(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 March 2003 (06.03.2003)

PCT

(10) International Publication Number
WO 03/019231 A1

(51) International Patent Classification[7]: G01S 17/06, 17/66, 17/42, 17/87, B25J 13/08, G01B 11/26, G01C 1/00

(21) International Application Number: PCT/US02/26628

(22) International Filing Date: 22 August 2002 (22.08.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/313,807 22 August 2001 (22.08.2001) US

(71) Applicant: AUTOMATED PRECISION INC. [US/US]; 15000 Johns Hopkins Drive, Rockville, MD 20850 (US).

(72) Inventor: LAU, Kam, C.; 12700 Greenbrier Road, Potomac, MD 20854 (US).

(74) Agent: VICK, Jason, H.; Nixon Peabody LLP, 8180 Greensborpo Drive, Suite 800, McLean, VA 22102 (US).

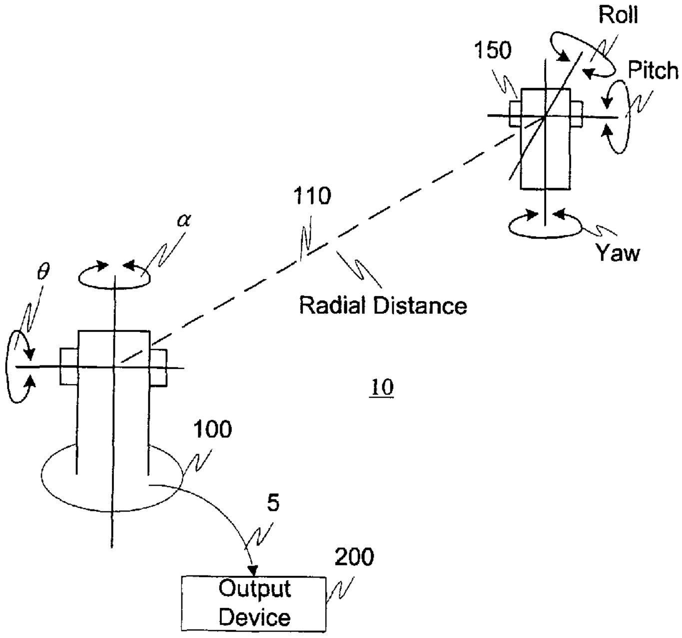
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

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

(54) Title: SIX DIMENSIONAL LASER TRACKING SYSTEM AND METHOD



(57) Abstract: A laser based tracking unit communicates with a target to obtain position information about the target. Specifically, the target is placed at the point to be measured. The pitch, yaw and roll of the target, and the spherical coordinates of the target relative to the tracking unit are then obtained. The target can be, for example, an active device incorporated into a moveable device such a remote controlled robot.

WO 03/019231 A1

SIX DIMENSIONAL LASER TRACKING SYSTEM AND METHOD

Background of the Invention

Field of the Invention

[0001] In general, the systems and methods of this invention relate to a laser tracking system. In particular, the systems and methods of this invention are directed toward a six dimensional (6-D) laser tracking system.

Description of Related Art

[0002] Precision measuring systems have a wide variety of applications. For example, in robotics, accurate positioning and orientation of a robot is often required. To achieve a high degree of precision, a robot position measuring system can be used. Such a system typically uses a laser beam interferometer to determine the position and/or orientation of an end-effector of the robot. This system can monitor the position and orientation of the robot end-effector in real-time while providing accuracy, speed and measurement data.

[0003] For example, a Three and Five Access Laser Tracking System is discussed in Applicant's Patent No. 4,714,339 and a Five-Access Six-Access Laser Measuring System is discussed in U.S. Patent No. 6,049,377, both of which are incorporated herein by reference in their entirety.

Summary of the Invention

[0004] The systems and methods of this invention employ a combination of a tracking unit and an active target to accomplish six-dimensional laser tracking. In particular, the six dimensions are pitch, yaw, and roll of the active target, and the spherical coordinates, i.e., the

2 angles α, θ and the radial distance, of the target relative to the tracking unit. By using an active target, the active target coordinates maintain a relatively perpendicular relation to the incoming beam. Additionally, by employing an absolute distance measurement technique, absolute ranging is possible.

[0005] In general, the pitch and yaw based measurements can be derived from an encoder present on the active target. The roll measurements can be based on, for example, a polarization or an electronic level technique (discussed hereinafter). The absolute distance measurements (ADM) can be accomplished using, for example, repetitive time of flight pulses, a pulsed laser, phase/intensity modulation, or the like.

[0006] Specifically, a repetitive time of flight (RTOF) based system comprises a photodetector, such as a PIN photodetector, a laser amplifier, a laser diode and a frequency counter. A first laser pulse is fired to the target. Upon detecting the return pulse, the detector triggers the laser amplifier and causes the laser diode to fire a second pulse, with the pulses being detected by the frequency counter. However, it is to be appreciated that the reverse logic will also work with equal success. The distance (D) of the target from the tracking unit would then be given by:

$$D = \frac{C}{4}\left(\frac{1}{f} - \frac{1}{f_0}\right)$$

such that:

$$D=0; f=f_0$$

where C is the speed of light, f_0 is a reference frequency and f is the frequency of the pulses.

[0007] The systems and methods of this invention have various applications. In general, the systems and methods of this invention allow the monitoring of six degrees of freedom of an object. For example, the systems and methods of this invention can be used for structural assembly, real-time alignment and feedback control, machine tool calibration, robotic position control, position tracking, milling machine control, calibration, parts assembly, or the like.

[0008] Additionally, the systems and methods of this invention, using the 6-D tracking system, lend themselves to use in the robotic arts. For example, the 6-D laser tracking system can be incorporated into a robot, that is, for example, capable of scaling various objects such that, for example, precise measurements can be taken of those objects and/or various functions performed at specific locations on the object.

[0009] In accordance with an exemplary embodiment of the invention, aspects of the invention relate to a 6-D laser tracking system.

[0010] An additional aspect of the invention relates to determining roll based on measurements from a polarized laser head.

[0011] Additionally, aspects of the invention relate to the design and use of an active target in conjunction with a tracking unit.

[0012] Additionally, aspects of the invention relate to the use of the active target on a robotic device.

[0013] Additional aspects of the invention also relate to a remotely controlled robot that incorporates active target technology.

[0014] These and other features and advantages of this invention are described in or are apparent from the following detailed description of the embodiments.

Brief Description of the Drawings

[0015] The embodiments of the invention will be described in detail, with reference to the following figures wherein:

[0016] Fig. 1 illustrates an exemplary 6-D tracking system according to this invention;

[0017] Fig. 2 is a block diagram illustrating a roll determination system according to this invention;

[0018] Fig. 3 is a block diagram illustrating an exemplary pitch, yaw, roll and distance measuring system according to this invention;

[0019] Fig. 4 is an exemplary remote controlled robot incorporating the active target system according to this invention;

[0020] Fig. 5 is a cross-sectional view of the remote controlled robot according to this invention; and

[0021] Fig. 6 is a flowchart illustrating an exemplary method of taking measurements according to this invention.

Detailed Description of the Invention

[0022] Fig. 1 illustrates an exemplary 6-D laser tracking system. In particular, the laser tracking system comprises a tracking unit 100 and an active target 150. The tracking unit 100 emits one or more lasers 110 that communicate with the active target 150 to determine the six dimensional measurements which are output on output device 200. In particular, the six dimensions illustrated are pitch, yaw and roll of the active target and the spherical, and once converted Cartesian, coordinates of the tracking unit 100.

[0023] As discussed in Applicant's previous patents, the pitch, yaw and spherical coordinate measurements can be based on various technologies. For example, the pitch and yaw measurements can be based on, for example, a rotary encoder.

[0024] Additionally, the distance measurements can be based on, for example, a pulsed laser configuration, a repetitive time of flight pulse, phase and/or intensity modulation of the laser beam, or the like. These various systems can provide absolute ranging of the active target. Thus, the active target need not be returned to a known position, such as with a passive target, before distance measurements can commence. Specifically, an absolute distance measurement technique can be used to determine an approximate initial distance and then an interferometer based technique used to refine the initial distance measurement.

[0025] The tracking unit 100 and the active target 150 can be, for example, motorized units that allow one or more portions of the tracking unit 100 and the active target 150 to maintain a perpendicular orientation to the incoming laser beam 110 emitted from the tracking unit 100. Thus, through a combination of rotary encoders and motors that employ position signals from one or more photodetectors, as discussed hereinafter, the active target is capable of remaining perpendicular to the incoming laser beam 110. For example, through the use of a gimbal type mount and corresponding position motors, such as stepping motors, servo motors and/or encoders, the active target "tracks" the tracking unit 100. Based upon the relationship of the active target to the incoming laser, the 6-D laser tracking system 10 is able to determine the orientation of the active target. Alternatively, the target can be a passive device, for example, a hand-held device such as a corner cube, for which a user would be responsible for maintaining a line of site between the target and the tracking unit 100.

[0026] The tracking unit 100 is also capable of being miniaturized by incorporating both the absolute distance measurement and interferometer electronics in, for example, the gimbaled portion of the tracking unit 100. This provides various exemplary advantages including reduced weight, reduced size, minimization of external connections, quicker tracking speeds, and the like.

[0027] The output device 200, connected to one or more of the tracking unit 100 and target 150 via a wired or wireless link 5, outputs position information about the target 150. For example, the output device 200 can be a computer, a feedback input for a position control device, a display, a guidance system, or the like. In general, the output device can be any device capable of outputting target position information.

[0028] Additionally, the one or more lasers 110 can be used to communicate position information about the target 150 back to the tracking unit 100. For example, after an initial distance is determined, the laser used for the absolute distance measurement can be used for data communication and the interferometer based laser used for the radial distance measurements. Alternatively, a dedicated laser can be incorporated into the system that would allow full time communication between the target and the tracking unit.

[0029] Fig. 2 illustrates an exemplary system for determining roll in accordance with this invention. In particular, the system comprises a laser source, such as a laser head, (not shown) located in the tracking unit 100, a polarized laser beam 210, a polarizing beam splitter 220, a first photodetector 230, a second photodetector 240 and a roll determination circuit 250, such as a differential amplifier.

[0030] In operation, the laser source 100 emits a polarized laser beam 210 that is received by the polarizing beam splitter 220. The polarizing beam splitter splits the incoming beam into two paths. A first path is directed toward the first photodetector 230 and a second path of the polarized laser beam 210 is directed toward the second photodetector 240. When the polarized laser beam encounters the polarizing beam splitter 220, the polarized laser beam 210 is split into horizontally polarized and vertically polarized components as a result of the properties of the beam splitter 220. The horizontally polarized portion of the beam passes through the polarized beam splitter 220 to the photodetector 240 that generates an output signal corresponding to the intensity of the horizontally polarized portion of the beam. The vertically polarized portion of the beam is directed by the beam splitter 220 onto the photodetector 230 that also produces a signal corresponding to the intensity of the vertically polarized portion of the beam. The intensity measurements of the photodetectors 230 and 240 can be connected to, for example, the positive and negative inputs, respectively, of a high-gain differential amplifier 250, which provides an output signal representative of the roll between the laser source 100 and the active target 150.

[0031] The polarized laser beam 210 is split into two different polarized portions based on the exact roll orientation between the tracking unit 100 and the active target 150. At a 45° roll orientation, the photodetectors 230 and 240 will receive the same intensity. However, as the active target 150 is rolled in either direction, one of the detectors will receive a greater intensity of the polarized laser beam than the other. The difference between these outputs is measured by, for example, the differential amplifier 250, to provide an indication of the roll.

This subtraction operation of the differential amplifier 250 also advantageously compensates for background and extraneous noise, such as that produced by fluctuations in the beam intensity and/or background light.

[0032] Specifically, variations in the beam output, as well as other signal noise that may be present, can be measured by both the photodetector 230 and photodetector 240. These variations can be negated by the differential amplifier's operation. This, for example, increases the sensitivity and accuracy of the system.

[0033] The signal representative of the roll can be output to, for example, a computer (not shown) provided with software that is capable of recording, analyzing or initiating further action based on the roll measurement.

[0034] Alternatively, other techniques may be used for roll determination. These techniques include, but are not limited to, electronic levels, such as pendulum based techniques, conductive fluid capillary tube techniques, liquid mercury reflective sensors, or, in general, any technique that allows the roll of the target to be determined.

[0035] Fig. 3 illustrates the exemplary orientation determining components used for the 6-D laser tracking system. In particular, the components of the 6-D laser tracking system 10 comprise a laser source present in the tracking unit 100, a polarized laser beam 310, a beam splitter 320, a corner cube 330, a concentrator lens 340, a two-dimensional photodetector 350, the first photodetector 230, the second photodetector 240, the polarizing beam splitter 220 and the roll signal determination device 250.

[0036] In operation, the laser source in the tracking unit 100 emits a polarized laser beam 310 that is split by the beam splitter 320 into three paths directed toward the concentrator lens 340, the corner cube 330 and the polarizing beam splitter 220, respectively.

[0037] The path directed toward the concentrator lens 340 is focused onto the two-dimensional photodetector 350 from which the pitch and yaw signals that drive the motors for the active target are derived. In particular, as the active target 150 moves relative to the laser source 100, the laser path directed through the concentrator lens 340 moves relative to the 2-

D photodetector 350. This movement can be detected and a corresponding signal representative of the pitch and/or yaw measurement obtained. Then, as discussed above, the pitch and/or yaw measurements can be used to control one or more motors on the active target 150 to maintain the perpendicular orientation of the active target 150 to the tracking unit 100.

[0038] The path of the polarized laser beam 310 passing directly through the beam splitter 320 is reflected by the corner cube 330 and returned to the tracking unit 100. The tracking unit 100, as discussed in Applicants' related patents, is then able to determine the distance between the active target 150 and the tracking unit 100. However, it is to be appreciated that any method of determining an absolute distance measurement can be used with equal success with the systems and methods of this invention.

[0039] The path of the beam reflected by the beam splitter 320 and directed toward the polarized beam splitter 220 is used to determine the roll measurements, as discussed above. The combination of the roll, the pitch and the yaw measurements made by the active target, along with the spherical coordinates made the tracking unit 100, allows the tracking system to obtain the six-dimensional tracking of the active target.

[0040] Fig. 4 illustrates an exemplary robotic active target 400. The robotic active target 400 comprises a plurality of suction cup type devices 410, a drive mechanism 420, a controller 430, an accessory 440, a suction device 450 and the active target 460. The robotic active target 400 also comprises various other components such as a power supply, battery, solar panels, or the like that have been omitted for sake of clarity and would be readily apparent to those of ordinary skill in the art.

[0041] In operation, the combination of the active target 460 in conjunction with the robotic active target 400 allows, for example, precise movement and location tracking of the robot. While a particular robotic active target is discussed below, it is to be appreciated that in general the active target can be fixably attached to any object to allow monitoring of up to six degrees of freedom of the object, or, alternatively, the active target attached to a movable device and the position of that device monitored.

[0042] The suction cup type devices 410 are connected to the suction device 450 via, for example, hoses (not shown) that enable the robot 400 to remain affixed to a surface. For example, the controller 430, in conjunction with the suction device 450 and the suction cup type devices 410 can cooperate with the drive systems 420 such that the robot 400 is able to traverse a surface. For example, the suction cup type devices 410 and the drive mechanism 420 can cooperate such that sufficient suction is applied to the suction cup type devices 410 to keep the robot 400 affixed to a surface, while still allowing the drive mechanism 420 to move the robot 400 over the surface. For example, the drive mechanism 420 can be four wheels, and associated drive and suspension components (not shown), as illustrated. The wheels allow the traversal of the robot 400 over a surface while maintaining the rotational orientation of the robot relative to the tracking unit 100. However, in general, while it is simpler to operate the robot 400 such that the rotational orientation remains constant relative to the tracking unit 100, the system can be modified in conjunction with the use of the polarized laser to account for any rotational movement which may occur. Specifically, for example, the rotational movement of the robot 400 can be algorithmically "backed-out" of the orientation measurements based on the polarized laser to account for any rotation of the robot 400.

[0043] Furthermore, it should be appreciated that while exemplary robot 400 comprises a suction device 450 and suction cup type devices 410, any device, or combination of devices, that are capable of movably fixing the robot to a surface would work equally well with the systems and methods of the invention. For example, depending on the surface type, a magnetic, gravitational, resistive, or the like type of attachment system could be employed.

[0044] The controller 430, which can, for example, be in wired or wireless communication with a remote controller (not shown), allows for navigation of the robot 400 in cooperation with the drive mechanism 420. For example, the drive mechanism can be a plurality of electric motors connected to the drive wheels 420, or the like.

[0045] The accessory 440, can be, for example, a marking device, a tool, such as a drill, a painting attachment, a welding or cutting device, or any other known or later developed device that needs precise placement on a surface. The accessory can be activated, for example remotely, in cooperation with the controller 430.

[0046] Since the accessory 440 is located a known distance from the active target 460, the exact position of the accessory 440 is always known. Thus, a user can position the accessory 440 in an exact location such that the accessory 440 can perform an action at that location. For example, a local effect sensor like a strip camera, a Moire' fringe patent sensor, or a touch probe can be attached to the end of the target. The tracking unit combined with the active target can provide the orientation of the local sensor in a spatial relationship with the part to be measured while the local sensor is measuring the contours of a part, such as a car body, a building, a part in an environmentally hazardous area, or the like.

[0047] Fig. 5 illustrates an exemplary cross-sectional view of the robot 400. In addition to position sensing equipment associated with the active target 460, a movable distance determining device 540 extends from the base of the robot 400 to a surface 510. The distance determining device 540 measures the exact distance between the active target 460 and the surface 510 such that the exact location of the surface 510 relative to the active target 460 is always known.

[0048] As illustrated in Fig. 5, the suction cup type devices 410 are located a fixed distance above the surface 510 via the spacers 530. For example, the spacers 530 can be a bearing, or other comparable device that allows for the suction cup type devices 410 to remain a fixed distance above the surface 510 while still allowing the air 520 to create a suction between the robot 400 and the surface 510.

[0049] Given the mobility of the robot 400, it is foreseeable that the robot may not always be in communication with the tracking unit 100. In the event the robot 400 loses line-of-sight with the tracking unit 100, the 6-D laser tracking system can then enter a target acquisition mode. In this mode, a user can, for example, with a joystick, aim the tracking unit generally in the vicinity in the robot 400. The tracking unit 100 then commences a target acquisition process in which the tracking unit begins a spiral type pattern that spirals outward to locate the active target. Upon acquisition of the target, communication between the tracking unit and the active target 150 is established and the six-dimensional measurements are again available.

[0050] Alternatively, for example, the active target 150 can maintain communication with the tracking unit 100 via, for example, a radio communication link, or other known or later developed system that allows the tracking unit 100 to track the relative position of the active target 150 regardless of whether line-of-sight is present. Thus, when line-of-sight is reestablished, as discussed above, the six-dimensional measurements are available.

[0051] Fig. 6 illustrates an exemplary method of making measurements according to an exemplary embodiment of this invention. In particular, control begins in step S100 and continues to step S110 where communication between the tracking unit and target are established. For example, for an interferometer based system, the target can be placed at a known position to both establish communication with the tracking unit as well as to initialize the system. For an absolute distance measurement system the target is placed in communication with the laser and an approximate radial distance (R) obtained. Next, in step S120, the target is placed at the point(s) to be measured. Then, in step S130, the pitch, yaw, roll and spherical coordinates obtained. Control the continues to step S140.

[0052] In step S140, the spherical coordinates are converted to Cartesian (x,y,z) coordinates, where x is the horizontal position, y the in/out position and z the up/down position of the target. Then, in step S150, the position measurements are output. Control then continues to step S160 where the control sequence ends.

[0053] As illustrated in Figs. 1-5, the 6-D laser tracking system 10 can be implemented either on a single programmed general purpose computer, or a separate programmed general purpose computer and associated laser generating and detecting, motor and rotary encoder components. However, various portions of the 6-D laser tracking system can also be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element, an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as a discrete element circuit, a programmable logic device such as a PLD, PLA, FPGA, PAL, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the measurement techniques discussed herein and illustrated in Fig. 6 can be used to implement the 6-D laser tracking system according to this invention.

[0054] Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation hardware platforms. Alternatively, the disclosed 6-D laser tracking system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software and/or hardware systems or microprocessor or microcomputer systems being utilized. The 6-D laser tracking system and methods illustrated herein, however, can be readily implemented in hardware and/or software using any known or later-developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and a general basic knowledge of the computer and optical arts.

[0055] Moreover, the disclosed methods may be readily implemented as software executed on a programmed general purpose computer, a special purpose computer, a microprocessor, or the like. In these instances, the methods and systems of this invention can be implemented as a program embedded on a personal computer such as a Java® or CGI script, as a resource residing on a server or graphics workstation, as a routine embedded in a dedicated 6-D laser tracking system, or the like. The 6-D laser tracking system can also be implemented by physically incorporating the system and method into a software and/or hardware system, such as the hardware and software systems of a 6-D laser tracking system.

[0056] It is, therefore, apparent that there has been provided, in accordance with the present invention, systems and methods for 6-D laser tracking. While this invention has been described in conjunction with a number of exemplary embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, the invention is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

I Claim:

1. A multi-dimensional measurement system comprising:

a tracking unit that emits a laser and has spherical coordinates;

a target in communication with the tracking unit, the target having a pitch, a yaw and a roll;

a distance determining module that determines a distance between the tracking unit and the target; and

an output device that outputs position information about the target relative to the tracking unit based on the pitch, yaw, roll and spherical coordinates.

2. The system of claim 1, further comprising an output module that outputs the position information about the target.

3. The system of claim 1, wherein the roll is based on at least one of a comparison between a horizontally polarized and a vertically polarized portion of the laser and an electronic level.

4. The system of claim 3, further comprising a first photodetector that detects the horizontally polarized portion of the laser and a second photodetector that detects the vertically polarized portion of the laser.

5. The system of claim 4, further comprising a differential amplifier that receives an output of the first photodetector and an output of the second photodetector.

6. The system of claim 1, wherein the target is an active target that is capable of moving relative to the laser.

7. The system of claim 6, wherein the active target is at least one of incorporated into a robotic device, fixably attached to an object, used for feedback control, used for calibration, used for machine tool control, used for parts assembly, and used for structural assembly.

8. The system of claim 7, wherein the robotic device comprises a drive system and one or more traction devices that allow the robotic device to adhere to a surface.

9. The system of claim 8, wherein the traction devices are suction cup type devices.

10. The system of claim 7, further comprising a vacuum system.

11. The system of claim 7, wherein the robotic device is remotely controlled.

12. The system of claim 7, further comprising on or more accessories that allow a function to be performed based at least on the position of the target.

13. A method of measuring the position of an object comprising:

monitoring spherical coordinates of a laser emitting tracking unit;

monitoring a pitch, a yaw and a roll of a target in communication with the tracking unit;

determining a distance between the tracking unit and the target; and

outputting position information about the target relative to the tracking unit based on the spherical coordinates, pitch, yaw and roll.

14. The method of claim 13, wherein the roll is based on at least one of a comparison between a horizontally polarized and a vertically polarized portion of the laser and en electronic level.

15. The method of claim 14, wherein a differential amplifier performs the comparison between the horizontally polarized and the vertically polarized portion of the laser.

16. The method of claim 13, wherein the target is an active target that is capable of moving relative to the laser.

17. The method of claim 16, wherein the active target is at least one of incorporated into a robotic device, fixably attached to an object, used for feedback control, used for calibration, used for machine tool control, used for parts assembly, and used for structural assembly.

18. The method of claim 17, wherein the robotic device comprises a drive system and one or more traction devices that allow the robotic device to adhere to a surface.

19. The method of claim 18, wherein the traction devices are suction cup type devices used in conjunction with a vacuum system

20. The method of claim 18, wherein the robotic device is remotely controlled.

21. The method of claim 17, further comprising allowing a function to be performed by an accessory based at least on the position of the target.

22. A system for measuring the position of an object comprising:

means for monitoring spherical coordinates of a laser emitting tracking unit;

means for monitoring a pitch, a yaw and a roll of a target in communication with the tracking unit;

means for determining a distance between the tracking unit and the target; and

means for outputting position information about the target relative to the tracking unit based on the spherical coordinates, pitch, yaw, and roll.

23. The system of claim 22, wherein the roll is based on at least one of a comparison between a horizontally polarized and a vertically polarized portion of the laser and an electronic level.

24. The system of claim 23, wherein a differential amplifier performs the comparison between the horizontally polarized and the vertically polarized portion of the laser.

25. The system of claim 22, wherein the target is an active target that is capable of moving relative to the laser.

26. The system of claim 25, wherein the active target is at least one of incorporated into a robotic device, fixably attached to an object, used for feedback control, used for calibration, used for machine tool control, used for parts assembly, and used for structural assembly.

27. The system of claim 26, wherein the robotic device comprises a drive system and one or more traction devices that allow the robotic device to adhere to a surface.

28. The system of claim 27 wherein the one or more traction devices are suction cup type devices used in conjunction with a vacuum system

29. The system of claim 27, wherein the robotic device is remotely controlled.

30. The system of claim 22, further comprising means for allowing a function to be performed based at least on the position of the target.

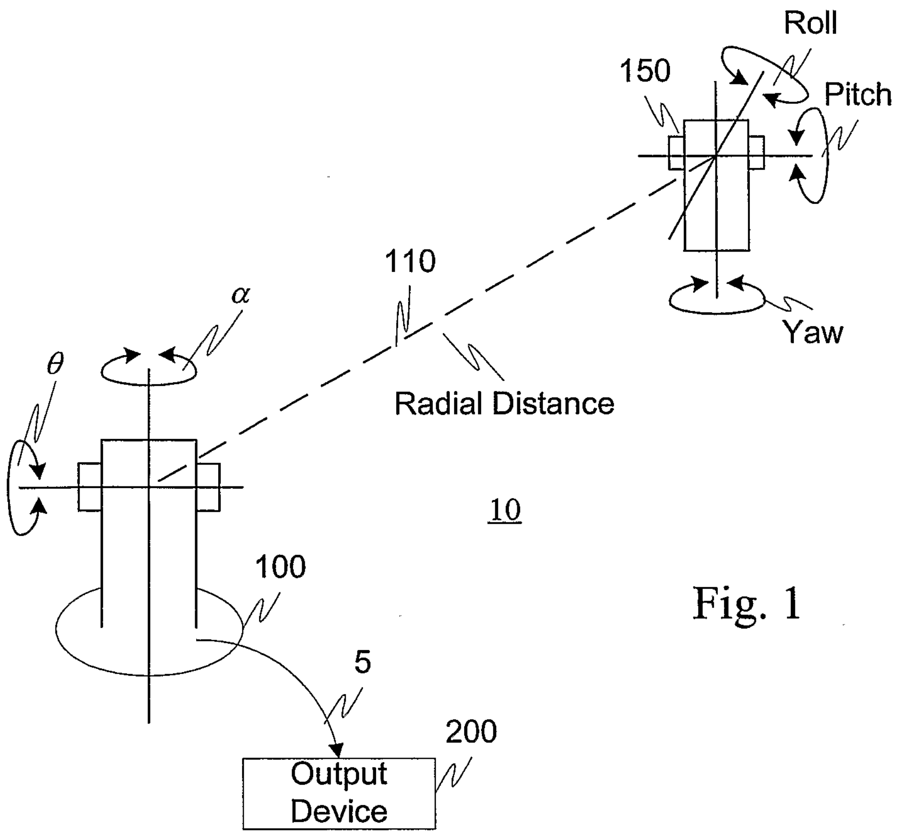

Roll
150
Pitch
110
α
Yaw
θ
Radial Distance
10
100
5
200
Output Device

Fig. 1

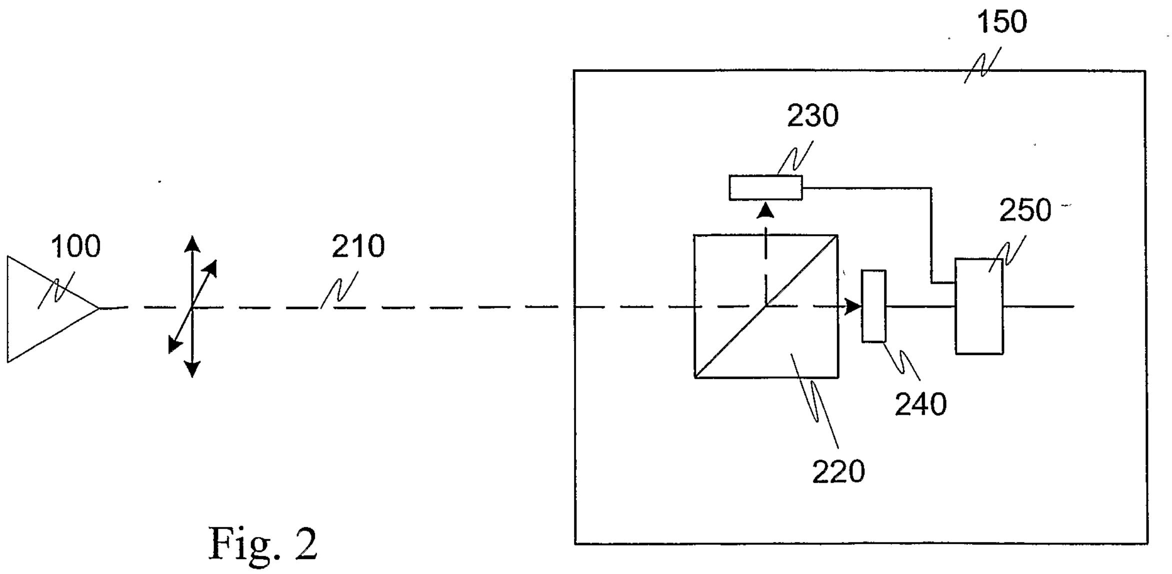

150
230
250
100
210
240
220

Fig. 2

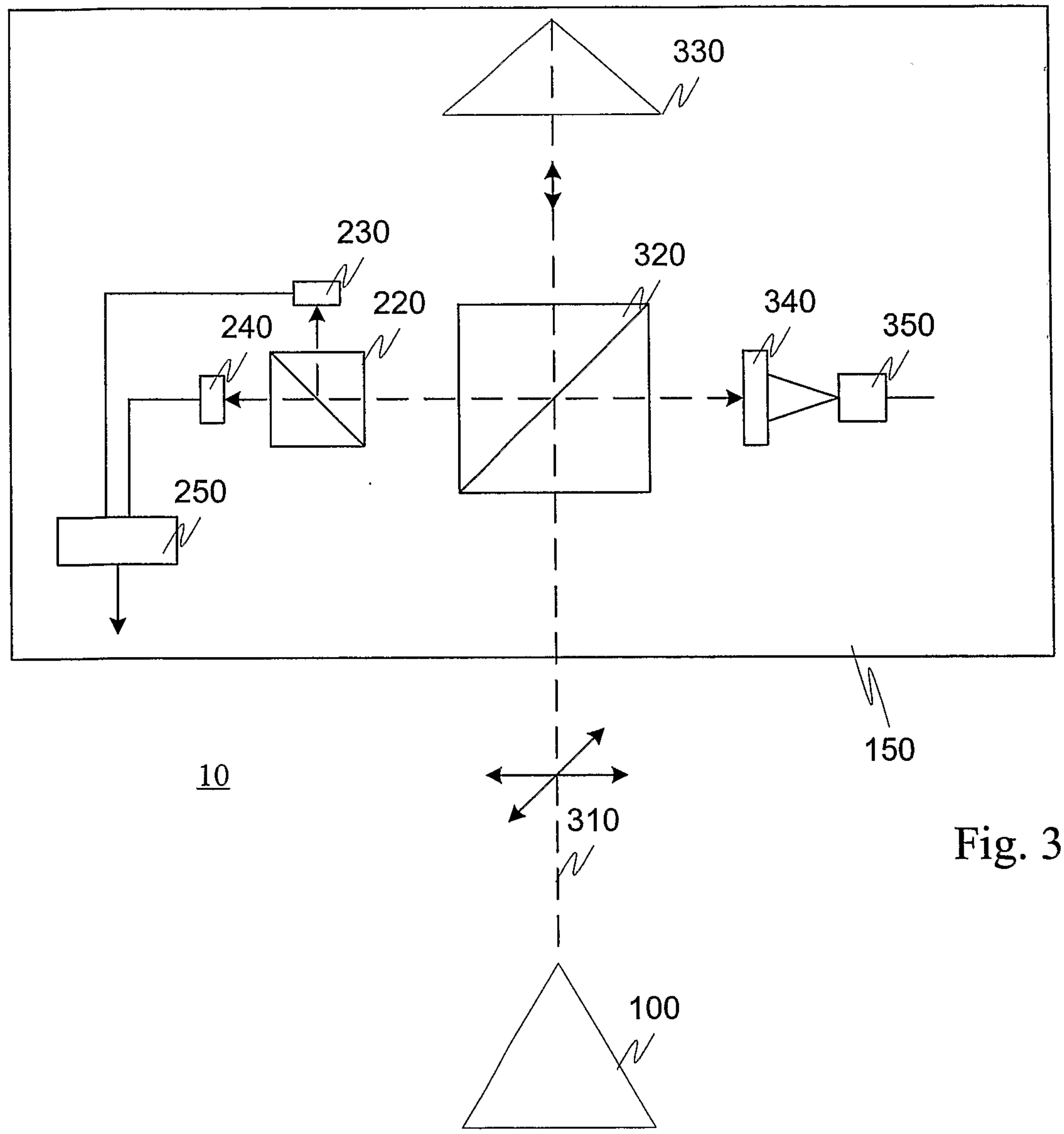


Fig. 3

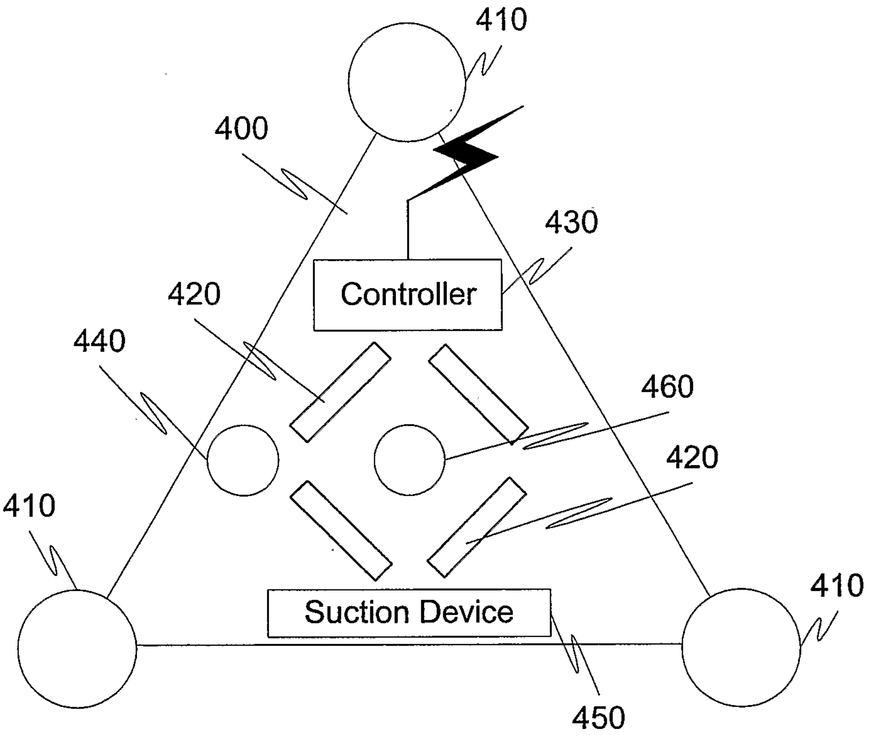

410
400
430
Controller
420
440
460
420
410
410
Suction Device
450

Fig. 4

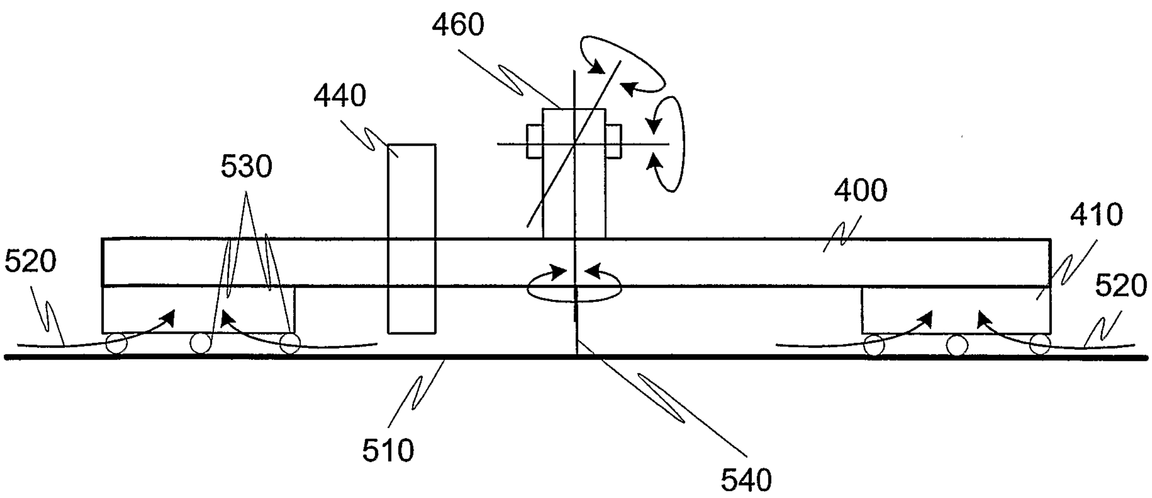


Fig. 5

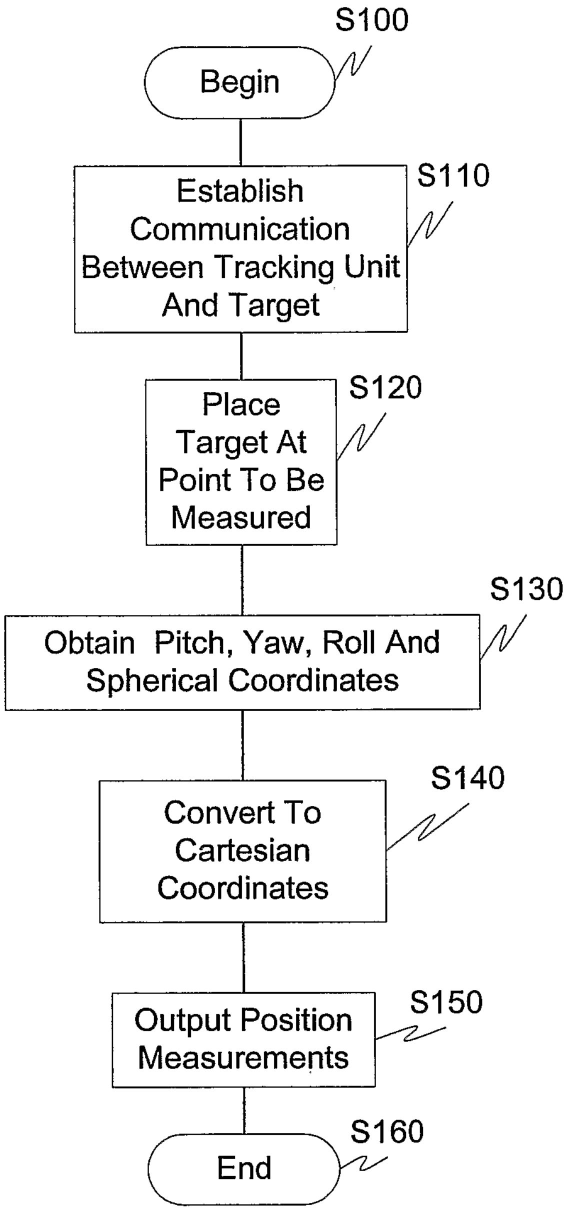

S100
Begin
S110
Establish Communication Between Tracking Unit And Target
S120
Place Target At Point To Be Measured
S130
Obtain Pitch, Yaw, Roll And Spherical Coordinates
S140
Convert To Cartesian Coordinates
S150
Output Position Measurements
S160
End

Fig. 6

INTERNATIONAL SEARCH REPORT

Inter ial Application No
PCT/US 02/26628

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01S17/06 G01S17/66 G01S17/42 G01S17/87 B25J13/08
G01B11/26 G01C1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01S B25J G01B G01C

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 049 377 A (LAU KAM C ET AL) 11 April 2000 (2000-04-11) cited in the application abstract; figures column 2, line 8 - line 39 column 3, line 9 -column 6, line 16 ---	1-30
X	EP 0 081 651 A (PERKIN ELMER CORP) 22 June 1983 (1983-06-22) page 2, line 15 - line 32 page 4, line 3 -page 7, line 24 figures ---	1-30
X	US 5 596 403 A (SCHIFF TOD F ET AL) 21 January 1997 (1997-01-21) abstract; figures 1,2 column 3, line 19 -column 4, line 34 --- -/--	1-30

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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

"E" earlier document 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	Date of mailing of the international search report
3 December 2002	09/12/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Dollinger, F

INTERNATIONAL SEARCH REPORT

Inte ıal Application No
PCT/US 02/26628

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 714 339 A (LAU KAM C ET AL) 22 December 1987 (1987-12-22) the whole document ---	1-30
A	US 3 871 771 A (SCOTT RICHARD NELSON) 18 March 1975 (1975-03-18) the whole document -----	1-30

INTERNATIONAL SEARCH REPORT

....-rmation on patent family members

Inter[ ]al Application No

PCT/US 02/26628

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 6049377	A	11-04-2000	EP	0866954	A1	30-09-1998
			JP	2001503133	T	06-03-2001
			WO	9807012	A1	19-02-1998
EP 0081651	A	22-06-1983	CA	1192286	A1	20-08-1985
			DE	3280084	D1	15-02-1990
			EP	0081651	A2	22-06-1983
			JP	1637046	C	31-01-1992
			JP	2062801	B	26-12-1990
			JP	58127184	A	28-07-1983
US 5596403	A	21-01-1997	AU	4507496	A	26-06-1996
			EP	0795115	A2	17-09-1997
			WO	9618080	A2	13-06-1996
US 4714339	A	22-12-1987	NONE			
US 3871771	A	18-03-1975	GB	1428372	A	17-03-1976
			CH	572607	A5	13-02-1976
			DE	2329483	A1	20-12-1973
			FR	2188141	A1	18-01-1974
			IT	984670	B	20-11-1974
			JP	49052690	A	22-05-1974
			JP	54023820	B	16-08-1979
			NL	7308165	A	11-12-1973
			SE	411486	B	27-12-1979
			BE	800681	A1	01-10-1973