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(54) **POSITION MEASURING SYSTEM, POSITION MEASURING DEVICE, AND POSITION MEASURING METHOD**

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(57) **ABSTRACT**

It is an object of the present invention to provide a position measuring system, a position measuring device, and a method for measuring a position that can accurately measure the position of an object to be measured without being limited by an environment or an optical axis.

A position measuring device **20** according to the present invention is characterized by including a light receiving unit **21** configured to receive scattered light Lsc emitted from a side surface of an optical fiber **50**, a database **22** configured to store a correspondence between information on the scattered light and a position of the object to be measured, and a determination unit **23** configured to determine, based on the correspondence stored in the database, a position of the object to be measured from information on the scattered light received by the light receiving unit.

[1]

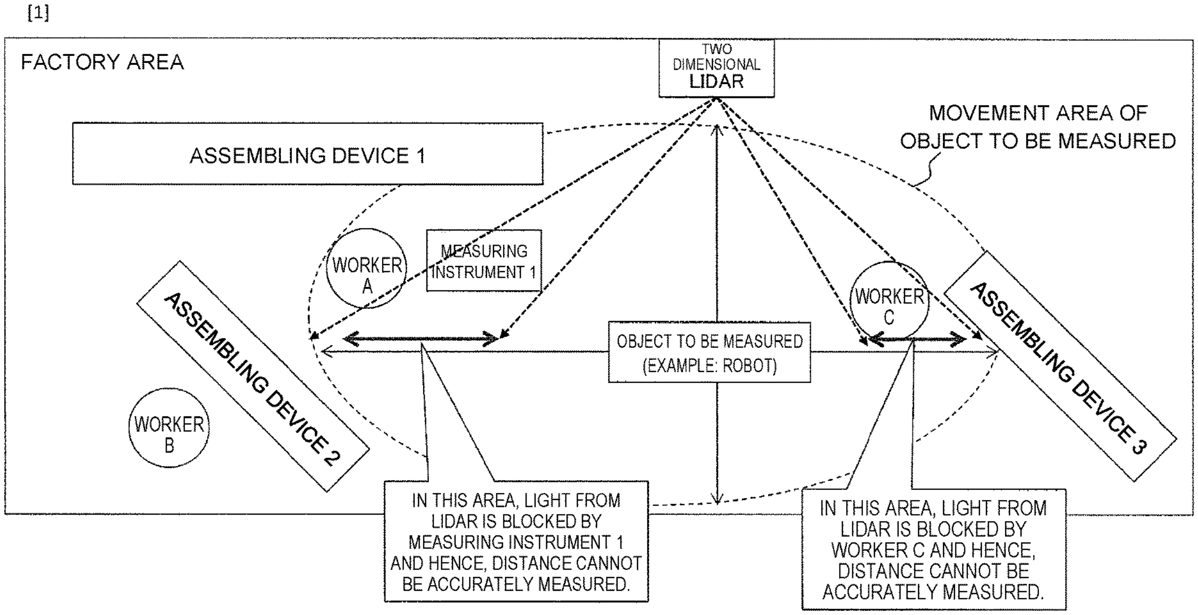


Fig. 1

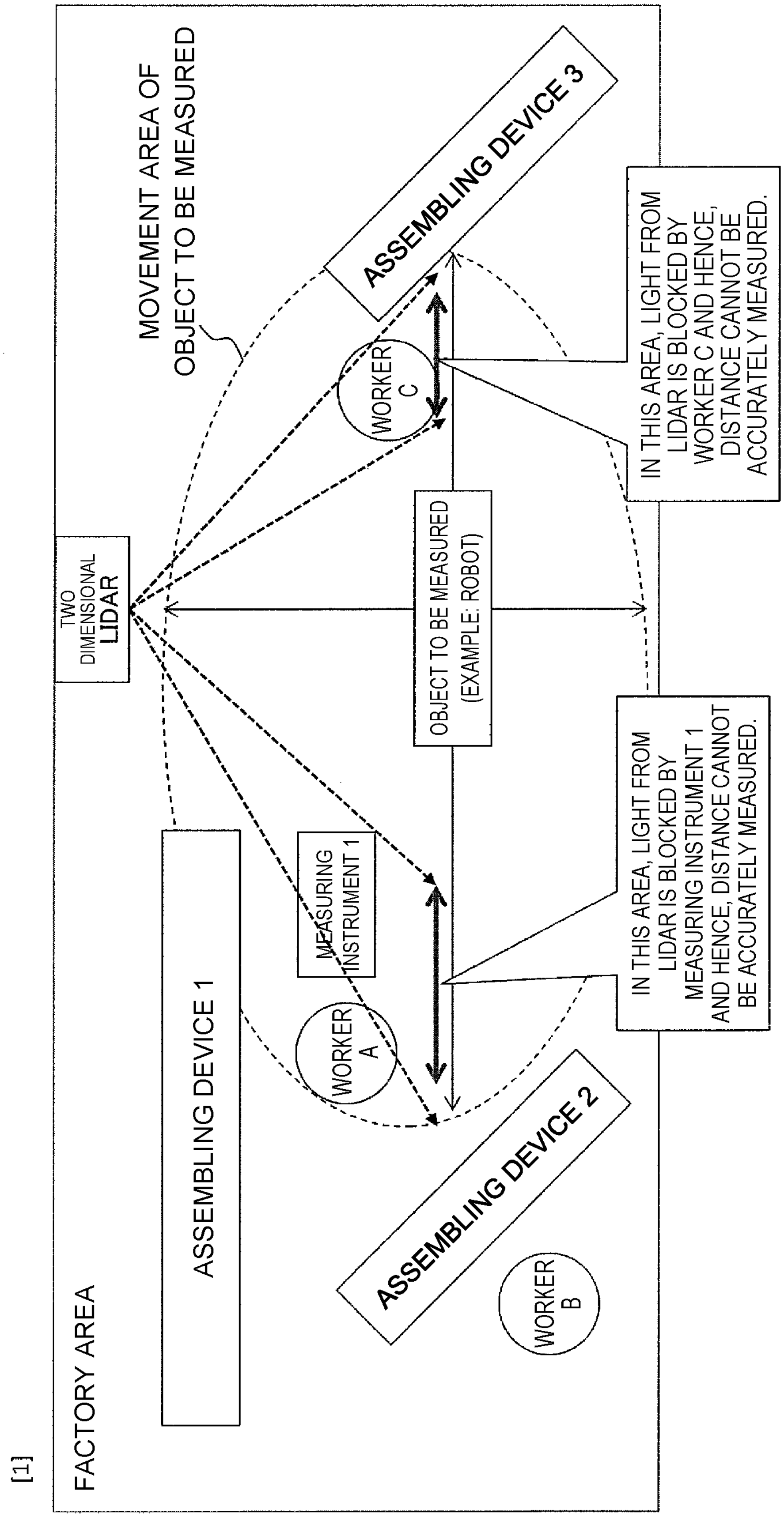

[1]
FACTORY AREA
MOVEMENT AREA OF OBJECT TO BE MEASURED
ASSEMBLING DEVICE 3
ASSEMBLING DEVICE 1
ASSEMBLING DEVICE 2
TWO DIMENSIONAL LIDAR
WORKER C
WORKER A
WORKER B
MEASURING INSTRUMENT 1
OBJECT TO BE MEASURED (EXAMPLE: ROBOT)
IN THIS AREA, LIGHT FROM LIDAR IS BLOCKED BY WORKER C AND HENCE, DISTANCE CANNOT BE ACCURATELY MEASURED.
IN THIS AREA, LIGHT FROM LIDAR IS BLOCKED BY MEASURING INSTRUMENT 1 AND HENCE, DISTANCE CANNOT BE ACCURATELY MEASURED.

Fig. 2

[2]

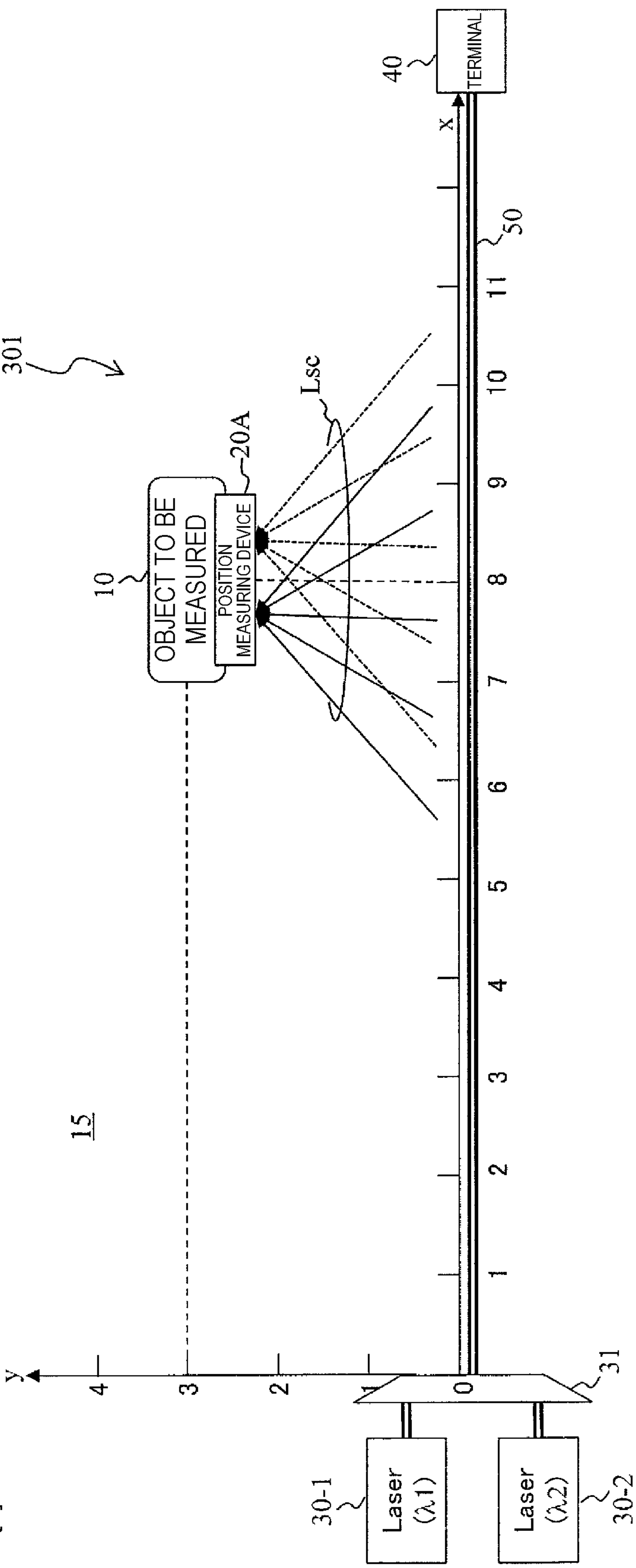

301
OBJECT TO BE MEASURED
10
POSITION MEASURING DEVICE
20A
Lsc
15
TERMINAL
40
50
x
y
0
1
2
3
4
5
6
7
8
9
10
11
31
Laser (λ1)
30-1
Laser (λ2)
30-2

Fig. 3

[3]

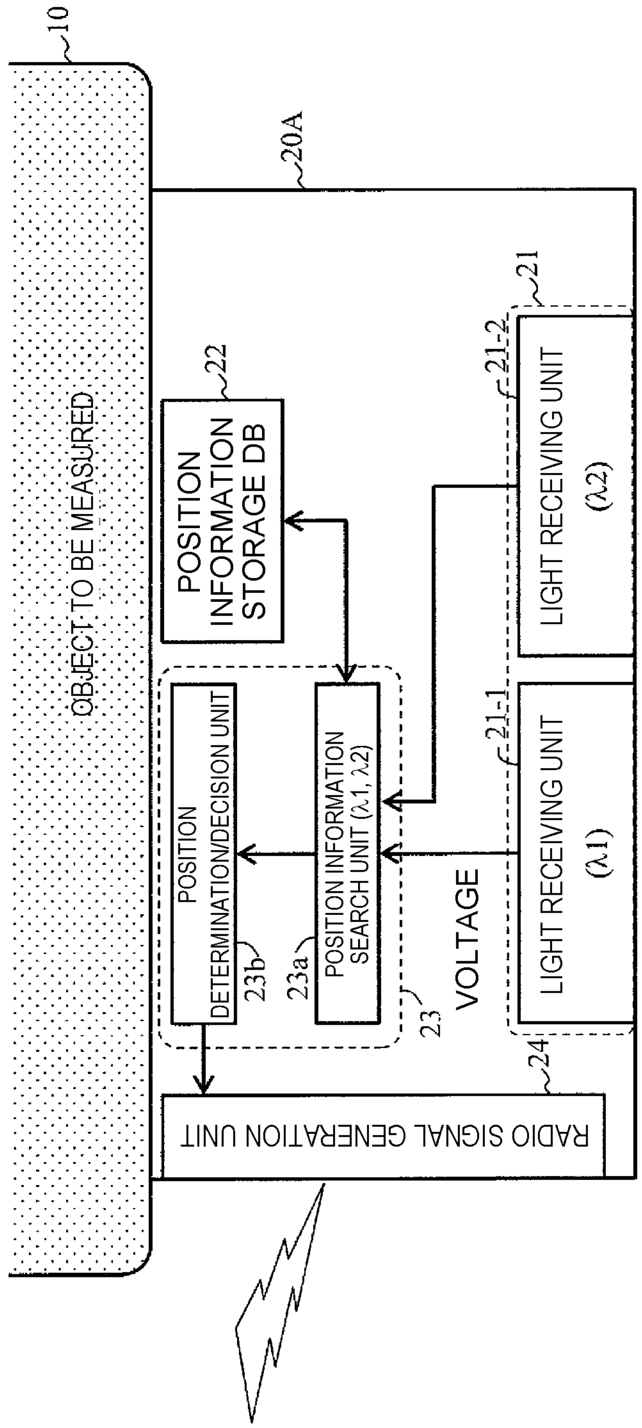

10
OBJECT TO BE MEASURED
20A
POSITION INFORMATION STORAGE DB
22
21
21-2
LIGHT RECEIVING UNIT (λ2)
21-1
LIGHT RECEIVING UNIT (λ1)
POSITION DETERMINATION/DECISION UNIT
23b
POSITION INFORMATION SEARCH UNIT (λ1, λ2)
23a
23
VOLTAGE
24
RADIO SIGNAL GENERATION UNIT

Fig. 4

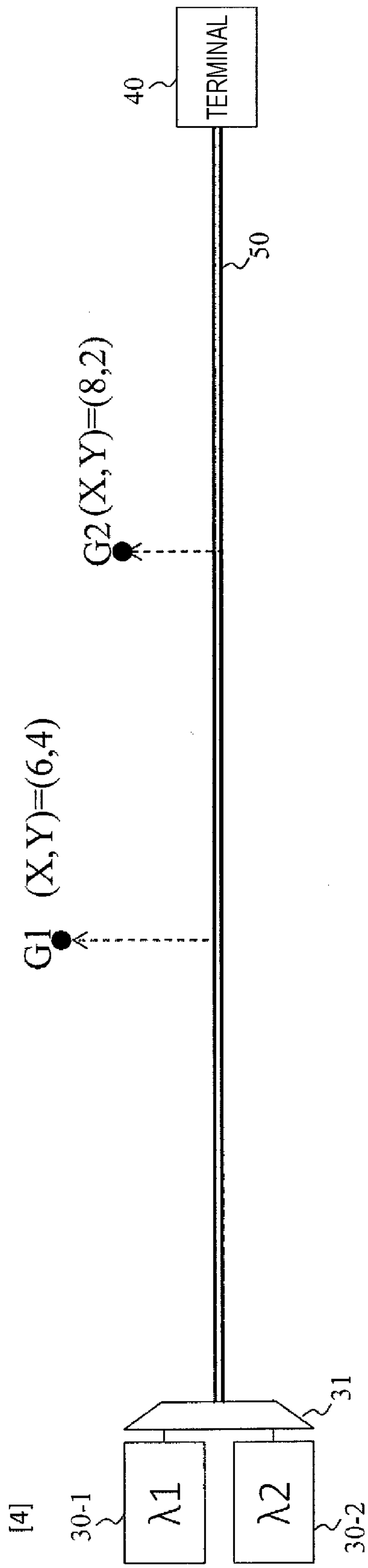


Fig. 5

[5]

OBTAINED VOLTAGE VALUES (λ1, λ2) (mV)

x \ y	1	2	3	...	9	10
1	(377, 331)	(359, 313)	(341, 295)		(233,187)	(215, 169)
2	(354, 312)	(336, 294)	(318, 276)		(210, 168)	(192, 151)
3	(331, 293)	(313, 275)	(295, 257)		(181, 149)	(169, 132)
...						
9	(193, 179)	(175, 161)	(157, 143)		(39, 35)	(31, 17)
10	(170, 160)	(152, 142)	(134, 124)		(16, 16)	(8, 0)

Fig. 6

[6]

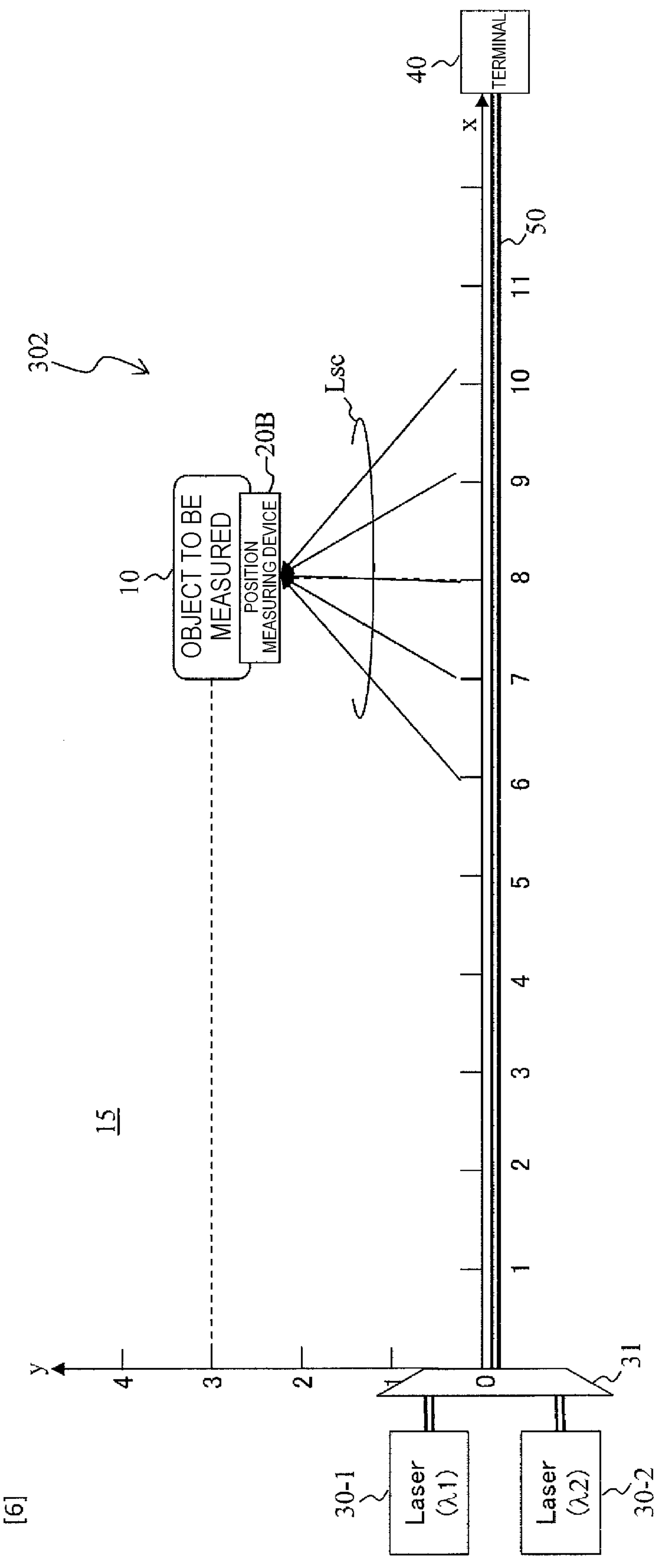
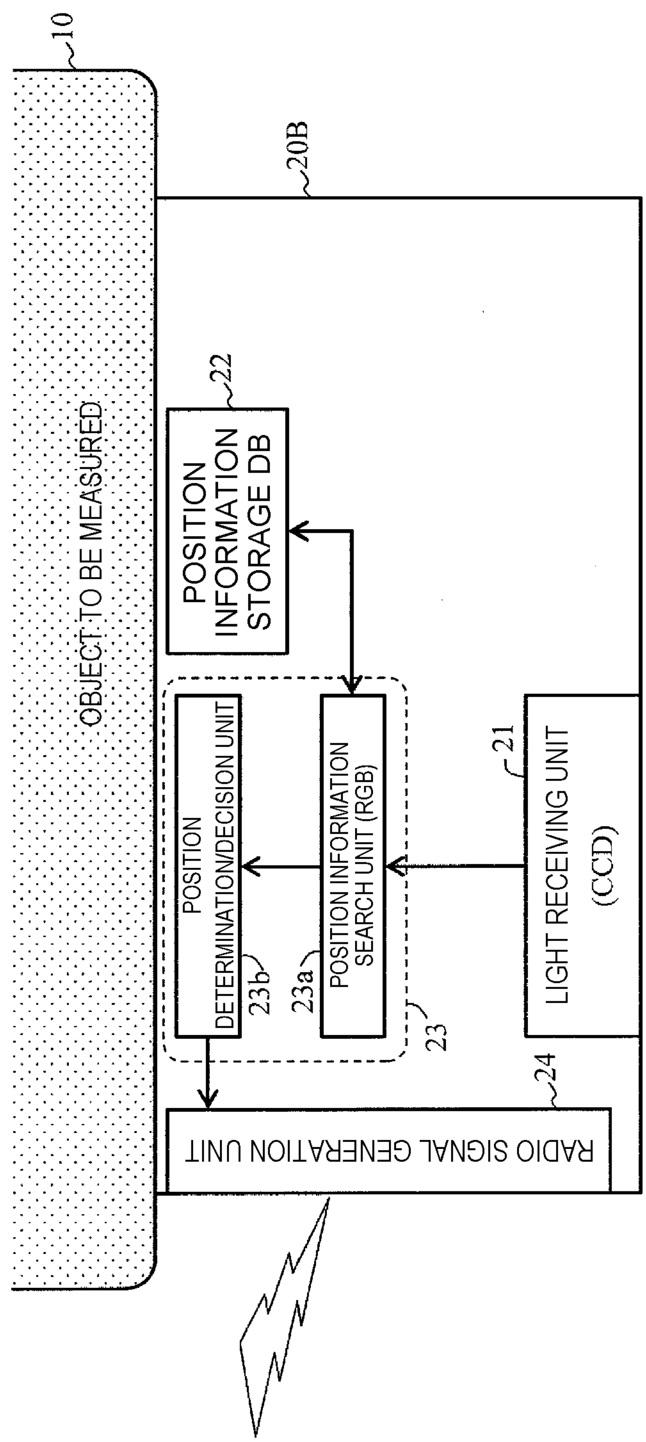

302
OBJECT TO BE MEASURED
10
POSITION MEASURING DEVICE
20B
Lsc
TERMINAL
40
50
x
y
15
0
1
2
3
4
5
6
7
8
9
10
11
31
Laser (λ1)
30-1
Laser (λ2)
30-2

Fig. 7



10
OBJECT TO BE MEASURED
20B
22
POSITION INFORMATION STORAGE DB
POSITION DETERMINATION/DECISION UNIT
23b
POSITION INFORMATION SEARCH UNIT (RGB)
23a
23
21
LIGHT RECEIVING UNIT (CCD)
24
RADIO SIGNAL GENERATION UNIT

[7]

Fig. 8

[8]

COLOR INFORMATION (R, G, B)

x \ y	1	2	3	...	9	10
1	(250,0,240)	(245,0,225)	(240,0,210)		(210,0,105)	(205,0,90)
2	(242,0,232)	(237,0,217)	(232,0,202)		(202,0,97)	(197,0,82)
3	(234,0,224)	(229,0,209)	(224,0,194)		(194,0,89)	(189,0,74)
...						
9	(186,0,176)	(181,0,161)	(176,0,146)		(146,0,41)	(141,0,26)
10	(178,0,168)	(173,0,153)	(168,0,131)		(138,0,33)	(133,0,18)

[9]

Fig. 9

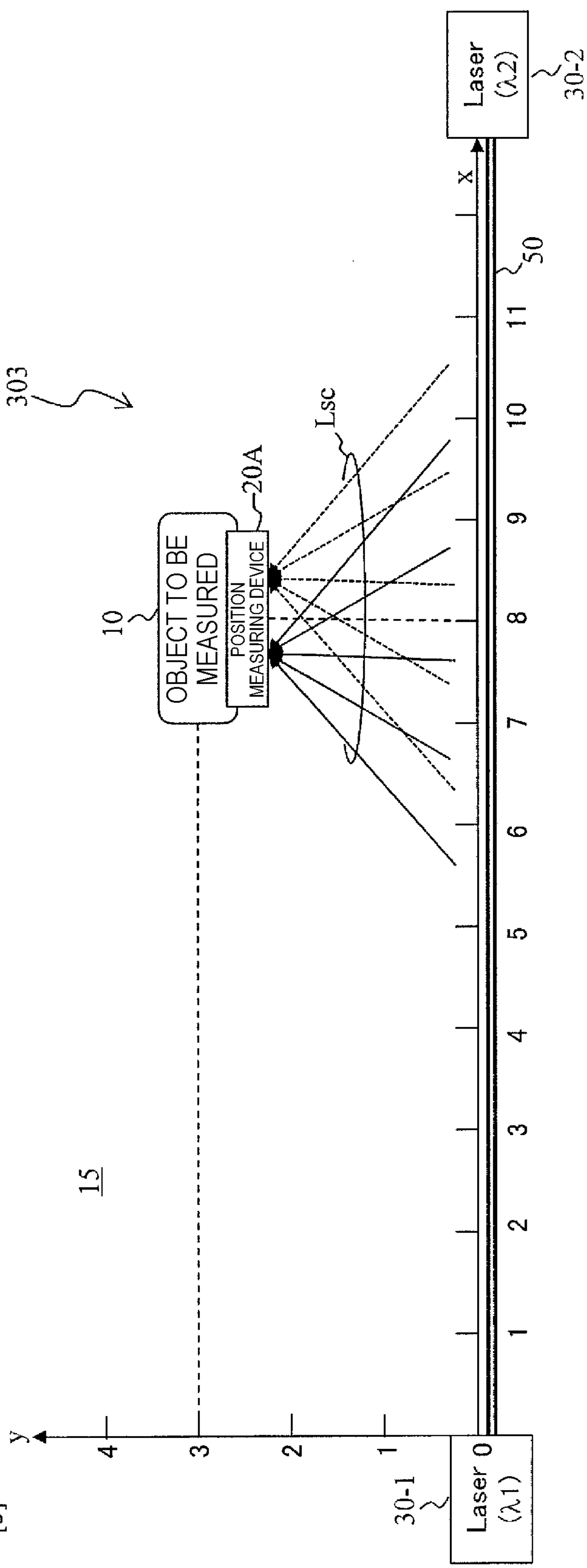

303
15
10
OBJECT TO BE MEASURED
POSITION MEASURING DEVICE
20A
Lsc
50
Laser (λ1)
30-1
Laser (λ2)
30-2
x
y
0
1
2
3
4
5
6
7
8
9
10
11

Fig. 10

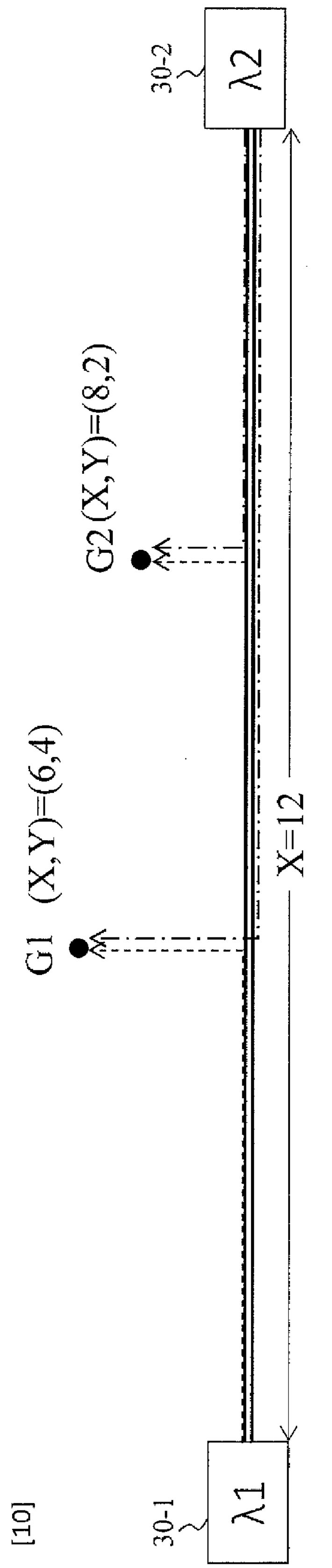


Fig. 11

[11]

OBTAINED VOLTAGE VALUES ($\lambda 1$, $\lambda 2$) (mV)

x \ y	1	2	3	…	9	10
1	(377, 169)	(359, 187)	(341, 205)		(233,313)	(215, 331)
2	(354, 151)	(336, 168)	(318, 186)		(210, 294)	(192, 312)
3	(331, 132)	(313, 149)	(295, 167)		(181, 275)	(169, 293)
…						
9	(193, 17)	(175, 35)	(157, 53)		(39, 161)	(31, 179)
10	(170, 0)	(152, 16)	(134, 34)		(16, 142)	(8, 160)

Fig. 12

[12]

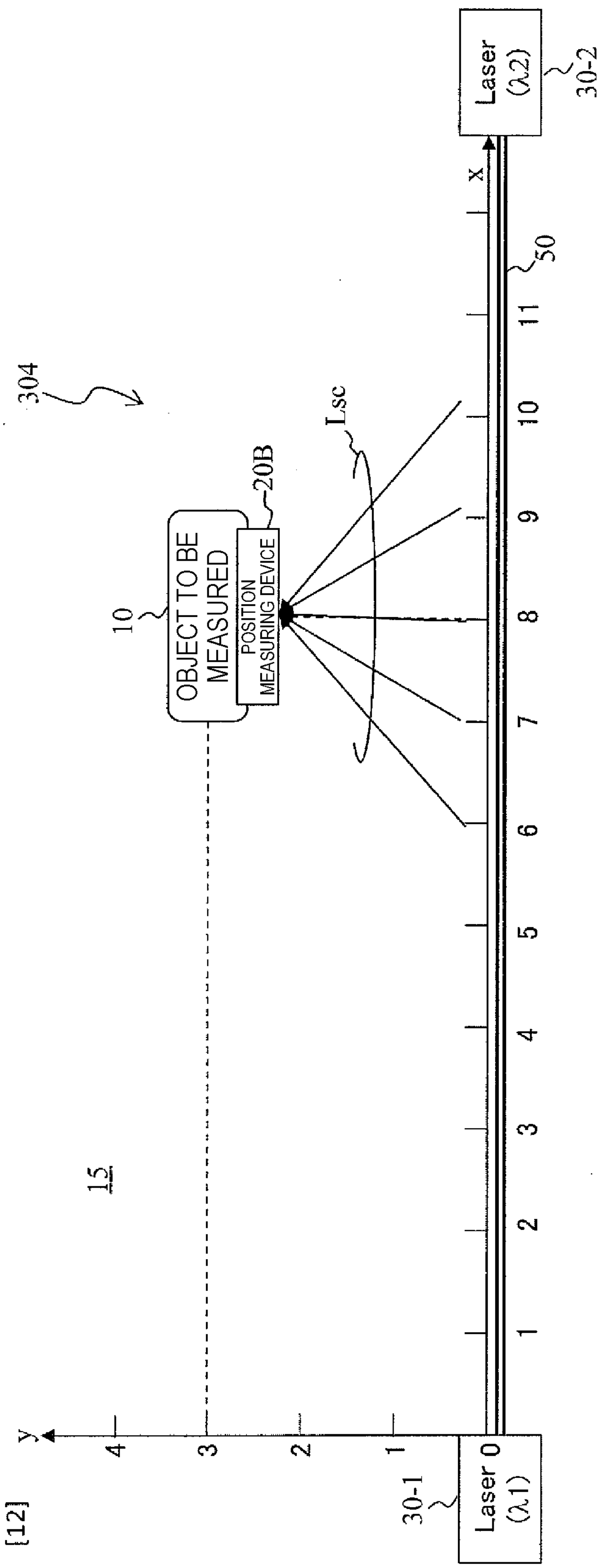

304
15
OBJECT TO BE MEASURED
10
POSITION MEASURING DEVICE
20B
Lsc
Laser 0 (λ1)
30-1
Laser (λ2)
30-2
50
x
y
0
1
2
3
4
5
6
7
8
9
10
11

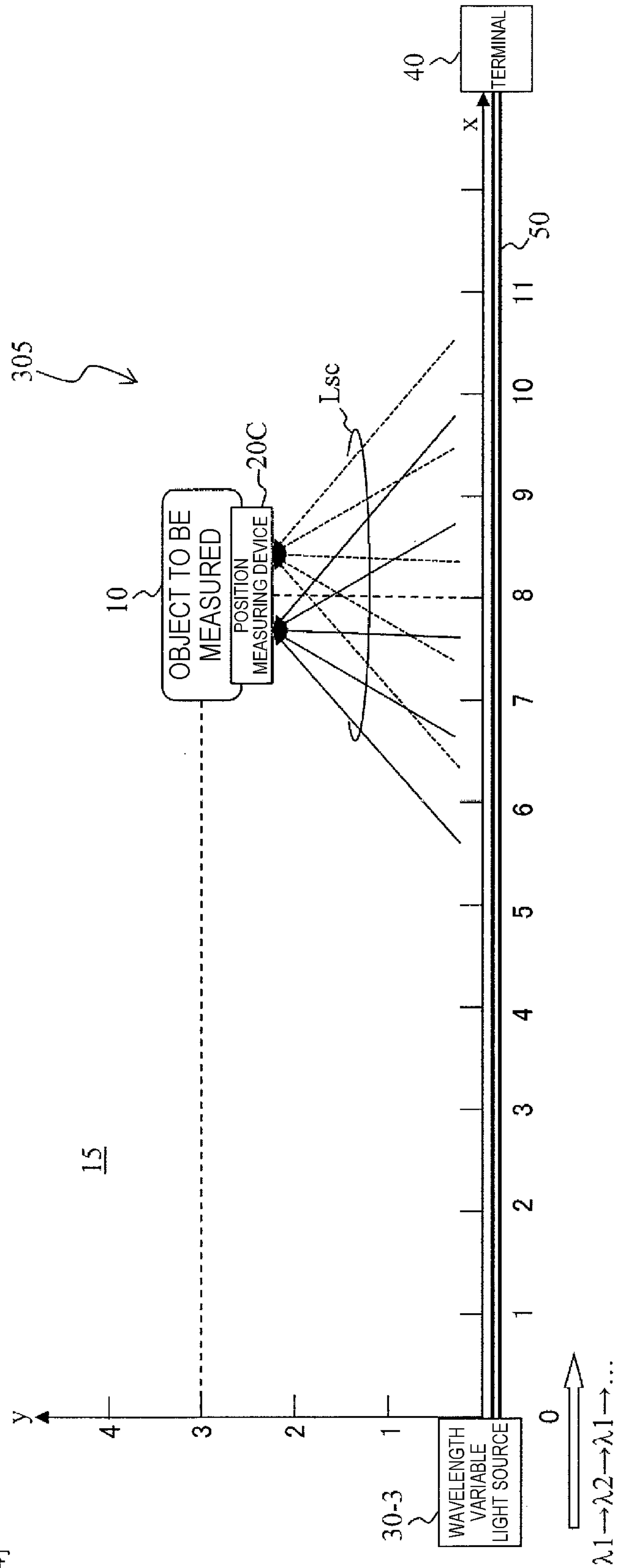
Fig. 13

[13]

COLOR INFORMATION (R, G, B)

x \ y	1	2	3	…	9	10
1	(250,0,18)	(245,0,33)	(240,0,48)		(210,0,138)	(205,0,153)
2	(242,0,26)	(237,0,41)	(232,0,56)		(202,0,146)	(197,0,161)
3	(234,0,34)	(229,0,49)	(224,0,64)		(194,0,154)	(189,0,169)
…						
9	(186,0,82)	(181,0,97)	(176,0,112)		(146,0,202)	(141,0,217)
10	(178,0,90)	(173,0,105)	(168,0,120)		(138,0,210)	(133,0,225)

Fig. 14


305
15
10
OBJECT TO BE MEASURED
20C
POSITION MEASURING DEVICE
Lsc
40
TERMINAL
50
x
y
30-3
WAVELENGTH VARIABLE LIGHT SOURCE
λ1→λ2→λ1→...
0
1
2
3
4
5
6
7
8
9
10
11

[14]

Fig. 15

[15]

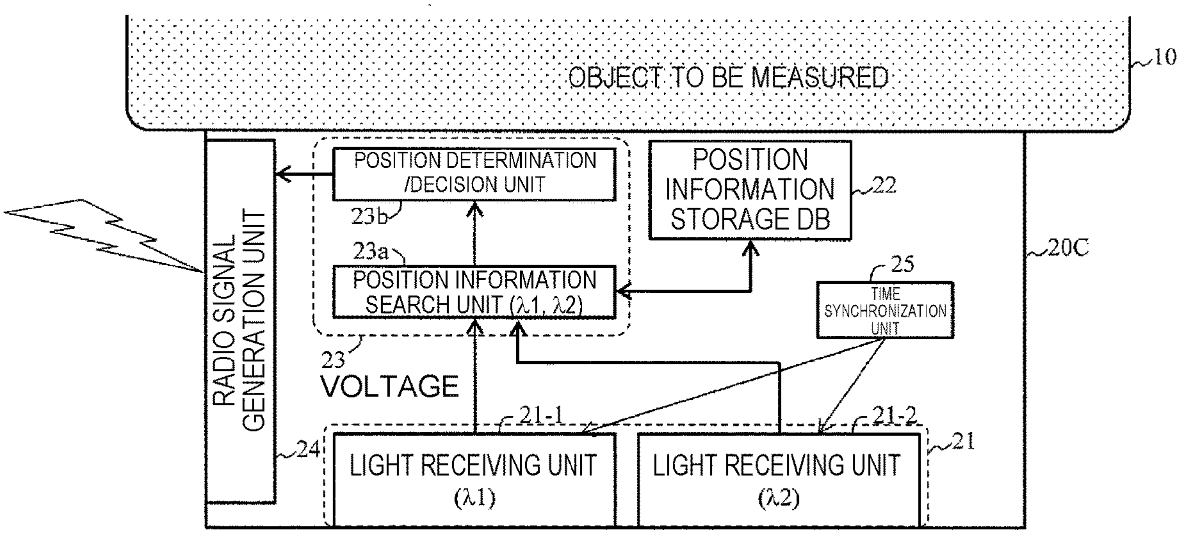
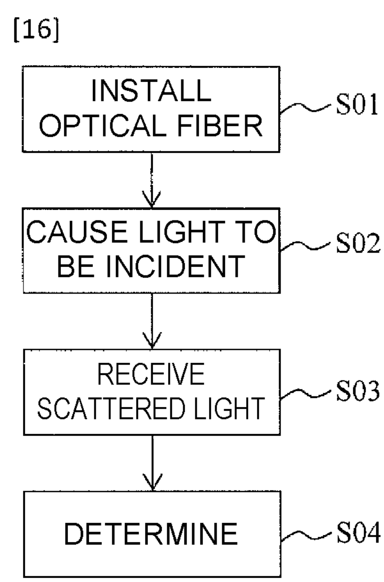

OBJECT TO BE MEASURED
10
POSITION DETERMINATION /DECISION UNIT
23b
23a
POSITION INFORMATION SEARCH UNIT (λ1, λ2)
23
VOLTAGE
POSITION INFORMATION STORAGE DB
22
20C
25
TIME SYNCHRONIZATION UNIT
RADIO SIGNAL GENERATION UNIT
24
21-1
21-2
21
LIGHT RECEIVING UNIT (λ1)
LIGHT RECEIVING UNIT (λ2)

Fig. 16


[16]
INSTALL OPTICAL FIBER
S01
CAUSE LIGHT TO BE INCIDENT
S02
RECEIVE SCATTERED LIGHT
S03
DETERMINE
S04

POSITION MEASURING SYSTEM, POSITION MEASURING DEVICE, AND POSITION MEASURING METHOD

TECHNICAL FIELD

[0001] The present disclosure relates to a position measuring system, a position measuring device, and a method for measuring a position that measure the position of an object.

BACKGROUND ART

[0002] An example of a typical method used for measuring the position of an object includes a distance measurement method that uses satellites or light. As the most typical technique for satellite distance measurement, there is the global positioning system (hereinafter referred to as "GPS"). The GPS is a system where signals from a plurality of GPS satellites in the sky are received by a GPS receiver, and a simultaneous equation based on three-point positioning is solved from three or more pieces of information from the satellites, such as "time" or "position", to allow a receiver to know the current position of the receiver. It is said that the GPS has a measurement accuracy of approximately several meters due to atmospheric delay, the effect of multipathing caused by the environment, and the effect of the number of satellites in arrangement (the number of captured satellites).

[0003] In contrast, an example of a typical technique for distance measurement that uses light includes LiDAR (light detection and ranging). In LiDAR, the distance from an object to be measured is measured based on the time of flight (hereinafter referred to as "ToF") of light that propagates through the space by making use of a light receiver and a light source having high coherence, such as a laser light source. It is said that LiDAR has a measurement accuracy of approximately several centimeters due to the effect of modulated pulse repetition period, pulse width, and shot noise from background light other than light from the light source.

CITATION LIST

Patent Literature

[0004] Patent Literature 1: Japanese Patent No. 6187500

[0005] Patent Literature 2: Japanese Translation of PCT International Application Publication No. 2016-526148

SUMMARY OF THE INVENTION

Technical Problem

[0006] The above-mentioned two distance measurement techniques have a problem in that there is a limitation on the use of each technique depending on the measurement environment.

[0007] For example, when an indoor environment exposed to electromagnetic noise, such as a factory, is considered, distance measurement by a GPS cannot be used due to reduction in measurement accuracy and electromagnetic interference caused with indoor use. In comparison, in the case of LiDAR, light wave interference from a device that makes use of other light is considered. However, light has a higher rectilinearity compared with radio waves and hence, LiDAR is less affected by electromagnetic noise even in an environment exposed to the electromagnetic noise, therefore distance measurement can be performed.

[0008] However, when position measurement (distance measurement) is performed by LiDAR in an environment in a factory shown in FIG. **1**, measurement accuracy is reduced and hence, it becomes difficult to obtain an accurate position of an object to be measured. For example, in the case where it is necessary to perform position measurement (distance measurement) to monitor and control an object to be measured (a robot, for example) shown in FIG. **1**, a method that makes use of a two dimensional LiDAR can be considered. In the environment, such as in a factory, it is anticipated that various devices and workers are present in the movement range of the object to be measured. When a blocking object that blocks light is present in a space and with respect to the object to be measured (on an optical axis), it becomes difficult for LiDAR to accurately perform distance measurement.

[0009] To cope with the above-mentioned reduction in measurement accuracy of LiDAR, the following measures can be considered:

[0010] (1) the position where LiDAR is installed is designed by taking into account the driving range of the object to be measured;

[0011] (2) a plurality of LiDARs are used and results from the plurality of LiDARs are processed; and

[0012] (3) as described in Patent Literature 1, safety fences are provided on both sides of a motion trajectory of the object to be measured, and landmarks for self-position estimation are attached to the safety fences.

[0013] However, to take such measures, it is necessary to take into account the motion range of the object to be measured and hence, a limitation is imposed on the design of a factory. Further, the number of LiDARs installed increases, and it is necessary to install planar safety fences and landmarks for self-position estimation and hence, cost increases.

[0014] When an attempt is made to perform position measurement in water, the following problems occur in the same manner:

[0015] (1) radio waves significantly attenuate in water and hence, the GPS cannot be used; and

[0016] (2) in the case of LiDAR, as described in Patent Literature 2, for example, there is a system that inspects an undersea structure or an underwater structure by using autonomous underwater equipment provided with a three dimensional LiDAR. However, measurement of an object to be measured is limited only on the optical axis of LiDAR and hence, LiDAR is required to have a steering function of changing the direction of the optical axis of LiDAR toward the position of the undersea structure or the underwater structure whereby cost increases. Further, when a blocking object that blocks light is present in a space (water) and with respect to the object to be measured, it is difficult to accurately perform position measurement.

[0017] That is, in measuring the position of an object, there are the following problems: it is difficult for the GPS to measure the position of the object in an environment exposed to electromagnetic noise, such as in a factory, or in water where radio waves are significantly attenuated. In the case of LiDAR, the cost to install LiDAR increases when the relationship between the position of the object and the optical axis is taken into consideration.

[0018] In view of the above, to solve the above-mentioned problems, it is an object of the present invention to provide a position measuring system, a position measuring device, and a method for measuring a position that can accurately measure the position of an object to be measured without being limited by an environment or an optical axis.

Means for Solving the Problem

[0019] To achieve the above-mentioned object, in a position measuring system according to the present invention, a position measuring device installed to an object to be measured receives scattered light emitted from a side surface of an optical fiber installed along a trajectory of the object to be measured, and a position of the object to be measured is estimated based on intensity or color information of the scattered light received.

[0020] Specifically, a position measuring system according to the present invention includes:

[0021] a position measuring device mounted on an object to be measured;

[0022] an optical fiber installed in a movement area of the object to be measured; and

[0023] a light source configured to cause light having at least two wavelengths to be incident on the optical fiber, the position measuring system being characterized in that

[0024] the position measuring device includes

[0025] a light receiving unit configured to receive scattered light emitted from a side surface of the optical fiber,

[0026] a database configured to store a correspondence between information on the scattered light and a position of the object to be measured, and

[0027] a determination unit configured to determine, based on the correspondence stored in the database, a position of the object to be measured from information on the scattered light received by the light receiving unit.

[0028] Further, a position measuring device according to the present invention is a position measuring device mounted on an object to be measured, the position measuring device being characterized by including:

[0029] a light receiving unit configured to receive scattered light emitted from a side surface of an optical fiber installed in a movement area of the object to be measured, the optical fiber being subject to incidence of light having at least two wavelengths;

[0030] a database configured to store a correspondence between information on the scattered light and a position of the object to be measured; and

[0031] a determination unit configured to determine, based on the correspondence stored in the database, a position of the object to be measured from information on the scattered light received by the light receiving unit.

[0032] Still further, a method for measuring a position according to the present invention is characterized by including:

[0033] installing an optical fiber in a movement area of an object to be measured;

[0034] causing light having at least two wavelengths to be incident on the optical fiber;

[0035] receiving scattered light emitted from a side surface of the optical fiber; and

[0036] determining, based on a correspondence between information on the scattered light and a position of the object to be measured, a position of the object to be measured from information on the scattered light received.

[0037] The position measuring system of the present invention measures light intensity of scattered light emitted from the side surface of the optical fiber, thus allowing the measurement of the position of a portion to be measured even in a place where it is difficult to perform GPS measurement. The position measuring system of the present invention measures scattered light emitted from the side surface of the optical fiber and hence, it is possible to perform distance measurement in plane irrespective of the presence or absence of a blocking object between the light source and an object to be measured. Further, the position measuring system of the present invention uses a plurality of wavelengths and makes use of a difference in attenuation amount between the respective wavelengths and hence, it is possible to measure the position of an object to be measured that moves two-dimensionally.

[0038] Accordingly, the present invention can provide a position measuring system, a position measuring device, and a method for measuring a position that can accurately measure the position of an object to be measured without being limited by an environment or an optical axis.

[0039] The position measuring system of the present invention may be configured such that the light source is connected to one end of the optical fiber, and the position measuring system further includes a terminator connected to the other end of the optical fiber. In this case, it is preferable that the light source be formed of one wavelength variable light source that performs wavelength switching in a predetermined cycle, and the position measuring device further have a function of detecting the wavelength switching of the light source.

[0040] Further, the position measuring system of the present invention may be configured such that one of the light sources is connected to one end of the optical fiber, and the other light source is connected to the other end of the optical fiber, the other light source outputting light having wavelength different from wavelength of light outputted from the one of the light sources.

[0041] In the position measuring system of the present invention, the information on the scattered light may be light intensity at each wavelength. Further, in the position measuring system of the present invention, the information on the scattered light may be color information.

[0042] The above-mentioned respective inventions may be combined as practically as possible.

Effects of the Invention

[0043] The present invention can provide a position measuring system, a position measuring device, and a method for measuring a position that can accurately measure the position of an object to be measured without being limited by an environment or an optical axis.

BRIEF DESCRIPTION OF DRAWINGS

[0044] FIG. **1** is a view for describing a task of the present invention.

[0045] FIG. **2** is a view for describing a position measuring system according to the present invention.

[0046] FIG. **3** is a view for describing a position measuring device according to the present invention.

[0047] FIG. **4** is a view for describing the measurement principle of the position measuring system according to the present invention.

[0048] FIG. **5** is a view for describing a database in the position measuring device according to the present invention.

[0049] FIG. **6** is a view for describing a position measuring system according to the present invention.

[0050] FIG. **7** is a view for describing a position measuring device according to the present invention.

[0051] FIG. **8** is a view for describing a database in the position measuring device according to the present invention.

[0052] FIG. **9** is a view for describing a position measuring system according to the present invention.

[0053] FIG. **10** is a view for describing the measurement principle of the position measuring system according to the present invention.

[0054] FIG. **11** is a view for describing a database in a position measuring device according to the present invention.

[0055] FIG. **12** is a view for describing the measurement principle of a position measuring system according to the present invention.

[0056] FIG. **13** is a view for describing a database in a position measuring device according to the present invention.

[0057] FIG. **14** is a view for describing a position measuring system according to the present invention.

[0058] FIG. **15** is a view for describing a position measuring device according to the present invention.

[0059] FIG. **16** is a view for describing a method for measuring a position according to the present invention.

DESCRIPTION OF EMBODIMENTS

[0060] Embodiments of the present invention will be described with reference to attached drawings. The embodiments described hereinafter merely form examples of the present invention, and the present invention is not limited to the following embodiments. In this specification and drawings, constitutional elements given the same reference symbols are identical to each other.

Embodiment 1

[0061] FIG. **2** is a view for describing a position measuring system **301** of this embodiment. The position measuring system **301** includes

[0062] a position measuring device **20**A mounted on an object to be measured **10**,

[0063] an optical fiber **50** installed in a movement area **15** of the object to be measured **10**, and

[0064] a light source **30** configured to cause light having at least two wavelengths to be incident on the optical fiber **50**.

[0065] In this embodiment, the light source **30** is connected to one end of the optical fiber **50**. Specifically, the light source **30** includes a laser **30-1**, a laser **30-2**, and an optical multiplexer **31**. The laser **30-1** outputs light having wavelength $\lambda 1$. The laser **30-2** outputs light having wavelength $\lambda 2$. The optical multiplexer **31** multiplexes light outputted from the laser **30-1** and light outputted from the laser **30-2**, and causes the light to be incident on one end of the optical fiber **50**. In this embodiment, light having two wavelengths is caused to be incident on the optical fiber **50**. However, light having three or more wavelengths may be caused to be incident on the optical fiber **50**.

[0066] The position measuring system **301** further includes a terminator **40** connected to the other end of the optical fiber **50**.

[0067] FIG. **3** is a view for describing the configuration of the position measuring device **20**A.

[0068] The position measuring device **20**A is characterized by including

[0069] a light receiving unit **21** configured to receive scattered light Lsc emitted from the side surface of the optical fiber **50**,

[0070] a database **22** configured to store a correspondence between information on the scattered light and the position of the object to be measured, and

[0071] a determination unit **23** configured to determine, based on the correspondence stored in the database **22**, the position of the object to be measured **10** from information on the scattered light received by the light receiving unit **21**.

[0072] It is sufficient that the light receiving unit **21** can convert the light intensity of received light to a voltage value. For example, the light receiving unit **21** may be formed of a PD (photo diode).

[0073] In this embodiment, light caused to be incident on the optical fiber **50** has two wavelengths, that is, $\lambda 1$ and $\lambda 2$. Therefore, the light receiving unit **21** is formed of the light receiving unit **21-1**, which can receive light having wavelength $\lambda 1$ and the light receiving unit **21-2**, which can receive light having wavelength $\lambda 2$. However, in the case where a light receivable range includes the wavelength $\lambda 1$ and the wavelength $\lambda 2$, one light receiving unit may be used.

[0074] This embodiment is characterized in that the information on the scattered light Lsc is light intensity of each wavelength.

[0075] The position measuring system **301** estimates the position of the object to be measured **10** from a voltage value at the time of the scattered light Lsc being received.

[0076] In the position measuring system **301**, light (continuous light or pulse light) having two wavelengths from two light sources (**30-1**, **30-2**) is multiplexed by the optical multiplexer **31**, and is caused to be incident on one end of the optical fiber **50**. The terminator **40** is provided at the other end of the optical fiber **50**. The optical fiber **50** is an optical fiber that emits light (scattered light) from the side surface thereof in the manner of an LDF (light defusing fiber), for example. Therefore, light caused to be incident on the optical fiber **50** leaks to the outside of the optical fiber **50** as scattered light having light intensity corresponding to a distance from the one end. The position measuring device **20**A estimates the position of the object to be measured **10** from light intensity (voltage value) at the time of the scattered light being received.

[0077] FIG. **4** is a view for describing the measurement principle of the position measuring system **301**. The position measuring system **301** makes use of the characteristic of the optical fiber where a propagation loss varies depending on wavelength.

[0078] Output power of the laser **30-1** is taken as "P1", and output power of the laser **30-2** is taken as "P2". A propagation loss of light having wavelength $\lambda 1$ per unit length in the optical fiber **50** is taken as "α", and a propagation loss of light having wavelength $\lambda 1$ per unit length in a space is taken as "γ". A propagation loss of light having wavelength $\lambda 2$ per unit length in the optical fiber **50** is taken as "β", and a propagation loss of light having wavelength $\lambda 2$ per unit length in the space is taken as "γ".

[0079] In this case, the light intensity of light having wavelength λ**1** and the light intensity of light having wavelength λ**2** at a position G**1** with coordinates (X, Y)=(6, 4) can be calculated as follows.

(Light intensity of light having wavelength λ**1**, light intensity of light having wavelength λ2)=(P1−6α−4γ, P2−6β−4γ)

[0080] The light intensity of light having wavelength λ**1** and the light intensity of light having wavelength λ**2** at a position G**1** with coordinates (X, Y)=(8, 2) can be calculated as follows.

(Intensity of light having wavelength λ**1**, intensity of light having wavelength λ2)=(P1−8α−2γ, P2−8β−2γ)

[0081] For each position in the movement area **15** of the object to be measured **10**, the light intensity of light having wavelength λ**1** and the light intensity of light having wavelength λ**2** are calculated as described above, are converted to voltage values at the time of light being received by the light receiving unit **21**, and are kept in the position information storage database **22**. Alternatively, for each position in the movement area **15** of the object to be measured **10**, values obtained by actually measuring the light intensity (voltage value) of light having wavelength λ**1** and the light intensity (voltage value) of light having wavelength λ**2** may be kept in advance in the position information storage database **22**. FIG. **5** is a view for describing an example of a correspondence between coordinates and light intensities (voltage values), which is kept in the position information storage database **22**.

[0082] The position measuring device **20**A receives the scattered light Lsc from the optical fiber **50** with the light receiving unit **21** at an arbitrary point of time, and compares the light intensity (voltage value) of light having wavelength λ**1** and the light intensity (voltage value) of light having wavelength λ**2** with the correspondence kept in the position information storage database **22** to estimate the position of the object to be measured **10**.

[0083] Specifically, the light receiving unit **21** converts the light intensities of received light to voltage values. A position information search unit **23***a* collates the voltage values with values in the correspondence held in advance in the position information storage DB **22**. Then, a position determination/decision unit **23***b* estimates that the object to be measured **10** is present at a position where the voltage values match the values in the correspondence. In the case where the voltage values do not match values in the correspondence held in the position information storage DB **22**, the position determination/decision unit **23***b* estimates that the position of values in the correspondence closest to the voltage values is the position of the object to be measured **10** at that time. A radio signal generation unit **24** transmits information on the determined position to an external measurer.

[0084] The description has been made with reference to FIG. **3** for the case where the position measuring device **20**A includes the light receiving unit that receives light having wavelength λ**1** and the light receiving unit that receives light having wavelength λ**2**. The position measuring system **301** may have another configuration where the position measuring device **20**A includes one light receiving unit that can detect both wavelength λ**1** and wavelength λ**2**, light is outputted from the light source **30** in a state where the wavelength of the light is time divided, and the light intensity of light having wavelength λ**1** and the light intensity of light having wavelength λ**2** are detected for each time period.

[0085] The position measuring system **301** can detect, by a simple method, the position of the object to be measured **10** having the degree of freedom in movement in two dimensions.

Embodiment 2

[0086] FIG. **6** is a view for describing a position measuring system **302** of this embodiment. The position measuring system **302** differs from the position measuring system **301** shown in FIG. **2** with respect to a point that the position measuring system **302** includes a position measuring device **20**B in place of the position measuring device **20**A. Hereinafter, the description will be made only with respect to points which make the position measuring system **302** different from the position measuring system **301**.

[0087] FIG. **7** is a view for describing the configuration of the position measuring device **20**B.

[0088] The position measuring device **20**B is characterized by including

[0089] the light receiving unit **21** configured to receive the scattered light Lsc emitted from the side surface of the optical fiber **50**,

[0090] the database **22** configured to store a correspondence between information on the scattered light and the position of the object to be measured, and

[0091] the determination unit **23** configured to determine, based on the correspondence stored in the database **22**, the position of the object to be measured **10** from information on the scattered light received by the light receiving unit **21**.

[0092] This embodiment is characterized in that the information on the scattered light Lsc is color information (RGB).

[0093] It is sufficient that the light receiving unit **21** can convert received light to RGB values. For example, the light receiving unit **21** may be formed of a CCD (charge-coupled device) image sensor. The position measuring system **302** converts the scattered light Lsc received by the light receiving unit **21** to RGB values, and estimates the position of the object to be measured **10** from such values.

[0094] The measurement principle of the position measuring system **302** is equivalent to the measurement principle described with reference to FIG. **4**. As described with reference to FIG. **4**, based on a loss of each color per unit length in the optical fiber **50** and a propagation loss of each color per unit length in a space, it is possible to calculate RGB values at each position in the movement area **15** of the object to be measured **10**.

[0095] For each position in the movement area **15** of the object to be measured **10**, RGB values are calculated as described above, and are kept in the position information storage database **22**. Alternatively, for each position in the movement area **15** of the object to be measured **10**, values obtained by actually measuring RGB may be kept in advance in the position information storage database **22**. FIG. **8** is a view for describing an example of a correspondence between coordinates and RGB values, which is kept in the position information storage database **22**.

[0096] The position measuring device **20**B receives the scattered light Lsc from the optical fiber **50** with the light receiving unit **21** at an arbitrary point of time, and compares the RGB values of the scattered light Lsc with the correspondence kept in the position information storage database **22** to estimate the position of the object to be measured **10**.

[0097] Specifically, the light receiving unit **21** converts the light intensities of received light to RGB values. The position information search unit **23*a*** collates the RGB values with values in the correspondence held in advance in the position information storage DB **22**. Then, the position determination/decision unit **23*b*** estimates that the object to be measured **10** is present at a position where the RGB values match the values in the correspondence. In the case where the RGB values do not match values in the correspondence held in the position information storage DB **22**, the position determination/estimation unit **23*b*** estimates that the position of values in the correspondence closest to the RGB values is the position of the object to be measured **10** at that time. The radio signal generation unit **24** transmits information on the determined position to an external measurer.

[0098] The position measuring system **302** can detect, by a simple method, the position of the object to be measured **10** having the degree of freedom in movement in two dimensions.

Embodiment 3

[0099] FIG. **9** is a view for describing a position measuring system **303** of this embodiment. The position measuring system **303** differs from the position measuring system **301** shown in FIG. **2** with respect to a point that the laser **30-1** for wavelength λ**1** is connected to one end of the optical fiber **50** and the laser **30-2** for wavelength λ**2** is connected to the other end of the optical fiber **50**. The position measuring system **303** also estimates the position of the object to be measured **10** from voltage values at the time of the scattered light Lsc being received.

[0100] In the position measuring system **303**, light (continuous light or pulse light) from two light sources (**30-1**, **30-2**) having two wavelengths is respectively caused to be incident on different ends of the optical fiber **50**. The position of an object to be measured is estimated from the obtained voltage values of scattered light. Light caused to be incident on the optical fiber **50** leaks to the outside of the optical fiber **50** as scattered light having light intensity corresponding to a distance from one end. The position measuring device **20**A estimates the position of the object to be measured **10** from light intensity (voltage value) at the time of the scattered light being received.

[0101] FIG. **10** is a view for describing the measurement principle of the position measuring system **303**. The position measuring system **303** makes use of the fact that a propagation loss in the optical fiber **50** differs depending on wavelength.

[0102] Output power of the laser **30-1** is taken as "P1", and output power of the laser **30-2** is taken as "P2". A propagation loss of light having wavelength λ**1** in the optical fiber **50** is taken as "α", and a propagation loss of light having wavelength λ**1** in a space is taken as "γ". A propagation loss of light having wavelength λ**2** in the optical fiber **50** is taken as "β", and a propagation loss of light having wavelength λ**2** in the space is taken as "γ".

[0103] In this case, the light intensity of light having wavelength λ**1** and the light intensity of light having wavelength λ**2** at a position G**1** with coordinates (X, Y)=(6, 4) can be calculated as follows:

(Light intensity of light having wavelength γ**1**, light intensity of light having wavelength λ2)=(P1−6α−4γ, P2−6β−4γ)

[0104] The light intensity of light having wavelength λ**1** and the light intensity of light having wavelength λ**2** at a position G1 with coordinates (X, Y)=(8, 2) can be calculated as follows:

(Light intensity of light having wavelength λ**1**, light intensity of light having wavelength λ2)=(P1−8α−2γ, P2−4β−2γ)

[0105] For each position in the movement area **15** of the object to be measured **10**, the light intensity of light having wavelength λ**1** and the light intensity of light having wavelength λ**2** are calculated as described above, are converted to voltage values at the time of light being received by the light receiving unit **21**, and are kept in the position information storage database **22**. Alternatively, for each position in the movement area **15** of the object to be measured **10**, values obtained by actually measuring the light intensity (voltage value) of light having wavelength λ**1** and the light intensity (voltage value) of light having wavelength λ**2** may be kept in advance in the position information storage database **22**. FIG. **11** is a view for describing an example of a correspondence between coordinates and light intensities (voltage values), which is kept in the position information storage database **22**.

[0106] A method for estimating the position of the object to be measured **10** by the position measuring device **20**A is substantially equivalent to the method described with respect to the position measuring system **301** of the embodiment 1. Accordingly, the position measuring system **303** can also detect, by a simple method, the position of the object to be measured **10** having the degree of freedom in movement in two dimensions.

Embodiment 4

[0107] FIG. **12** is a view for describing a position measuring system **304** of this embodiment. The position measuring system **304** differs from the position measuring system **303** shown in FIG. **9** with respect to a point that the position measuring system **304** includes the position measuring device **20**B in place of the position measuring device **20**A. That is, in the position measuring system **304**, a CCD camera is used as the light receiving unit **21**, received scattered light Lsc is converted to RGB values, and the position of the object to be measured **10** is estimated from such values.

[0108] The measurement principle of the position measuring system **304** is equivalent to the measurement principle described with reference to FIG. **10**. As described with reference to FIG. **10**, based on a loss of each color per unit length in the optical fiber **50** and a propagation loss of each color per unit length in a space, it is possible to calculate RGB values at each position in the movement area **15** of the object to be measured **10**.

[0109] For each position in the movement area **15** of the object to be measured **10**, RGB values are calculated as described above, and are kept in the position information storage database **22**. Alternatively, for each position in the movement area **15** of the object to be measured **10**, values obtained by actually measuring RGB may be kept in advance in the position information storage database **22**. FIG. **13** is a view for describing an example of a correspondence between coordinates and RGB values, which is kept in the position information storage database **22**.

[0110] A method for estimating the position of the object to be measured **10** by the position measuring device **20**B is equivalent to the method described with respect to the position measuring system **302** of the embodiment 2. Accordingly, the position measuring system **304** can also detect, by a simple method, the position of the object to be measured **10** having the degree of freedom in movement in two dimensions.

Embodiment 5

[0111] FIG. **14** is a view for describing a position measuring system **305** of this embodiment. The position measuring system **305** differs from the position measuring system **301** shown in FIG. **2** with respect to a point that the position measuring system **305** includes one light source. Specifically, the light source of the position measuring system **305** is formed of one wavelength variable light source **30-3** that performs wavelength switching in a predetermined cycle. The cycle of performing wavelength switching is set to a cycle sufficiently short relative to the movement speed of the object to be measured **10**. For example, in the case where a movement speed v of the object to be measured **10** is 5 m/sec and it is desired to set position measurement accuracy Ac to 0.1 m or less, a switching cycle is set to a value that satisfies Ac/v=0.02 sec or less.

[0112] In this embodiment, light having two wavelengths is caused to be incident on the optical fiber **50**. However, light having three or more wavelengths may be caused to be incident on the optical fiber **50**.

[0113] FIG. **15** is a view for describing the configuration of a position measuring device **20**C of the position measuring system **305**.

[0114] The position measuring device **20**C differs from the position measuring device **20**A shown in FIG. **3** with respect to a point that the position measuring device **20**C further has a function of detecting wavelength switching of the wavelength variable light source **30-3**. The function of detecting wavelength switching is achieved by a time synchronization unit **25**. In synchronization with wavelength switching of the wavelength variable light source **30-3**, the time synchronization unit **25** switches between a light receiver **21-1** and a light receiver **21-2** to switch wavelength to be measured. It is desirable that the timing of wavelength switching performed by the time synchronization unit **25** be synchronized, by wireless communication, with the timing of wavelength switching performed by the wavelength variable light source **30-3**.

[0115] Based on information from the time synchronization unit **25**, the light receiving unit **21-1** acts to receive light having wavelength **λ1** outputted from the wavelength variable light source **30-3**, and the light receiving unit **21-2** acts to receive light having wavelength **λ2** outputted from the wavelength variable light source **30-3**. Each of the light receiving units (**21-1**, **21-2**) converts the light intensity of received light to a voltage value. As described in the embodiment 1, the determination unit **23** collates the voltage values with the correspondence shown in FIG. **5** and held in advance in the position information storage DB **22**, and determines that the object to be measured **10** is present at a position with coordinates which match the voltage values. Further, in the case where voltage values held in the position information storage DB **22** do not match obtained voltage values as a result of collation, the position determination/estimation unit **23***b* estimates the position of the object to be measured **10** as described in the embodiment 1. The radio signal generation unit **24** transmits data of information on the position of the object to be measured **10** to an external measurer.

ANOTHER EXAMPLE 1

[0116] A configuration may be adopted where a light receiving unit is not provided for each wavelength, so that a single light receiving unit receives light at all wavelengths and wavelength of light is specified for each time slot based on information from the time synchronization unit **25**.

ANOTHER EXAMPLE 2

[0117] As described in the embodiment 2, the position measuring device **20**C may include the light receiving unit **21** formed of a CCD image sensor. A configuration may be adopted where the light receiving unit **21** obtains RGB values rather than voltage values, collates the RGB values with the correspondence shown in FIG. **8** and held in advance in the position information storage DB **22**, and determines that the object to be measured **10** is present.

ANOTHER EXAMPLE 3

[0118] The function of detecting wavelength switching may not be achieved by the time synchronization unit **25**, but may be achieved by the following configuration: the wavelength variable light source **30-3** delivers light in a state where the light is modulated at a frequency which differs for each wavelength, and the position measuring device **20**C is caused to have a function of detecting the frequency. Therefore, it is possible to determine what wavelength the received light has. This configuration can determine wavelength without requiring time synchronization.

Embodiment 6

[0119] FIG. **16** is a flowchart for describing an operation of performing position measurement by the position measuring system (**301** to **304**).

[0120] A method for performing the operation includes:

[0121] installing the optical fiber **50** in the movement area **15** of the object to be measured **10** (step S**01**);

[0122] causing light having at least two wavelengths to be incident on the optical fiber **50** (step S**02**);

[0123] receiving the scattered light Lsc emitted from the side surface of the optical fiber **50** (step S**03**); and

[0124] determining, based on a correspondence between information on the scattered light Lsc and the position of the object to be measured **10**, the position of the object to be measured **10** from the information on the scattered light Lsc received (step S**04**).

Another Embodiment

[0125] The position measuring device (**20**, **20***a*) of the present invention can also be achieved by a computer and a program. The program can be recorded in a recording medium or can be provided through a network.

REFERENCE SIGNS LIST

[0126] **10** Object to be measured

[0127] **15** Movement area

[0128] **20**A, **20**B, **20**C Position measuring device

[0129] **21**, **21-1**, **21-2** Light receiving unit

[0130] **22** Database
[0131] **23** Determination unit
[0132] **23***a* Position information search unit
[0133] **23***b* Position determination/decision unit
[0134] **24** Radio signal generation unit
[0135] **25** Time synchronization unit
[0136] **30**, **30-1**, **30-2** Light source
[0137] **31** Optical multiplexer
[0138] **40** Terminator
[0139] **50** Optical fiber
[0140] **301** to **305** Position measuring system

1. A position measuring system comprising:
a position measuring device mounted on an object to be measured;
an optical fiber installed in a movement area of the object to be measured; and
a light source configured to cause light having at least two wavelengths to be incident on the optical fiber, wherein
the position measuring device includes
a light receiving unit configured to receive scattered light emitted from a side surface of the optical fiber,
a database configured to store a correspondence between information on the scattered light and a position of the object to be measured, and
a determination unit configured to determine, based on the correspondence stored in the database, a position of the object to be measured from information on the scattered light received by the light receiving unit.

2. The position measuring system according to claim **1**, wherein
the light source is connected to one end of the optical fiber, and
the position measuring system further comprises a terminator connected to the other end of the optical fiber.

3. The position measuring system according to claim **2**, wherein
the light source is formed of one wavelength variable light source that performs wavelength switching in a predetermined cycle, and
the position measuring device further has a function of detecting the wavelength switching of the light source.

4. The position measuring system according to claim **1**, wherein
one of the light sources is connected to one end of the optical fiber, and another of the light sources is connected to the other end of the optical fiber, the another of the light sources outputting light having wavelength different from wavelength of light outputted from the one of the light sources.

5. The position measuring system according to claim **1**, wherein the information on the scattered light is light intensity at each wavelength.

6. The position measuring system according to claim **1**, wherein the information on the scattered light is color information.

7. A position measuring device mounted on an object to be measured, the position measuring device comprising:
a light receiving unit configured to receive scattered light emitted from a side surface of an optical fiber installed in a movement area of the object to be measured, the optical fiber being subject to incidence of light having at least two wavelengths;
a database configured to store a correspondence between information on the scattered light and a position of the object to be measured; and
a determination unit configured to determine, based on the correspondence stored in the database, a position of the object to be measured from information on the scattered light received by the light receiving unit.

8. A method for measuring a position, the method comprising:
installing an optical fiber in a movement area of an object to be measured;
causing light having at least two wavelengths to be incident on the optical fiber;
receiving scattered light emitted from a side surface of the optical fiber; and
determining, based on a correspondence between information on the scattered light and a position of the object to be measured, a position of the object to be measured from information on the scattered light received.

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