one or more axes during a scan, reducing (and possibly eliminating) the areas which are not measurable due to being blocked by a foreground object or surface. A more complete 3D model of the room or other space being measured is thus provided. In addition, it is also possible to combine measurement data from multiple scans into a single model as above if desired.

[0074] Exemplary embodiments of these additional aspects of the invention will now be described with reference in particular to FIGS 7-13. Referring first to FIG. 7, the apparatus 210 is similar to the apparatus 10 of FIG. 1A, and is comprised of a fixture 212 upon which are mounted the various components for measuring and imaging a room 2. The fixture 212 may include a mounting plate or framework (not shown) for the mounting of various components. The fixture 212 may include a housing 214, which encloses certain various components to be described subsequently in this disclosure. In certain embodiments (not shown), the fixture 212 may include releasable fastening means for clamping the fixture to a rod, bracket, countertop edge, or other available structure to position it for acquiring dimensional data and/or images of the room 2.

[0075] In the embodiment depicted in FIGS. 7-9, the fixture 212 is engaged with a rod 216. The housing 214 is provided with an open bore therethrough to accommodate the rod 216 and its engagement with the fixture 212. The rod 216 may be in a horizontal position, a vertical position as shown, or another position. The rod 216 may be provided with threads similar to the threads of the apparatus 10 of FIG. 1A and 1B, or teeth (not shown), which engage with corresponding threads (not shown) or gears (not shown) of the fixture 12. For the sake of simplicity of illustration, threads or teeth are not shown on the rod 216 of the apparatus 210 of FIGS. 7- 9 and subsequent related FIGS.

[0076] The threads or teeth serve as a means to traverse the fixture 212 vertically as indicated by arrow 217 along the rod 216, and rotationally as indicated by arrow 219 around the rod 216. The direction of rotation and translation may be opposite of or in addition to that indicated by arrows 217 and 219. During such linear and rotational motion of the fixture 212, dimensional data and images of the room 2 are obtained, as will be explained subsequently herein. The rod 216 may be mounted on a tripod 15 as shown in FIG. 1A, and may extend vertically from near the floor 3 to the ceiling 4 of the room 2. Alternatively, the rod 216 may be provided with a flat base 215 to enable the fixture to be placed on a flat surface such as a table top (not shown) or on the floor 4 of the room as shown in FIG. 9, and acquire dimensional data and/or images of the room 2 from that position.

[0077] Referring again to FIGS. 7-9, the apparatus 210 is comprised of a plurality of laser light sources joined to supports that extend from the housing 214. In the embodiment depicted in FIG. 7, the apparatus 210 is comprised of a first laser 222A joined to first support 223, a second laser 224A joined to second support 225, third laser 226A joined to third support 227, and a fourth laser 228A joined to fourth support 229. When the apparatus is operated to scan a room or other surrounding space, the respective lasers 222A-228A and supports 223-229 are rotated around and translated along the rod 216, thereby projecting their respective beams upon the surrounding surfaces.

[0078] In certain embodiments, more than one laser may be supported by each of the supports 223-229. The lasers may be provided in sets of at least two lasers. In the embodiment depicted in FIGS. 7-9, the lasers are provided in sets of three lasers, the sets being first set 222 comprised of lasers 222A, 222B, and 222C, and in like manner for laser sets 224, 226, and 228. In certain embodiments, the lasers of any of the respective sets are of different wavelengths. In certain embodiments, a laser set may be comprised of a red laser, and blue laser, and a green laser. Such a configuration is advantageous because common charge coupled device (CCD) imaging sensors that are contained in digital cameras typically have a red light detector, and green light detector, and a blue light detector in each pixel of the CCD array.

[0079] It is noted that for the sake of simplicity of illustration, that in FIG. 8 only the second and fourth laser sets 224A/B/C and 228 A/B/C are shown, and that in FIG. 9 only the first and third laser sets 222A/B/C and 226 A/B/C are shown. However, it is also noted that in certain embodiments, the apparatus may be provided with only second and fourth laser sets 224A/B/C and 228 A/B/C, or only first and third laser sets 222A/B/C and 226 A/B/C, or any combination of one or more laser light sources 224A/B/C, 228 A/B/C, 222 A/B/C, or 226 A/B/C while still being able to make satisfactory measurements of certain surroundings. The configuration of the apparatus depicted in FIG. 7 is considered advantageous, however, because in a scan of the room, more data is acquired. Additionally, in instances where there may be objects in the room not in contact with the walls of the room and/or objects mounted to or placed against the walls of the room, the use of the additional lasers provides for the impingement of laser light on surfaces that otherwise might be “in the shadows,” thereby acquiring data on them so that they are included in a resulting 3D model of the room. In certain embodiments, more than four sets of lasers may be used with the apparatus 210.

[0080] Referring again to FIGS. 7-9, the apparatus 210 is further comprised of a camera 250 that is mounted on or contained in the housing 214. The camera 250 includes lenses (such as lens 252), and may further comprise means for focusing, a view finder, a display, and other features to make up an overall camera system.

[0081] The camera 250 is further characterized in that it has an angle of view 251 bisected by an optical axis 253, or three dimensionally, a cone of view having an axis of rotation being the optical axis 253. The entrance pupil 255 of the camera 250 is at the vertex of the angle of view 251. In acquiring images, the camera 250 has image planes, such as image plane 257 (FIG. 8), which is perpendicular to the optical axis 253. The optics of the camera 250 are configured to be in focus at a particular image plane when objects of interest are present at that image plane.

[0082] In the operation of the apparatus 210 and computing dimensions of a room, for any given laser, the origin of that laser is considered to be the location where the light beam from that laser passes through the plane 259 that is parallel to the image plane and perpendicular to the optical axis 253. For example, referring to FIG. 8, the origin of the lasers 224A, 224B, and 224C is point 264 on plane 259. In like manner, the origin for lasers 222A/B/C is point 262; the origin for lasers 226A/B/C is point 266; and the origin for lasers 228A/B/C is point268.

[0083] The operation of the apparatus 210 and its principles of operation will now be described. These are best understood by first referring to FIGS. 10A-10C, which are side elevation views depicting the apparatus of FIGS. 7-9 during the operation of making measurements of a room. Referring first to FIG. 10A, the apparatus 210 is shown just after having begun a scan of a room 2, with the housing 214 of the apparatus 210 engaged with the upper region of the pole 216. The room 2 may have a simple rectangular shape, or a more complex shape. For the sake of simplicity of illustration, a simple rectangular room is depicted, with the room 2 having a ceiling 4, a floor 3, a first side wall 5, a second side wall (not shown) opposed to the first side wall, a third side wall 7, and a fourth side wall (not shown) opposed to the second side wall 7. Within the room 2, there may be objects (not shown) disposed on the floor, and/or objects placed against or mounted on the walls. In FIGS. 10A-10C, a wall-mounted cabinet 80 and a hutch or dresser 90 are shown along wall 5.

[0084] In performing a scan of the room 2 and objects therein, the housing 214, laser sets 222 and 226, and laser sets 224 and 228 (see FIG. 7) rotate around the pole 216 and traverse the pole downwardly as indicated by arrows 219 and 217. The twelve laser beams 232A/B/C, 236A/B/C, beams (not shown) from laser set 234, and beams (not shown) from laser set 238 sweep the ceiling 4, walls 5 and 7 and their opposed walls, and floor 3 of the room 2, as well as the exposed surfaces of the cabinet 80 and hutch 90. The laser beams are highly collimated and compact, and thus project bright illuminated spots on the ceiling, floor, walls, and surfaces. In the illustrations shown in FIGS. 10A-10C, spots 242A/B/C and 246A/B/C are shown, some of which impinge upon the cabinet 80 and hutch 90.

[0085] FIG. 10B depicts the continuation of the room scan shown in FIG. 10A, at a point of about half completion. FIG. 10C depicts the continuation of the room scan at a point near completion. It can be seen that over the course of the room scan and the objects therein, all exposed surfaces are illuminated by at least one laser beam. In certain embodiments, the apparatus is configured such that all exposed surfaces are illuminated by at least two lasers.

[0086] As the room scan proceeds, the camera system 250 acquires images of the room. The image acquisition rate is preferably at least about 5 images per second, but may be much higher, on the order of as much as 1000 images per second. Although there is currently a significant cost to having such a high image acquisition rate, as cameras continue to improve, and image processor capabilities become more powerful, such image acquisition rates will likely become affordable for general use. It will be apparent that higher image capture rates will enable a higher resolution and more accurate 3D model of the room and objects contained therein. It will be further apparent that the optimum image acquisition rate will also be dependent upon the angular and linear velocities of the camera system 250 and laser sets 222, 224, 226, and 228 as they rotate around and traverse along the pole 216 of the apparatus. Lower velocities enable lower image acquisition rates to be sufficient for the purpose of making room measurements, but at the expense of taking a longer period of time to scan a room.

[0087] Because the laser beams are of highly collimated high intensity radiation, the resulting spots (e.g., spots 242A/B/C and 246A/B/C) will be very bright relative to their surroundings. These spots will be easily detected and imaged by the camera system 250. The locations of the spots can thus be analyzed by image processing techniques and analysis as will be described subsequently.

[0088] FIG. 11 is a schematic diagram of a portion of the embodiment of the room measurement apparatus 210 of FIGS. 7-10C. The apparatus 210 may include many of the same components as the apparatus 10 described previously and shown in FIG. 2; hence those components in common will not be described here. The apparatus 210 differs from the apparatus 10 in that it has a camera system 250, and external lasers 222, 224, 226, and 228, or laser sets 222A/B/C, 224A/B/C, 226A/B/C, and 228A/B/C. (As noted previously, in a simplified version of the apparatus 210, it may be comprised of only two lasers.)

[0089] The camera 250 is in signal communication with a processor 36, such that it can receive instructions to acquire images, as well as receive settings such as focus and F-stop; additionally, the camera communicates the digital images to the processor 36, which it acquires during a room scan. The lasers may also be in signal communication with the processor 36, such that they can receive instructions to operate and illuminate surfaces within the room during a scan.

[0090] In a further embodiment (not shown), the base 215 which supports the pole 216 of the apparatus 210 may include means for moving the base 215 (and thus the entire apparatus 210) within the room along any axis of motion. In that manner, multiple scans of the room may be made from different locations therein, resulting in a more accurate 3D model of the room. In such a configuration, the motion control module 44 is in communication with the motion means in the base 215, as well as the rotary and linear motion means in the housing 214 to traverse it along and around the pole 216. Additionally, the motion control module 44 contains sensors and/or encoders (not shown) to track the linear and rotary positions of the housing 214, camera system 250, and laser sets 222A/B/C, 224A/B/C, 226A/B/C, and 228A/B/C during a scan. The positional data from motion control module 44 is communicated to the processor 36. This data may be stored in the memory of the processor 36. The data is also correlated with the acquired images such that for any image, the exact position of the camera and lasers when that image was acquired are known. This combination of data may be used by the processor in calculating the dimensions of the room and/or objects contained therein.

[0091] When a room scan is completed, the images acquired by the camera 250 are communicated to the processor 36 for storage and analysis. The processor 36 may include a central processing unit (CPU), a memory, a bus for communication with the various devices shown in FIG. 11. The memory may contain an algorithm for analyzing the images acquired by a room scan and producing a 3D model of the room, or converting the images to data with which other external software may produce the 3D model. Alternatively, the image processing to produce the 3D model may be performed entirely by a processor (not shown) that is external to the housing 214. In such circumstances, the digital images and the correlated apparatus positional data may be communicated to the external processor, or to an external memory or other data storage device such as a hard disk drive or memory card. The communication to the external processor may be in real time during a scan of an enclosed space, or after completion of the scan. The communication may be via wireless communication means 40, or a hard-wired network connection (not shown) that may be connected to the processor 36 after a room scan is completed and the apparatus is not in motion.

[0092] In any event, the overall method of measuring a room using the apparatus 210 is as shown in FIG. 6, which has been described previously. The main differences with room measurement method described previously and the method using the apparatus 210 is in the room scanning step 140 (due to the different configuration of the apparatus 210 being comprised of a camera system and a plurality of lasers); and in step 160, the analysis of the images. This latter step 160 will now be described for the room measurement method using the apparatus 210.

[0093] As noted previously, the mathematical model for calculating the location of a point on a surface of a room, or of a point on a surface of an object in the room is based on the principles of parallax triangulation measurement. By combining the known distance between the camera system's entrance pupil and the laser spot's origin, the pointing direction of the laser illuminating the laser spot, the azimuth and elevation angle at which the point was detected within the image, as well as the known current position and rotation of the entrance pupil of the camera system at the time of the image capture, it is possible to calculate the precise position of the surface at the point of the laser dot in relation to a fixed reference point. By taking multiple images with the camera system as the system rotates and/or moves along one or more axes, as has been described with reference to FIGS. 10A-10C, a sufficiently high number of individual surface distance measurements are gathered to generate a three-dimensional ("3D") model of the space being measured. Also as noted previously and shown in FIGS. 10A-10C, multiple laser light sources may be used simultaneously to increase the number of measurement points detected and/or to provide multiple illumination perspectives in images acquired by the camera system 250, in order to enable better detection of surfaces at various angles and orientations in relation to the apparatus 210.

[0094] The use of the principles of parallax triangulation in making measurements of a room with the apparatus 210 are best understood with reference to FIG. 12A. A portion of the apparatus 210 is depicted in FIG. 12A, which is a top view of the apparatus 210, much the same as the top view of the apparatus 210 as shown in FIG. 8. In particular, the rotating and translating housing 214, the camera system 250 having entrance pupil 255, support 229, and laser set 228 comprising lasers 228A, 228B, and 228C are shown. The apparatus is shown at the instant during a scan when the beam 238A from laser 228A illuminates a spot 248A on the surface 83 of an object 82.

[0095] Because data on the position of the camera system 250 and lasers 228 are acquired for every image that is acquired, certain dimensions are known, from which certain distances can be calculated according to parallax triangulation. In any triangle, if any three facts are known out of the three interior angles and the length of the sides of that triangle, it is possible to calculate the values for the remaining angles and sides, provided that at least one of the known data points is the length of a side. The values for the unknown angles and/or sides can be calculated by using the following mathematical facts:

[0096] 1) The sum of the interior angles of any triangle equals 180 degrees.

[0097] 2) The Squares Rule: In a right triangle, the square of the length of the hypotenuse is equal to the sum of the squares of the other two sides.

[0098] 3) The Sine Rule: if the lengths of the sides of a triangle are referred to as A, B, and C, and the interior angles opposite those sides are referred to respectively as a, b, and c, then:

A/sine a = B/sine b = C/sine c.

[0099] Referring again to FIG. 12A, A is the distance 278 from the entrance pupil 255 of the camera system 250 to the “origin” of the laser beam 238A, i.e., the point at which the beam 238A from laser 228A crosses the plane 259 that passes through the entrance pupil and is parallel to an image plane of the camera system 250. A is a known distance and is chosen at the time of the setup of the apparatus 210.

[00100] Furthermore, the directional angle of the laser light beam from its origin point, which is angle b in FIG. 12A, is also a known angle and is chosen at the time of apparatus setup. The third piece of information required to calculate the complete triangle side lengths and angles can be extracted from an image produced by the camera system 250. If the properties of the lens 252 in the camera system 250 are known or are calibrated, then by locating the laser spot 248A within an image, it is possible to calculate the angle between the image axis and the detected point 248A, shown as angle c in FIG. 12A. That angle may then be used to calculate angle a, which is the angle formed between the laser beam 238A and the line segment from the

laser spot 248A and the entrance pupil. Thus knowing the angles a and b and the distance A of the triangle ABC formed by the laser origin 268, the laser spot 248A, and the entrance pupil 255, the remaining angle c (the angle between the laser spot-entrance pupil line of sight and the plane 259), the distance C (length of the laser beam from its origin 268 to the spot 248A), and the distance B (distance between the entrance pupil and the laser spot 248A) may all be calculated.

[00101] Once all of the sides and angles of the triangle ABC are calculated, that information can be combined with the known positional coordinates and rotation (pointing direction) of the entrance pupil 255 of the camera system to calculate the position of the detected point 248A verses a fixed reference point. In any given room scan, the fixed reference point may be chosen as a point along the central axis of the pole 216, about which the lasers and the camera system are rotated. The fixed reference point may be at any location so long as the relative position between that point and the camera system's entrance pupil is known or can be calculated for every image captured during the scanning process. For simplicity, the reference point may be the center of the rotational axis of the apparatus at the level of the image axis at the beginning of the scanning process. This enables the combination of multiple detected points measured from different camera system positions to be combined into a single 3-dimensional model.

[00102] A further example of a calculation when the camera has been rotated at an angle relative to its starting position, i.e. a reference angle of zero degrees, is shown in FIG. 12B. The calculation of the absolute position of the point 248A on a surface 83 within a reference grid 200. The origin of the reference grid 200 is at the central axis of the rod 216, and for the sake of simplicity of calculation with respect to FIG. 12B, the origin is also located in the same horizontal plane as the entrance pupil 255 of the camera system 250.

[00103] At the point of room measurement depicted in FIG. 12B, the camera system 250 has been rotated 35 degrees counterclockwise from the zero angle of the reference grid. By choice in the setup/design of the apparatus, the camera entrance pupil plane 259 is 0.25 units from the rotational axis at the center of the pole 216. From the above principles of parallax triangulation, the surface 83 is calculated by parallax triangulation to be 3.1869 units from the entrance pupil 255, at an angle of 82 degrees from the entrance pupil plane 259.

[00104] The absolute position of the point (laser spot) 248A in the reference grid may be calculated as follows:

[00105] – Calculation of offset from rotational axis to entrance pupil (with reference to FIG. 12C):

[00106] y= 180 - 90 - 35

[00107] $\Rightarrow$ y = 55 degrees

[00108] X/Sin(35) = Y/Sin(55) = 0.25/Sin(90)

[00109] X/Sin(35) = Y/Sin(55) = 0.25

[00110] X = 0.25 * Sin (35)

[00111] $\Rightarrow$ X = 0.1434 grid units

[00112] Y = 0.25 * Sin (55)

[00113] $\Rightarrow$ Y = 0.2048 grid units

[00114] – Calculation from the entrance pupil 255 to the surface spot 248A: (with reference to FIG. 12D):

[00115] y= 180 - 35 – 82

[00116] $\Rightarrow$ y = 63 degrees

[00117] x= 180 - 90 - 63

[00118] $\Rightarrow$ x = 27 degrees

[00119] X/Sin(27) = Y/Sin(63) = 3.1869/Sin(90)

[00120] X = 3.1869 * Sin(27)

[00121] $\Rightarrow$ X = 1.4468 grid units

[00122] Y = 3.1869 * Sin(63)

[00123] $\Rightarrow$ Y = 2.8395 grid units

[00124] The respective X and Y values are added together to obtain the absolute position of the surface spot 248A relative to the fixed reference point, which is the origin, i.e., the center of the axis of rotation of the pole 216:

[00125] X = 0.1434 + 1.4468

[00126] $\Rightarrow$ X = 1.5902 grid units

[00127] Y = 0.2048 + 2.8395

[00128] Y = 3.0443 grid units

[00129] In X-Y coordinates, the absolute position of the spot 248A may be expressed as the ordered pair (1.5902, 3.0443). (It is noted that counterclockwise rotation in the above example is considered to be the positive direction; hence in the

numbering of the Y-axis of the grid, the positive direction is to the left, contrary to conventional practice.)

[00130] It is to be understood that the preceding calculation was done to determine only the X-Y position of a spot. If the data presented were for a laser spot that was in the horizontal X-Y plane passing through the entrance pupil 255 of the camera system 250, the calculation would be complete, since there would be no Z-axis offset of the spot. (i.e. Z = 0.) However, in most instances, a laser spot will be located with a Z-axis offset. In such instances, to obtain the Z-coordinate of the spot location, the calculation of the Z coordinate is performed in the same manner according to the principles of parallax triangulation. (It is noted that in the preceding calculation, the Z-axis is the vertical axis along the central axis of the pole 216. However, the z-axis may be located elsewhere, so long as it is orthogonal to the X-Y plane and its location relative to the entrance pupil 255 and the rotational axis of the apparatus 210 are known.)

[00131] It is noted that analyzing the data output from the apparatus 210 and calculating absolute positions of a plurality of surface spots illuminated by the lasers, when the positions of these multiple points are calculated and combined into a single model, such a model is commonly referred to as a "point cloud." (See, for example, the Internet encyclopedia disclosure at http://en.wikipedia.org/wiki/Point_cloud, which describes a point cloud as a set of X, Y, and Z axis position measurements for each point therein, which are typically intended to be representative of the external surface of an object. In the instant invention, the point cloud is representative of the internal surfaces of a room, and the external surfaces of objects therein.

[00132] The data of a point cloud may be combined with the desired color for the surface at that point or region of points. Several mathematical processes can be used to convert adjacent points into a surface "mesh", such as the Marching Cubes method described by Lorensen and Cline (*Computer Graphics*, Vol. 21, Nr. 4, July 1987) in order to create a 3-dimensional model that can be used in a computer system. (See also the disclosure at http://meshlabstuff.blogspot.com/2009/09/meshing-point-clouds.html)

[00133] In an alternative embodiment (not shown), "line laser" systems may also be used with the apparatus 210 to project laser spots within the images captured by the camera system 250, instead of the one or more lasers described previously. A

line laser projects a thin line emanating from a point at that laser source, instead of a single dot. This line appears longer at further distances from the source, due to the lens system over the laser light source which spreads the laser light in one axis only. By knowing, measuring, calculating, or calibrating the exact source point, pointing direction, and rotational angle of the line laser, it is possible to calculate the distance from the entrance pupil of the camera system to each point along the detected laser line within a captured image.

[00134] In this embodiment, the number of measurement points per image depends on the resolution of the camera system, and how long the line appears in each image captured (i.e. how many image pixels the line covers in the captured image). In a normal 1080p video image frame, this could be up to 1920 individual measurement points if the laser were aligned with the horizontal (long) axis of the image sensor, 1080 points if aligned with the vertical (short) axis of the image sensor, or possibly more if aligned diagonally. For optimal measurement data and accuracy and to ensure that the origin angle can be properly calculated for each detected point within the laser line, the laser line projected from the laser source should be aligned perpendicular to the axis between the entrance pupil of the camera system and the line laser source. The pointing direction of the laser source is optimally calculated so that at the shortest desired measurement distance, it appears at the near edge of the camera system's angle of view, and at the furthest desired measurement distance it appears at the far edge of the camera system's angle of view. However, this may be adjusted as necessary to accommodate specific measurement results that are desired from a particular measurement space.

[00135] It is noted that in the design of a room measurement apparatus 210, the values of certain parameters are dependent upon the particular application, i.e. the size of the rooms to be scanned, and the desired accuracy of the resulting data. The accuracy of measurement data is dependent on several factors:

[00136] – The resolution of the camera system's image capture capabilities.

[00137] – The accuracy of locating the precise position of each projected laser dot within each captured image.

[00138] – The accuracy of detecting the precise location and pointing direction of the scanning system's reference point when each image was captured by the system.

[00139] – The distance between the center of the entrance pupil of the camera system and the origin of each laser light source. Larger distances are preferable for better accuracy, but larger distances result in a larger overall apparatus, which may limit the range of motion of the apparatus in confined spaces. This in turn may reduce the variation of perspectives from which the apparatus can capture measurement data. To compensate for this, the apparatus may be provided with different fixtures for the laser light sources of varying lengths for different applications. Alternatively, fixtures that can extend or contract (such as telescopically) may be provided.

[00140] – The choice of distance between the center of the entrance pupil of the camera system and the origin of the laser light source(s) and their pointing direction. An optimal balance between system size, range of motion, and ensuring coverage of as many surfaces as possible in each scan is desired. If multiple laser light sources are used, the angle and origin position of each should be chosen to ensure that each illuminate additional regions within the sensing areas instead of just overlapping with the areas sensed with other laser sources; ideally, all surfaces within a room are illuminated by at least one laser.

[00141] – The accuracy of calibration of the system. Calibration of the apparatus may include establishment of the known origin points, the pointing direction of each laser light source, and calibration to account for any lens or other imaging system distortions.

[00142] To achieve measurement accuracy of calibration, the following information about the configuration of the apparatus 210 must be known. The accuracy of this information directly impacts the quality of calibration and the accuracy of the resulting measurements made subsequently.

[00143] – The location of the center of the "entrance pupil" of the camera system.

[00144] – The angle of view of the camera system 250, and the distortion properties of the lens within that angle of view. This information may be given by the manufacturer of a lens, or may be measured and calibrated for by making an image with the lens of a target with marks at known locations and calculating the error between the location of those marks in the image and where they would appear through a perfect lens. It must be possible to know or calculate the delta in angle of view between a fixed reference point within the image (typically the center of the image) and each detected laser dot within each captured image.

[00145] – Locating the origin point of each laser source as it crosses the plane 259 of the entrance pupil of the camera system 250. (This point is referred to as the "origin" of the laser elsewhere in this disclosure.)

[00146] – Measuring or calculating the angle at which each laser source is pointing, compared to a fixed reference point and direction within the field of view of the camera system 250, which is typically along the optical axis of the camera system 250. If the apparatus 210 is positioned at a precisely known distance from a flat surface such as a vertical flat wall 9 (see FIG. 9) that is parallel to the image plane of the camera system 250, these angles can be calculated using the Sine Rule and sum of the interior angles of the resulting triangle as disclosed previously herein.

[00147] In order to use images created by the camera system 250 to determine the angle between the entrance pupil 255 of the camera system 250 and a laser spot within the field of view of the camera system 250, it is necessary to know certain properties of the camera system lens 252 and CCD sensor(s).

[00148] Specifically, the angle of view of the lens 252 across the area sensed by the camera system 250 in each image it creates must be known. Because it is possible that the system creates a geometrically distorted image, it is preferable to calibrate the precise angle between the center of the image and multiple points across both the horizontal and vertical axes in the field of view. In an ideal setup for best accuracy, one would calibrate the precise angle for every individual pixel in an image. However, this is impractical due to the very large number of pixels in an image captured by the camera system, and is also not necessary to achieve satisfactory accuracy in making room measurements by the apparatus 210.

[00149] FIG 13 depicts a control target that may be used for calibrating the angle of view of a camera system 250 used in the room measurement apparatus 210. To calibrate the camera system 250, the control target 280 may be placed in the field of view of the camera system 250, an image acquired by the camera system 250, and known points located within the image, according to the following procedure:

[00150] 1) The camera system is set up so that the image plane of the camera 250 is parallel to a reference surface, such as the surface of the wall 9 of FIG. 9, so that the reference surface fills the field of view of the camera 250. The distance from the entrance pupil 255 of the camera 250 to the reference surface must be precisely known or measured,

and should be within the normal range at which the apparatus 210 would normally operate.

[00151] 2) A measuring tape or other accurately calibrated measurement target is placed flat against the reference surface and secured there, such as by adhesive, aligned along the horizontal and vertical centers of the field of view of the camera system. The target should be large enough along both axes to extend the full width or height of the field of view of the camera. Distance markings on the target should have high contrast with the background, so that they are easily identified in an image taken by the camera system. One example of a suitable measurement target is the target 280 depicted in FIG. 13, although the target 280 could be numbered with a zero value at the intersection of the two axes, and negative and positive numbers on opposed portions of the axes in a conventional X-Y plot.

[00152] 3) An image of the target is taken by the camera.

[00153] 4) In the resulting image file, the precise angle between the image or optical axis 253 of the camera system 250 (i.e., the axis perpendicular to the image plane which passes through the entrance pupil 255 of the camera 250, and which is located in the exact center of the image of the target taken with the camera system 250), and the axis from the entrance pupil 255 and the location represented by each individual pixel along the horizontal and vertical axis in the resulting image can be determined. If the image does not suffer from "pincushion" or "barrel" distortion, this will be sufficient for calibrating the angle to all pixels in the image file. If there is pincushion, barrel, or other distortion present, more in-depth calibration may be required by using additional measurement points.

[00154] 5) Standard mathematical "Curve Fitting", such as using a multi-dimensional polynomial equation may be used to interpolate the angle to points that are between the points that are actually measured within the calibration image.

[00155] Accordingly, by performing this calibration, the resulting effect of any distortion by the camera system on an acquired image is known. This effect can then

be included in the algorithm that is used to calculate room dimensions from the acquired images obtained during a room scan.

[00156] It is therefore, apparent that there have been provided, in accordance with the present invention, apparatus and methods for measuring rooms and other three-dimensional spaces having boundaries. Having thus described the basic concept of the invention, it will be rather apparent to those skilled in the art that the foregoing detailed disclosure is intended to be presented by way of example only, and is not limiting. Various alterations, improvements, and modifications will occur and are intended to those skilled in the art, though not expressly stated herein. These alterations, improvements, and modifications are intended to be suggested hereby, and are within the spirit and scope of the invention. Additionally, the recited order of processing elements or sequences, or the use of numbers, letters, or other designations therefore, is not intended to limit the claimed processes to any order except as may be specified in the claims.

We claim:

1. An apparatus for measuring the dimensions of an enclosed space containing surfaces, the apparatus comprising:
    a) a support pole;
    b) a fixture engaged with the support pole;
    c) a first driving device engaged with the fixture so as to rotate the fixture around the support pole and translate the fixture along the support pole;
    d) a camera configured to acquire images of the enclosed space, the camera mounted on the fixture and positioned facing outwardly from the fixture and having an image pupil and a field of view containing a portion of the surfaces of the enclosed space;
    e) a motion control module in signal communication with the first driving device and obtaining linear position data and angular position data of the camera;
    f) a plurality of lasers joined to the fixture, the lasers directing laser beams outwardly from the fixture to the portion of the surfaces of the enclosed space that are contained within the field of view of the camera; and
    g) a first processor in signal communication with the camera and with the motion control module, the first processor containing a program to correlate each image of the surfaces of the enclosed space acquired by the camera with the linear and angular position of the camera when the image was acquired.

2. The apparatus of claim 1, wherein the program includes steps to process the images of the surfaces of the enclosed space, and for each acquired image, to identify laser spots on the surfaces of the enclosed space, and calculate distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired.

3. The apparatus of claim 2, wherein the program includes a calculation of the dimensions of the enclosed space based upon the calculated distances from the image pupil to the laser spots on the surfaces and the linear and angular position data obtained when images of the surfaces of the enclosed space are captured by the camera.

4. The apparatus of claim 3, wherein the enclosed space includes surfaces of walls bounding the enclosed space, and surfaces of objects contained within the wall

surfaces, and the program includes a calculation of the dimensions of the wall surfaces and the object surfaces.

5. The apparatus of claim 3, wherein the program includes characterization of textures of the surfaces of the enclosed volume.

6. The apparatus of claim 3, wherein the program includes characterization of colors of the surfaces of the enclosed volume.

7. The apparatus of claim 1, further comprising a second processor located external to the fixture and in signal communication with the first processor.

8. The apparatus of claim 7, wherein the second processor includes program instructions to process the images of the surfaces of the enclosed space, and for each acquired image, to identify laser spots on the surfaces of the enclosed space, and calculate distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired.

9. The apparatus of claim 1, wherein the program includes instructions for calibrating the field of view of the camera to account for the effect of distortion by the camera on an acquired image.

10. The apparatus of claim 1, wherein a first laser is mounted on a first support extending outwardly from the fixture, and a second laser is mounted on a second support extending outwardly from the fixture in a direction opposite to the first support.

11. The apparatus of claim 1, further comprising four lasers, wherein a first laser is mounted on a first support extending vertically upwardly from the fixture, a second laser is mounted on a second support extending vertically downwardly from the fixture, a third laser is mounted on a third support extending horizontally from the fixture, and a fourth laser is mounted on a fourth support extending horizontally from the fixture in a direction opposite of the third support.

12. The apparatus of claim 1, further comprising four laser sets, wherein a first laser set is mounted on a first support extending vertically upwardly from the fixture, a second laser set is mounted on a second support extending vertically downwardly from the fixture, a third laser set is mounted on a third support extending horizontally from the

fixture, and a fourth laser set is mounted on a fourth support extending horizontally from the fixture in a direction opposite of the third support.

13. The apparatus of claim 12, wherein each of the first, second, third, and fourth laser sets is comprised of at least two lasers.

14. The apparatus of claim 12, wherein each of the first, second, third, and fourth laser sets is comprised of a red laser, a blue laser, and a green laser.

15. The apparatus of claim 1, further comprising a second driving device engaged with the support pole of the apparatus and configured to move the support pole and the fixture within the enclosed space.

16. The apparatus of claim 1, wherein the support pole in the enclosed space is vertical.

17. A method for measuring the dimensions of an enclosed space bounded by surfaces, the method comprising:

a) moving a fixture supporting a camera and at least two lasers in rotational and linear motion so as to scan the laser beams of the at least two lasers along the surfaces of the enclosed space to produce laser spots on the surfaces, the laser spots being within the field of view of the camera;
b) capturing images of the surfaces of the enclosed space with the camera while acquiring rotational and linear position data of the camera;
c) identifying the rotational and linear position of the camera for each acquired image; and
d) identifying within each acquired image the laser spots on the surfaces of the enclosed space, and calculating distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired.

18. The method of claim 17, further comprising calculating the dimensions of the enclosed space based upon the calculated distances from the image pupil to the laser spots on the surfaces and the linear and angular position data obtained when images of the surfaces of the enclosed space are captured by the camera.

19. The method of claim 17, further comprising calibrating the field of view of the camera to identify the amount of distortion by the camera on the captured images, and

calculating the dimensions of the enclosed space based also upon the amount of distortion by the camera on the captured images.

20. The method of claim 17, further comprising creating a three-dimensional model of the enclosed space.

21. The method of claim 20, wherein the three dimensional model includes textures of the surfaces of the enclosed space.

22. The method of claim 20, wherein the three dimensional model includes colors of the surfaces of the enclosed space.

23. The method of claim 20, wherein the three dimensional model includes wall surfaces of the enclosed space, and objects contained within the wall surfaces.

24. The method of claim 17, wherein the calculating distances from the image pupil of the camera to the laser spots on the surfaces when the image was acquired is performed by an algorithm using parallax triangulation.

25. The method of claim 17, comprising capturing images of the surfaces of the enclosed space with the camera while acquiring rotational and linear position data of the camera in a first location within the enclosed space, and then capturing images of the surfaces of the enclosed space with the camera while acquiring rotational and linear position data of the camera in a second location within the enclosed space.

26. A computer-implemented method of for measuring the dimensions of an enclosed space bounded by surfaces, the method comprising:

a) moving a fixture supporting a camera and at least two lasers in rotational and linear motion so as to scan the laser beams of the at least two lasers along the surfaces of the enclosed space to produce laser spots on the surfaces, the laser spots being within the field of view of the camera;
b) capturing digital images of the surfaces of the enclosed space with the camera while acquiring rotational and linear position data of the camera, and communicating the digital images and the corresponding rotational and linear position of the camera when each digital image was acquired to a processor;
c) processing the digital images with the processor to identify within each acquired image the laser spots on the surfaces of the enclosed space;

d) with the processor, calculating distances from the image pupil of the camera to the laser spots on the surfaces; and

e) with the processor, calculating the dimensions of the enclosed space based upon the calculated distances from the image pupil to the laser spots on the surfaces.

27. The method of claim 26, further comprising creating a three-dimensional model of the enclosed space.

28. The method of claim 26, wherein the calculating distances from the image pupil of the camera to the laser spots on the surfaces is performed by an algorithm using parallax triangulation.

29. An apparatus for measuring the dimensions of a room bounded by surfaces, the apparatus comprising:

a) a support structure;

b) a fixture engaged with the support structure;

c) a plurality of light sources joined to the fixture, the light sources directing light beams outwardly from the fixture;

d) a distance meter for detecting the light impinging on the room surfaces and measuring the distances from the fixture to the room surfaces;

wherein the fixture is operable so as to scan the light beams over the room surfaces while measuring the distances from the fixture to the room surfaces.

30. The apparatus of claim 29, further comprising a camera for acquiring images of the room surfaces.

31. The apparatus of claim 29, wherein the light sources are lasers emanating laser beams, and the distance meter is a laser distance meter.

32. The apparatus of claim 31, wherein the laser beams are directed to the room surfaces and the images are acquired by the camera through a shared fiber optic.

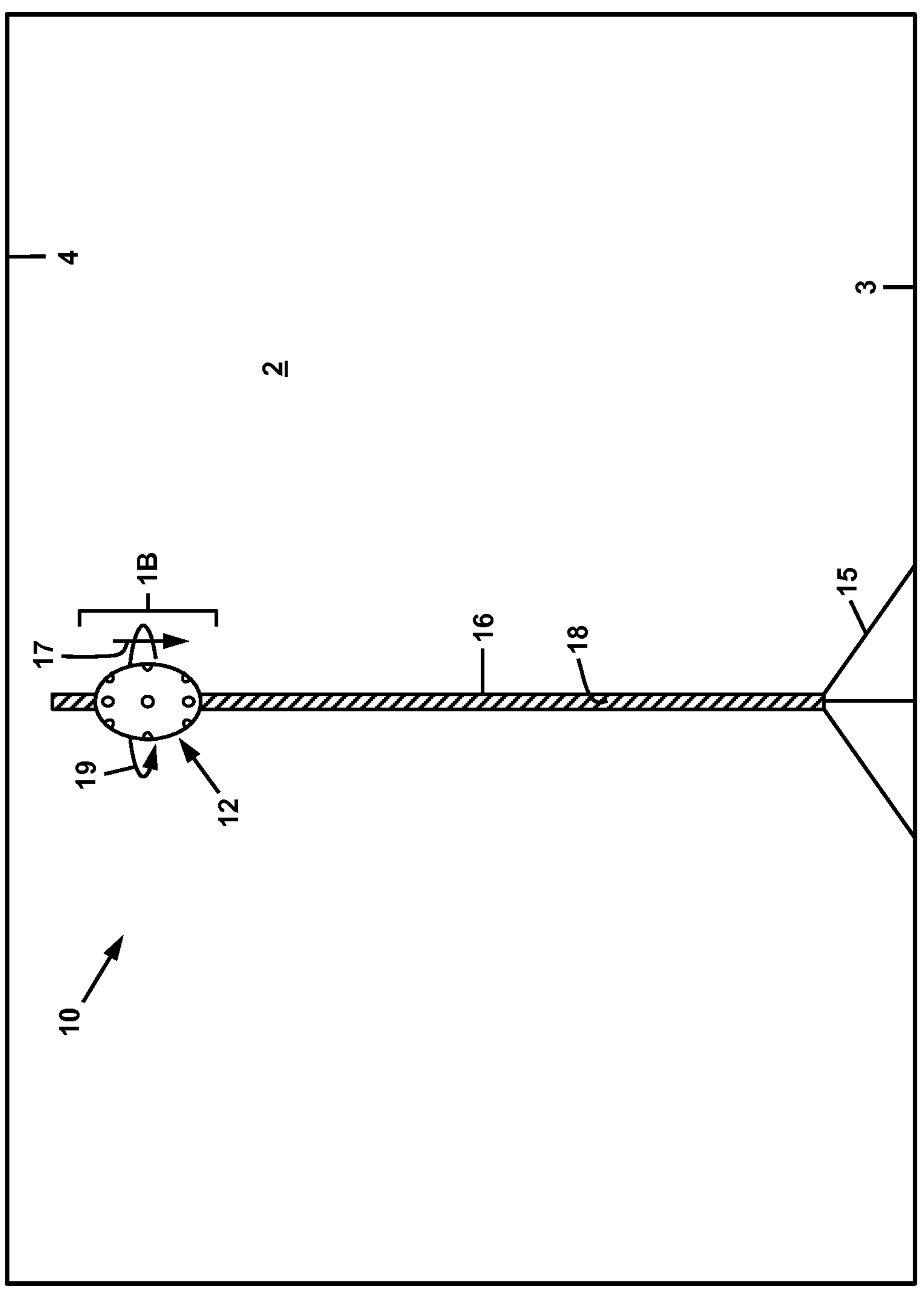


FIG. 1A

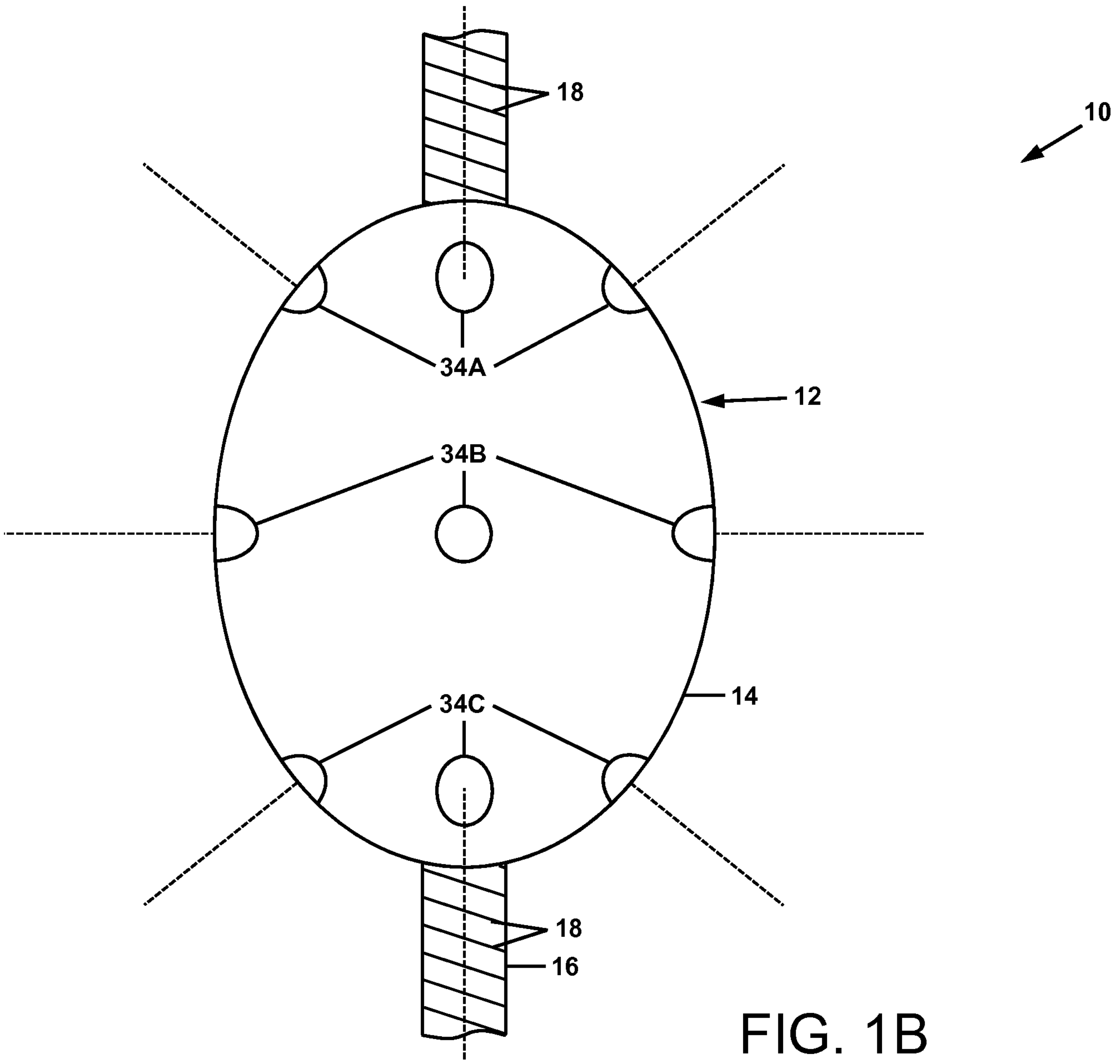


FIG. 1B

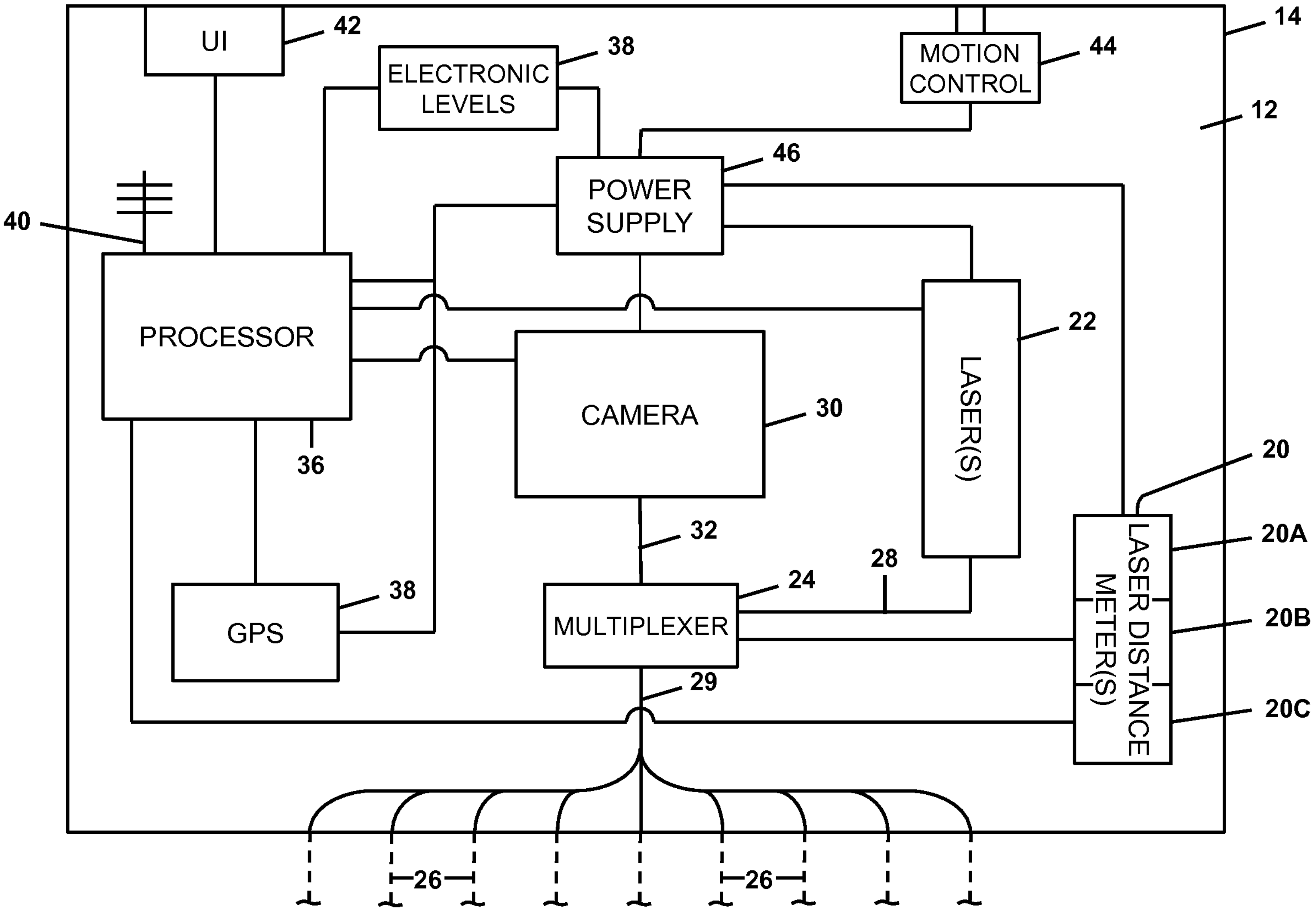

UI
42
ELECTRONIC LEVELS
38
MOTION CONTROL
44
14
12
40
POWER SUPPLY
46
PROCESSOR
22
LASER(S)
CAMERA
30
36
20
20A
32
28
GPS
38
24
MULTIPLEXER
LASER DISTANCE METER(S)
20B
29
20C
26
26

FIG. 2

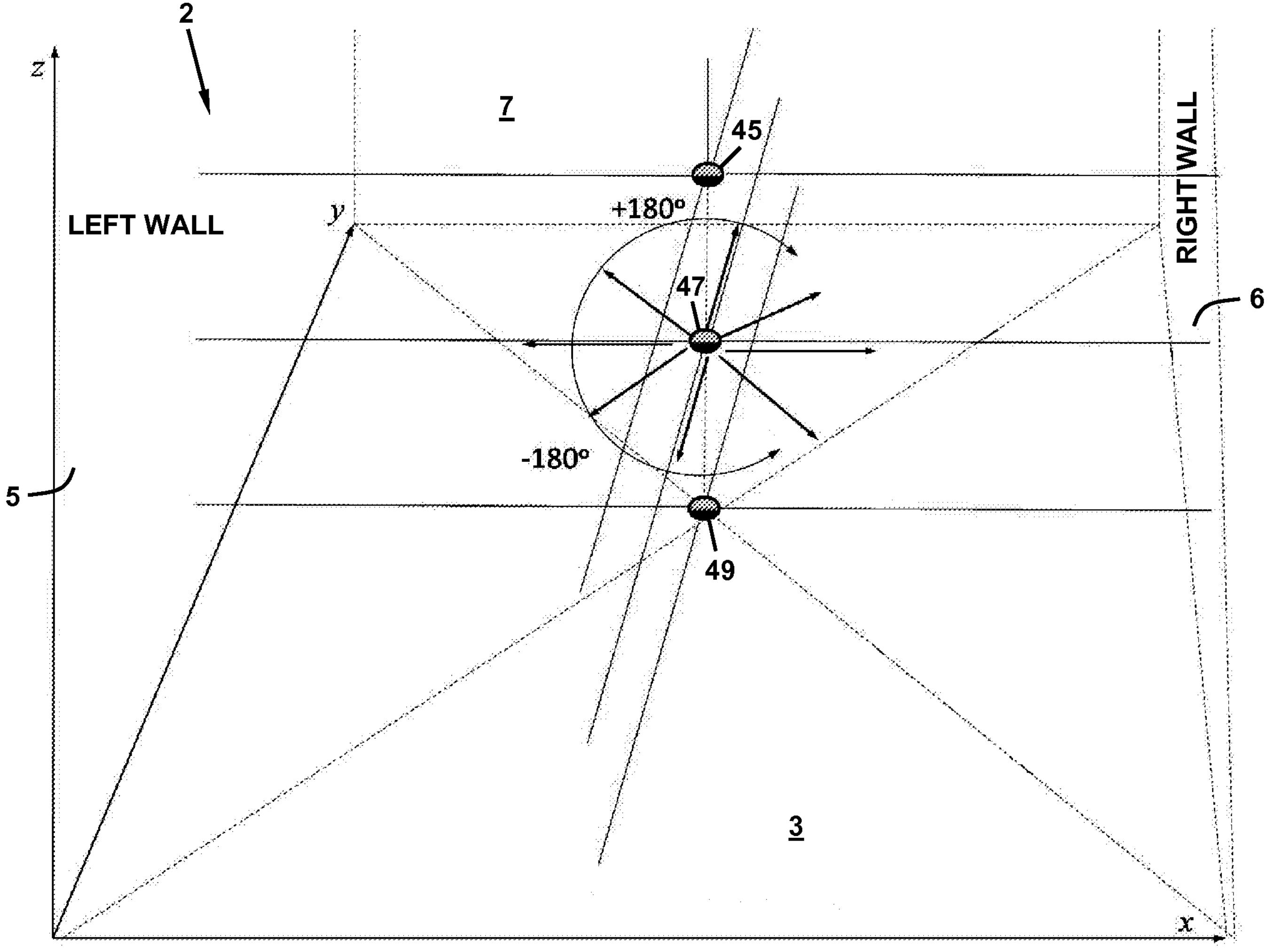


FIG. 3

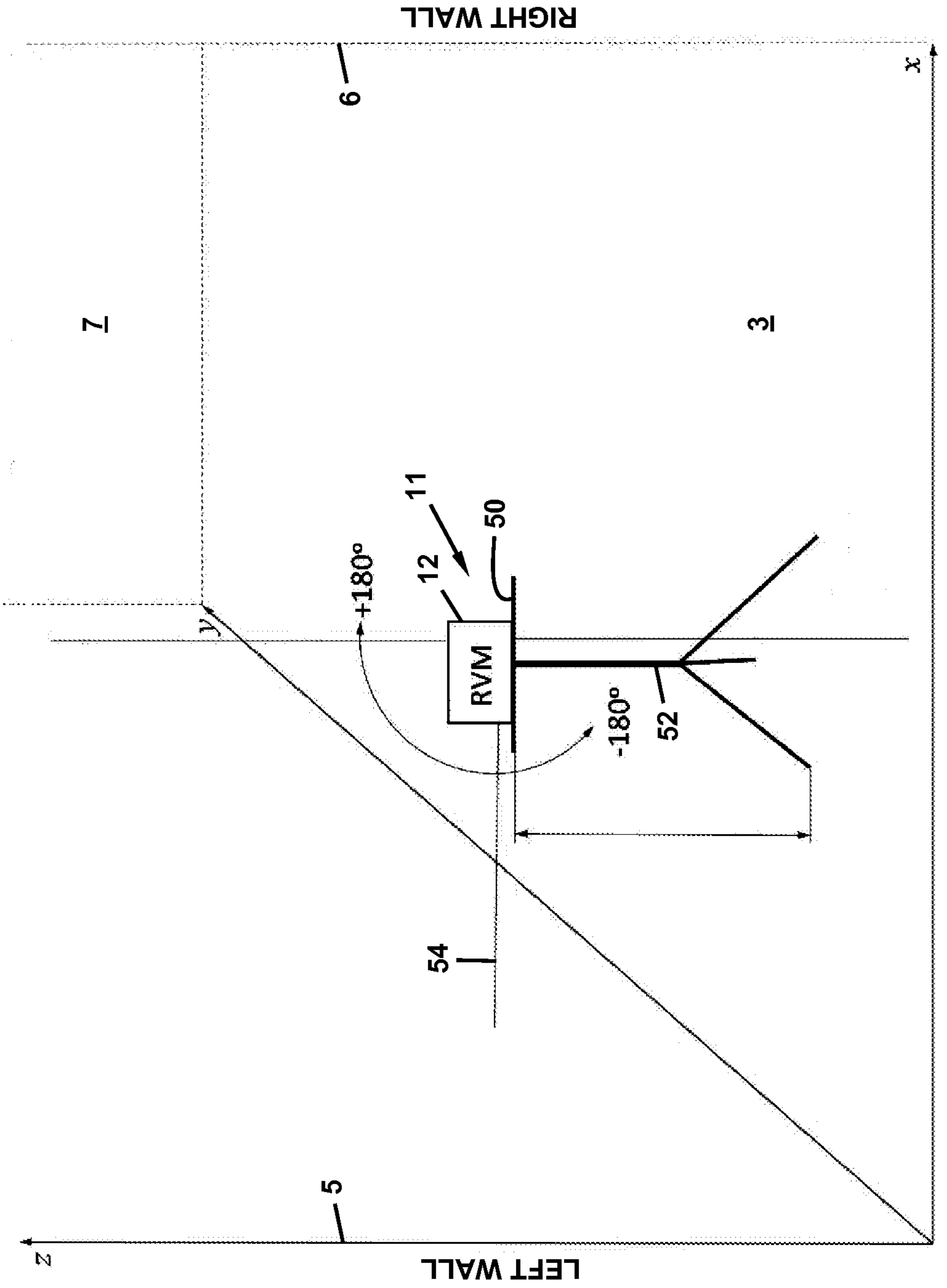


FIG. 4

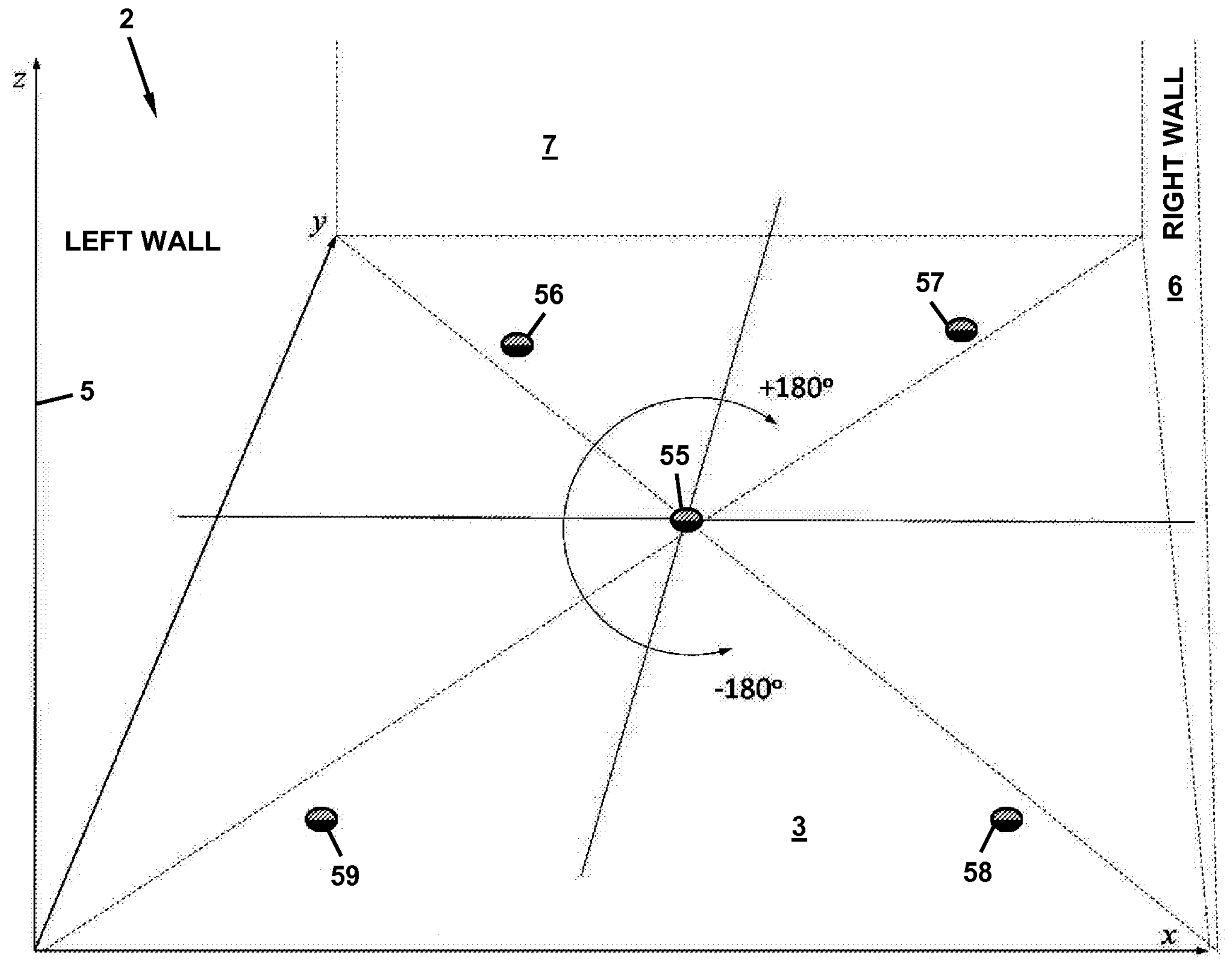


FIG. 5

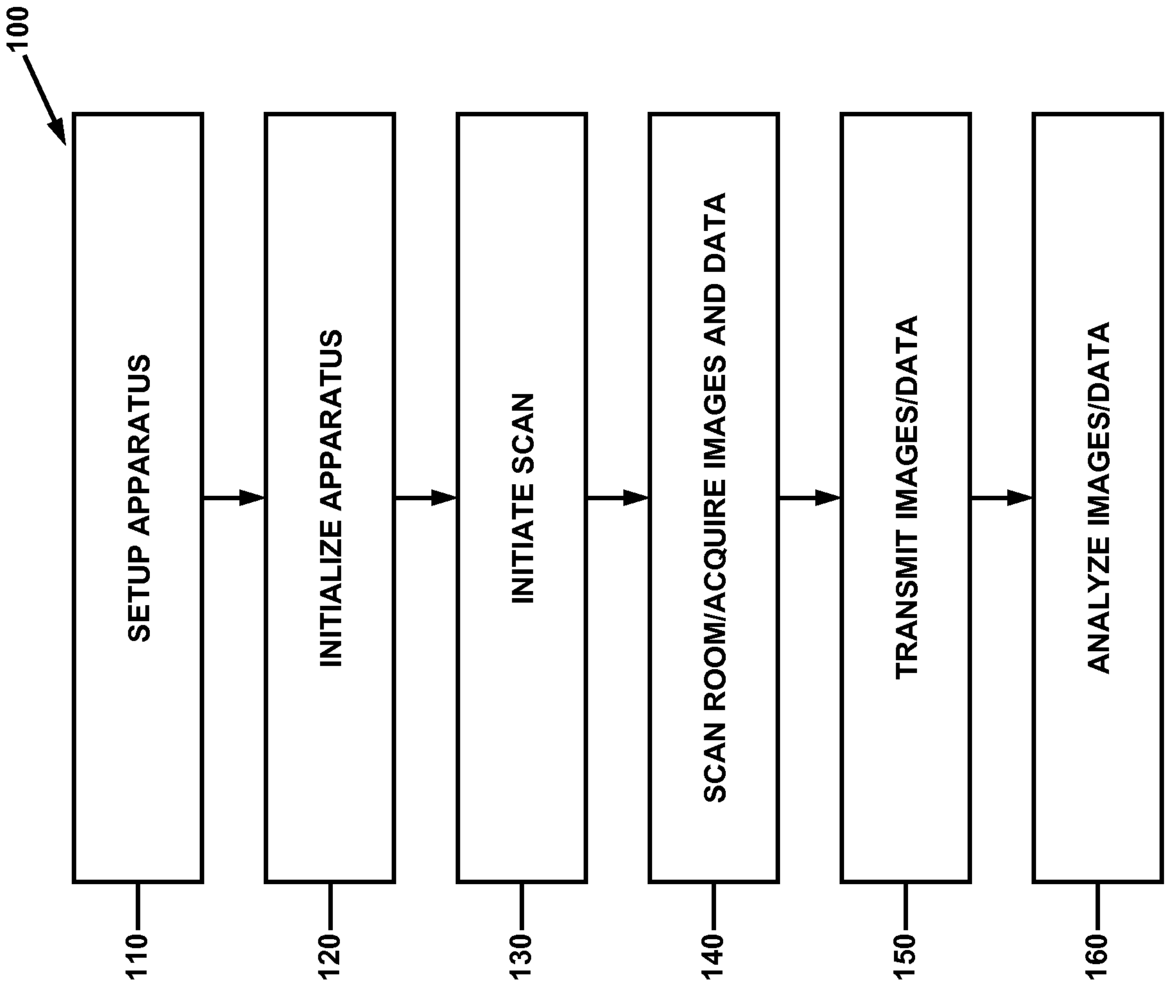
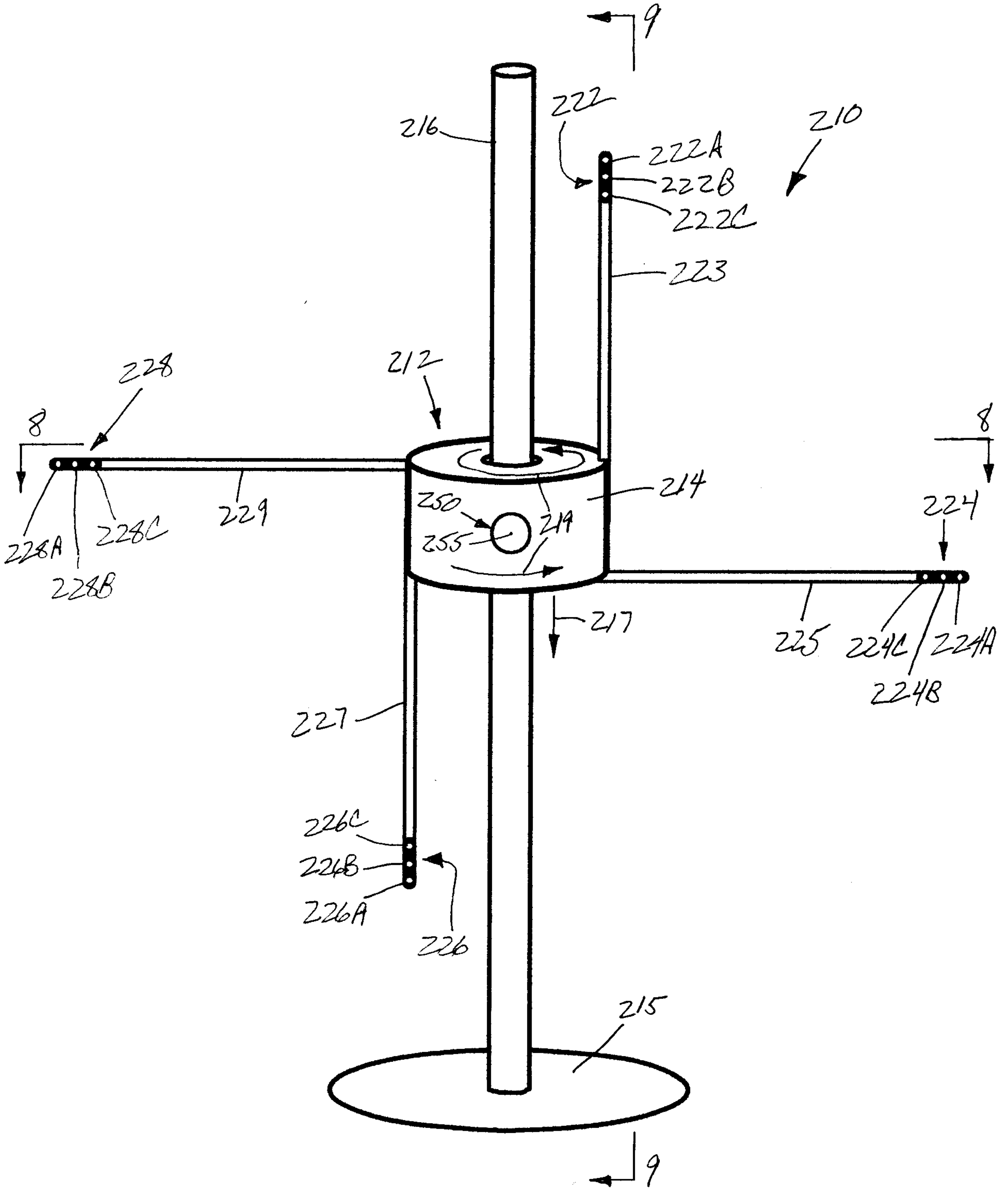

100
SETUP APPARATUS
INITIALIZE APPARATUS
INITIATE SCAN
SCAN ROOM/ACQUIRE IMAGES AND DATA
TRANSMIT IMAGES/DATA
ANALYZE IMAGES/DATA
110
120
130
140
150
160

FIG. 6


9
9
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216
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219
219
222
222A
222B
222C
223
224
224A
224B
224C
225
226
226A
226B
226C
227
228
228A
228B
228C
229
250
255

FIG. 7

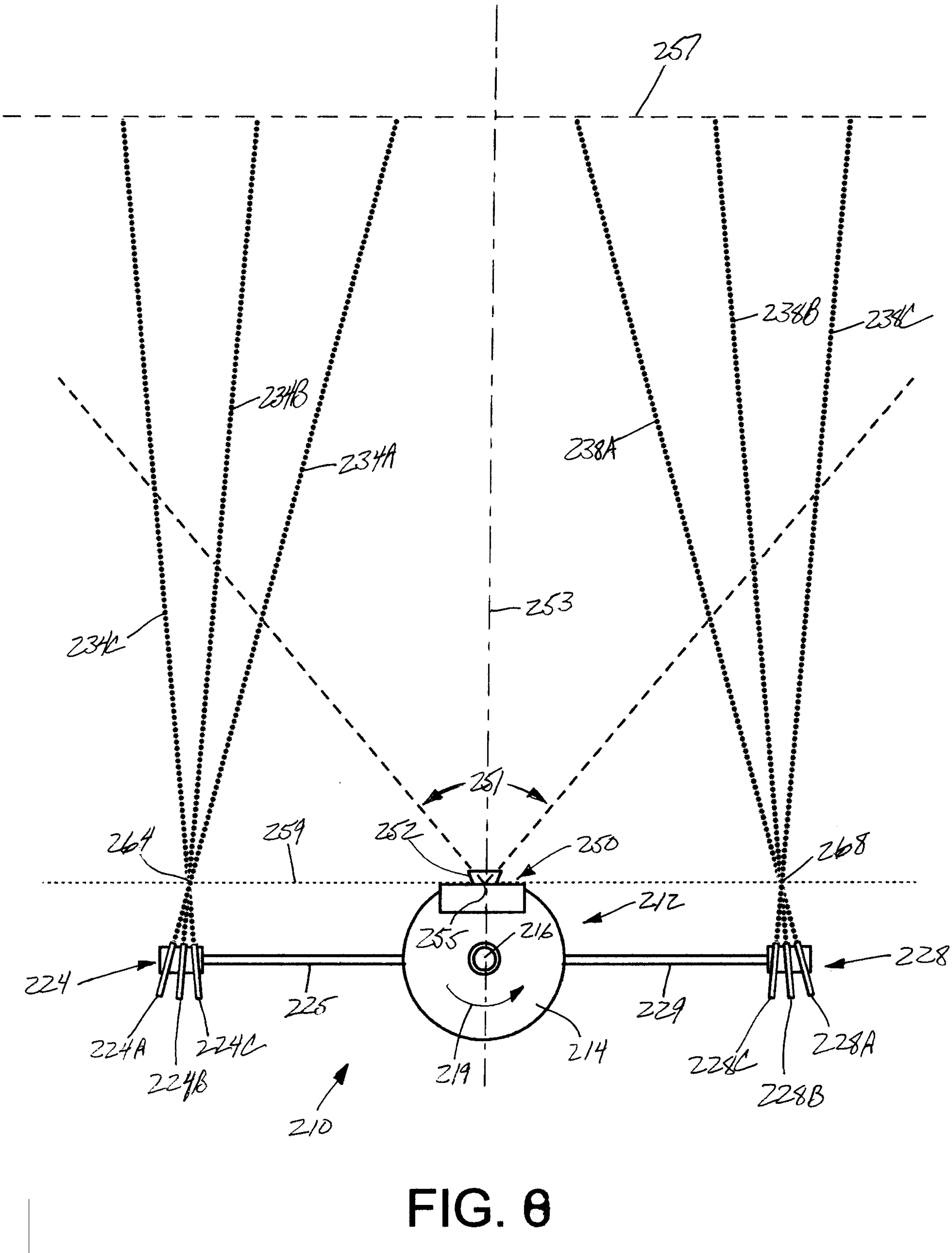
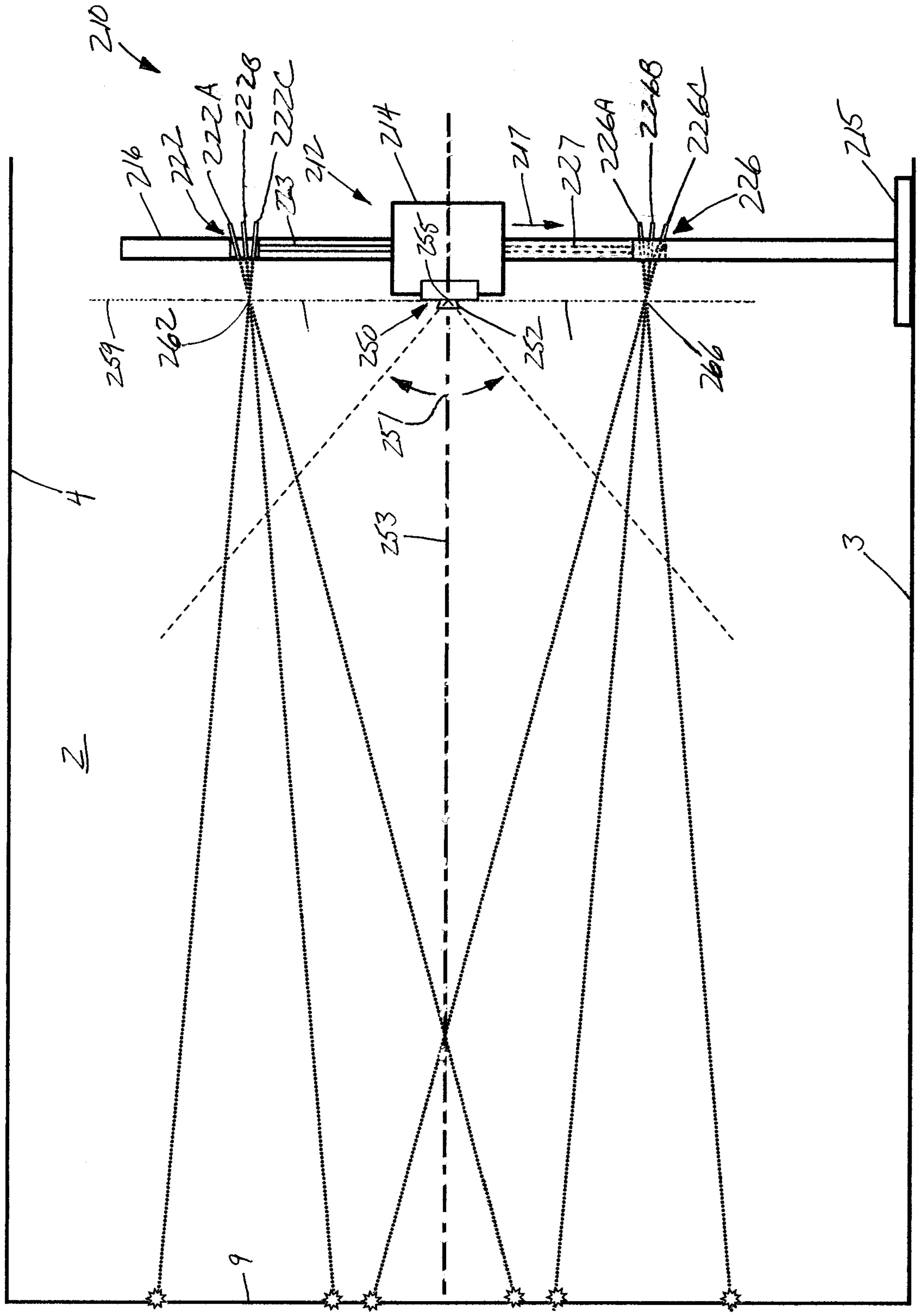

257
238B
238C
234B
234A
238A
253
234C
251
264
259
252
250
268
212
255
216
228
224
225
229
224A
224C
224B
219
214
228C
228A
228B
210

FIG. 8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222
222A
222B
222C
223
212
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255
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227
226A
226B
226C
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259
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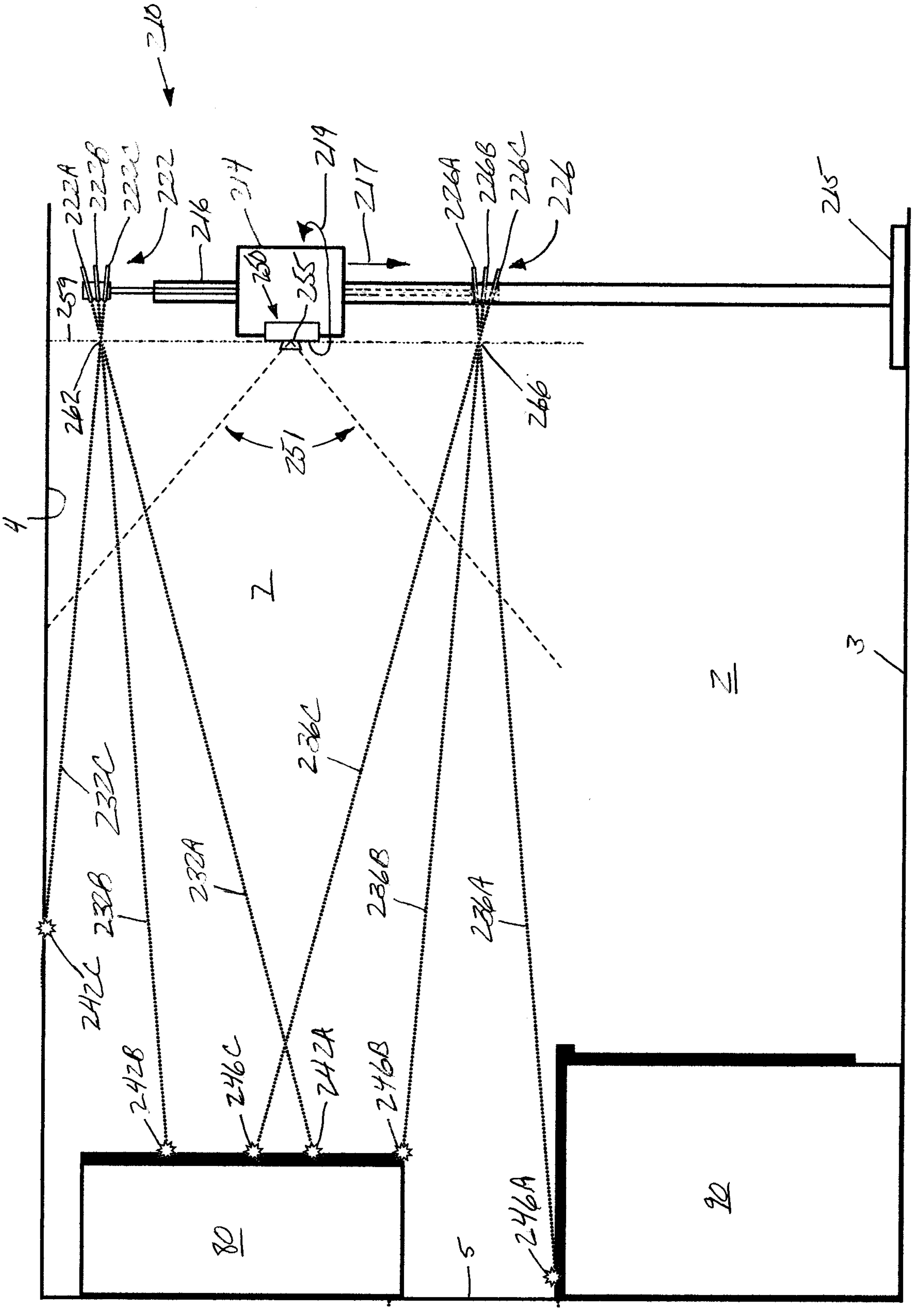
250
252
266
251
253
4
2
3
9

FIG. 9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222C
222
216
214
219
217
226A
226B
226C
226
215
259
262
250
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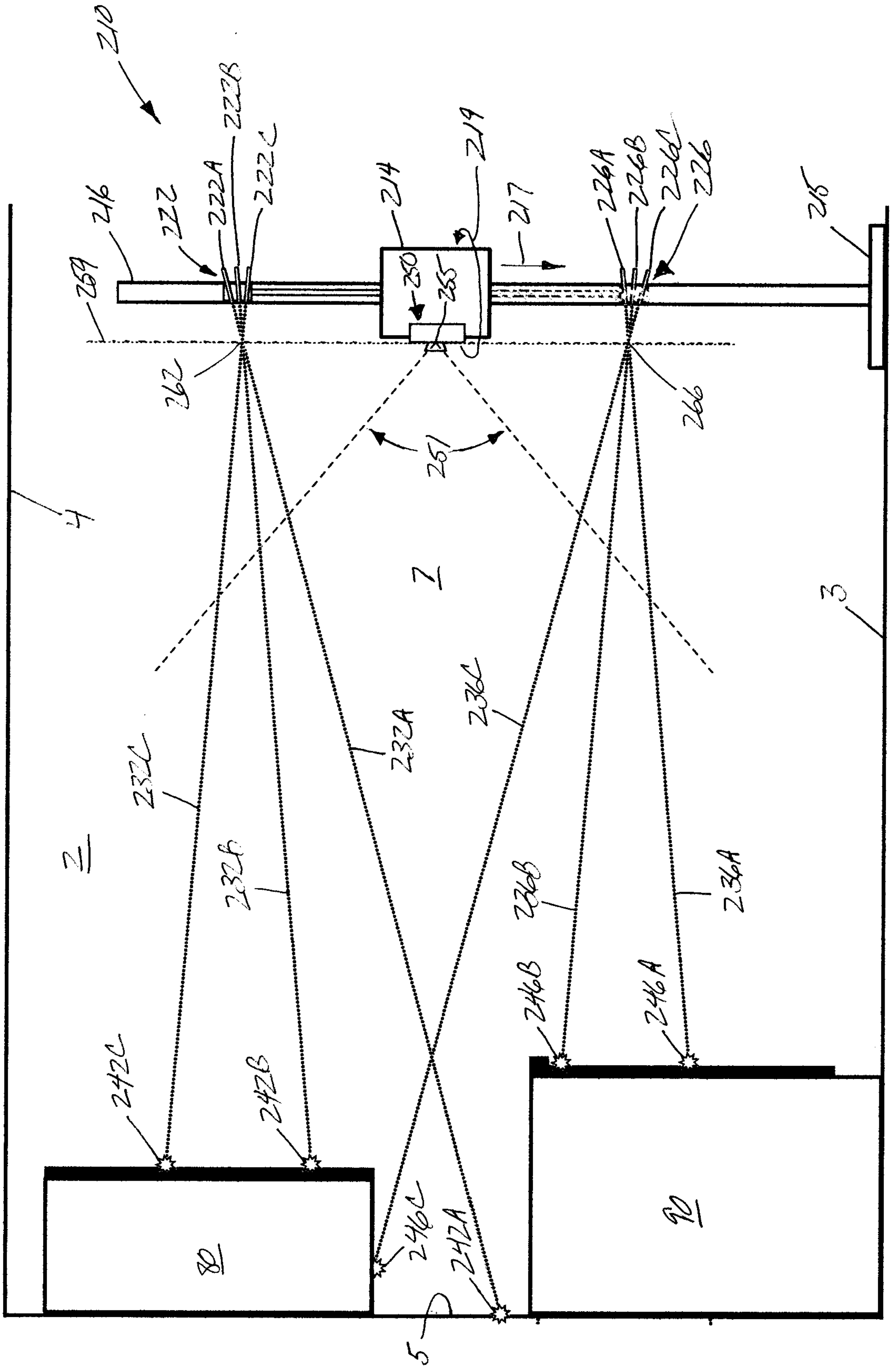
266
251
4
1
2
3
232C
232B
232A
236C
236B
236A
242C
242B
246C
242A
246B
246A
80
90
5

FIG. 10A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222
222A
222B
222C
216
259
214
219
217
226A
226B
226C
226
215
250
255
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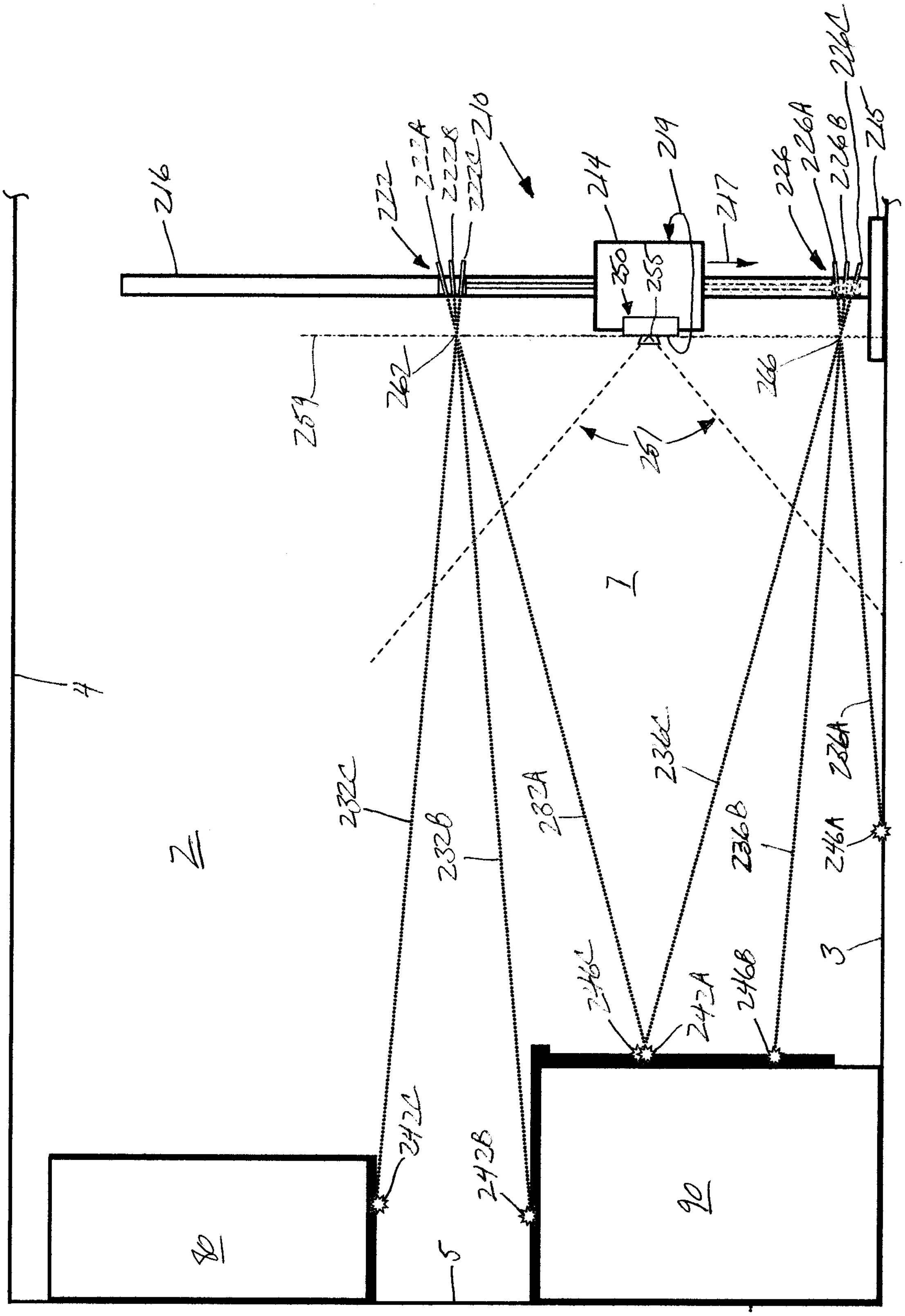
266
261
4
7
3
2
232C
232B
232A
236C
236B
236A
242C
242B
246B
246A
246C
242A
5
80
90

FIG. 10B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222
222A
222B
222C
210
214
219
217
226
226A
226B
226C
215
250
255
259
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261
266
1
4
2
232C
232B
232A
236C
236B
236A
246A
3
246C
242A
246B
242C
242B
5
80
90

FIG. 10C

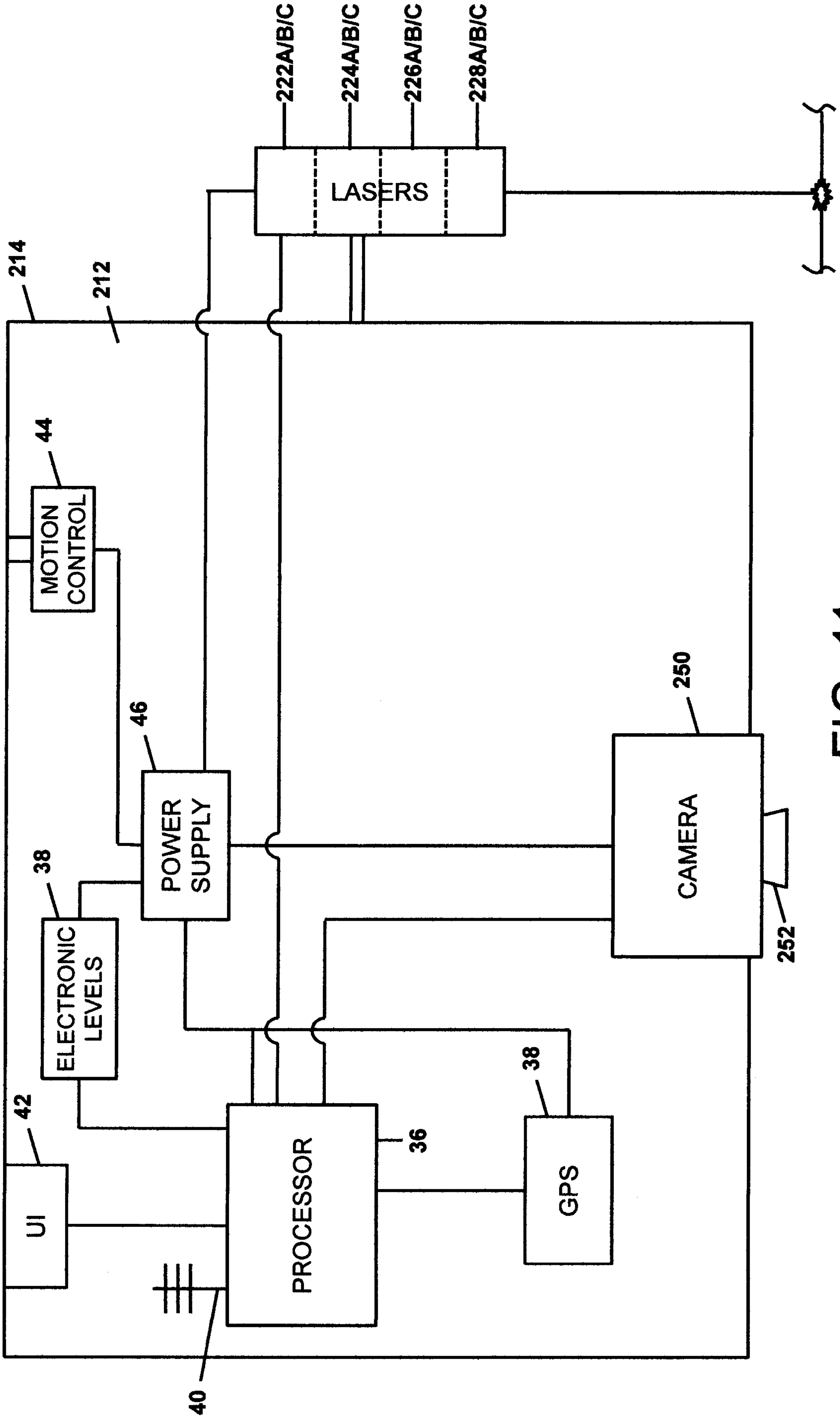
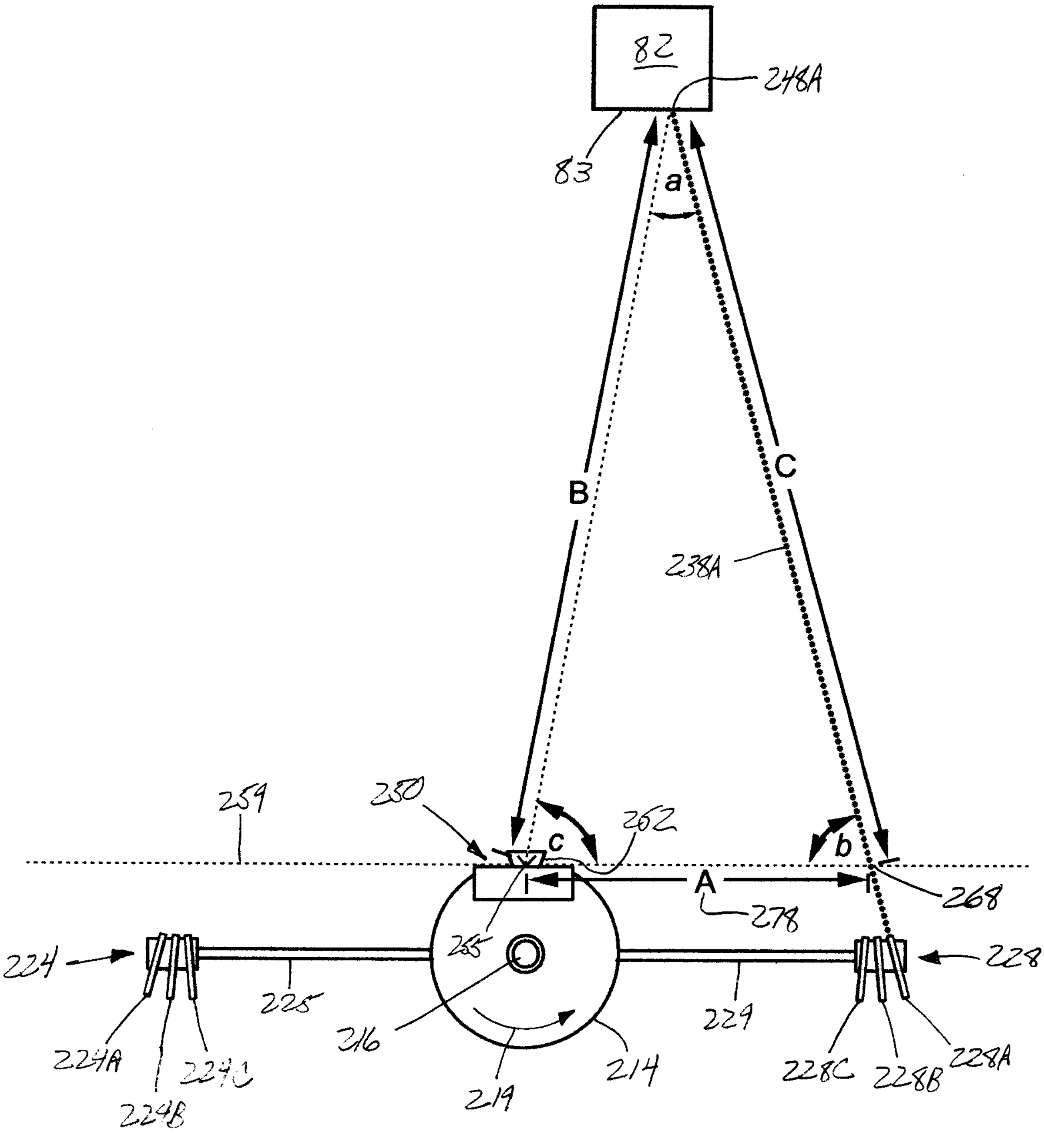

222A/B/C
224A/B/C
226A/B/C
228A/B/C
LASERS
214
212
44
MOTION CONTROL
46
POWER SUPPLY
38
ELECTRONIC LEVELS
250
CAMERA
252
38
GPS
42
UI
PROCESSOR
36
40

FIG. 11


82
248A
83
a
B
C
238A
259
250
262
c
b
A
278
268
265
224
225
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219
214
229
228
224A
224B
224C
228C
228B
228A

FIG. 12A

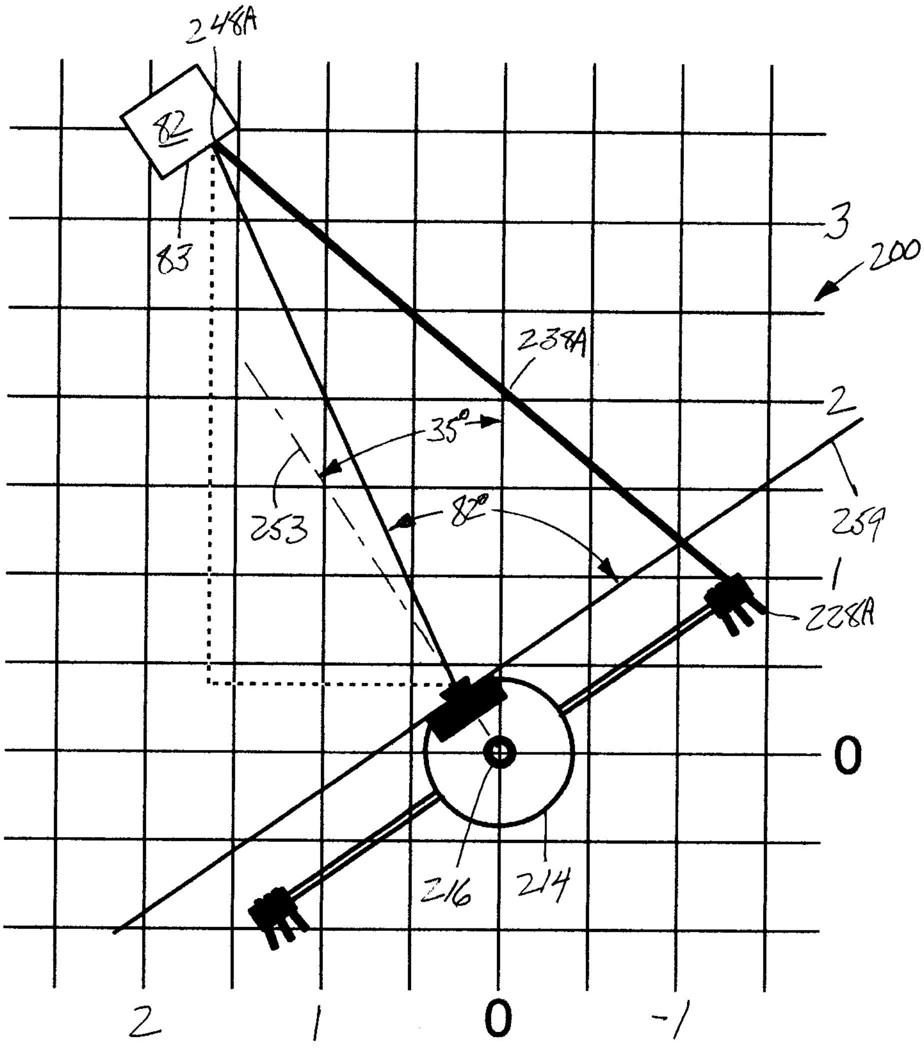

FIG. 12B

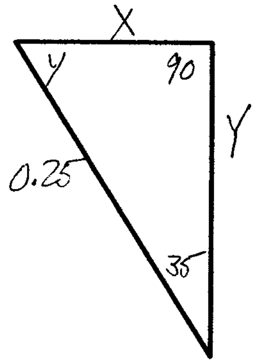

FIG. 12C

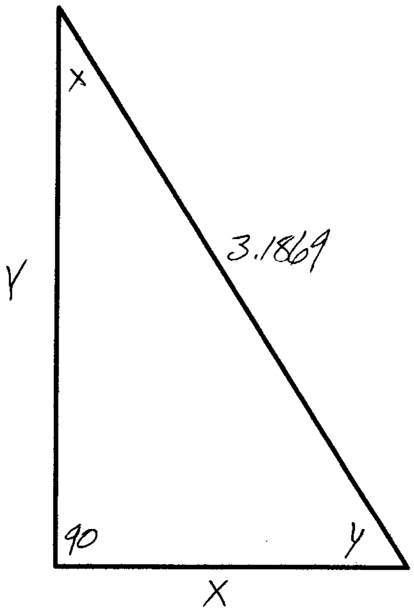

FIG. 12D

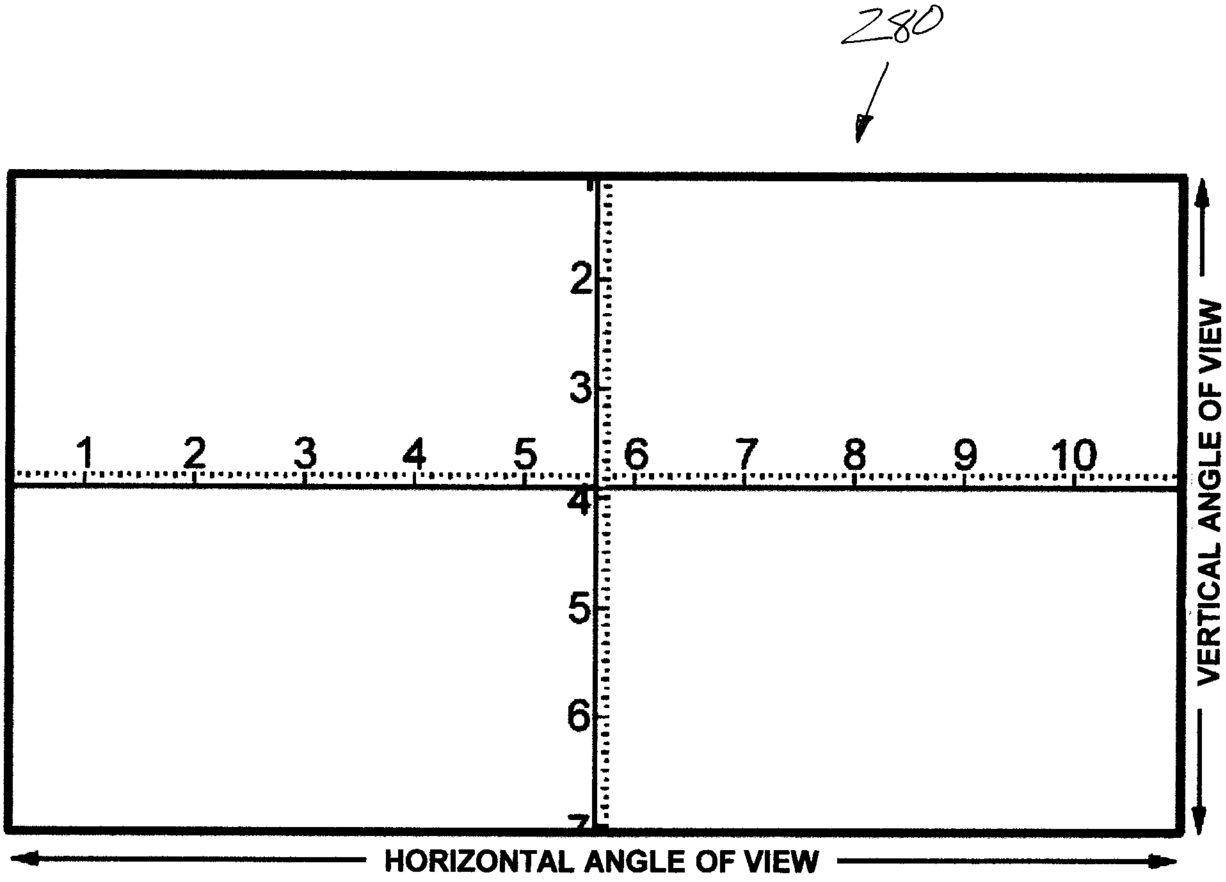
280
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
VERTICAL ANGLE OF VIEW
HORIZONTAL ANGLE OF VIEW

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 12/61188

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01B 15/00 (2012.01)
USPC - 702/155
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)
USPC:702/155

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC:702/1, 57, 127, 150, 155, 158; 700/303; 250/458.1; G01B 15/00

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase; Google Scholar
Search terms: processor, computer, CPU, controller, camera, motion, move, vertical, rise, translate, up, rotate, fixture, platform, housing, pole, rod, support, laser, light source, measure, distance, dimension, room, enclosed space

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ------ Y	US 2009/0262974 A1 (Lothopoulos). 22 October 2009 (22.10.2009) entire document; para [0034]-[0037] and claim 1	29-31 ------ 1-28, 32
Y	US 5,124,524 A (Schuster et al.) 23 June 1992 (23.06.1992), entire document, especially abstract and col 5, ln 6-25	1-28
Y	US 2009/0131141 A1 (Walker et al.) 21 May 2009 (21.05.2009) entire document; para [0247]	32
A	US 7,302,359 B2 (McKitterick) 27 November 2007 (27.11.2007) entire document.	1-32
A	US 2010/0296075 A1 (Hinderling et al.) 25 November 2010 (25.11.2010) entire document.	1-32
A	US 2003/0193657 A1 (Uomori et al.) 16 October 2003 (16.10.2003) entire document.	1-32
A	US 2008/0218739 A1 (Yamazaki et al.) 11 September 2008 (11.09.2008) entire document.	1-32

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
17 December 2012 (17.12.2012)

Date of mailing of the international search report
10 JAN 2013

Name and mailing address of the ISA/US
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450
Facsimile No. 571-273-3201

Authorized officer:
Lee W. Young
PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774