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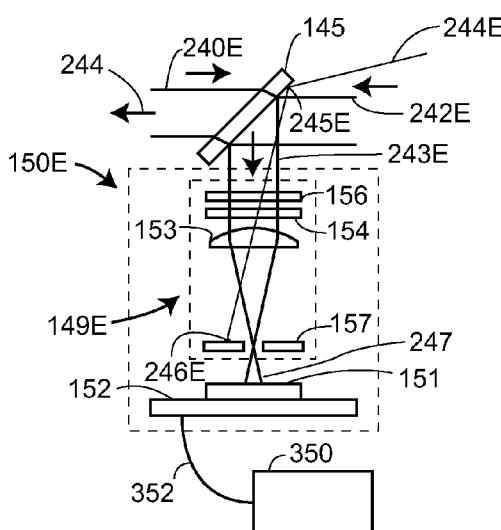
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[Continued on nextpage]

(54) Title: ENHANCED POSITION DETECTOR IN LASER TRACKER



(57) Abstract: A coordinate measurement device sends a first beam of light to a retroreflector target which returns a portion of the first beam as a second beam. The device includes first and second motors that direct the first beam of light to a first direction determined by first and second angles of rotation about first and second axes, first and second angle measuring devices that measure the first and second angles of rotation, respectively. A distance meter measures a first distance from the device to the target. The device also includes a position detector and a diffuser, a second portion of the second beam passing through the diffuser and onto the position detector, the position detector configured to produce a first signal in response to a position of the second portion on the position detector. A control system sends a second signal to the first motor and a third signal to the second motor, the second and third signals based at least in part on the first signal, the control system configured to adjust the first direction of the first beam to the position of the target. A processor provides a 3D coordinate of the target.

FIG. 6E

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ENHANCED POSITION DETECTOR IN LASER TRACKER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Provisional Patent Application No. 61/592,049 filed January 30, 2012, and U.S. Provisional Patent Application No. 61/475,703 filed April 15, 2011, the entire contents of both of which are hereby incorporated by reference.

BACKGROUND

[0002] The present disclosure relates to a coordinate measuring device. One set of coordinate measurement devices belongs to a class of instruments that measure the three-dimensional (3D) coordinates of a point by sending a laser beam to the point. The laser beam may impinge directly on the point or on a retroreflector target in contact with the point. In either case, the instrument determines the coordinates of the point by measuring the distance and the two angles to the target. The distance is measured with a distance-measuring device such as an absolute distance meter or an interferometer. The angles are measured with an angle-measuring device such as an angular encoder. A gimbaled beam-steering mechanism within the instrument directs the laser beam to the point of interest.

[0003] The laser tracker is a particular type of coordinate-measuring device that tracks the retroreflector target with one or more laser beams it emits. Coordinate-measuring devices closely related to the laser tracker are the laser scanner and the total station. The laser scanner steps one or more laser beams to points on a surface. It picks up light scattered from the surface and from this light determines the distance and two angles to each point. The total station, which is most often used in surveying applications, may be used to measure the coordinates of diffusely scattering or retroreflective targets. Hereinafter, the term laser tracker is used in a broad sense to include laser scanners and total stations.

[0004] Ordinarily the laser tracker sends a laser beam to a retroreflector target. A common type of retroreflector target is the spherically mounted retroreflector (SMR), which comprises a cube-corner retroreflector embedded within a metal sphere. The cube-corner retroreflector comprises three mutually perpendicular mirrors. The vertex, which is the common point of intersection of the three mirrors, is located at the center of the sphere. Because of this placement of the cube corner within the sphere, the perpendicular distance from the vertex to any surface on which the SMR rests remains constant, even as the SMR is

rotated. Consequently, the laser tracker can measure the 3D coordinates of a surface by following the position of an SMR as it is moved over the surface. Stating this another way, the laser tracker needs to measure only three degrees of freedom (one radial distance and two angles) to fully characterize the 3D coordinates of a surface.

[0005] One type of laser tracker contains only an interferometer (IFM) without an absolute distance meter (ADM). If an object blocks the path of the laser beam from one of these trackers, the IFM loses its distance reference. The operator must then track the retroreflector to a known location to reset to a reference distance before continuing the measurement. A way around this limitation is to put an ADM in the tracker. The ADM can measure distance in a point-and-shoot manner, as described in more detail below. Some laser trackers contain only an ADM without an interferometer. U.S. Patent No. 7,352,446 to Bridges et al., the contents of which are herein incorporated by reference, describes a laser tracker having only an ADM (and no IFM) that is able to accurately scan a moving target. Prior to this invention, absolute distance meters were too slow to accurately find the position of a moving target.

[0006] A gimbal mechanism within the laser tracker may be used to direct a laser beam from the tracker to the SMR. Part of the light retroreflected by the SMR enters the laser tracker and passes onto a position detector. A control system within the laser tracker can use the position of the light on the position detector to adjust the rotation angles of the mechanical axes of the laser tracker to keep the laser beam centered on the SMR. In this way, the tracker is able to follow (track) an SMR that is moved over the surface of an object of interest.

[0007] Angle measuring devices such as angular encoders are attached to the mechanical axes of the tracker. The one distance measurement and two angle measurements performed by the laser tracker are sufficient to completely specify the three-dimensional location of the SMR.

[0008] Several laser trackers are available or have been proposed for measuring six, rather than the ordinary three, degrees of freedom. Exemplary six degree-of-freedom (six-DOF) systems are described by U.S. Patent No. 7,800,758 ('758) to Bridges et al., the contents of which are herein incorporated by reference, and U.S. Published Patent Application No. 2010/0128259 to Bridges et al., the contents of which are herein incorporated by reference.

[0009] As explained above, tracking of a retroreflector target by the beam of light from a laser tracker is accomplished by sending a portion of the retroreflected light that enters

the tracker onto a position detector. A beam reflected onto the position detector may not vary smoothly but may instead have "hot spots" that may cause the position of the retroreflector target to be improperly determined. In addition, unwanted ghost beams reflected off optical elements may strike the position detector, also causing the position of the retroreflector target to be improperly determined. What is needed is a way to eliminate the problems in the illumination of the position detector, thereby improving tracking and angular measurement accuracy of the laser tracker.

SUMMARY

[0010] According to an embodiment of the present invention, a coordinate measurement device sends a first beam of light to a remote retroreflector target, the retroreflector target having a position in space, the position in space being a function of time, the retroreflector target returning a portion of the first beam as a second beam. The measurement device includes a first motor and a second motor that together direct the first beam of light to a first direction, the first direction determined by a first angle of rotation about a first axis and a second angle of rotation about a second axis, the first angle of rotation produced by the first motor and the second angle of rotation produced by the second motor. The measurement device also includes a first angle measuring device that measures the first angle of rotation and a second angle measuring device that measures the second angle of rotation; a distance meter that measures a first distance from the coordinate measurement device to the retroreflector target based at least in part on a first portion of the second beam received by a first optical detector; and a position detector assembly that includes a position detector and a diffuser, a second portion of the second beam passing through the diffuser and onto the position detector, the position detector configured to produce a first signal in response to a position of the second portion on the position detector. The measurement device further includes a control system that sends a second signal to the first motor and a third signal to the second motor, the second signal and the third signal based at least in part on the first signal, the control system configured to adjust the first direction of the first beam to the position in space of the retroreflector target; and a processor that provides a three-dimensional coordinate of the retroreflector target, the three-dimensional coordinate based at least in part on the first distance, the first angle of rotation, and the second angle of rotation.

[0011] According to another embodiment of the present invention, a coordinate measurement device sends a first beam of light to a remote retroreflector target, the

retroreflector target having a position in space, the position in space being a function of time, the retroreflector target returning a portion of the first beam as a second beam. The measurement device includes a first motor and a second motor that together direct the first beam of light to a first direction, the first direction determined by a first angle of rotation about a first axis and a second angle of rotation about a second axis, the first angle of rotation produced by the first motor and the second angle of rotation produced by the second motor. The measurement device also includes a first angle measuring device that measures the first angle of rotation and a second angle measuring device that measures the second angle of rotation; a distance meter that measures a first distance from the coordinate measurement device to the retroreflector target based at least in part on a first portion of the second beam received by a first optical detector; and a position detector assembly that includes a position detector, a lens, and a spatial filter, the lens having a positive focal length, the spatial filter placed a second distance from the lens approximately equal to the lens focal length, the spatial filter placed between the lens and the position detector, a second portion of the second beam passing through the lens and spatial filter onto the position detector, the position detector configured to produce a first signal in response to a position of the second portion on the position detector. The measurement device further includes a control system that sends a second signal to the first motor and a third signal to the second motor, the second signal and the third signal based at least in part on the first signal, the control system configured to adjust the first direction of the first beam to the position in space of the retroreflector target; and a processor that provides a three-dimensional coordinate of the retroreflector target, the three-dimensional coordinate based at least in part on the first distance, the first angle of rotation, and the second angle of rotation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Referring now to the drawings, exemplary embodiments are shown which should not be construed to be limiting regarding the entire scope of the disclosure, and wherein the elements are numbered alike in several FIGURES:

[0013] FIG. 1 is a perspective view of a laser tracker system with a retroreflector target in accordance with an embodiment of the present invention;

[0014] FIG. 2 is a perspective view of a laser tracker system with a six-DOF target in accordance with an embodiment of the present invention;

[0015] FIG. 3 is a block diagram describing elements of laser tracker optics and electronics in accordance with an embodiment of the present invention;

[0016] FIG. 4, which includes FIGs. 4A and 4B, shows two types of prior art afocal beam expanders;

[0017] FIG. 5 shows a prior art fiber-optic beam launch;

[0018] FIGs. 6A-D are schematic figures that show four types of prior art position detector assemblies, and FIGs. 6E-F are schematic figures showing position detector assemblies according to embodiments of the present invention;

[0019] FIG. 7 is a block diagram of electrical and electro-optical elements within a prior art ADM;

[0020] FIG. 8A and 8B are schematic figures showing fiber-optic elements within a prior art fiber-optic network;

[0021] FIG. 8C is a schematic figure showing fiber-optic elements within a fiber-optic network in accordance with an embodiment of the present invention;

[0022] FIG. 9 is an exploded view of a prior art laser tracker;

[0023] FIG. 10 is a cross-sectional view of a prior art laser tracker; and

[0024] FIG. 11 is a block diagram of the computing and communication elements of a laser tracker in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0025] An exemplary laser tracker system 5 illustrated in FIG. 1 includes a laser tracker 10, a retroreflector target 26, an optional auxiliary unit processor 50, and an optional auxiliary computer 60. An exemplary gimbaled beam-steering mechanism 12 of laser tracker 10 comprises a zenith carriage 14 mounted on an azimuth base 16 and rotated about an azimuth axis 20. A payload 15 is mounted on the zenith carriage 14 and rotated about a zenith axis 18. Zenith axis 18 and azimuth axis 20 intersect orthogonally, internally to tracker 10, at gimbal point 22, which is typically the origin for distance measurements. A laser beam 46 virtually passes through the gimbal point 22 and is pointed orthogonal to zenith axis 18. In other words, laser beam 46 is approximately perpendicular to any plane parallel to both the zenith axis 18 and the azimuth axis 20. Outgoing laser beam 46 is pointed in the desired direction by rotation of payload 15 about zenith axis 18 and by rotation of zenith carriage 14 about azimuth axis 20. A zenith angular encoder, internal to the tracker, is attached to a zenith mechanical axis aligned to the zenith axis 18. An azimuth angular encoder, internal to

the tracker, is attached to an azimuth mechanical axis aligned to the azimuth axis 20. The zenith and azimuth angular encoders measure the zenith and azimuth angles of rotation to relatively high accuracy. Outgoing laser beam 46 travels to the retroreflector target 26, which might be, for example, a spherically mounted retroreflector (SMR) as described above. By measuring the radial distance between gimbal point 22 and retroreflector 26, the rotation angle about the zenith axis 18, and the rotation angle about the azimuth axis 20, the position of retroreflector 26 is found within the spherical coordinate system of the tracker.

[0026] Outgoing laser beam 46 may include one or more laser wavelengths, as described hereinafter. For the sake of clarity and simplicity, a steering mechanism of the sort shown in FIG. 1 is assumed in the following discussion. However, other types of steering mechanisms are possible. For example, it is possible to reflect a laser beam off a mirror rotated about the azimuth and zenith axes. The techniques described herein are applicable, regardless of the type of steering mechanism.

[0027] Magnetic nests 17 may be included on the laser tracker for resetting the laser tracker to a "home" position for different sized SMRs - for example, 1.5, 7/8, and ½ inch SMRs. An on-tracker retroreflector 19 may be used to reset the tracker to a reference distance. In addition, an on-tracker mirror, not visible from the view of FIG. 1, may be used in combination with the on-tracker retroreflector to enable performance of a self-compensation, as described in U.S. Patent No. 7,327,446, the contents of which are incorporated by reference.

[0028] FIG. 2 shows an exemplary laser tracker system 7 that is like the laser tracker system 5 of FIG. 1 except that retroreflector target 26 is replaced with a six-DOF probe 1000. In FIG. 1, other types of retroreflector targets may be used. For example, a cateye retroreflector, which is a glass retroreflector in which light focuses to a small spot of light on a reflective rear surface of the glass structure, is sometimes used.

[0029] FIG. 3 is a block diagram showing optical and electrical elements in a laser tracker embodiment. It shows elements of a laser tracker that emit two wavelengths of light - a first wavelength for an ADM and a second wavelength for a visible pointer and for tracking. The visible pointer enables the user to see the position of the laser beam spot emitted by the tracker. The two different wavelengths are combined using a free-space beam splitter. Electrooptic (EO) system 100 includes visible light source 110, isolator 115, optional first fiber launch 170, optional interferometer (IFM) 120, beam expander 140, first beam splitter 145, position detector assembly 150, second beam splitter 155, ADM 160, and second fiber launch 170.

[0030] Visible light source 110 may be a laser, superluminescent diode, or other light emitting device. The isolator 115 may be a Faraday isolator, attenuator, or other device capable of reducing the light that reflects back into the light source. Optional IFM may be configured in a variety of ways. As a specific example of a possible implementation, the IFM may include a beam splitter 122, a retroreflector 126, quarter waveplates 124, 130, and a phase analyzer 128. The visible light source 110 may launch the light into free space, the light then traveling in free space through the isolator 115, and optional IFM 120. Alternatively, the isolator 115 may be coupled to the visible light source 110 by a fiber optic cable. In this case, the light from the isolator may be launched into free space through the first fiber-optic launch 170, as discussed herein below with reference to FIG. 5.

[0031] Beam expander 140 may be set up using a variety of lens configurations, but two commonly used prior-art configurations are shown in FIGs. 4A, 4B. FIG. 4A shows a configuration 140A based on the use of a negative lens 141A and a positive lens 142A. A beam of collimated light 220A incident on the negative lens 141A emerges from the positive lens 142A as a larger beam of collimated light 230A. FIG. 4B shows a configuration 140B based on the use of two positive lenses 141B, 142B. A beam of collimated light 220B incident on a first positive lens 141B emerges from a second positive lens 142B as a larger beam of collimated light 230B. Of the light leaving the beam expander 140, a small amount reflects off the beam splitters 145, 155 on the way out of the tracker and is lost. That part of the light that passes through the beam splitter 155 is combined with light from the ADM 160 to form a composite beam of light 188 that leaves the laser tracker and travels to the retroreflector 90.

[0032] In an embodiment, the ADM 160 includes a light source 162, ADM electronics 164, a fiber network 166, an interconnecting electrical cable 165, and interconnecting optical fibers 168, 169, 184, 186. ADM electronics send electrical modulation and bias voltages to light source 162, which may, for example, be a distributed feedback laser that operates at a wavelength of approximately 1550 nm. In an embodiment, the fiber network 166 may be the prior art fiber-optic network 420A shown in FIG. 8A. In this embodiment, light from the light source 162 in FIG. 3 travels over the optical fiber 184, which is equivalent to the optical fiber 432 in FIG. 8A.

[0033] The fiber network of FIG. 8A includes a first fiber coupler 430, a second fiber coupler 436, and low-transmission reflectors 435, 440. The light travels through the first fiber coupler 430 and splits between two paths, the first path through optical fiber 433 to the second fiber coupler 436 and the second path through optical fiber 422 and fiber length

equalizer 423. Fiber length equalizer 423 connects to fiber length 168 in FIG. 3, which travels to the reference channel of the ADM electronics 164. The purpose of fiber length equalizer 423 is to match the length of optical fibers traversed by light in the reference channel to the length of optical fibers traversed by light in the measure channel. Matching the fiber lengths in this way reduces ADM errors caused by changes in the ambient temperature. Such errors may arise because the effective optical path length of an optical fiber is equal to the average index of refraction of the optical fiber times the length of the fiber. Since the index of refraction of the optical fibers depends on the temperature of the fiber, a change in the temperature of the optical fibers causes changes in the effective optical path lengths of the measure and reference channels. If the effective optical path length of the optical fiber in the measure channel changes relative to the effective optical path length of the optical fiber in the reference channel, the result will be an apparent shift in the position of the retroreflector target 90, even if the retroreflector target 90 is kept stationary. To get around this problem, two steps are taken. First, the length of the fiber in the reference channel is matched, as nearly as possible, to the length of the fiber in the measure channel. Second, the measure and reference fibers are routed side by side to the extent possible to ensure that the optical fibers in the two channels see nearly the same changes in temperature.

[0034] The light travels through the second fiber optic coupler 436 and splits into two paths, the first path to the low-reflection fiber terminator 440 and the second path to optical fiber 438, from which it travels to optical fiber 186 in FIG. 3. The light on optical fiber 186 travels through to the second fiber launch 170.

[0035] In an embodiment, fiber launch 170 is shown in prior art FIG. 5. The light from optical fiber 186 of FIG. 3 goes to fiber 172 in FIG. 5. The fiber launch 170 includes optical fiber 172, ferrule 174, and lens 176. The optical fiber 172 is attached to ferrule 174, which is stably attached to a structure within the laser tracker 10. If desired, the end of the optical fiber may be polished at an angle to reduce back reflections. The light 250 emerges from the core of the fiber, which may be a single mode optical fiber with a diameter of between 4 and 12 micrometers, depending on the wavelength of the light being used and the particular type of optical fiber. The light 250 diverges at an angle and intercepts lens 176, which collimates it. The method of launching and receiving an optical signal through a single optical fiber in an ADM system was described in reference to FIG. 3 in patent '758.

[0036] Referring to FIG. 3, the beam splitter 155 may be a dichroic beam splitter, which transmits different wavelengths than it reflects. In an embodiment, the light from the ADM 160 reflects off dichroic beam splitter 155 and combines with the light from the visible

laser 110, which is transmitted through the dichroic beam splitter 155. The composite beam of light 188 travels out of the laser tracker to retroreflector 90 as a first beam, which returns a portion of the light as a second beam. That portion of the second beam that is at the ADM wavelength reflects off the dichroic beam splitter 155 and returns to the second fiber launch 170, which couples the light back into the optical fiber 186.

[0037] In an embodiment, the optical fiber 186 corresponds to the optical fiber 438 in FIG. 8A. The returning light travels from optical fiber 438 through the second fiber coupler 436 and splits between two paths. A first path leads to optical fiber 424 that, in an embodiment, corresponds to optical fiber 169 that leads to the measure channel of the ADM electronics 164 in FIG. 3. A second path leads to optical fiber 433 and then to the first fiber coupler 430. The light leaving the first fiber coupler 430 splits between two paths, a first path to the optical fiber 432 and a second path to the low reflectance termination 435. In an embodiment, optical fiber 432 corresponds to the optical fiber 184, which leads to the light source 162 in FIG. 3. In most cases, the light source 162 contains a built-in Faraday isolator that minimizes the amount of light that enters the light source from optical fiber 432. Excessive light fed into a laser in the reverse direction can destabilize the laser.

[0038] The light from the fiber network 166 enters ADM electronics 164 through optical fibers 168, 169. An embodiment of prior art ADM electronics is shown in FIG. 7. Optical fiber 168 in FIG. 3 corresponds to optical fiber 3232 in FIG. 7, and optical fiber 169 in FIG. 3 corresponds to optical fiber 3230 in FIG. 7. Referring now to FIG. 7, ADM electronics 3300 includes a frequency reference 3302, a synthesizer 3304, a measure detector 3306, a reference detector 3308, a measure mixer 3310, a reference mixer 3312, conditioning electronics 3314, 3316, 3318, 3320, a divide-by-N prescaler 3324, and an analog-to-digital converter (ADC) 3322. The frequency reference, which might be an oven-controlled crystal oscillator (OCXO), for example, sends a reference frequency fREF, which might be 10 MHz, for example, to the synthesizer, which generates two electrical signals - one signal at a frequency fRF and two signals at frequency fLO. The signal fRF goes to the light source 3102, which corresponds to the light source 162 in FIG. 3. The two signals at frequency fLO go to the measure mixer 3310 and the reference mixer 3312. The light from optical fibers 168, 169 in FIG. 3 appear on fibers 3232, 3230 in FIG. 7, respectively, and enter the reference and measure channels, respectively. Reference detector 3308 and measure detector 3306 convert the optical signals into electrical signals. These signals are conditioned by electrical components 3316, 3314, respectively, and are sent to mixers 3312, 3310, respectively. The mixers produce a frequency fIF equal to the absolute value of fLO - fRF.

The signal fRF may be a relatively high frequency, for example, 2 GHz, while the signal fIF may have a relatively low frequency, for example, 10 kHz.

[0039] The reference frequency fREF is sent to the prescaler 3324, which divides the frequency by an integer value. For example, a frequency of 10 MHz might be divided by a 40 to obtain an output frequency of 250 kHz. In this example, the 10 kHz signals entering the ADC 3322 would be sampled at a rate of 250 kHz, thereby producing 25 samples per cycle. The signals from the ADC 3322 are sent to a data processor 3400, which might, for example, be one or more digital signal processor (DSP) units located in ADM electronics 164 of FIG. 3.

[0040] The method for extracting a distance is based on the calculation of phase of the ADC signals for the reference and measure channels. This method is described in detail in U.S. Patent No. 7,701,559 ('559) to Bridges, et al., the contents of which are herein incorporated by reference. Calculation includes use of equations (1) - (8) of patent '559. In addition, when the ADM first begins to measure a retroreflector, the frequencies generated by the synthesizer are changed some number of times (for example, three times), and the possible ADM distances calculated in each case. By comparing the possible ADM distances for each of the selected frequencies, an ambiguity in the ADM measurement is removed. The equations (1) - (8) of patent '559 combined with synchronization methods described with respect to FIG. 5 of patent '559 and the Kalman filter methods described in patent '559 enable the ADM to measure a moving target. In other embodiments, other methods of obtaining absolute distance measurements, for example, by using pulsed time-of-flight rather than phase differences, may be used.

[0041] The part of the return light beam 190 that passes through the beam splitter 155 arrives at the beam splitter 145, which sends part of the light to the beam expander 140 and another part of the light to the position detector assembly 150. The light emerging from the laser tracker 10 or EO system 100 may be thought of as a first beam and the portion of that light reflecting off the retroreflector 90 or 26 as a second beam. Portions of the reflected beam are sent to different functional elements of the EO system 100. For example, a first portion may be sent to a distance meter such as an ADM 160 in FIG. 3. A second portion may be sent to a position detector assembly 150. In some cases, a third portion may be sent to other functional units such as an optional interferometer 120. It is important to understand that, although, in the example of FIG. 3, the first portion and the second portion of the second beam are sent to the distance meter and the position detector after reflecting off beam splitters

155 and 145, respectively, it would have been possible to transmit, rather than reflect, the light onto a distance meter or position detector.

[0042] Four examples of prior art position detector assemblies 150A - 150D are shown in FIGs. 6A-D. FIG. 6A depicts the simplest implementation, with the position detector assembly including a position sensor 151 mounted on a circuit board 152 that obtains power from and returns signals to electronics box 350, which may represent electronic processing capability at any location within the laser tracker 10, auxiliary unit 50, or external computer 60. FIG. 6B includes an optical filter 154 that blocks unwanted optical wavelengths from reaching the position sensor 151. The unwanted optical wavelengths may also be blocked, for example, by coating the beam splitter 145 or the surface of the position sensor 151 with an appropriate film. FIG. 6C includes a lens 153 that reduces the size of the beam of light. FIG. 6D includes both an optical filter 154 and a lens 153.

[0043] FIG. 6E shows a position detector assembly according to an embodiment of the present invention that includes an optical conditioner 149E. Optical conditioner contains a lens 153 and may also contain optional wavelength filter 154. In addition, it includes at least one of a diffuser 156 and a spatial filter 157. As explained hereinabove, a popular type of retroreflector is the cube-corner retroreflector. One type of cube corner retroreflector is made of three mirrors, each joined at right angles to the other two mirrors. Lines of intersection at which these three mirrors are joined may have a finite thickness in which light is not perfectly reflected back to the tracker. The lines of finite thickness are diffracted as they propagate so that upon reaching the position detector they may not appear exactly the same as at the position detector. However, the diffracted light pattern will generally depart from perfect symmetry. As a result, the light that strikes the position detector 151 may have, for example, dips or rises in optical power (hot spots) in the vicinity of the diffracted lines. Because the uniformity of the light from the retroreflector may vary from retroreflector to retroreflector and also because the distribution of light on the position detector may vary as the retroreflector is rotated or tilted, it may be advantageous to include a diffuser 156 to improve the smoothness of the light that strikes the position detector 151. It might be argued that, because an ideal position detector should respond to a centroid and an ideal diffuser should spread a spot symmetrically, there should be no effect on the resulting position given by the position detector. However, in practice the diffuser is observed to improve performance of the position detector assembly, probably because the effects of nonlinearities (imperfections) in the position detector 151 and the lens 153. Cube corner retroreflectors made of glass may also produce non-uniform spots of light at the position detector 151. Variations in a spot of

light at a position detector may be particularly prominent from light reflected from cube corners in six-DOF targets, as may be understood more clearly from commonly assigned U.S. Patent Application Nos. 13/370,339 filed February 10, 2012, and 13/407,983, filed February 29, 2012, the contents of which are incorporated by reference. In an embodiment, the diffuser 156 is a holographic diffuser. A holographic diffuser provides controlled, homogeneous light over a specified diffusing angle. In other embodiments, other types of diffusers such as ground glass or "opal" diffusers are used.

[0044] The purpose of the spatial filter 157 of the position detector assembly 150E is to block ghost beams that may be the result, for example, of unwanted reflections off optical surfaces, from striking the position detector 151. A spatial filter includes a plate 157 that has an aperture. By placing the spatial filter 157 a distance away from the lens equal approximately to the focal length of the lens, the returning light 243E passes through the spatial filter when it is near its narrowest - at the waist of the beam. Beams that are traveling at a different angle, for example, as a result of reflection of an optical element strike the spatial filter away from the aperture and are blocked from reaching the position detector 151. An example is shown in FIG. 6E, where an unwanted ghost beam 244E reflects off a surface of the beam splitter 145 and travels to spatial filter 157, where it is blocked. Without the spatial filter, the ghost beam 244E would have intercepted the position detector 151, thereby causing the position of the beam 243E on the position detector 151 to be incorrectly determined. Even a weak ghost beam may significantly change the position of the centroid on the position detector 151 if the ghost beam is located a relatively large distance from the main spot of light.

[0045] A retroreflector of the sort discussed here, a cube corner or a cateye retroreflector, for example, has the property of reflecting a ray of light that enters the retroreflector in a direction parallel to the incident ray. In addition, the incident and reflected rays are symmetrically placed about the point of symmetry of the retroreflector. For example, in an open-air cube corner retroreflector, the point of symmetry of the retroreflector is the vertex of the cube corner. In a glass cube corner retroreflector, the point of symmetry is also the vertex, but one must consider the bending of the light at the glass-air interface in this case. In a cateye retroreflector having an index of refraction of 2.0, the point of symmetry is the center of the sphere. In a cateye retroreflector made of two glass hemispheres symmetrically seated on a common plane, the point of symmetry is a point lying on the plane and at the spherical center of each hemisphere. The main point is that, for the type of

retroreflectors ordinarily used with laser trackers, the light returned by a retroreflector to the tracker is shifted to the other side of the vertex relative to the incident laser beam."

[0046] This behavior of a retroreflector 90 in FIG. 3 is the basis for the tracking of the retroreflector by the laser tracker. The position sensor has on its surface an ideal retrace point. The ideal retrace point is the point at which a laser beam sent to the point of symmetry of a retroreflector (e.g., the vertex of the cube corner retroreflector in an SMR) will return. Usually the retrace point is near the center of the position sensor. If the laser beam is sent to one side of the retroreflector, it reflects back on the other side and appears off the retrace point on the position sensor. By noting the position of the returning beam of light on the position sensor, the control system of the laser tracker 10 can cause the motors to move the light beam toward the point of symmetry of the retroreflector.

[0047] If the retroreflector is moved transverse to the tracker at a constant velocity, the light beam at the retroreflector will strike the retroreflector (after transients have settled) a fixed offset distance from the point of symmetry of the retroreflector. The laser tracker makes a correction to account for this offset distance at the retroreflector based on scale factor obtained from controlled measurements and based on the distance from the light beam on the position sensor to the ideal retrace point.

[0048] As explained hereinabove, the position detector performs two important functions - enabling tracking and correcting measurements to account for the movement of the retroreflector. The position sensor within the position detector may be any type of device capable of measuring a position. For example, the position sensor might be a position sensitive detector or a photosensitive array. The position sensitive detector might be lateral effect detector or a quadrant detector, for example. The photosensitive array might be a CMOS or CCD array, for example.

[0049] In an embodiment, the return light that does not reflect off beam splitter 145 passes through beam expander 140, thereby becoming smaller. In another embodiment, the positions of the position detector and the distance meter are reversed so that the light reflected by the beam splitter 145 travels to the distance meter and the light transmitted by the beam splitter travels to the position detector.

[0050] The light continues through optional IFM, through the isolator and into the visible light source 110. At this stage, the optical power should be small enough so that it does not destabilize the visible light source 110.

[0051] In an embodiment, the light from visible light source 110 is launched through a beam launch 170 of FIG. 5. The fiber launch may be attached to the output of light source 110 or a fiber optic output of the isolator 115.

[0052] In an embodiment, the fiber network 166 of FIG. 3 is prior art fiber network 420B of FIG. 8B. Here the optical fibers 184, 186, 168, 169 of FIG. 3 correspond to optical fibers 443, 444, 424, 422 of FIG. 8B. The fiber network of FIG. 8B is like the fiber network of FIG. 8A except that the fiber network of FIG. 8B has a single fiber coupler instead of two fiber couplers. The advantage of FIG. 8B over FIG. 8A is simplicity; however, FIG. 8B is more likely to have unwanted optical back reflections entering the optical fibers 422 and 424.

[0053] In an embodiment, the fiber network 166 of FIG. 3 is fiber network 420C of FIG. 8C. Here the optical fibers 184, 186, 168, 169 of FIG. 3 correspond to optical fibers 447, 455, 423, 424 of FIG. 8C. The fiber network 420C includes a first fiber coupler 445 and a second fiber coupler 451. The first fiber coupler 445 is a 2 x 2 coupler having two input ports and two output ports. Couplers of this type are usually made by placing two fiber cores in close proximity and then drawing the fibers while heated. In this way, evanescent coupling between the fibers can split off a desired fraction of the light to the adjacent fiber. The second fiber coupler 451 is of the type called a circulator. It has three ports, each having the capability of transmitting or receiving light, but only in the designated direction. For example, the light on optical fiber 448 enters port 453 and is transported toward port 454 as indicated by the arrow. At port 454, light may be transmitted to optical fiber 455. Similarly, light traveling on port 455 may enter port 454 and travel in the direction of the arrow to port 456, where some light may be transmitted to the optical fiber 424. If only three ports are needed, then the circulator 451 may suffer less losses of optical power than the 2 x 2 coupler. On the other hand, a circulator 451 may be more expensive than a 2 x 2 coupler, and it may experience polarization mode dispersion, which can be problematic in some situations.

[0054] FIGs. 9 and 10 show exploded and cross sectional views, respectively, of a prior art laser tracker 2100, which is depicted in FIGs. 2 and 3 of U.S. Published Patent Application No. 2010/0128259 to Bridges et al., incorporated by reference. Azimuth assembly 2110 includes post housing 2112, azimuth encoder assembly 2120, lower and upper azimuth bearings 2114A, 2114B, azimuth motor assembly 2125, azimuth slip ring assembly 2130, and azimuth circuit boards 2135.

[0055] The purpose of azimuth encoder assembly 2120 is to accurately measure the angle of rotation of yoke 2142 with respect to the post housing 2112. Azimuth encoder assembly 2120 includes encoder disk 2121 and read-head assembly 2122. Encoder disk 2121

is attached to the shaft of yoke housing 2142, and read head assembly 2122 is attached to post assembly 2110. Read head assembly 2122 comprises a circuit board onto which one or more read heads are fastened. Laser light sent from read heads reflect off fine grating lines on encoder disk 2121. Reflected light picked up by detectors on encoder read head(s) is processed to find the angle of the rotating encoder disk in relation to the fixed read heads.

[0056] Azimuth motor assembly 2125 includes azimuth motor rotor 2126 and azimuth motor stator 2127. Azimuth motor rotor comprises permanent magnets attached directly to the shaft of yoke housing 2142. Azimuth motor stator 2127 comprises field windings that generate a prescribed magnetic field. This magnetic field interacts with the magnets of azimuth motor rotor 2126 to produce the desired rotary motion. Azimuth motor stator 2127 is attached to post frame 2112.

[0057] Azimuth circuit boards 2135 represent one or more circuit boards that provide electrical functions required by azimuth components such as the encoder and motor. Azimuth slip ring assembly 2130 includes outer part 2131 and inner part 2132. In an embodiment, wire bundle 2138 emerges from auxiliary unit processor 50. Wire bundle 2138 may carry power to the tracker or signals to and from the tracker. Some of the wires of wire bundle 2138 may be directed to connectors on circuit boards. In the example shown in Fig. 30, wires are routed to azimuth circuit board 2135, encoder read head assembly 2122, and azimuth motor assembly 2125. Other wires are routed to inner part 2132 of slip ring assembly 2130. Inner part 2132 is attached to post assembly 2110 and consequently remains stationary. Outer part 2131 is attached to yoke assembly 2140 and consequently rotates with respect to inner part 2132. Slip ring assembly 2130 is designed to permit low impedance electrical contact as outer part 2131 rotates with respect to the inner part 2132.

[0058] Zenith assembly 2140 comprises yoke housing 2142, zenith encoder assembly 2150, left and right zenith bearings 2144A, 2144B, zenith motor assembly 2155, zenith slip ring assembly 2160, and zenith circuit board 2165.

[0059] The purpose of zenith encoder assembly 2150 is to accurately measure the angle of rotation of payload frame 2172 with respect to yoke housing 2142. Zenith encoder assembly 2150 comprises zenith encoder disk 2151 and zenith read-head assembly 2152. Encoder disk 2151 is attached to payload housing 2142, and read head assembly 2152 is attached to yoke housing 2142. Zenith read head assembly 2152 comprises a circuit board onto which one or more read heads are fastened. Laser light sent from read heads reflect off fine grating lines on encoder disk 2151. Reflected light picked up by detectors on encoder

read head(s) is processed to find the angle of the rotating encoder disk in relation to the fixed read heads.

[0060] Zenith motor assembly 2155 comprises azimuth motor rotor 2156 and azimuth motor stator 2157. Zenith motor rotor 2156 comprises permanent magnets attached directly to the shaft of payload frame 2172. Zenith motor stator 2157 comprises field windings that generate a prescribed magnetic field. This magnetic field interacts with the rotor magnets to produce the desired rotary motion. Zenith motor stator 2157 is attached to yoke frame 2142.

[0061] Zenith circuit board 2165 represents one or more circuit boards that provide electrical functions required by zenith components such as the encoder and motor. Zenith slip ring assembly 2160 comprises outer part 2161 and inner part 2162. Wire bundle 2168 emerges from azimuth outer slip ring 2131 and may carry power or signals. Some of the wires of wire bundle 2168 may be directed to connectors on circuit board. In the example shown in FIG. 10, wires are routed to zenith circuit board 2165, zenith motor assembly 2150, and encoder read head assembly 2152. Other wires are routed to inner part 2162 of slip ring assembly 2160. Inner part 2162 is attached to yoke frame 2142 and consequently rotates in azimuth angle only, but not in zenith angle. Outer part 2161 is attached to payload frame 2172 and consequently rotates in both zenith and azimuth angles. Slip ring assembly 2160 is designed to permit low impedance electrical contact as outer part 2161 rotates with respect to the inner part 2162. Payload assembly 2170 includes a main optics assembly 2180 and a secondary optics assembly 2190.

[0062] FIG. 11 is a block diagram depicting a dimensional measurement electronics processing system 1500 that includes a laser tracker electronics processing system 1510, peripheral elements 1582, 1584, 1586, computer 1590, and other networked components 1600, represented here as a cloud. Exemplary laser tracker electronics processing system 1510 includes a master processor 1520, payload functions electronics 1530, azimuth encoder electronics 1540, zenith encoder electronics 1550, display and user interface (UI) electronics 1560, removable storage hardware 1565, radio frequency identification (RFID) electronics, and an antenna 1572. The payload functions electronics 1530 includes a number of subfunctions including the six-DOF electronics 1531, the camera electronics 1532, the ADM electronics 1533, the position detector (PSD) electronics 1534, and the level electronics 1535. Most of the subfunctions have at least one processor unit, which might be a digital signal processor (DSP) or field programmable gate array (FPGA), for example. The electronics units 1530, 1540, and 1550 are separated as shown because of their location within the laser tracker. In an embodiment, the payload functions 1530 are located in the payload 2170 of

FIGs. 9, 10, while the azimuth encoder electronics 1540 is located in the azimuth assembly 2110 and the zenith encoder electronics 1550 is located in the zenith assembly 2140.

[0063] Many types of peripheral devices are possible, but here three such devices are shown: a temperature sensor 1582, a six-DOF probe 1584, and a personal digital assistant, 1586, which might be a smart phone, for example. The laser tracker may communicate with peripheral devices in a variety of means, including wireless communication over the antenna 1572, by means of a vision system such as a camera, and by means of distance and angular readings of the laser tracker to a cooperative target such as the six-DOF probe 1584.

[0064] In an embodiment, a separate communications bus goes from the master processor 1520 to each of the electronics units 1530, 1540, 1550, 1560, 1565, and 1570. Each communications line may have, for example, three serial lines that include the data line, clock line, and frame line. The frame line indicates whether or not the electronics unit should pay attention to the clock line. If it indicates that attention should be given, the electronics unit reads the current value of the data line at each clock signal. The clock signal may correspond, for example, to a rising edge of a clock pulse. In an embodiment, information is transmitted over the data line in the form of a packet. In an embodiment, each packet includes an address, a numeric value, a data message, and a checksum. The address indicates where, within the electronics unit, the data message is to be directed. The location may, for example, correspond to a processor subroutine within the electronics unit. The numeric value indicates the length of the data message. The data message contains data or instructions for the electronics unit to carry out. The checksum is a numeric value that is used to minimize the chance that errors are transmitted over the communications line.

[0065] In an embodiment, the master processor 1520 sends packets of information over bus 1610 to payload functions electronics 1530, over bus 1611 to azimuth encoder electronics 1540, over bus 1612 to zenith encoder electronics 1550, over bus 1613 to display and UI electronics 1560, over bus 1614 to removable storage hardware 1565, and over bus 1616 to RFID and wireless electronics 1570.

[0066] In an embodiment, master processor 1520 also sends a synch (synchronization) pulse over the synch bus 1630 to each of the electronics units at the same time. The synch pulse provides a way of synchronizing values collected by the measurement functions of the laser tracker. For example, the azimuth encoder electronics 1540 and the zenith electronics 1550 latch their encoder values as soon as the synch pulse is received. Similarly, the payload functions electronics 1530 latch the data collected by the electronics contained within the payload. The six-DOF, ADM, and position detector all latch data when

the synch pulse is given. In most cases, the camera and inclinometer collect data at a slower rate than the synch pulse rate but may latch data at multiples of the synch pulse period.

[0067] The azimuth encoder electronics 1540 and zenith encoder electronics 1550 are separated from one another and from the payload electronics 1530 by the slip rings 2130, 2160 shown in FIGs. 9, 10. This is why the bus lines 1610, 1611, and 1612 are depicted as separate bus line in FIG. 11.

[0068] The laser tracker electronics processing system 1510 may communicate with an external computer 1590, or it may provide computation, display, and UI functions within the laser tracker. The laser tracker communicates with computer 1590 over communications link 1606, which might be, for example, an Ethernet line or a wireless connection. The laser tracker may also communicate with other elements 1600, represented by the cloud, over communications link 1602, which might include one or more electrical cables, such as Ethernet cables, and one or more wireless connections. An example of an element 1600 is another three dimensional test instrument - for example, an articulated arm CMM, which may be relocated by the laser tracker. A communication link 1604 between the computer 1590 and the elements 1600 may be wired (e.g., Ethernet) or wireless. An operator sitting on a remote computer 1590 may make a connection to the Internet, represented by the cloud 1600, over an Ethernet or wireless line, which in turn connects to the master processor 1520 over an Ethernet or wireless line. In this way, a user may control the action of a remote laser tracker.

[0069] While the invention has been described with reference to example embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

CLAIMS

What is claimed is:

1. A coordinate measurement device that sends a first beam of light to a remote retroreflector target, the retroreflector target having a position in space, the position in space being a function of time, the retroreflector target returning a portion of the first beam as a second beam, the measurement device comprising:

a first motor and a second motor that together direct the first beam of light to a first direction, the first direction determined by a first angle of rotation about a first axis and a second angle of rotation about a second axis, the first angle of rotation produced by the first motor and the second angle of rotation produced by the second motor;

a first angle measuring device that measures the first angle of rotation and a second angle measuring device that measures the second angle of rotation;

a distance meter that measures a first distance from the coordinate measurement device to the retroreflector target based at least in part on a first portion of the second beam received by a first optical detector;

a position detector assembly that includes a position detector and a diffuser, a second portion of the second beam passing through the diffuser and onto the position detector, the position detector configured to produce a first signal in response to a position of the second portion on the position detector;

a control system that sends a second signal to the first motor and a third signal to the second motor, the second signal and the third signal based at least in part on the first signal, the control system configured to adjust the first direction of the first beam to the position in space of the retroreflector target; and

a processor that provides a three-dimensional coordinate of the retroreflector target, the three-dimensional coordinate based at least in part on the first distance, the first angle of rotation, and the second angle of rotation.

2. The coordinate measurement device of claim 1 wherein the diffuser is a holographic diffuser.

3. The coordinate measurement device of claim 1 wherein the position detector assembly further includes a lens and a spatial filter, the lens having a positive focal length,

the spatial filter placed a second distance from the lens approximately equal to the lens focal length, the spatial filter placed between the lens and the position detector.

4. A coordinate measurement device that sends a first beam of light to a remote retroreflector target, the retroreflector target having a position in space, the position in space being a function of time, the retroreflector target returning a portion of the first beam as a second beam, the measurement device comprising:

a first motor and a second motor that together direct the first beam of light to a first direction, the first direction determined by a first angle of rotation about a first axis and a second angle of rotation about a second axis, the first angle of rotation produced by the first motor and the second angle of rotation produced by the second motor;

a first angle measuring device that measures the first angle of rotation and a second angle measuring device that measures the second angle of rotation;

a distance meter that measures a first distance from the coordinate measurement device to the retroreflector target based at least in part on a first portion of the second beam received by a first optical detector;

a position detector assembly that includes a position detector, a lens, and a spatial filter, the lens having a positive focal length, the spatial filter placed a second distance from the lens approximately equal to the lens focal length, the spatial filter placed between the lens and the position detector, a second portion of the second beam passing through the lens and spatial filter onto the position detector, the position detector configured to produce a first signal in response to a position of the second portion on the position detector;

a control system that sends a second signal to the first motor and a third signal to the second motor, the second signal and the third signal based at least in part on the first signal, the control system configured to adjust the first direction of the first beam to the position in space of the retroreflector target; and

a processor that provides a three-dimensional coordinate of the retroreflector target, the three-dimensional coordinate based at least in part on the first distance, the first angle of rotation, and the second angle of rotation.

5. The coordinate measurement device of claim 4 wherein the position detector assembly further includes a diffuser, the second portion of the second light passing through the diffuser.

6. The coordinate measurement device of claim 5 wherein the diffuser is a holographic diffuser.

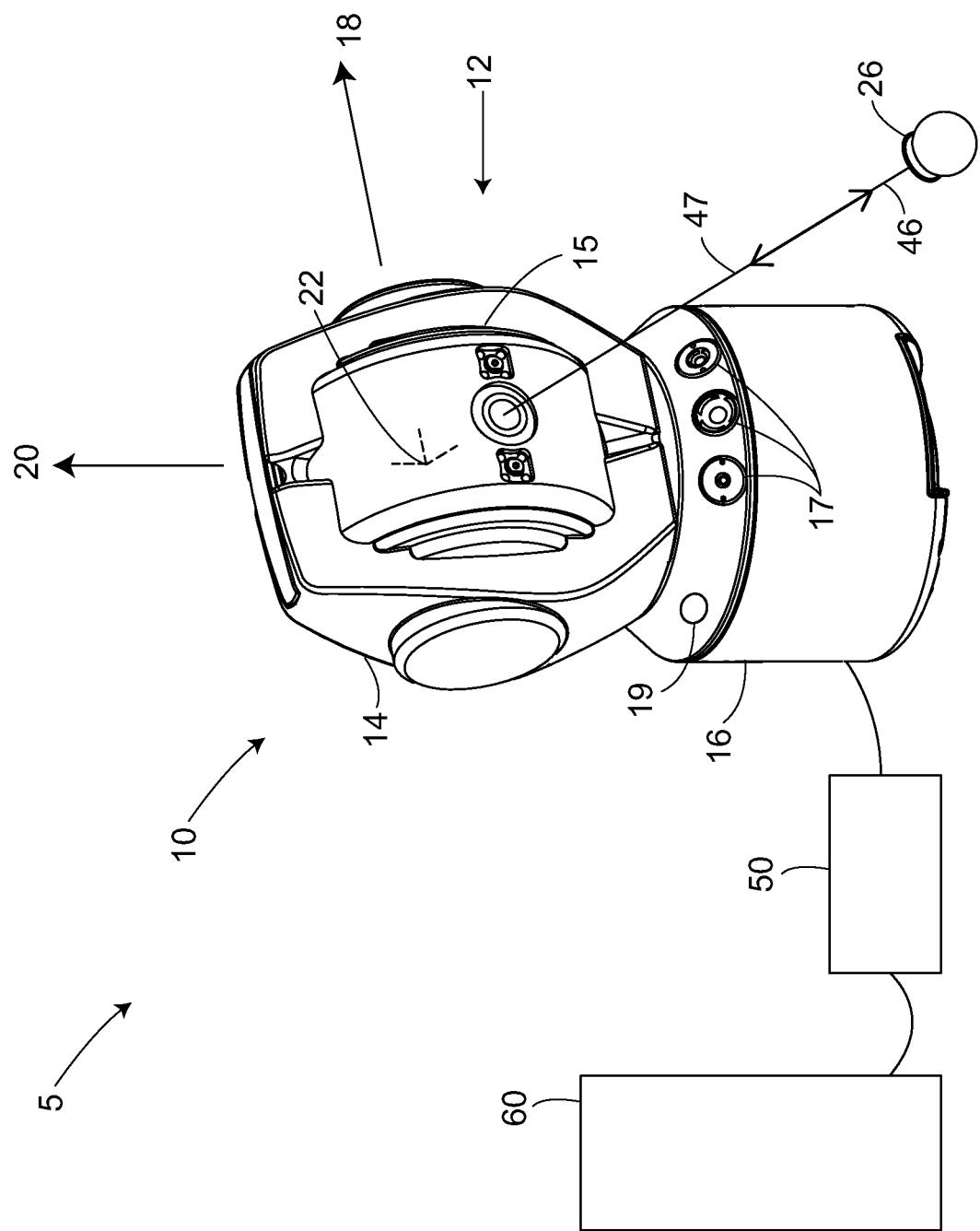


FIGURE 1

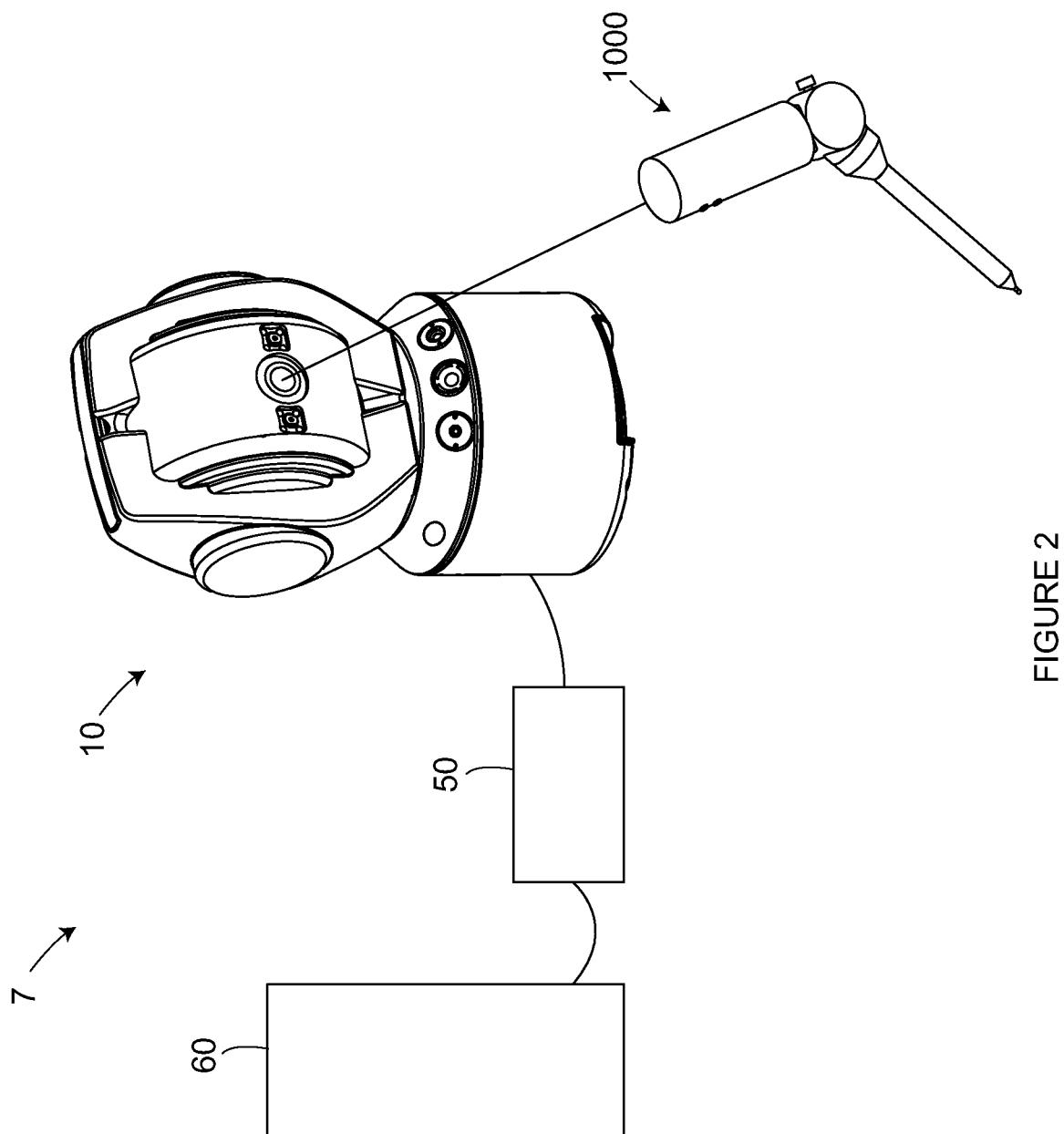


FIGURE 2

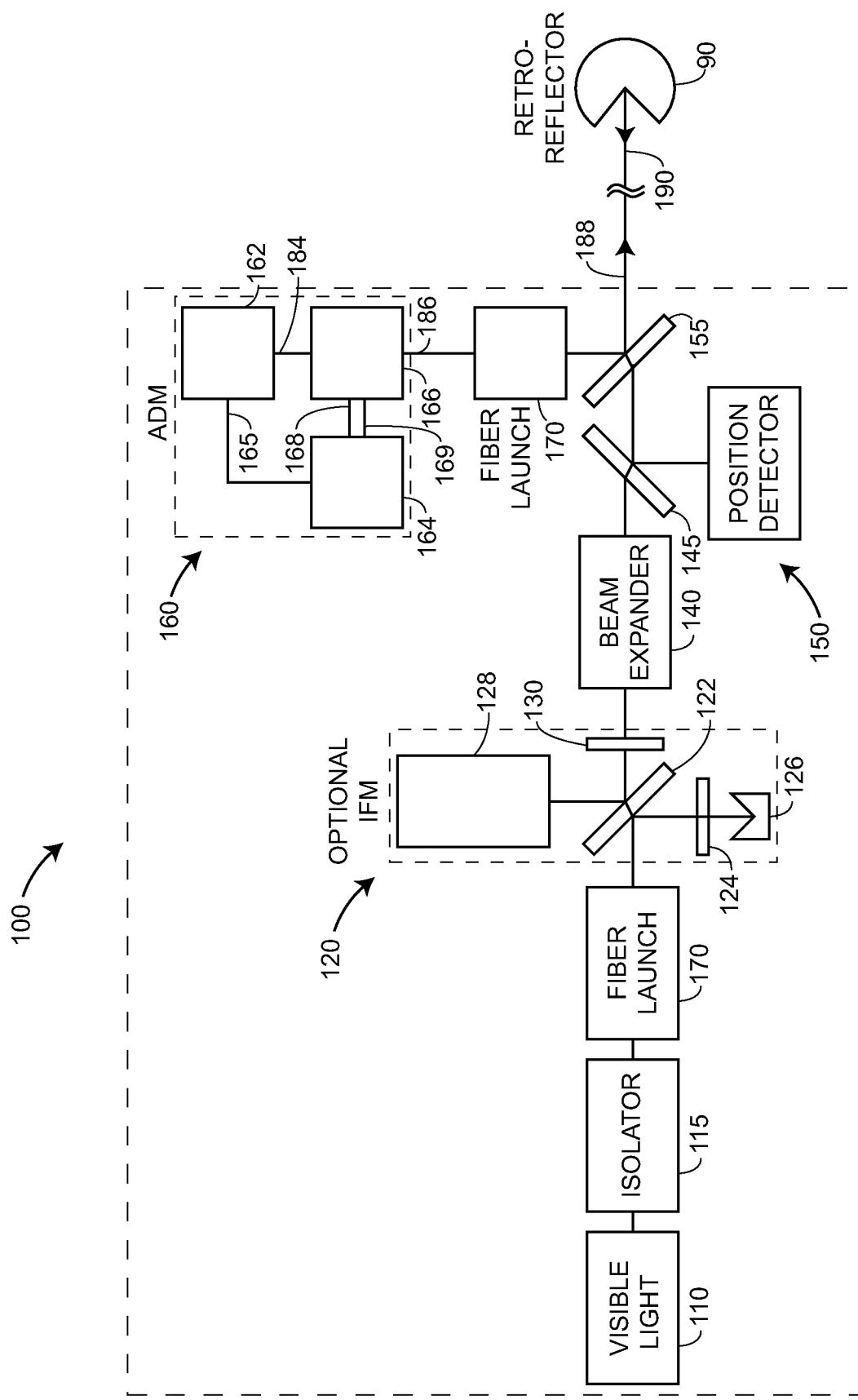
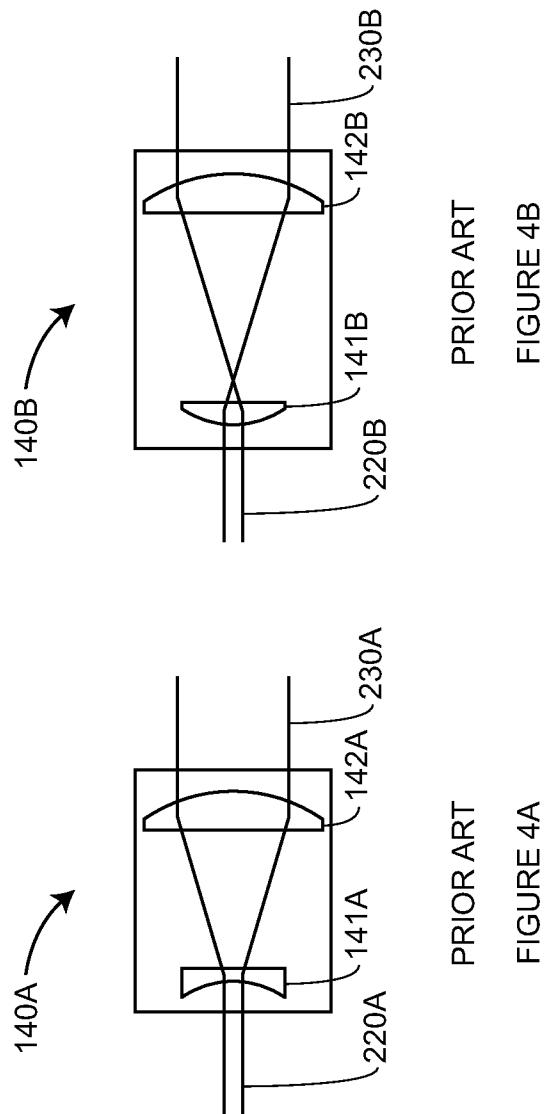
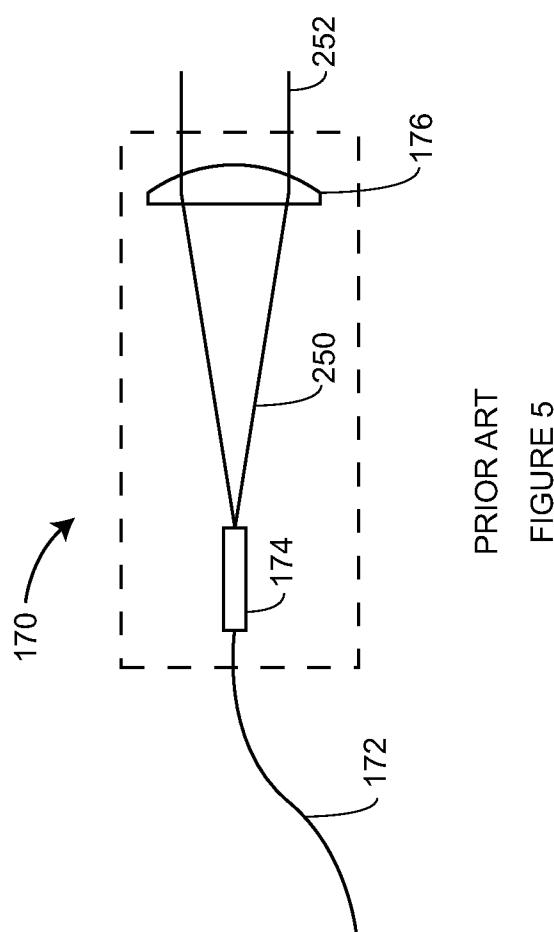
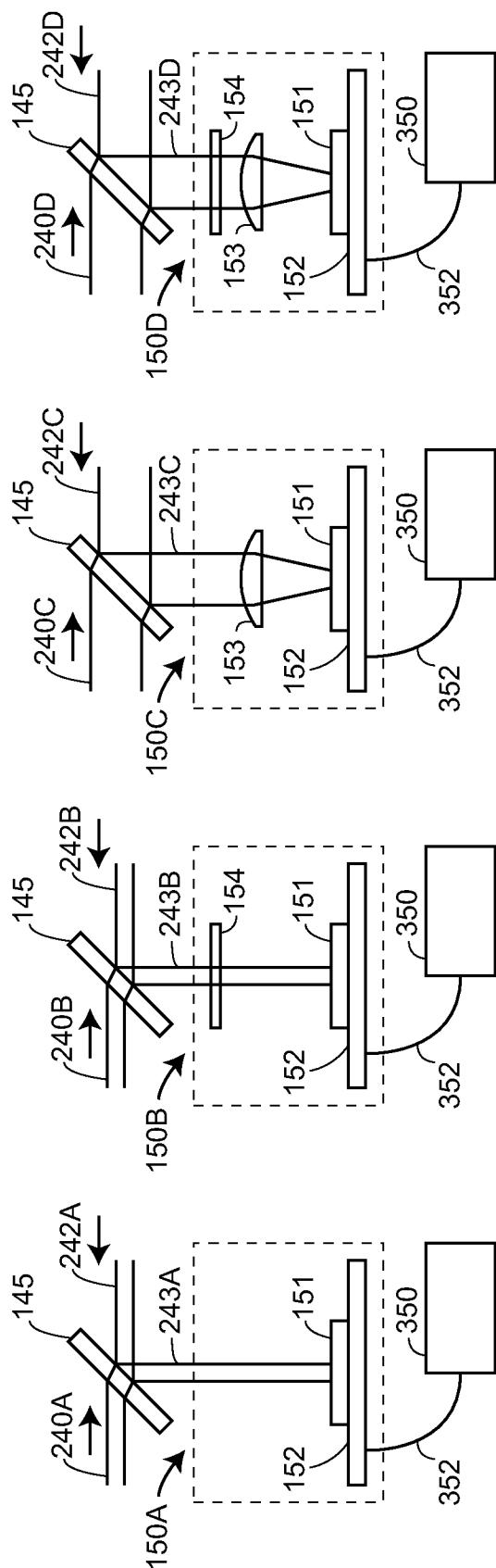


FIGURE 3





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PRIOR ART
FIG. 6A

PRIOR ART
FIG. 6B

PRIOR ART
FIG. 6D

PRIOR ART

FIG. 6D

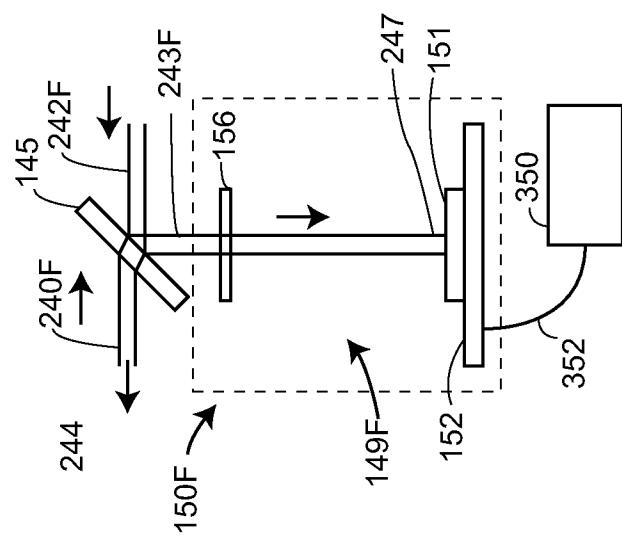


FIG. 6F

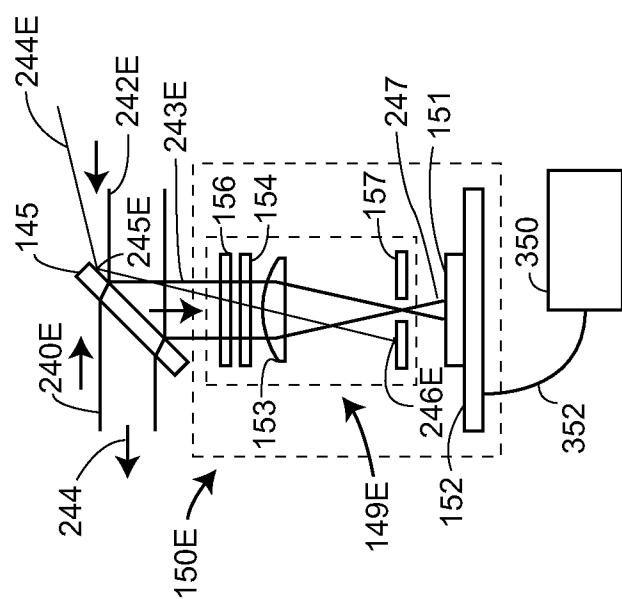
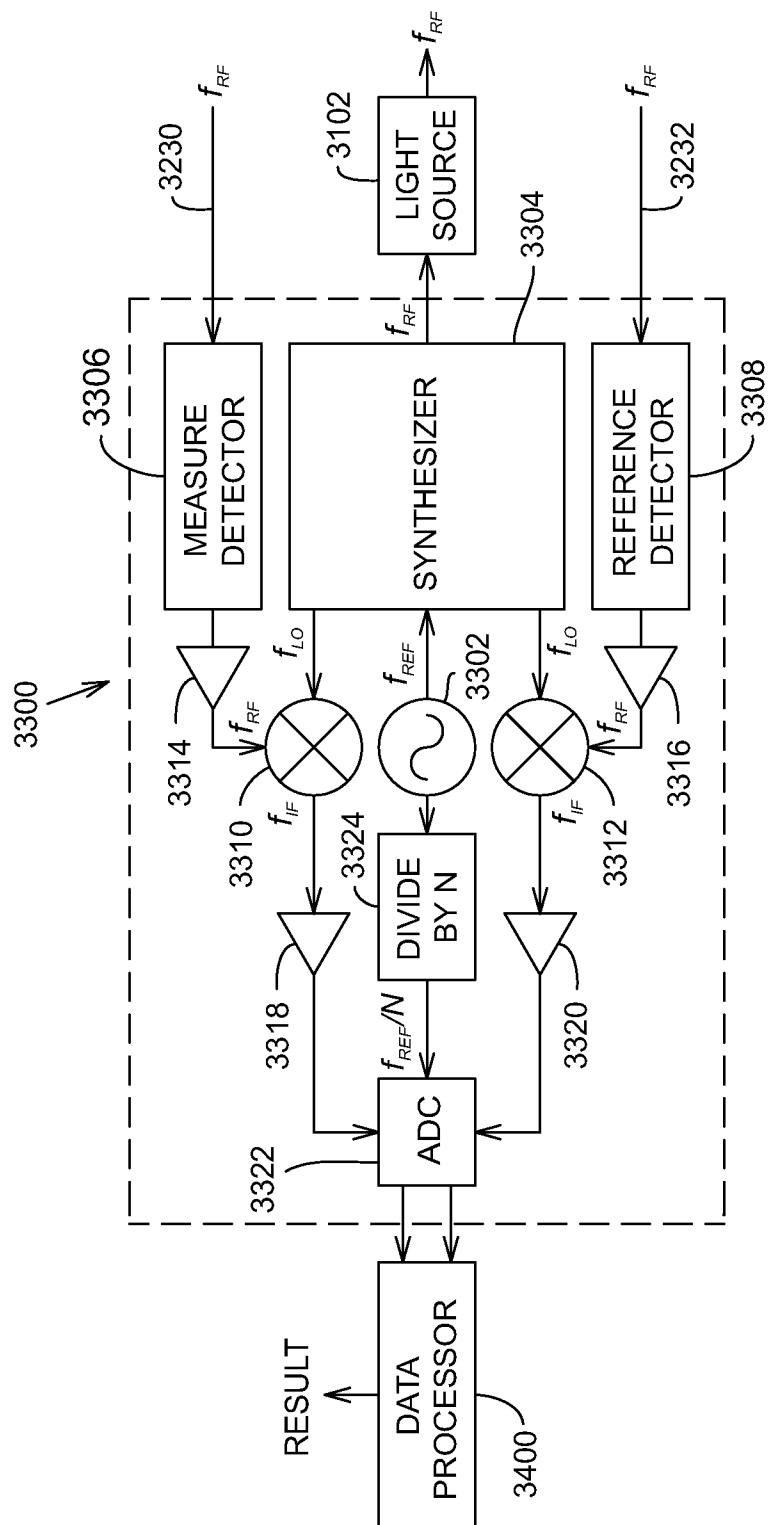
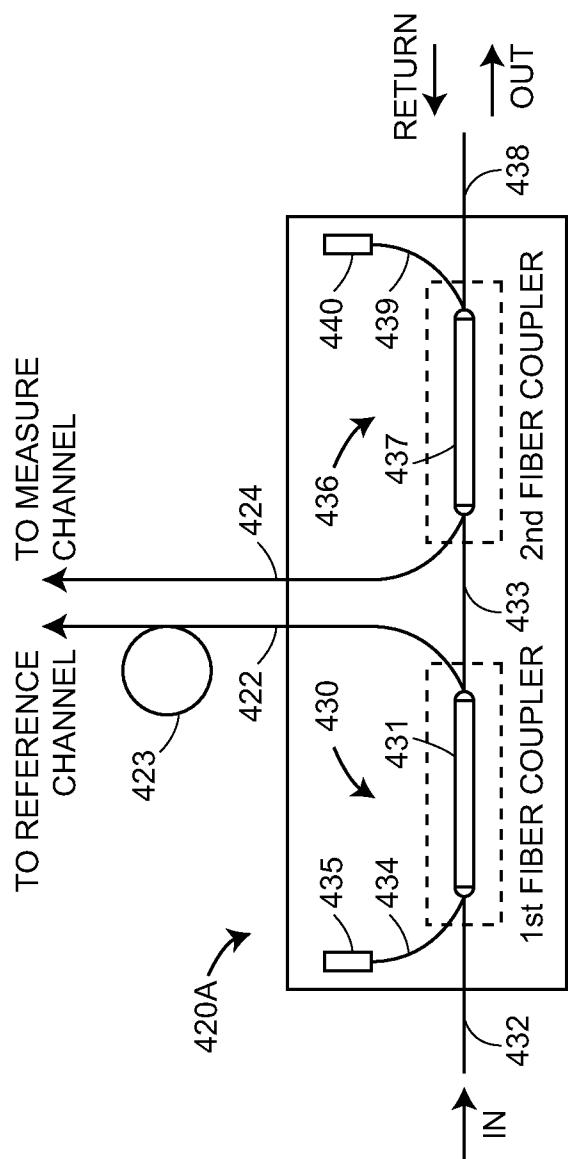


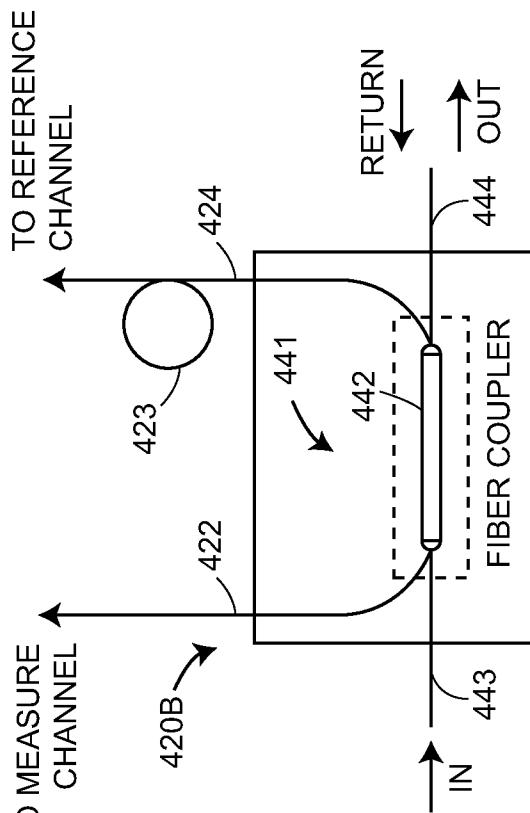
FIG. 6E



PRIOR ART
FIGURE 7



PRIOR ART
FIGURE 8A



PRIOR ART
FIGURE 8B

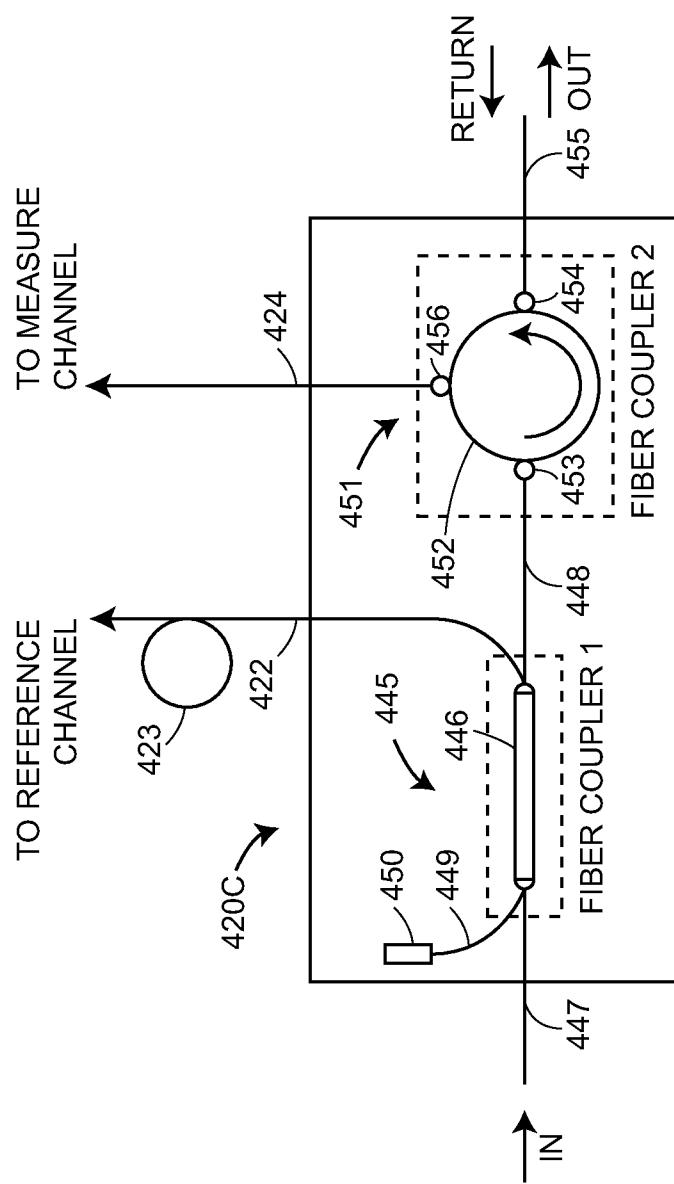
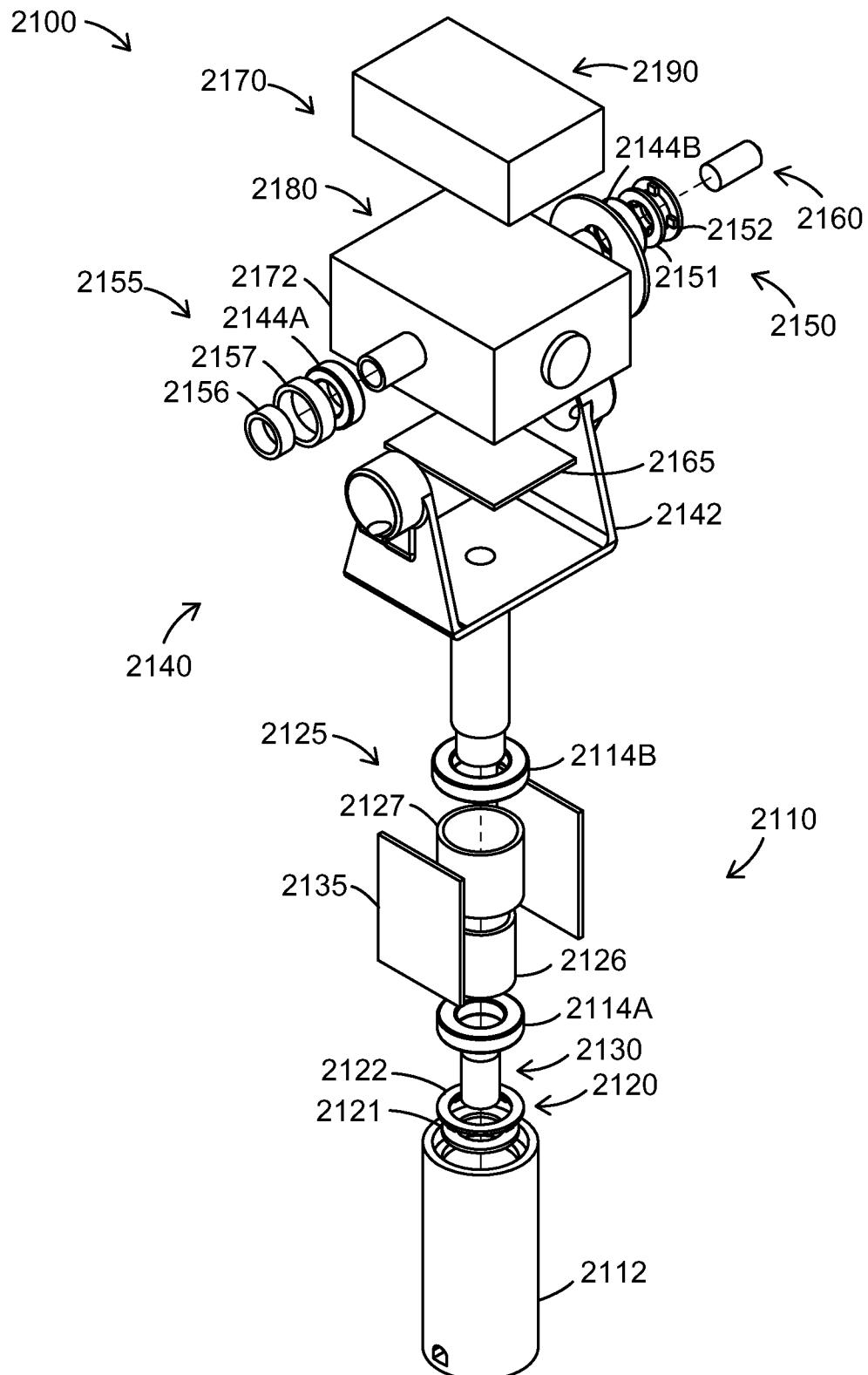


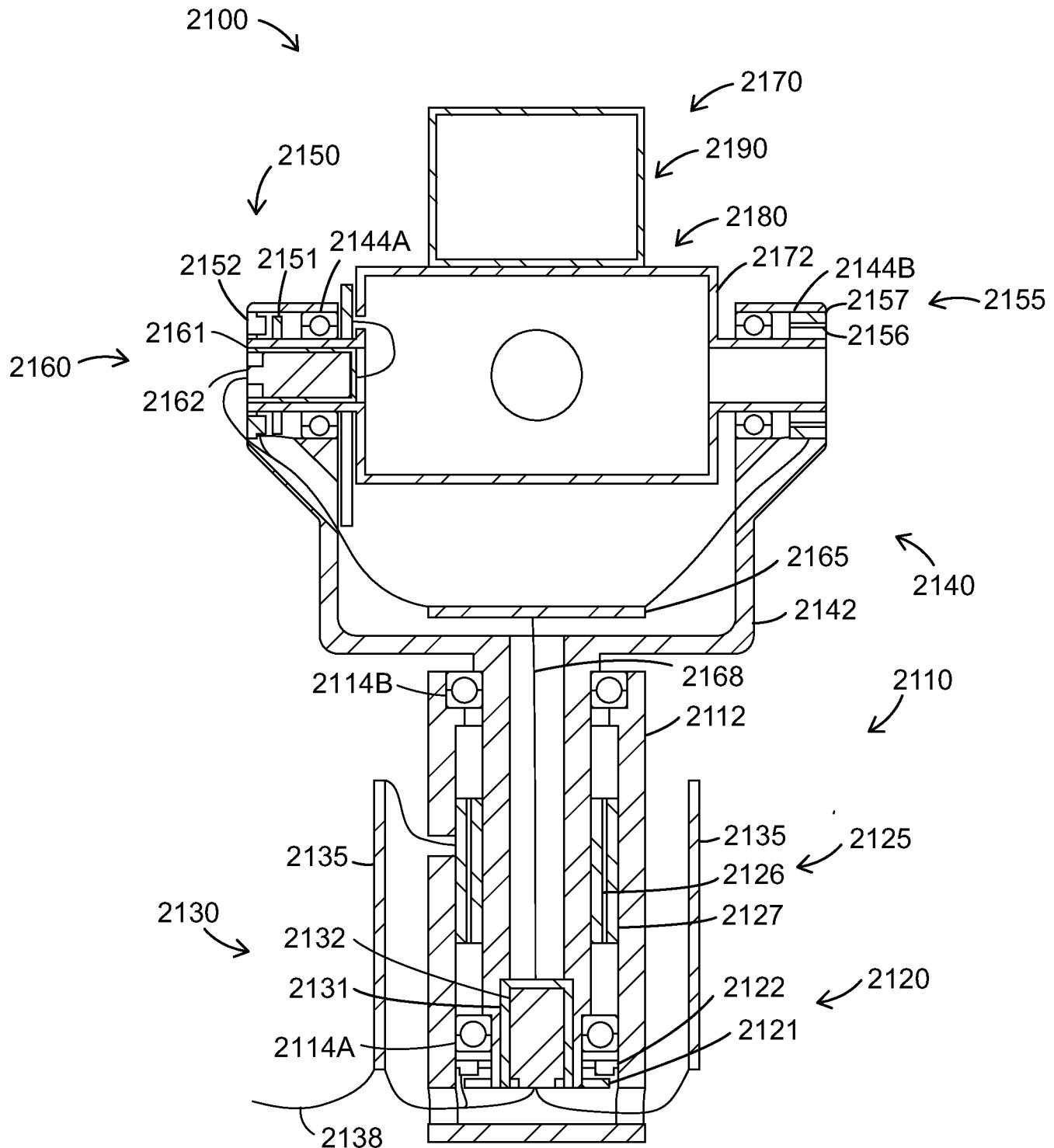
FIGURE 8C

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PRIOR ART
FIGURE 9

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PRIOR ART
FIGURE 10

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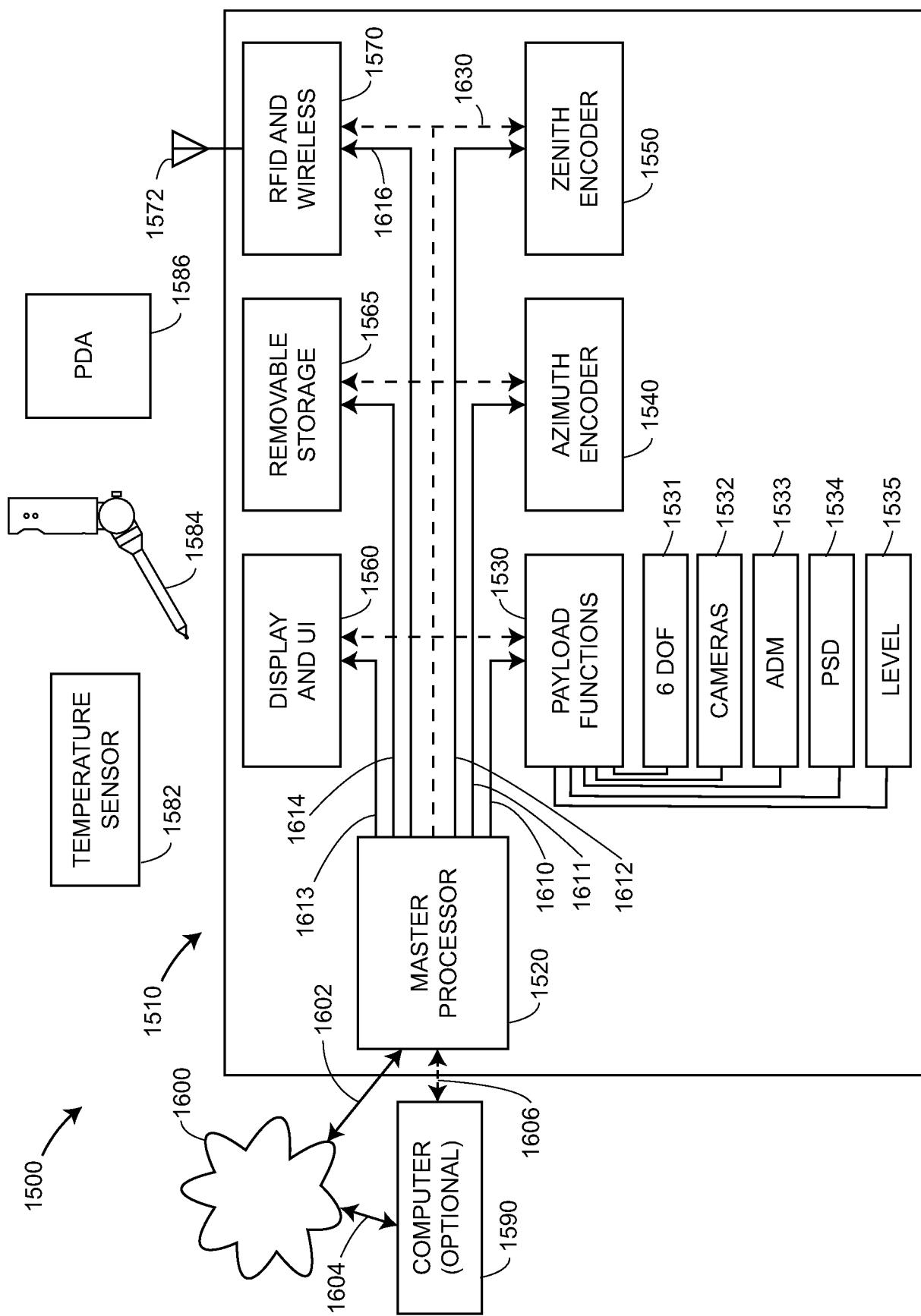


FIGURE 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/03Q225

| A. CLASSIFICATION OF SUBJECT MATTER | | | | |
|--|---|--|-----------|-----------------------|
| INV. G01B11/00 | | G01S7/481 | G01S17/66 | G01B11/03 |
| ADD. | | | | |
| 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) | | | | |
| G01B G01S | | | | |
| Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched | | | | |
| Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) | | | | |
| EPO-Internal | | | | |
| C. DOCUMENTS CONSIDERED TO BE RELEVANT | | | | |
| Category* | Citation of document, with indication, where appropriate, of the relevant passages | | | Relevant to claim No. |
| X | EP 1 067 363 A2 (TOPCON CORP [JP]) 10 January 2001 (2001-01-10) the whole document | | | 1 |
| Y | ----- us 2007/121Q95 AI (LEWIS ROBERT [US]) 31 May 2007 (2007-05-31) abstract; figure 10 paragraphs [0029] - [0032] , [0062] | | | 2 , 6 |
| Y | ----- us 7 800 758 B1 (BRIDGES ROBERT E [US] ET AL) 21 September 2010 (2010-09-21) the whole document | | | 3 - 6 |
| Y | ----- us 6 490 027 B1 (RAJCHEL SUZANNE K [US] ET AL) 3 December 2002 (2002-12-03) the whole document | | | 3-6 |
| | | | | - / - |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. | | <input checked="" type="checkbox"/> See patent family annex. | | |
| <p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"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</p> <p>"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</p> <p>"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</p> <p>"&" document member of the same patent family</p> | | | | |
| Date of the actual completion of the international search | | Date of mailing of the international search report | | |
| 20 September 2012 | | 28/09/2012 | | |
| Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016 | | Authorized officer Stanciu, C | | |

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/03Q225

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category [*] | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------------------|---|-----------------------|
| Y | US 3 497 695 A (SMITH WARREN J) 24 February 1970 (1970-02-24) the whole document ----- | 3,5,6 |

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/03Q225

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos. :

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims : 1, 2

Laser tracker for measuring the coordinates of a retroreflecting object, rotating around two axes with respective angular encoders, comprising a distance meter and a tracking module with a position sensitive detector, further comprising a diffuser in front of the position sensitive detector.

2. claims : 3-6

Laser tracker for measuring the coordinates of a retroreflecting object, rotating around two axes with respective angular encoders, a distance meter and a tracking module with a position sensitive detector, further comprising a lens together with a spatial filter in front of the position sensitive detector.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/03Q225

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