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(54) Title: DEVICE FOR OPTICALLY SCANNING AND MEASURING AN ENVIRONMENT

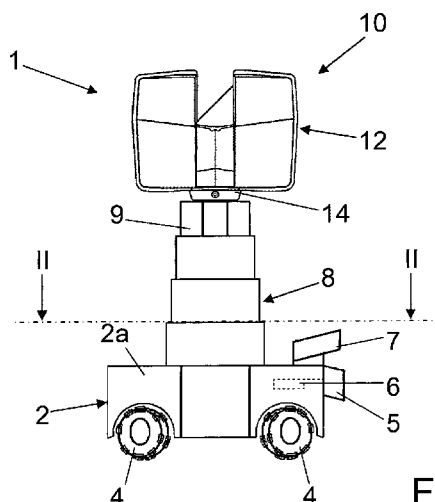


Fig. 1

(57) Abstract: Device for optically scanning and measuring an environment, said device being configured to be mobile and being provided with a laser scanner (10) or the like, which creates 3D-scans, and an autonomously moving robot (2), on which a laser scanner (10) or the like is mounted.

Device for optically scanning and measuring an environment

5 The invention relates to a device having the features of the generic term of Claim 1.

A device of this kind is known from DE 10 2007 037 162 A1. The laser scanner is mounted on an automobile which is driven by a driver. Said device is used in outdoor areas, in order to scan and measure over long distances wayside houses or tunnel walls.

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A further device of this kind is described in DE 10 2010 033 561 B3. The laser scanner is mounted on a manually movable trolley. Said device is suitable for the indoor areas, for example, in order to scan and measure single rooms of a building.

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The invention is based on the object of improving a device of the type mentioned in the introduction. This object is achieved according to the invention by means of a device having the features of Claim 1. The dependent claims relate to advantageous configurations.

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According to the invention, the laser scanner is mounted on an autonomously moving robot. Such robots are known per se for other applications, for example from US 2011/0288684 A1. The present application of the robot, however, creates new opportunities. The time-consuming creation of numerous 3D scans can take place with a considerably lower employment of human labor. In the event of commercial rooms, for example in industrial buildings and office buildings, the 3D-scans can be created outside the usual working time, for example by night, without disturbing the work process. Thanks to the autonomy of the robot, the entity of 3D-scans can ultimately be created without additional expenditure in labor time, with a higher precision and thoroughness. Instead of the laser scanner, it is also possible to use another measuring device, for example a measuring device working with photogrammetry or videogrammetry.

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In order to initialize the robot and thereby to provide information on the environment to be scanned, in particular as a 2D-map of the environment, preferably an initializing phase is provided prior to the scanning phase itself. During said initializing phase the robot creates, preferably by means of a horizontal scanner, the 2D-map by means of which the robot moves in the subsequent scanning phase. The 2D-map can be created also by other means.

In order to create the 2D-map, the robot may learn from a teacher during said initializing phase, e.g. the robot follows a teacher through the rooms to be measured, wherein the laser scanner remains, for example, out of operation. The tracking device used is preferably one from the games sector or a tracker for industrial uses. As an alternative to tracking, the teacher uses a remote control in order to maneuver the robot through the rooms to be measured during the initialization phase.

Instead of learning from a teacher, the robot may learn autodidactically during said initialization phase, e.g. the robot creates its 2D-map by means of a strategic (targeted) or stochastic procedure, such procedure usually being more time-intensive.

Alternatively, it is possible to provide the robot with an externally created 2D-map, on which, for example, the positions for the 3D-scans are marked. Then, the 2D-map is loaded by the robot during the initialization phase.

A facilitated and faster registration of the 3D-scans results from a networking of laser scanner and robot, by creating a relationship between the current positions on the 2D-map and the corresponding 3D-scans created on these positions. Different degrees of networking are possible. The robot may control the operation of the laser scanner, i.e. the robot defines when and where the laser scanner scans. For example, the robot may send signals to start scanning or to stop scanning to the laser scanner via a suitable interface.

The robot shows a complete mobility in two directions in space. In order to reach this mobility also in the third direction in space, at least to a limited extent, the laser is preferably height-adjustable, relative to the robot, for example by means of a height-adjustable support. The support can be, for example, a retractable pole, a hinged arm, a scissor-type stand or another lifting device with suitable guide-ways. Scanning by means of such a support is not limited to frog's eye perspective, what is advantageous, particularly in furnished rooms.

The laser scanner preferably has the structure known per se, as is described for example in DE 10 2010 033 561 B3, mentioned in the introduction. A mirror rotates around a horizontal axis. A measuring head rotates around a vertical axis. The "horizontal" arrangement of the axis of rotation of the mirror and the "vertical" arrangement of the axis of rotation of the measuring head refer to an ideal alignment of the laser scanner. In case of an alignment of the laser scanner which is inclined with respect to the ideal alignment, the notions "horizontal" and "vertical" are to be interpreted in a wider sense.

In spherical mode, both axis of rotation are used, i.e. the mirror and the measuring head rotate. The 3D-scan, i.e. a three-dimensional cloud of measuring points, may cover the whole space around the laser scanner except the bottom (being shadowed by the part of the measuring head below the mirror and by the robot). In particular, the upper hemisphere around the laser scanner may be scanned.

In helical mode, only the axis of rotation of the mirror is used, i.e. the mirror rotates and the measuring head rests, preferably locked. The 3D-scan may cover a helical part of the space (like a screw) except the bottom.

During the scanning phase, the interaction of robot and laser scanner is a combination of the navigation of the robot on the 2D-map and the one of the modes of the laser scanner. For example, the robot moves from one marked position on the 2D-map to another marked position, and, after reaching the new position, the robot stands still during the 3D-scan while the laser scanner scans using its spherical

mode (i.e. mirror and measuring head rotate). Or the robot moves, while the laser scanner scans using its helical mode (i.e. the measuring head stands still during the 3D-scan and the mirror rotates). In a mixed mode, the robot moves and at the same time the laser scanner scans in a spherical mode (i.e. measuring head and mirror rotate). Besides computing power, the mixed mode requires an accurate knowledge of the robot about the current position on the 2D-map constituting the current origin of the 3D-scan of the laser scanner. However, the mixed mode may be faster than the alternation of the movement of the robot and the pure spherical mode scanning of the laser scanner. And the mixed mode may avoid the problem of the helical mode, that surfaces perpendicular to the moving direction of the robot (e.g. walls of corridors branching off) might remain unscanned.

The robot may comprise scanners with the purpose of creating the 2D-map and/or of navigating. It is known, that said scanners use stereoscopy or optical flow. However, the present laser scanner having a rotating mirror may also provide a mode for said purpose. In such a mode, the measuring head may perform complete rotations, while the mirror may oscillate in a certain angular range thus scanning a ring-shaped part of the space around the robot. If the robot only needs the forward direction, the measuring head may also oscillate in a certain angular range. For the purpose of following a teacher, the laser scanner may run in a tracker mode.

For navigating on the 2D-map (e.g. between two marked positions for 3D-scans), the robot may also use said mode or a horizontal scanner or an inertial measurement unit or any other sensor system. To eliminate accumulated errors (e.g. created by an inertial measurement unit), a reinitialization will be useful from time to time.

The invention is explained in more detail below on the basis of an exemplary embodiment illustrated in the drawing, in which

Fig. 1 shows a schematic illustration of the device,

Fig. 2 shows a section along the line II-II in fig. 1,

Fig. 3 shows a perspective illustration of the laser scanner, and

Fig. 4 shows a schematic illustration of the laser scanner in operation.

5 A device 1 for optically scanning and measuring an environment has an autonomously moving robot 2, by means of which the device 1 is configured to be mobile. The robot 2 is provided with a platform 2a and - in a manner known per se - with an omnidirectional drive, i.e. a plurality of (in the present case four) omnidirectionally configured wheels 4 are provided. These wheels 4 have a substantially cylindrical
10 shape and carry, on their tread, a plurality of rollers, the axes of rotation of which are aligned tangentially to the tread. Being borne by the platform 2a, each wheel 4 can be driven by an own drive (i.e. motor with gear unit), independently of each other. Alternatively, instead of the omnidirectional drive, also other drives, for example chains, skids, floats or other wheel drives, are possible.

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A horizontal scanner 5 is mounted on platform 2a, said scanner being aligned in a preferred direction of travel and being able to scan a fan-shaped area which is ahead in said preferred direction of travel, in particular in order to capture obstacles in this closer environment (for example approximately ten meters). Preferably, the robot 2
20 is additionally provided with tactile sensors in order to capture obstacles in the immediate environment (centimeter range), also in other directions in the event of a contact. For such avoiding of obstacles, also other sensors can be used, for example cameras. A control unit 6, which is only implied in the figure, evaluates the data from the horizontal scanner 5 and preferably from the additional sensors, i.e. it re-
25 cognizes the captured obstacles and controls the drives of the wheels 4 in a suitable manner. The control unit 6 also stores the evaluated data of the horizontal scanner 5, i.e. it maps the environment of the robot 2 in order to create and to extend a 2D-map, for example by means of simultaneous localization and mapping. The 2D-map can be created also with alternative means, for example cameras, ultrasonic sensors
30 or the like, which then replace the horizontal scanner 5. A tracking device 7 is furthermore mounted on the platform 2a, said tracking device being able to capture and follow the movement of a person or another unit.

A support 8 is mounted in an upright position on the platform 2a of the robot 2. The length of the support 8 is preferably adjustable, i.e. the support 8 is height adjustable, for example by means of a lifting device 8a. The lifting device 8a can be
5 configured mechanically for example as a rack-and-pinion gear) or hydraulically/pneumatically (for example by means of a lifting cylinder or a gas-filled spring) and be provided with suitable guide-ways. The height-adjustable support 8 is provided preferably with a telescopic tube 8b as a housing which encloses and protects the lifting device 8a.

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On its top, the support 8 bears, preferably by means of a mounting device 9, a laser scanner 10, i.e. the laser scanner 10 is mounted on the robot 2. The mounting device 9 serves for the mechanical connection of the laser scanner 10 with the lifting device 8a and for the electrical connection with the robot 2, for which purpose corresponding cables 8c for energy supply and data transfer are guided within the tele-
15 scopic tube 8b, between the laser scanner 10 and the robot 2.

The laser scanner 10 has a measuring head 12 and a base 14. The measuring head 12 is mounted on the base 14 as a unit that can be rotated about a vertical axis. The
20 measuring head 12 has a mirror 16, which can be rotated about a horizontal axis. The intersection point of the two axes of rotation is designated center C_{10} of the laser scanner 10.

The measuring head 12 is further provided with a light emitter 17 for emitting an
25 emission light beam 18. The emission light beam 18 is preferably a laser beam in the range of approx. 300 to 1600 nm wave length, for example 790 nm, 905 nm or less than 400 nm, on principle, also other electro-magnetic waves having, for example, a greater wave length can be used, however. The emission light beam 18 is amplitude-modulated with a - for example sinusoidal or rectangular - modulation
30 signal. The emission light beam 18 is emitted by the light emitter 17 onto the rotary mirror 16, where it is deflected and emitted to the environment. A reception light beam 20 which is reflected in the environment by an object O or scattered other-

wise, is captured again by the rotary mirror 16, deflected and directed onto a light receiver 21. The direction of the emission light beam 18 and of the reception light beam 20 results from the angular positions of the rotary mirror 16 and the measuring head 12, which depend on the positions of their corresponding rotary drives
5 which, in turn, are registered by one encoder each.

A control and evaluation unit 22 has a data connection to the light emitter 17 and to the light receiver 21 in measuring head 12, whereby parts of it can be arranged also outside the measuring head 12, for example as a computer connected to the base 14.
10 The control and evaluation unit 22 is configured to determine, for a multitude of measuring points X, the distance d between the laser scanner 10 and the (illuminated point at) object O, from the propagation time of emission light beam 18 and reception light beam 20. For this purpose, the phase shift between the two light beams 18 and 20 can be determined and evaluated, for example.

15 Scanning takes place along a circle by means of the (quick) rotation of the rotary mirror 16. By virtue of the (slow) rotation of the measuring head 12 relative to the base 14, the whole space is scanned step by step, by means of the circles. The entity of measuring points X of such a measurement is designated scan. For such a scan,
20 the center C_{10} of the laser scanner 10 defines the origin of the local stationary reference system. The base 14 rests in this local stationary reference system.

In addition to the distance d to the center C_{10} of the laser scanner 10, each measuring point X comprises a brightness information which is determined by the control
25 and evaluation unit 22 as well. The brightness value is a gray-tone value which is determined, for example, by integration of the bandpass-filtered and amplified signal of the light receiver 21 over a measuring period which is assigned to the measuring point X. By means of a color camera, pictures by means of which colors (R,G,B) can be assigned to the measuring points as values, can be generated option-
30 ally.

The laser scanner 10 is mounted on the mounting device 9, and thus on the support 8, by means of the base 14. Between the laser scanner 10 and the robot 2 different degrees of a networking (with respect to the data transfer) are possible, said networking being set up in this system by means of the cables 8c and further cables.

5 The horizontal scanner 5, the tracking device 7 and the lifting device 8a can thus be connected to the control unit 6 which, in turn, can be connected to the control and evaluation unit 22, or the tracking device 7 is alternatively connected to the control and evaluation unit 22, or all named devices are integrated in a network with mutual data exchange. It is also conceivable, however, that the functions of the control and
10 evaluation unit 22 and of the control unit 6 are carried out by a common computer. Theoretically, it is also conceivable that the function of the tracking device 7 and/or of the horizontal scanner 5 is carried out by the laser scanner 10. Input means (and means for checking the input) are integrated into the networked system as well, said means being provided directly on the device 1 (in the form of control knobs, key-
15 boards or the like) or being provided as remote control (smartphone or the like). Finally, within this networked system, a connection (or several connections) for portable storage media, such as SD-cards, USB-sticks or the like, is provided for an external data access, or there is radio communication, for example by means of WLAN, to a stationary computer for data transfer.

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The device 1 serves in particular for autonomously scanning rooms. Operation is preferably subdivided into two phases, one initialization phase and one scanning phase. The initialization phase can be completely autonomous (i.e. robot 2 explores its environment systematically according to certain strategies), stochastically (i.e.
25 robot 2 explores its environment by means of a random walk) or by means of learning.

In the last-named case, the tracking device 7 is employed. A person acts as a teacher and paces off the rooms to be scanned, removes obstacles or opens doors, if need
30 be. Robot 2 (and thus the complete device 1) follows the teacher - who is preferably marked with a target - by means of the tracking device 7. The 2D-map is thus being created by means of the horizontal scanner 5 (or by means of the alternative media).

Alternatively, the robot 2 loads the externally created 2D-map during the initialization phase.

- 5 During the scanning phase the device 1 works autonomously, i.e. robot 2 moves autonomously through the rooms by means of the 2D-map. At the same time or alternating in view of time, the laser scanner 10 scans and measures the environment, i.e. it creates (a plurality) of 3D-scans. This is done, for example, in spherical mode, i.e. robot 2 stands still during the scan, and mirror 16 and measuring head 12 rotate,
10 or in helical mode, i.e. measuring head 12 stands still during the scan, mirror 16 rotates and robot 2 moves, or in a mixed mode, i.e. measuring head 12 and mirror 16 rotate, and robot 2 moves.

- The height-adjustable support 8 makes possible not only an adaptation to the rooms
15 to be scanned, but also to make a plurality of 3D-scans at the same position on the 2D-map, for example below a tabletop and above it. The respective height of the support 8 can be added to the 2D-map during the initialization phase - by means of the input means or by means of a corresponding movement of the teacher.

- 20 The position of robot 2 on the 2D-map, which is in a fixed relationship to the center C_{10} of the laser scanner 10, is preferably stored or transferred - by means of suitable means - synchronously (or in a manner that can be synchronized) together with the respective 3D-scan, for example by bringing the data together internally or separately with a time stamp. This facilitates registration (due to a reduced calculation
25 time), i.e. bringing together all 3D-scans in a common coordinate system. Scans which are taken at the same location, for example due to a stochastic movement of robot 2 or in a target manner, create redundancies in the data of the 3D scans. These redundancies are used to increase precision.

List of Reference Numerals

	1	device
5	2	robot
	2a	platform
	4	wheel
	5	horizontal scanner
	6	control unit
10	7	tracking device
	8	support
	8a	lifting device
	8b	telescopic tube
	8c	cable
15	9	mounting device
	10	laser scanner
	12	measuring head
	14	base
	16	mirror
20	17	light emitter
	18	emission light beam
	20	reception light beam
	21	light receiver
	22	control and evaluation unit
25	C ₁₀	center of the laser scanner
	O	object
	X	measuring point

Patent Claims

1. Device for optically scanning and measuring an environment, said device being configured to be mobile and being provided with a laser scanner (10) or the like, which creates 3D-scans, characterized in that the device (1) is provided with an autonomously moving robot (2), on which a laser scanner (10) or the like is mounted.
2. Device according to Claim 1, characterized in that the robot (2) is provided with means, in particular a horizontal scanner (5), in order to create a 2D-map for the autonomous movement of the robot (2).
3. Device according to Claim 1 or 2, characterized in that at least in one scanning phase the laser scanner (10) creates the 3D-scans while - at the same time and/or temporally alternately - the robot (2) moves autonomously by means of the 2D-map.
4. Device according to Claim 3, characterized in that means are provided for synchronously, or in a manner that can be synchronized, storing or transferring the 3D-scans of the laser scanner and the corresponding current positions of the robot (2) on the 2D-map.
5. Device according to one of the preceding claims, characterized in that the robot (2) is provided with a tracking device (7), in order to follow a teacher at least in an initialization phase.
6. Device according to one of the preceding claims, characterized in that the laser scanner (10) and the robot (2) are networked with one another, in particular a control and evaluation unit (22) of the laser scanner (10) and a control unit (6) of the robot (2) and/or a horizontal scanner (5) and/or a tracking device (7) are integrated in a network with mutual data exchange.

7. Device according to one of the preceding claims, characterized in that the laser scanner (10) is mounted on the robot (2) by means of a support (8) which is, in particular, height-adjustable.
- 5
8. Device according to one of the preceding claims, characterized in that the laser scanner (10) has a base (14), a measuring head (12) which is rotatable relative to the base (14) and a mirror (16) which is rotatable relative to the measuring head (12), wherein a light emitter (17) emitting an emission light beam (19) which is deflected into the environment by the mirror (16), and a light receiver (21) are provided in the measuring head (12), said light receiver receiving a reception light beam (20) which is reflected in the environment of the laser scanner (10) by an object O or scattered otherwise and deflected by the mirror (16), and wherein a control and evaluation unit (22) determines, for a multitude of measuring points (X), determines at least the distance to the object (O).
- 10
- 15
9. Method for operating a device according to one of the preceding claims, characterized in that, in an initialization phase, the robot (2) creates or loads a 2D-map and, in a scanning phase, the robot (2) moves autonomously by means of the 2D-map, and the laser scanner (10) creates the 3D-scans.
- 20
10. Method according to Claim 9, characterized in that the robot (2) creates the 2D-map by means of a strategic or stochastic procedure or by means of learning.
- 25

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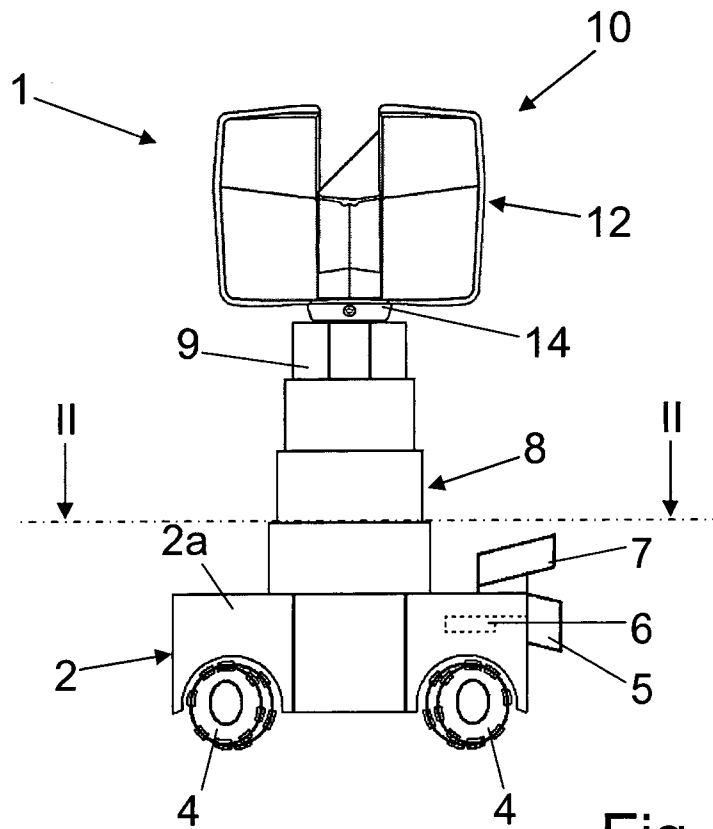


Fig. 1

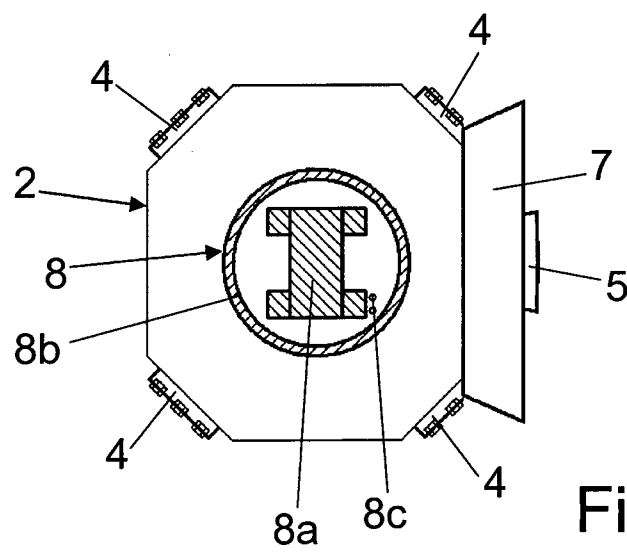


Fig. 2

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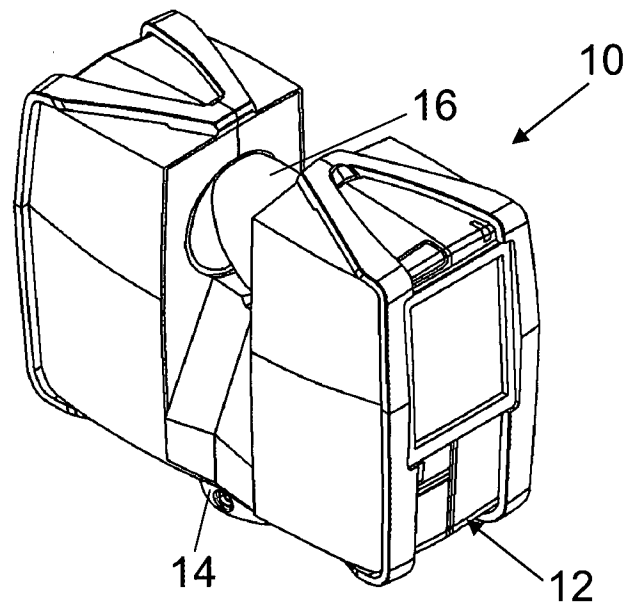


Fig. 3

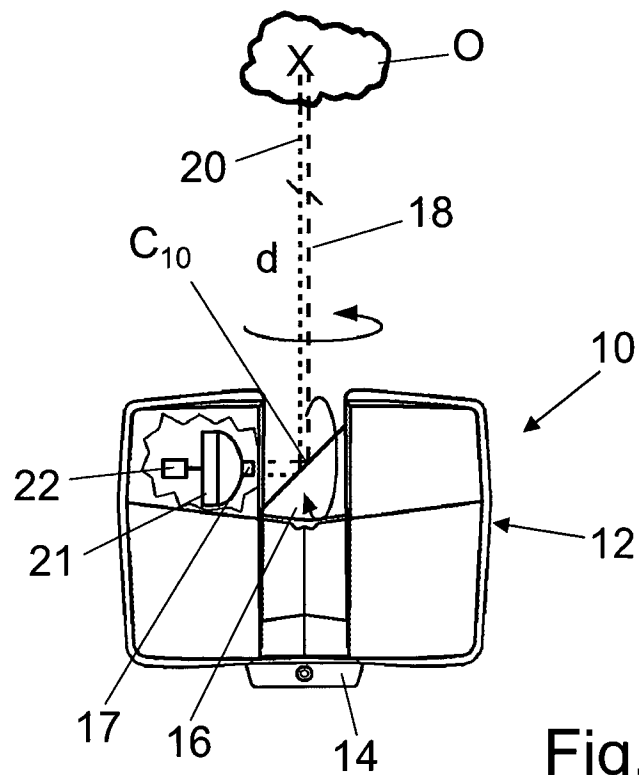


Fig. 4