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- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
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(54) Title: THREE-DIMENSIONAL SCANNER WITH SPECTROSCOPIC ENERGY DETECTOR

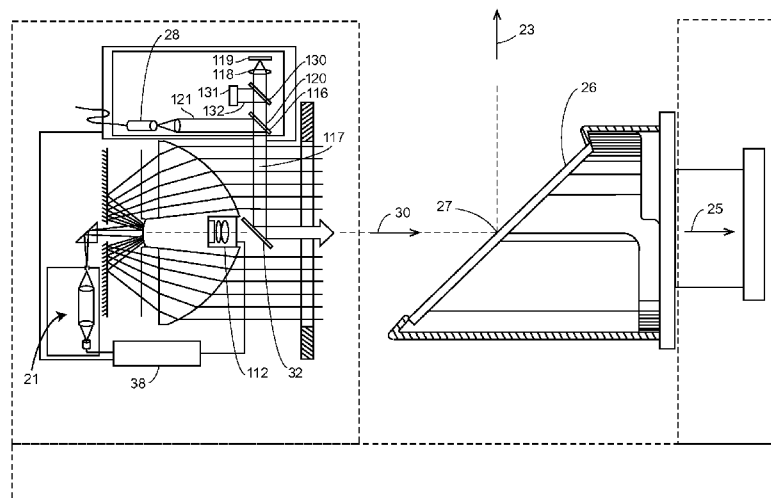


FIG. 6

(57) Abstract: A laser scanner has a light emitter, a rotary mirror, a light receiver, a first beam splitter to send electromagnetic energy from an electromagnetic energy generator into the environment, a second beam splitter to send reflected electromagnetic energy to a spectroscopic energy detector, and a control and evaluation unit, the spectroscopic energy detector configured to determine wavelengths in the reflected electromagnetic energy.

**THREE-DIMENSIONAL SCANNER WITH SPECTROSCOPIC ENERGY
DETECTOR**
CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Non-Provisional Patent Application No. 13/510,020, filed on June 15, 2012, which is a National Stage Application of PCT Application No. PCT/EP2010/006867, filed on November 11, 2010, which claims the benefit of U.S. Provisional Patent Application No. 61/299,166, filed on January 28, 2010, and of German Patent Application No. DE 10 2009 055988.4, filed on November 20, 2009, all of which being hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The invention relates to a device for optically scanning and measuring an environment.

[0003] By a device such as is known for example from U.S. Published Patent Application No. 2010/0134596, and which comprises a laser scanner, the environment of the laser scanner can be optically scanned and measured. A rotary mirror which rotates and which comprises a polished plate of a metallic rotor, deflects both an emission light beam and a reception light beam. A collimator of a light emitter is seated in the center of a receiver lens. The receiver lens reproduces the reception light beam on a light receiver which is arranged on an optical axis behind the receiver lens. For gaining additional information, a line scan camera, which takes RGB signals, is mounted on the laser scanner, so that the measuring points of the scan can be completed by color information.

SUMMARY OF THE INVENTION

[0004] Embodiments of the present invention are based on the object of creating an alternative to the device of the type mentioned hereinabove.

[0005] The arrangement of a color camera on the optical axis of the receiver lens, with respect to the rotary mirror on the same side, has the advantage of avoiding parallax errors almost completely, since the light receiver and the color camera take the environment

[0006] from the same angle of view and with the same side of the rotary mirror. The same mechanism can be used for the rotary mirror. The used side of the rotary mirror is the same as well. The reception light beam being reflected by the rotary mirror is running in parallel to the optical axis of the receiver lens and continuously hitting on the receiver lens. The receiver lens takes the place of the light receiver, so that there is no change of the shadowing effects. To be able to feed the emission light beam again, an emission mirror in front of the color camera is provided, where the emission mirror is reflecting for the emission light beam and is transparent for the color camera.

[0007] Due to the fact that a rear mirror, which reflects the reception light beam that has been refracted by the receiver lens towards the receiver lens, is provided on the optical axis behind the receiver lens, the available space can be better utilized. To complete the “folded optics,” a central mirror is provided between the receiver lens and the rear mirror, where the central mirror reflects the reception light beam towards the rear mirror. A suitable form of the mirrors supports focusing, wherein the focusing length with respect to the unfolded optics can still be increased. The central mirror can be used for near-field correction, similar to an additional mask, by reducing the intensity from the near field compared to the far field. Further savings in space result from an arrangement of the light receiver radial to the optical axis of the receiver lens in a cylinder-coordinate system which is defined by the optical axis.

[0008] The design of the rotor as a hybrid structure, i.e. as a multi-element structure from different materials, permits a relatively short design which, despite the inclination of the rotary mirror, remains balanced. A combination of a metallic holder, a rotary mirror of coated glass and a plastic housing may be used; however other combinations are possible as well. The holder which is dominating with respect to the mass makes balancing possible, while the housing serves as accidental-contact protection. Glue between the rotor components makes balancing of the different temperature coefficients of expansion possible without impairing the dynamic behavior.

[0009] By providing a dichroic beam splitter on the path of the return light to the light receiver, it is possible to split off an energy signal, which might be electromagnetic radiation, for example, to be received by a suitable detector. By further providing an additional source

[0010] of electromagnetic energy to illuminate an object in the environment, splitting off a portion of the reflected electromagnetic energy, and sending the electromagnetic energy to a spectroscopic energy detector that determines wavelengths of the electromagnetic energy, characteristics of the illuminated object may be determined.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The invention is explained in more detail below on the basis of an exemplary embodiment illustrated in the drawing, in which:

[0012] FIG. 1 is a partially sectional view of the laser scanner;

[0013] FIG. 2 is a schematic illustration of the laser scanner;

[0014] FIG. 3 is a perspective illustration of the rotor holder;

[0015] FIG. 4 is a partially sectional view of the laser scanner;

[0016] FIG. 5 is a partially sectional view of the laser scanner; and

[0017] FIG. 6 is a partially sectional view of the laser scanner.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Referring to FIGs. 1 and 2, a laser scanner 10 is provided as a device for optically scanning and measuring the 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.

[0019] The measuring head 12 is further provided with a light emitter 17 for emitting an emission light beam 18. The emission light beam 18 may be a laser beam in the range of approximately 340 to 1600 nm wave length; for example 790 nm, 905 nm or less than 400 nm. Also other electro-magnetic waves having, for example, a greater wave length can be used. The emission light beam 18 is amplitude-modulated, for example with a sinusoidal or with a rectangular-waveform 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 registered by one encoder each.

[0020] A control and evaluation unit 22 has a data connection to the light emitter 17 and to the light receiver 21 in the measuring head 12, whereby parts of the unit 22 can be arranged also outside the measuring head 12, for example a computer connected to the base 14. The control and evaluation unit 22 determines, 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 the emission light beam 18 and the reception light beam 20. For this purpose, the phase shift between the two light beams 18 and 20 is determined and evaluated.

[0021] Scanning takes place along a circle by means of the relatively quick rotation of the mirror 16. By virtue of the relatively slow rotation of the measuring head 12 relative to the base 14, the whole space is scanned step by step, by the circles. The entity of measuring points X of such a measurement is designated as a 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.

[0022] In addition to the distance d to the center C_{10} of the laser scanner 10, each measuring point X comprises brightness information which is determined by the control 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 attributed to the measuring point X. For certain applications it is desirable to have color information in addition to the gray-tone value. The laser scanner 10 is therefore also provided with a color camera 23 which is connected to the control and evaluation unit 22 as well. The color camera 23 may comprise, for example, a CCD camera or a CMOS camera and provides a signal which is three-dimensional in the color space, for example an RGB signal, for a two-dimensional picture in the real space. The control and evaluation unit 22 links the scan, which is three-dimensional in real space, of the laser scanner 10 with the colored pictures of the color camera 23, which are two-dimensional in real space, such process being designated "mapping". Linking takes place picture by picture for any of the colored pictures which have been taken to give as a final result a color in RGB shares to each of the measuring points X of the scan, i.e. to color the scan.

[0023] In the following, the measuring head 12 is described in details.

[0024] The reception light beam 20 which is reflected by the rotary mirror 16 hits on a plano-convex, spherical receiver lens 30 which, in embodiments of the present invention, has an approximate semi-spherical shape. The optical axis A of the receiver lens 30 is orientated towards the center C_{10} of the laser scanner. The convex side of the highly-refractive receiver lens 30 is orientated towards the rotary mirror 16. The color camera 23 is arranged on the same side of the rotary mirror 16 as the receiver lens 30 and on its optical axis A. In embodiments of the present invention, the color camera 23 is arranged on the point of the receiver lens 30 which is closest to the rotary mirror 16. The color camera 23 may be fixed on the untreated surface of the receiver lens 30, for example, be glued on it, or be placed in an appropriate recess of the receiver lens 30.

[0025] In front of the color camera 23, i.e. closer to the rotary mirror 16, an emission mirror 32 is arranged, which is dichroic, i.e. in embodiments of the present invention the mirror 32 transmits visible light and reflects red laser light. The emission mirror 32 is consequently transparent for the color camera 23, i.e. the mirror 32 offers a clear view onto the rotary mirror 16. The emission mirror 32 is at an angle with the optical axis A of the receiver lens 30, so that the light emitter 17 can be arranged at the side of the receiver lens 30. The light emitter 17, which comprises a laser diode and a collimator, emits the emission light beam 18 onto the emission mirror 32, from where the emission light beam 18 is then

projected onto the rotary mirror 16. For taking the colored pictures, the rotary mirror 16 rotates relatively slowly and step by step. However, for taking the scan, the rotary mirror 16 rotates relatively quickly (e.g., 100 cps) and continuously. The mechanism of the rotary mirror 16 remains the same.

[0026] Due to the arrangement of the color camera 23 on the optical axis A of the receiver lens 30, there is virtually no parallax between the scan and the colored pictures. Since, in known laser scanners, the light emitter 17 and its connection is arranged instead of the color camera 23 and its connection, for example a flexible printed circuit board, the shadowing effects of the receiver lens 30, due to the color camera 23 and to the emission mirror 32 do not change or change only insignificantly.

[0027] To also register remote measuring points X with a relatively large focal length on the one hand and, on the other hand, to require relatively little space, the laser scanner 10 has “folded optics.” For this purpose, a mask 42 is arranged on the optical axis A behind the receiver lens 30, where the mask is orientated coaxially to the optical axis A. The mask 42 is arranged radially inward (i.e., as referred to the optical axis A) and has a relatively large free area to let the reception light beam 20, which is reflected by the remote objects O, pass unimpeded, while the mask 42, arranged radially outward, has relatively smaller shaded regions to reduce intensity of the reception light beam 20 which is reflected by nearby objects O, so that comparable intensities are available.

[0028] A rear mirror 43 is arranged on the optical axis A behind the mask 42, where the mirror is plane and perpendicular to the optical axis A. The rear mirror 43 reflects the reception light beam 20 which is refracted by the receiver lens 30 and which hits on the central mirror 44. The central mirror 44 is arranged in the center of the mask 42 on the optical axis A, which is shadowed by the color camera 23 and the emission mirror 32. The central mirror 44 is an aspherical mirror which acts as both a negative lens, i.e. increases the focal length, and as a near-field-correction lens, i.e. shifts the focus of the reception light beam 20 which is reflected by the nearby objects O. Additionally, a reflection is provided only by such part of the reception light beam 20, which passes the mask 42 which is arranged on the central mirror 44. The central mirror 44 reflects the reception light beam 20 which hits through a central orifice at the rear of the rear mirror 43.

[0029] The light receiver 21, which comprises an entrance diaphragm, a collimator with a filter, a collecting lens and a detector, is arranged at the rear of the rear mirror 43. To save space, a reception mirror 45 may be provided, which deflects the reception light beam 20 by 90°, so that the light receiver 21 can be arranged radial to the optical axis A. With the folded optics, the focal length can be approximately doubled with respect to known laser scanners.

[0030] Referring also to FIG. 3, the rotary mirror 16 as a two-dimensional structure is part of a rotor 61 which can be turned as a three-dimensional structure by the corresponding rotary drive, and the angle position of the drive is measured by the assigned encoder. To save space also with respect to the rotary mirror 16 due to a relatively short design of the rotor 61 and to keep the rotor 61 balanced, the rotor 61 is designed as hybrid structure, comprising a holder 63, the rotary mirror 16 which is mounted at the holder 63 and a housing 65 made of plastic material, where the housing additionally holds the rotary mirror 16.

[0031] The metallic holder 63 has a cylindrical basic shape with a 45° surface and various recesses. Portions of material, for example blades, shoulders and projections, each of which serves for balancing the rotor 61, remain between these recesses. A central bore serves for mounting the motor shaft of the assigned rotary drive. The rotary mirror 16 is made of glass, which is coated and reflects within the relevant wave-length range. The rotary mirror 16 is fixed at the 45° surface of the holder 63 by glue, for which purpose special attachment surfaces 63b are provided at the holder 63.

[0032] The housing 65 made of plastic material has the shape of a hollow cylinder which has been cut below 45° and encloses at least the holder 63. The housing 65 can be glued to the rotary mirror 16 or be fixed otherwise. The housing 65 can clasp the rotary mirror 16 at its periphery, for example in a form-locking manner, if necessary with the interposition of a rubber sealing or the like. The housing 65 can also be glued to the holder 63 or be otherwise fixed to the holder 63 directly, or, by the mounting of the rotor 61, the housing 65 can be connected to the holder 63, for example screwed to it, by an end plate 67. The glue used on the one hand offsets the different temperature coefficients of expansion of the materials used and, on the other hand, leaves the dynamic behavior unaffected, for

example shows an elasticity which is not relatively too large, to avoid speed-dependent unbalances.

[0033] The rotor 61 rotates about the optical axis A. The rotary mirror 16 covers the holder 63 on one of its faces (namely on the 45° surface). The housing 65 covers the holder 63 radially outside with respect to the optical axis A. Thus, sharp edges of the holders 63 are covered to prevent injuries. The holder 63 is balancing the rotor 61. Instead of metal, the holder 63 may be made of another relatively heavy material, dominating the moment of inertia. Instead of plastic, the housing 65 may be made of another relatively light material, having few influences on the moment of inertia. Instead of coated glass, the rotary mirror 16 may be reflective (and transparent) otherwise. Designed as a hybrid structure, the rotary mirror 16, the holder 63, and the housing 65 are separately formed parts fixed together.

[0034] FIG. 4 shows a partially sectional view of the laser scanner, the view substantially the same as that of FIG. 1 except for the presence of a dichroic beam splitter 116, optional lens 118, and energy detector 119. The dichroic beam splitter includes a coating that splits off some wavelengths of electromagnetic energy (i.e., light) to travel on a path 121 to the light receiver 21 and other wavelengths of electromagnetic energy to travel on a path 120 to the optional lens 118 and energy detector 119.

[0035] Examples of electromagnetic energy that might be detected by energy detector 119 include thermal energy, ultraviolet radiation, millimeter-wave radiation, and X-ray radiation. For an energy detector 119 that detects thermal energy, the electromagnetic radiation may be in the near-infrared or mid-infrared region of the electromagnetic spectrum.

[0036] In many cases, a lens 118 is placed between the dichroic beam splitter 116 and the energy detector 119. In some cases, the lens may focus the electromagnetic radiation in the path 120 onto a small spot on the energy detector 119. In this case, the energy detector is collecting the electromagnetic radiation at the same time distance information is being collected during the scanning procedure. In other words, in this instance, the detector is collecting the energy information on a point-by-point basis.

[0037] In other cases, the lens 118 may be placed so as to form an image of a region of the environment. In this case, the lens 118 includes multiple detector elements (i.e.,

pixels). For this type of detector, the scanner probably collects information with the scanner moved to discrete steps, where the step size is selected to match the field-of-view of the lens system.

[0038] Although the dichroic beam splitter is shown at a position occupied by a mirror in FIG. 1, it is possible to locate the dichroic beam splitter in a variety of other positions. For example, the dichroic beam splitter 116 may be located near the dichroic emission mirror 32 in order to gain a wider field-of-view than would be possible in the position shown in FIG. 4 for the dichroic beam splitter 116.

[0039] It is also possible to change form a beam splitter by coating a right angle mirror to reflect one wavelength and transmit a second wavelength. FIG. 5 shows the right angle prism mirror 122 coated on a face 123 to reflect the wavelength of the light source 28 onto the light receiver 21. Electromagnetic energy of a different wavelength is transmitted through the prism 122 in a beam 124 to energy detector 125.

[0040] The use of multiple dichroic beam splitters such as elements 32 and 116 provide a means of obtaining, in a single 3D scanner, information about a variety of emissions. For example, it may be important to know the 3D coordinates and color of objects in an environment and, in addition, know the temperature of those objects. A simple example might be a scan of the interior or exterior of a house showing the temperature of the different areas of the house. By identifying the source of thermal leakage, remedial action such as adding insulation or filling gaps, may be recommended.

[0041] Dichroic beam splitters may also be used to obtain multiple wavelengths to provide diagnostic chemical information, for example, by making the energy detector a spectroscopic energy detector. A spectroscopic energy detector, as defined here, is characterized by its ability to decompose an electromagnetic signal into its spectral components. In many cases, a beam of light is projected onto an object. The reflecting light may be received and analyzed to determine the spectral components that are present. Today, gratings and other elements being found in spectroscopic energy detectors are being miniaturized through the use of micro electromechanical chips. For example, several companies are working on miniature devices today capable of analyzing the nutritional components of food. For example, Fraunhofer has reported working on a spectrometer of

only 9.5 x 5.3 x 0.5 mm for this purpose. An example of a device for which a scanner 10 may be particularly appropriate is one in which the spectral emissions may indicate the presence of explosives. Such a method is described in U.S. Patent No. 7,368,292 to Riegl et al.

[0042] FIG. 6 shows the elements of a spectroscopic system embedded within a scanner 10. A source of electromagnetic energy emits light that reflects off beam splitter 130. In one embodiment, beam splitter 130 is a non-polarizing beam splitter. In another embodiment, beam splitter 130 is a polarizing beam splitter, oriented in relation to the light source 131 so as to minimize losses. The energy detector 119 is a spectroscopic energy detector capable of determining the wavelengths of incident electromagnetic energy. The wavelengths of the reflected electromagnetic energy detected by the energy detector may, in some cases, be used to determine material properties of an object being scanned in the environment. In some embodiments, the electromagnetic energy source 131 and the beam splitter 130 are moved below the beam splitter 116 in FIG. 6.

[0043] While the invention has been described with reference to example embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

CLAIMS

1. A laser scanner for optically scanning and measuring an environment, the laser scanner comprising:

a light emitter, a rotary mirror, and a light receiver, the light emitter configured to emit an emission light beam, the light receiver configured to receive a reception light beam, the emission light beam being reflected by the rotary mirror to an object in the environment, a portion of the emission light beam being reflected by the object to produce the reception light beam;

an electromagnetic energy generator configured to emit a first electromagnetic energy, a first beam splitter configured to send the first electromagnetic energy into the environment;

a second beam splitter and a spectroscopic energy detector, the second beam splitter configured to pass the first electromagnetic energy reflected by the environment to the energy detector and to pass the reception light beam to the light receiver, the spectroscopic energy detector configured to determine a plurality of wavelengths in the reflected first electromagnetic energy; and

a control and evaluation unit configured to determine, for a multitude of measuring points, a distance to the object based at least in part on the reception light beam, the control and evaluation unit further configured to link the distance to the first electromagnetic energy received by the energy detector.

2. The laser scanner of Claim 1, the control and evaluation unit further configured to determine a composition of the object based at least in part on the plurality of wavelengths in the first electromagnetic energy.

3. The laser scanner of Claim 1, the laser scanner further including a receiver lens, the reception light beam being reflected by the rotary mirror and passing through the receiver lens, the receiver lens having an optical axis.

4. The laser scanner of Claim 3, the laser scanner further including a color camera configured to take colored pictures of the environment.

5. The laser scanner of Claim 4, wherein the control and evaluation unit is further configured, for the plurality of measuring points, to link the determined distances to the colored pictures.

6. The laser scanner of Claim 4, wherein the color camera is arranged on the optical axis of the receiver lens.

7. The laser scanner of Claim 1, wherein the energy detector detects energy selected from the group consisting of infrared energy, ultraviolet energy, X-ray energy, and millimeter wave energy.

8. The laser scanner of Claim 1, wherein the first beam splitter is between the second beam splitter and the energy detector.

9. The laser scanner of Claim 1, wherein the second beam splitter is between the first beam splitter and the energy detector.

10. The laser scanner of Claim 1, further including a second lens, the second lens being placed in front of the energy detector.

11. The laser scanner of Claim 10, wherein the second lens is configured to focus the first wavelength of electromagnetic energy onto the energy detector.

12. The laser scanner of Claim 1, wherein the first beam splitter is a dichroic beam splitter.

13. The laser scanner of Claim 1, wherein the second beam splitter is a dichroic beam splitter.

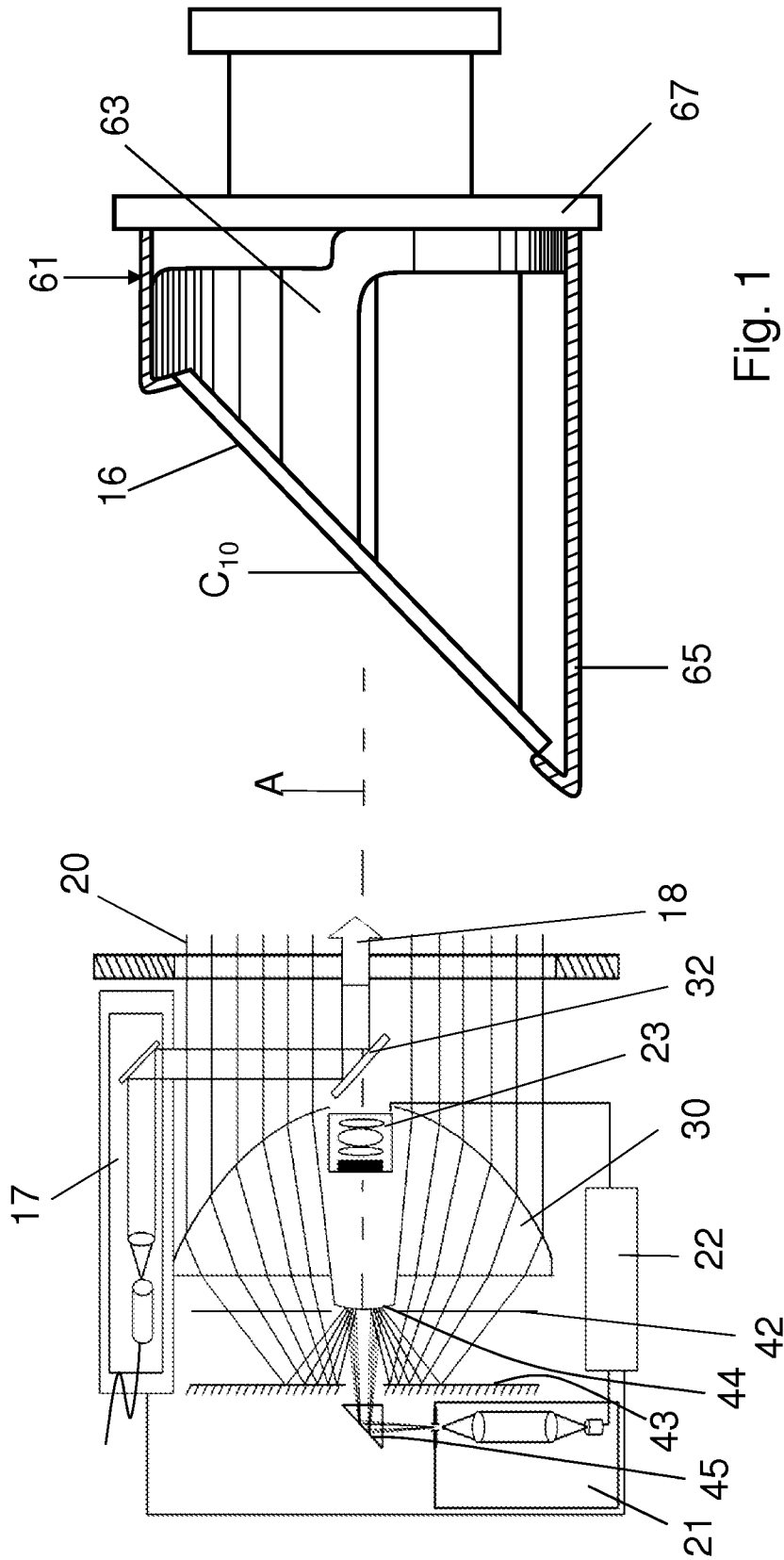


Fig. 1

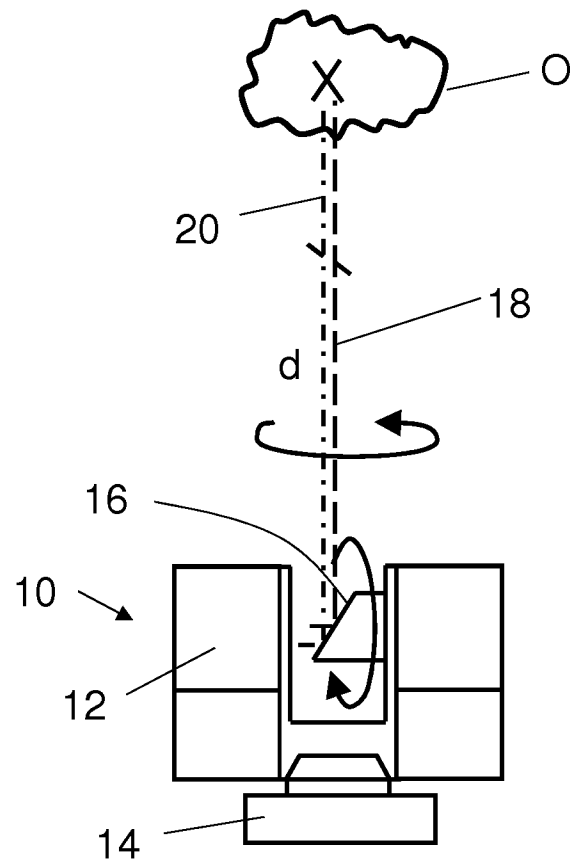


Fig. 2

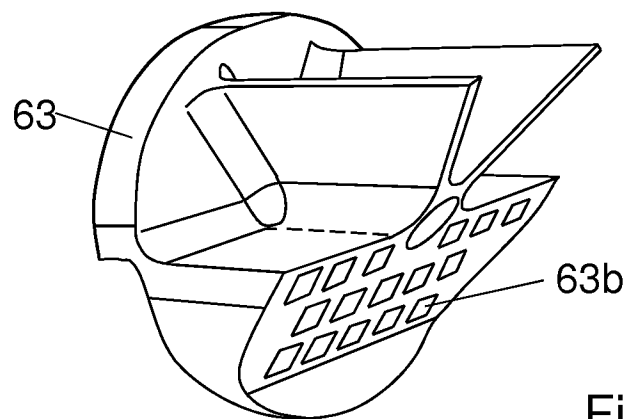


Fig. 3

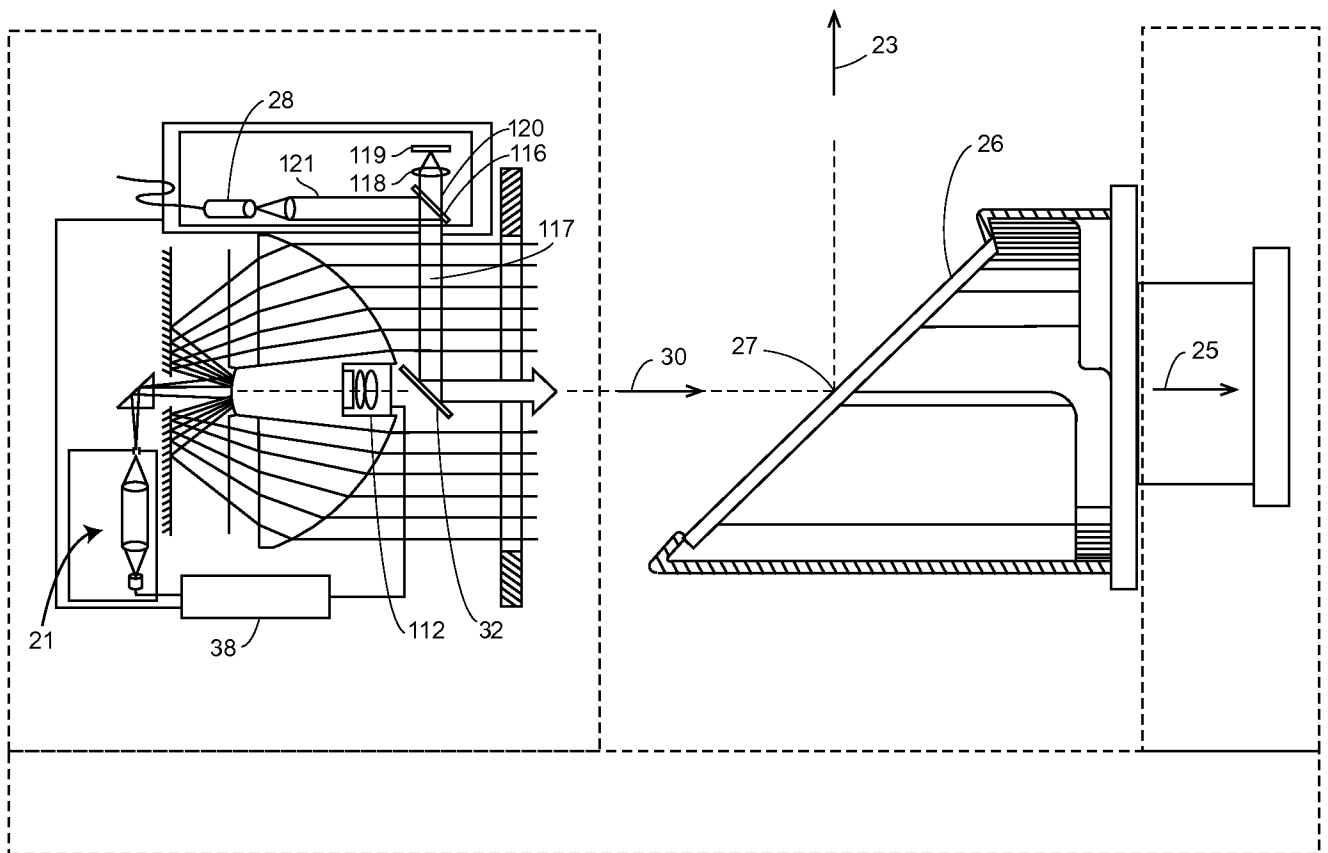


FIG. 4

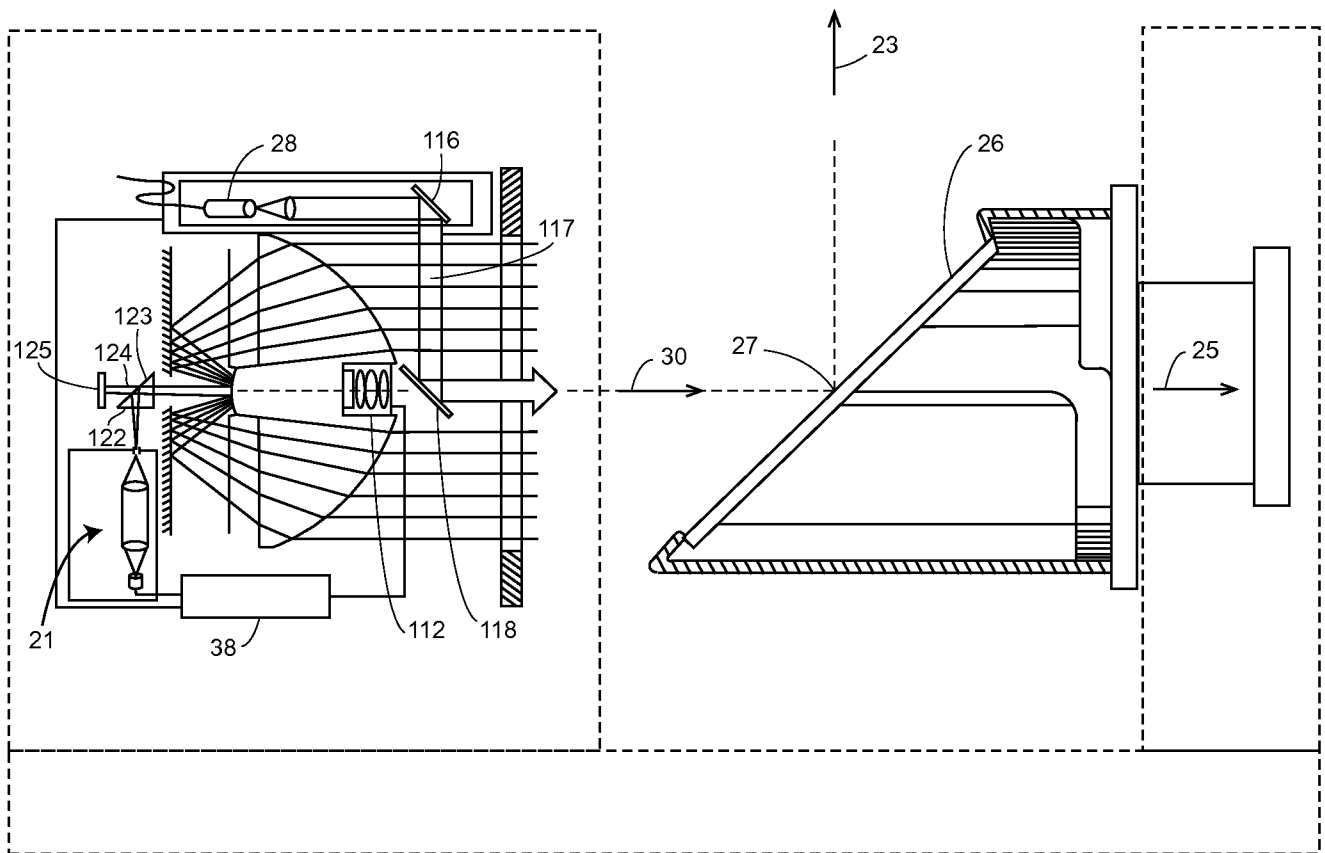


FIG. 5

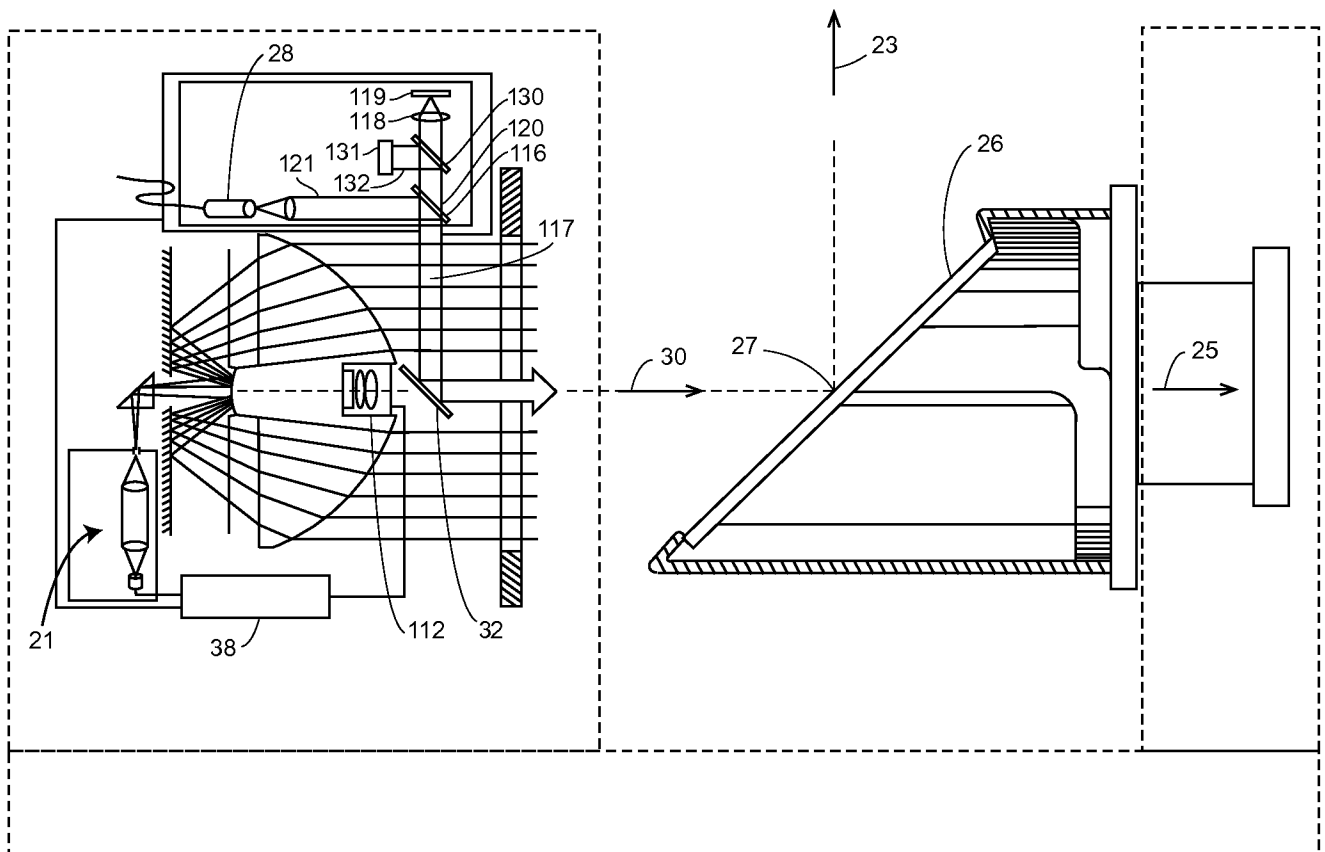


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/015737

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S7/481 G01S17/02 G01S17/42
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

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014/063489 A1 (STEFFEY KENNETH [US] ET AL) 6 March 2014 (2014-03-06) paragraph [0023] - paragraph [0031] paragraph [0043] abstract; figures 4,11 -----	1-13
A	EP 2 042 905 A1 (NIPPON KOGAKU KK [JP]) 1 April 2009 (2009-04-01) abstract; figure 1 -----	1
X,P	US 2014/362424 A1 (BRIDGES ROBERT E [US] ET AL) 11 December 2014 (2014-12-11) the whole document -----	1-13



Further documents are listed in the continuation of Box C.



See patent family annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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