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

(57) Abstract: A device for optically scanning and measuring an environment, with a laser scanner (10), having a base (14) and a measuring head which is rotatable relative to the base (14), with a light emitter, which emits an emission light beam, a light receiver which receives a reception light beam which is reflected by an object (O) in the environment of the laser scanner (10) or scattered otherwise, and a control and evaluation unit which, for a multitude of measuring points, determines at least the distance to the object, has a manually movable trolley (40), on which the laser scanner (10) is mounted by means of its base (14) and which can be taken from a resting state to a moving state, wherein the trolley (40) has a path measuring device for measuring its path.

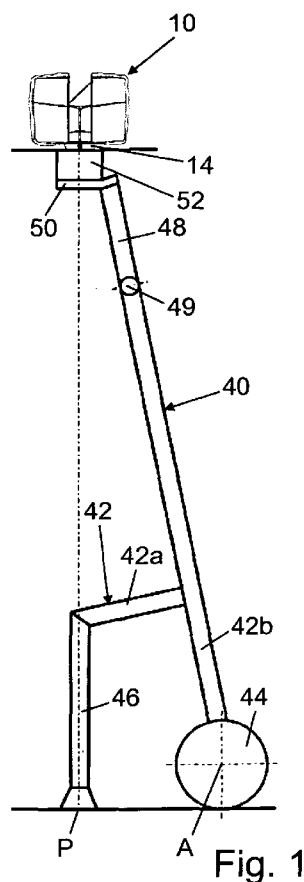


Fig. 1



HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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Device for optically scanning and measuring an environment

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

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US 7,193,690 B2 describes a device of this kind, in which the laser scanner is mounted on a tripod. For registering a scene by means of several scans, the laser scanner together with the tripod is taken to a new location after a scan.

15 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 comprising the features of Claim 1. The dependent claims relate to advantageous configurations.

20 The use of a manually movable trolley facilitates the change of location of the laser scanner compared to the transport of the tripod. It is furthermore less expensive than an automotive trolley. The laser scanner can remain mounted on the trolley during the scan, so that no additional stand is necessary. A positioning of the laser scanner vertically above a position of the trolley during the resting state provides for a safe
25 stand and a defined orientation.

When using the notions "horizontal" and "vertical" with respect to the geometry of the laser scanner and the trolley, it is assumed that the direction of the weight corresponds to the vertical, i.e. the trolley is on a horizontal plane. The trolley can,
30 however, also be slightly inclined, for example up to 15° towards the horizontal and/or the vertical (i.e. the axes of rotation of measuring head and mirror have a

corresponding inclination), without problems arising during the realization of the scan or its evaluation.

Basically, there are two possible operating modes of the laser scanner, during which the trolley is helpful. With the first operating mode, a complete scene can be registered with several scans from different locations, wherein the laser scanner carries out the scan at every location by means of the rotating measuring head and the rotating mirror. The trolley then serves only to change location. With the second operating mode („helical scan“), the measuring head can remain idle during the movement of the trolley, while only the mirror rotates in order to perform the scan. The trolley is then moved along a selected path during the measurement and records changes of position, for example by means of encoders in the wheels. This provides a method for quickly generating overview data along the specified path. The precision of movement can be improved by a higher number of wheels and consequently a more stable and more uniform movement of the trolley. Compared to a motor-driven trolley, the manually movable trolley is remarkably less expensive.

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 lateral view of the trolley with the mounted laser scanner,

Fig. 2 shows a further lateral view of the trolley from a direction which is by 90° displaced with respect to Fig. 1

Fig. 3 shows a section through the mounting device,

Fig. 4 shows a plain view of the mounting device, and

Fig. 5 shows a schematic, partially sectional view of the laser scanner during operation.

A laser scanner 10 is provided as part of a device for optically scanning and measuring an environment of the laser scanner 10. 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 measuring head 12 has a rotary mirror 16, which can be rotated about a horizontal axis. The intersection point of the two rotational axes 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 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 modulation 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 otherwise, 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 which, in turn, are measured 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 a computer connected to the base 14. 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.

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, 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.

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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 and evaluation unit 22 as well. The brightness value is a gray-scale 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 attributed to the measuring point X. Pictures can optionally be generated by means of a color camera, by means of which colors (R, G, B), can be attributed as value to the measuring points.

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In order to register a scene from different directions, several scans are generated from different locations and then registered with respect to a joint coordinate system of the scene. The laser scanner 10 must change its location for this purpose, thus moving each time the center C_{10} of the laser scanner 10 within the joint coordinate system. In order to simply change the location, the device for optically scanning and measuring an environment of the laser scanner 10, also comprises a trolley 40 (in addition to the above-described laser scanner 10 itself), onto which the laser scanner 10 is (continuously) mounted.

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The manually movable trolley 40 has a carriage 42 with at least two wheels 44 which rotate independently of one another about a common (imaginary or physical) axis A and each of which is provided with an encoder 45, and a support foot 46 which, when the trolley 40 is not moved, define a support at three points. The directions used refer to the (ideally horizontal) plane of this support, wherein the trolley 40, for being moved, is inclined with respect to its resting state. The point at which the support foot 46 supports the trolley 40 at the ground shall be denominated stand P. Instead of the support foot 46, also a third wheel may be provided which is displaced with respect to the axis A of the two other wheels 44 and which is preferably steerable. In the present invention, the carriage has a traverse 42a, from each of the

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two opposing ends of which a bearing 42b protrudes vertically (downward), which bears one of the two wheels 44 (or their axis A), and at the third end of which the support foot 46 protrudes obliquely (downward).

5 Furthermore, an arm 48 protrudes (upward) from the carriage 42, in the present invention two parallel square profiles 48a which are connected with one another, and which are fixed to the traverse 42a. On both sides of the arm 48 handles 49 protrude, that is one handle 49 from each of the two square profiles 48a, for example parallel to the axis A of the wheels 44. At the upper end of the arm 48, a mounting
10 plate 50 is fixed which, in the present invention, has a triangular shape with the two square profiles 48a (screwed) in two of the three corners of the mounting plate. The mounting plate 50 bears a mounting device 52, in the present invention a cylindrical or square block with a rotatable mounting screw 52 a, said mounting device 52 being screwed to the mounting plate 50 (within the area of the third corner). The
15 mounting plate 50 has a kink, so that the mounting device 52 is inclined obliquely to the support 48. The dimensions of the arm 48 and of the traverse 42 and the inclination angles between the support foot 46 and the traverse 42a on the one hand and between the mounting device 52 and the arm 48 on the other hand are selected in such a way that the mounting device 52 is arranged exactly in the extension of
20 the support foot 46, wherein, in the resting state of the trolley 40, the mounting device 52 is aligned exactly vertically above the stand P, and the upper side of the mounting device 50 is aligned horizontally.

The laser scanner 10 with its base 14 is arranged on the upper side of the mounting
25 device 52 of the trolley 40 and fixed to the mounting device 52, in the present invention it is screwed by means of the mounting screw 52a, so that the arm 48 bears the laser scanner 10. During a scan the trolley 40 is in its resting state, i.e. the laser scanner 10 (ideally) is aligned horizontally. Between two scans for a scene, the trolley 40 with the laser scanner 10 can be moved manually, the trolley 40 - by means
30 of the handles 49 - being inclined around the axis A of the wheels 44 so that the support foot 46 detaches from the ground, and the center C_{10} of the laser scanner 10 reaches the vertical through the axis A of the wheels 44 or passes this vertical and

the trolley 40 is then pushed or drawn in this (inclined) moving state by means of the handles 49.

Typical dimensions are, for example, that the center C_{10} of the laser scanner 10 is
5 1600 mm above the stand P, the wheels 44 are spaced apart from each other by 600 mm, the support foot 46 between the traverse 42a and the ground is 400 mm long, and the inclination angle between the arm 48 and the (vertical) line connecting mounting device 52 and stand P is 12° in the resting state. The square profiles 48a can measure 40 mm $\times$ 40 mm, and the mounting device 52 with the mounting plate
10 50 can be 64 mm high.

The trolley 40 has a path measuring device which, in the exemplary embodiment, comprises the two encoders 45 at the wheels 44 and a not illustrated connection from the encoders 45 to the laser scanner 10, particularly to the control and evalu-
15 ation unit 22. Each of these two encoders 45 measures the rotation of the assigned wheel 44, that means its path (as a function of time), so that the length of the path of every wheel 44 results directly, and the direction of the path of trolley 40 results from the combination of the information of the two wheels 44. Alternatively, an optical path measuring device is provided, which, for example, measures the optical
20 flow.

With the first operating mode of the laser scanner 10 (rotating measuring head 12, rotating mirror 16, resting trolley 40), for registering a scene by means of the path measuring device of the trolley 40, the change from one viewpoint to the next view-
25 point can be pursued, facilitating registering of the single scans in the joint coordinate system. With the second operating mode of the laser scanner 10 (resting measuring head 12, rotating mirror 16, moved trolley 40), with which the scan is generated during the movement of the trolley 40 with -more or less - the same inclination of the laser scanner, the data of the path measuring device of the trolley 40 go down in
30 the scan as further coordinates. Compared to the first operating mode, the data of the path measuring device replace those of the encoder of measuring head 12.

The control and evaluation unit 22 can immediately evaluate the data of the path measuring device or include them into the scan for a later evaluation or record them separately, so that they can be synchronized with the data of the scan. The path measuring device can also have a control unit of its own, which separately records
5 the data of the encoders 45 and transmits them later on to the control and evaluation unit 22.

A higher number of wheels, for example an additional third wheel which can be steerable, or a total of four wheels, stabilizes the movement of the trolley 40, particularly during the second operating mode, during which (by means of three wheels)
10 the inclination of the laser scanner 10 shall be maintained. Two encoders 45 at two wheels 44 which rotate independently of one another, are sufficient for the path measuring device. A higher number of wheels with additional encoders can, however, provide information - which is per se redundant - for error correction.

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The laser scanner 10 and/or the trolley 40 preferably have different sensors, for example thermometer, inclinometer, altimeter, compass, gyro compass, GPS; etc. which are preferably connected to the control and evaluation unit 22. By means of said sensors, the operating conditions of the laser scanner 10, which are defined by
20 certain parameters, for example geometric orientation or temperature, are monitored. If one or several parameters have a drift, this is recognized by the assigned sensors and can be compensated by the control and evaluation unit 22. By means of said sensors, also a sudden change of operating conditions can be recognized, for example a blow on the laser scanner 10 which changes its orientation, or a displacement of the laser scanner 10. If the extent of said change cannot be measured with
25 sufficient precision, the scanning process must be interrupted or aborted. If the extent of said change of operating conditions can be roughly estimated, the measuring head 12 can be turned back by some angular degrees (until there is an overlapping with the area which has been scanned before the sudden change), and the scanning
30 process continues. The two different parts of the scan can be joined together by an evaluation of the overlapping area.

With the second operating mode, the data of said sensors refine the data of the path measuring device of the trolley 40. During the first operating mode of the laser scanner 10, the orientation of the laser scanner 10 with respect to the horizontal and to the vertical can be checked before the scanning process - by means of the inclinometers. Preferably, the trolley 40 has adjusting possibilities, for example a length adjustment of the support foot 46 or an adjustment of the inclination of mounting device 52, in order to adjust the orientation of the trolley 40 and/or of the laser scanner 10.

List of Reference Symbols

	10	laser scanner
	12	measuring head
5	14	base
	16	mirror
	17	light emitter
	18	emission light beam
	20	reception light beam
10	21	light receiver
	22	control and evaluation unit
	40	trolley
	42	carriage
	42a	transverse
15	42b	bearing
	44	wheel
	45	encoder
	46	support foot
	48	arm
20	48	square profile
	49	handle
	50	mounting plate
	52	mounting device
	52a	mounting screw
25	A	axis
	C ₁₀	center of the laser scanner
	d	distance
	O	object
	P	stand
30	X	measuring point

Patent Claims

1. Device for optically scanning and measuring and environment with a laser
5 scanner (10), having a base (14) and a measuring head (12) which is rotatable
relative to the base (14), with a light emitter (17), which emits an emission
light beam (18), a light receiver (21) which receives a reception light beam
(20) which is reflected by an object (O) in the environment of the laser scan-
ner (10) or scattered otherwise, and a control and evaluation unit (22) which,
10 for a multitude of measuring points (X), determines at least the distance to the
object (O), characterized in that the device has a manually movable trolley
(40), on which the laser scanner (10) is mounted by means of its base (14) and
which can be taken from a resting state to a moving state, wherein the trolley
(40) has a path measuring device (45, 45) for measuring its path.
15
2. Device according to Claim 1, characterized in that the trolley (40) has a car-
riage (42) which is provided with at least two wheels (44), which are rotatable
independently of one another, particularly about a common axis (A).
- 20 3. Device according to Claim 2, characterized in that the path measuring device
(45, 45) has at least two encoders (45), each of which is assigned to one of the
at least two wheels (44).
4. Device according to Claim 2 or 3, characterized in that the carriage (42) is
25 provided with a support foot (46) or a third wheel which particularly is steer-
able, wherein supporting of the support foot (46) or of the third wheel at the
ground defines a stand (P).
5. Device according to any of Claims 2 to 4, characterized in that the trolley (40)
30 has an arm (48) which bears the laser scanner (10), wherein the arm (48) par-
ticularly protrudes from the carriage (42).

6. Device according to claim 5, characterized in that the arm (48) bears a mounting device (52), particularly on a mounting plate (50) which is fixed to the arm (49), wherein the mounting device (52) must be connected with the base (14) of the laser scanner (10).

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7. Device according to Claims 4 and 6, characterized in that the mounting device (52), during the rest state of the trolley (40), is vertically above the stand (P).

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8. Device according to Claim 7, characterized in that the arm (48) is inclined obliquely towards the line connecting the mounting device (52) and the stand (P) in the rest state of the trolley (40).

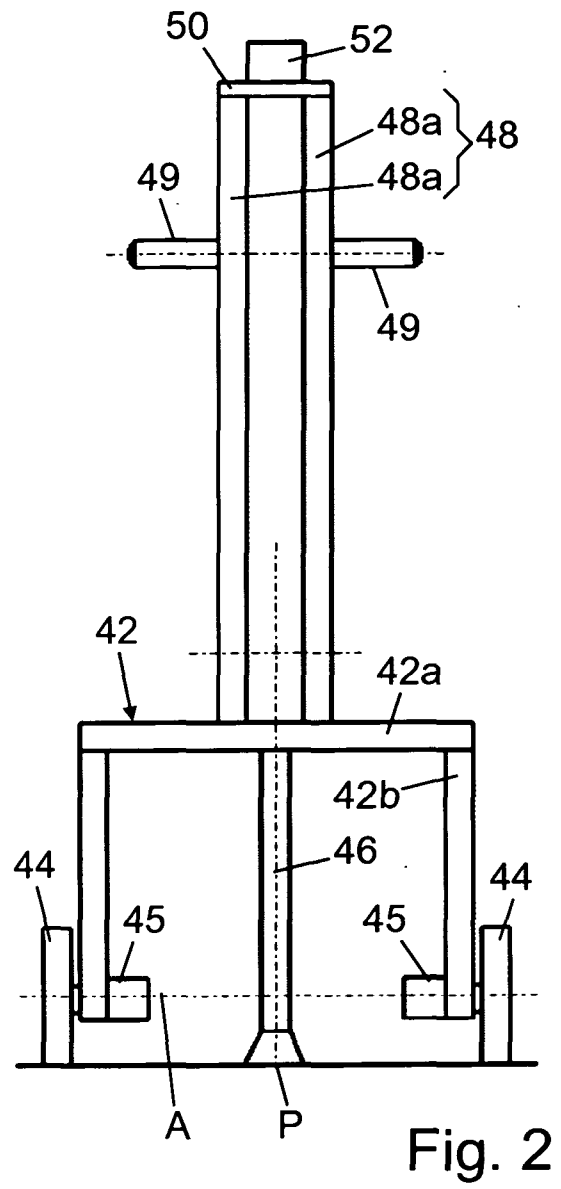
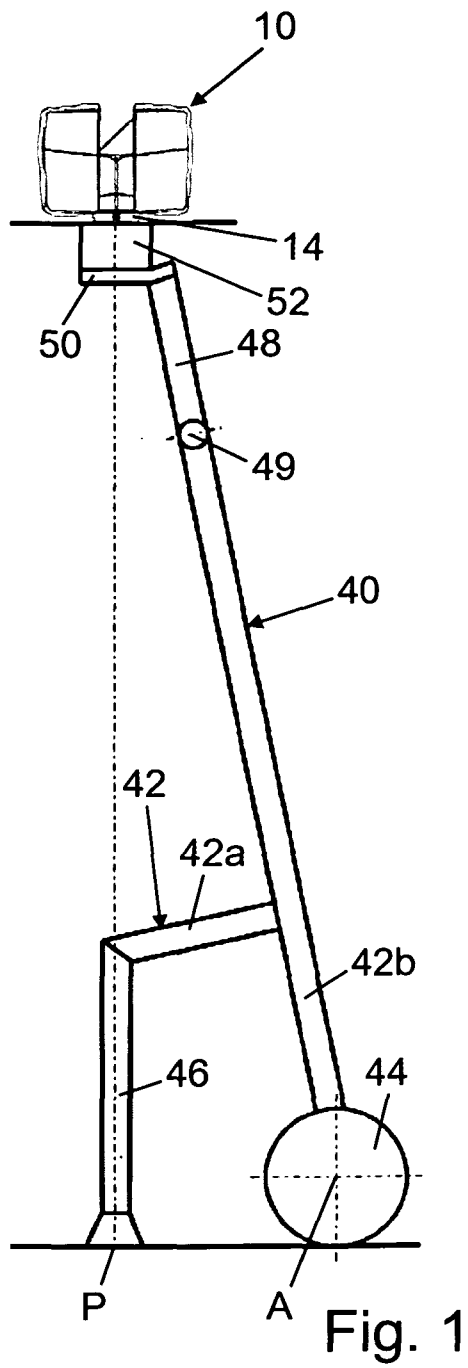
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9. Device according to any of Claims 6 to 8, characterized in that the mounting device (52), in the moving state of the trolley (40) is vertically above the axis (A) of the wheels (44) or, while the trolley (40) gets inclined from the rest state to the moving state, has passed the vertical through the axis (A) of the wheels (44).

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10. Device according to any of the preceding Claims, characterized in that the trolley (40) has adjusting possibilities for adjusting the alignment of the laser scanner (10) and/or of the trolley (40).

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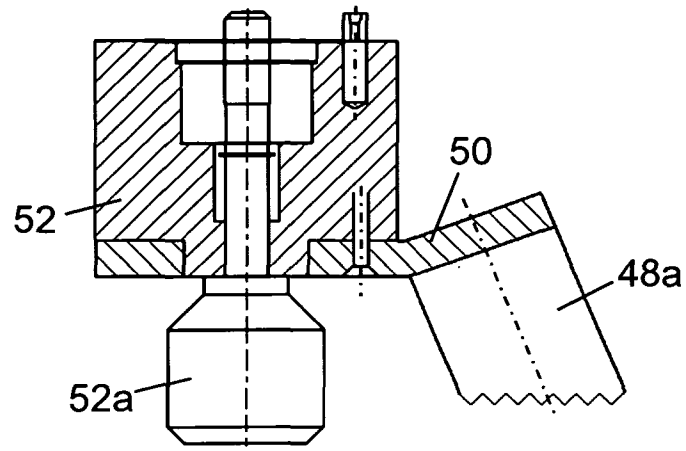


Fig. 3

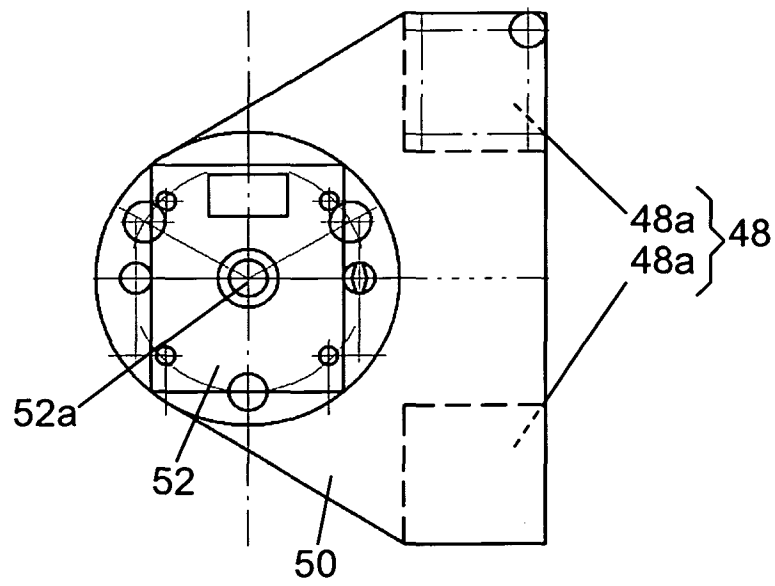


Fig. 4

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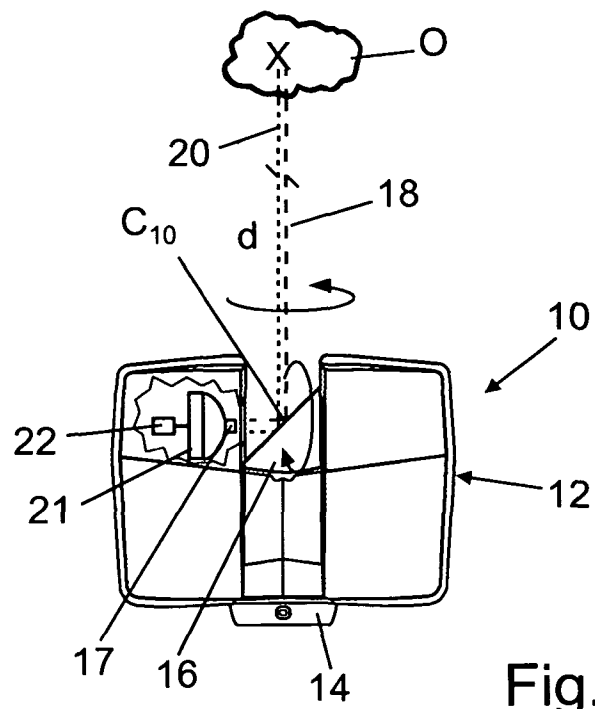


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/003264

A. CLASSIFICATION OF SUBJECT MATTER INV. G01S17/89 G01C15/00 G01C22/00 G01C22/02 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G01S 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, WPI Data, INSPEC		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 388 661 A (AEA TECHNOLOGY PLC [GB]) 19 November 2003 (2003-11-19) abstract page 4, line 3 - page 7, line 13 figures 1, 2 claim 1	1-10
X	----- US 5 675 326 A (JUDS SCOTT [US] ET AL) 7 October 1997 (1997-10-07) abstract column 9, line 41 - column 10, line 17 figure 18	1-10
A	----- US 5 402 365 A (KOZIKARO ELISHA M [US] ET AL) 28 March 1995 (1995-03-28) abstract figures 1-3 column 1, line 17 - column 2, line 62 ----- -/--	1-10
☒ Further documents are listed in the continuation of Box C. ☒ See patent family 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 10 October 2011		Date of mailing of the international search report 19/10/2011
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Van den Bosch, I

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/003264

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 5 745 225 A (WATANABE HIROMITSU [JP] ET AL) 28 April 1998 (1998-04-28) column 6, line 60 - line 67 figure 13 -----	1-10
A	BOUVET D ET AL: "Precise 3-D localization by automatic laser theodolite and odometer for civil-engineering machines", PROCEEDINGS OF THE 2001 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION. ICRA 2001. SEOUL, KOREA, MAY 21 - 26, 2001; [PROCEEDINGS OF THE IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION], NEW YORK, NY : IEEE, US, vol. 2, 21 May 2001 (2001-05-21), pages 2045-2050, XP010550445, DOI: 10.1109/ROBOT.2001.932908 ISBN: 978-0-7803-6576-6 the whole document -----	1-10
A	WO 2007/051972 A1 (QINETIQ LTD [GB]; KAUSHAL TEJ PAUL [GB]; SMITH RONALD VINCENT [GB]; SM) 10 May 2007 (2007-05-10) the whole document -----	1-10
A	BRENNEKE C ET AL: "Using 3d laser range data for slam in outdoor environments", PROCEEDINGS OF THE 2003 IEEE/RSJ INTERNATIONAL CONFERENCE ON INTELLIGENT ROBOTS AND SYSTEMS. (IROS 2003). LAS VEGAS, NV, OCT. 27 - 31, 2003; [IEEE/RSJ INTERNATIONAL CONFERENCE ON INTELLIGENT ROBOTS AND SYSTEMS], NEW YORK, NY : IEEE, US, vol. 1, 27 October 2003 (2003-10-27), pages 188-193, XP010672337, DOI: 10.1109/IROS.2003.1250626 ISBN: 978-0-7803-7860-5 the whole document -----	1-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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Patent document cited in search report		Publication date	Patent family member(s)	Publication date
GB 2388661	A	19-11-2003	NONE	

US 5675326	A	07-10-1997	NONE	

US 5402365	A	28-03-1995	DE 69319887 D1	27-08-1998
			DE 69319887 T2	04-03-1999
			EP 0619873 A1	19-10-1994
			JP 3392418 B2	31-03-2003
			JP H07502825 A	23-03-1995
			WO 9410537 A1	11-05-1994

US 5745225	A	28-04-1998	GB 2308256 A	18-06-1997
			SE 506753 C2	09-02-1998
			SE 9504480 A	15-06-1997

WO 2007051972	A1	10-05-2007	NONE	
