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(54) **Title**: IMAGING DEVICE FOR IMAGING A SCENE USING TIME - OF - FLIGHT AND THERMOGRAPHIC MEASUREMENTS

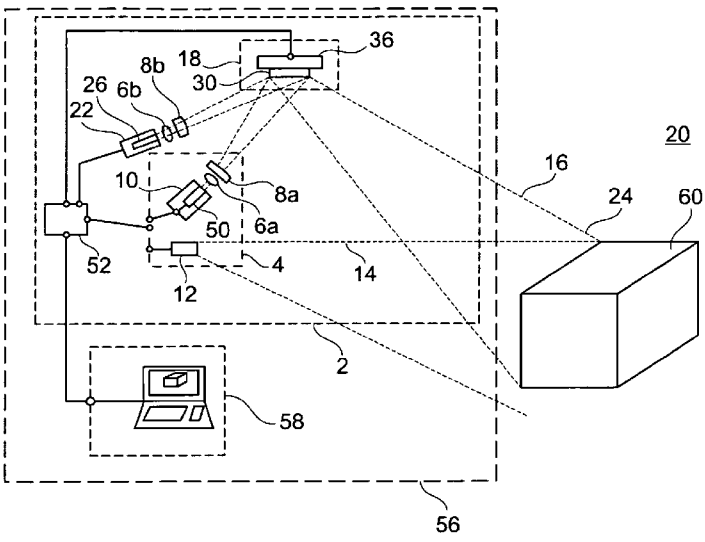


Fig. 1

(57) **Abstract**: An imaging device (2) for imaging a scene (20) comprises a range detector (4) and a scanning device (18). The range detector, which is configured to operate using the time-of-flight measurement method, includes a modulated light source (12), which emits intensity-modulated light into the scene and a light sensor (10), which receives a part of the intensity-modulated light scattered within its field of view. The light sensor is configured to carry out range measurements based on the part of intensity-modulated light it receives. The scanning device is arranged with respect to the light sensor in such a way as to scan the field of view of the light sensor through the scene. A thermographic sensor (22) configured to carry out thermographic measurements based on thermal radiation is arranged with respect to the scanning device (18) in such a way it receives thermal radiation (24) via the scanning device (18). That way, the scanning device maps the scene in a time-division multiplexed manner onto the light sensor and onto the thermographic sensor (22) as it scans the scene (20).

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IMAGING DEVICE FOR IMAGING A SCENE USING TIME - OF - FLIGHT AND THERMOGRAPHIC MEASUREMENTS

Technical field

[0001] The present invention generally relates to an imaging device, more particularly to an imager operating according to the time-of-flight principle.

Background Art

[0002] Systems for creating a 3-D representation of a given portion of space have a variety of potential applications in many different fields. Examples are automotive sensor technology (e.g. vehicle occupant detection and classification), robotic sensor technology (e.g. object identification) or safety engineering (e.g. plant monitoring, people counting and pedestrian detection) to name only a few. As opposed to conventional 2-D imaging, a 3-D imaging system requires depth information about the target scene. In other words, the distances between one or more observed objects and an optical receiver of the system need to be determined. A well-known approach for distance measurement, which is used e.g. in radar applications, consists in timing the interval between emission and echo-return of a measurement signal. This so called time-of-flight (TOF) approach is based on the principle that, for a signal with known propagation speed in a given medium, the distance to be measured is given by the product of the propagation speed and half the time the signal spends to travel back and forth.

[0003] In case of optical imaging systems, the measurement signals are light waves. For the purposes of the present description, the term “light” is to be understood as including visible, infrared (IR) and ultraviolet (UV) light. In other words, “light” is intended to cover electromagnetic radiation in the spectral range from about 10 nm to 20 μm, preferably in the range from about 100 nm to 20 μm.

[0004] Distance measurement by means of light waves generally requires varying the intensity (the amplitude) of the emitted light in time. The TOF method can e.g. be using the phase-shift technique or the pulse technique. With the phase-shift technique, the amplitude of the emitted light is periodically modulated (e.g. by sinusoidal modulation) and the phase of the modulation at emission is compared to

the phase of the modulation at reception. With the pulse technique, light is emitted in discrete pulses without the requirement of periodicity. In phase-shift measurements, the modulation period is normally in the order of twice the difference between the maximum measurement distance and the minimum measurement distance divided by the velocity of light. In this approach, the propagation time interval is determined as phase difference by means of a phase comparison between the emitted and the received light signal. Such phase comparison requires synchronization of the demodulation signal with the emitted light signal. Due to the high propagation speed given by the velocity of light, a fundamental difficulty encountered in distance measurements based on the pulse technique or the phase-shift technique resides in the required temporal resolution of the measurement device. In fact, a spatial resolution in the order of centimetres requires a temporal resolution in the order of 10^{-11} seconds (10 ps).

[0005] A method and system for acquiring a 3-D image has been proposed in the international patent application WO2008/034738. This patent application discloses a 3-D imaging system comprising an illumination unit for emitting light into a scene and an imaging sensor for imaging the scene by detecting scattered light. The system also comprises an evaluation unit, for determining distance information related to the scene on the basis of light propagation time, and synchronization means for providing synchronization information to the evaluation unit.

Technical problem

[0006] It is an object of the present invention to provide an apparatus improving detection, localization and recognition of objects. This object is achieved by an imaging device as claimed in claim 1.

General Description of the Invention

[0007] According to the invention, an imaging device for imaging a scene comprises a range detector and a scanning device. The range detector, which is configured to operate using the time-of-flight measurement method, includes a modulated light source, which emits intensity-modulated light into the scene and a light sensor, which receives a part of the intensity-modulated light scattered within its field of view. The light sensor is configured to carry out range measurements

(distance measurements) based on the part of intensity-modulated light it receives. The imaging device comprises a scanning device arranged with respect to the light sensor in such a way as to scan (sweep) the field of view of the light sensor through the scene. That way, the scanning device maps the scene onto the light sensor in a time-division multiplexed manner, i.e. different points of the scene are imaged at different times.

[0008] A thermographic sensor configured to carry out thermographic measurements based on thermal radiation received from the scene is arranged with respect to the scanning device in such a way that the thermographic sensor receives thermal radiation from the scene via the scanning device. In that way, the scene is mapped onto the thermographic sensor in a time-division multiplexed manner when the scanning device scans the scene. Any object in the scene emits thermal radiation induced by its temperature. The thermographic sensor is preferably configured to detect light having wavelengths within the range from 1 to 20 μm and particularly from 5 to 14 μm. It is to be noted that human beings usually emit light having wavelengths within the range from 5 to 14 μm. Preferably, the thermographic sensor is an infrared light sensor, such as e.g. a pyroelectric sensor or an infrared photodiode or a thermopile.

[0009] Alternatively or additionally, the imaging device may comprise an RGB (red – green – blue) sensor configured to determine RGB values of visible light coming from the scene. The RGB sensor is arranged with respect to the scanning device in such a way that it receives the visible light via the scanning device. In that way, the scene is mapped onto the RGB sensor in a time-division multiplexed manner when the scanning device scans the scene. That way a colour image of the scene is obtained in addition to the range image.

[0010] The range detector itself may be configured to carry out measurements of the thermal radiation background and thus implement the thermographic sensor. The light incident on the range detector can be decomposed in two parts, i.e. a first part, which corresponds to the thermal background, i.e. thermal radiation originating from the objects in the scene, and a second part, which corresponds to intensity-modulated light originating from the modulated light source and back-scattered by the objects in the scene.

[0011] Preferably, the scanning device comprises a resonance-type micro-mechanical mirror mounted on first torsion bars and an actuator. These first torsion bars define a first tilting axis, about which an actuator drives the micro-mechanical mirror in angular oscillatory motion.

[0012] According to a variant of this embodiment, the micro-mechanical mirror and the first torsion bars are mounted on second torsion bars. These second torsion bars define a second tilting axis. The actuator is, in this variant, configured for driving the micro-mechanical mirror in a two-dimensional angular oscillatory motion about the first and the second tilting axis. The micro-mechanical mirror thus achieves a two-dimensional scanning curve when driven by the actuator. This curve can be a Lissajou curve.

[0013] According to another variant of this embodiment, the scanning device comprises a second resonance-type micro-mechanical mirror mounted on second torsion bars and a second actuator. The second torsion bars define a second tilting axis, and the second actuator is configured to drive the second micro-mechanical mirror in angular oscillatory motion about the second tilting axis. The first and second tilting axis are chosen relative to one another such that the micro-mechanical mirrors jointly achieve a two-dimensional scanning curve when their respective actuators drive them. This curve can be a Lissajou curve. Furthermore, an intermediary mirror can be arranged in the light path between the micro-mechanical mirrors.

[0014] Preferably, the light sensor comprises at least one lock-in light sensor synchronized with the modulated light source and configured to carry out the range measurement based on phase-sensitive detection of the received part of the intensity-modulated light.

[0015] The imaging device preferably comprises a controller, which is operatively connected to the range detector and to the scanning device to control both of them.

[0016] The controller preferably computes a range image of the scene by associating each range measurement, and, possibly, each thermographic measurement or thermal radiation background measurement, with a corresponding position within the scene.

[0017] The imaging device is preferably implemented in a computer vision system comprising further a processor operatively connected to the imaging device. The processor receives measurement data from the imaging device. These measurement data including range measurement data, and possibly thermographic measurement data. By computing these data, the processor can recognize objects and/or positions of objects in the scene on the basis of the measurement data.

Brief Description of the Drawings

[0018] Further details and advantages of the present invention will now be described, from the following detailed description of several not limiting embodiments with reference to the accompanying drawings, wherein:

Fig. 1 is a schematic layout of a computer vision system comprising an imaging device according to a first preferred embodiment of the invention and a scanned scene;

Fig. 2 is a schematic layout of a computer vision system comprising an imaging device according to a second preferred embodiment of the invention and a scanned scene;

Fig. 3 is a schematic front view of a resonance-type micro-mechanical mirror with two tilting axes;

Fig. 4 is a two-dimensional scanning curve (Lissajou curve) produced in an imaging device according to Fig. 1 or Fig. 2 by means of a scanning device that comprises a resonance-type micro-mechanical mirror as represented in Fig. 3;

Fig. 5 is a graph representing intensity of detected light as a function of time;

Fig. 6 is a schematic front view of a first resonance-type micro-mechanical mirror of the imaging device as represented in Fig. 2; and

Fig. 7 is a schematic front view of a second resonance-type micro-mechanical mirror of the imaging device as represented in Fig. 2;

Fig. 8 is a schematic layout of an imaging device according to a third preferred embodiment of the invention and a scanned scene;

Fig. 9 is a schematic layout of an imaging device according to a fourth preferred embodiment of the invention and a scanned scene.

Description of Preferred Embodiments

[0019] Fig. 1 shows a computer vision system 56 comprising a processor 58 operatively connected to an imaging device 2 for recognizing and localizing objects 60 present in a scene 20 according to size, shape, position in the scene 20 and temperature. The imaging device 2 is placed in front of a scene 20 to be imaged. The imaging device 2 sends data including range measurement data and thermographic measurement data to the processor 58. These data are used by the processor (58) to build images of the objects 60. The imaging device 2 interacts with the processor 58 by means of a controller 52 that is comprised in the imaging device 2. To ensure smooth and efficient operation of the imaging device 2, the controller 52 is connected to a scanning device 18, to a thermographic sensor 22, to a range detector 4 and to a processor 58. For acquiring range images (i.e. images with depth or distance information) of the concerned scene 20, the controller controls the range detector 4 and the scanning device 18. In addition, the controller 52 acquires thermographic images by controlling the thermographic sensor.

[0020] To obtain range data, the range detector 4 operates according to the time-of-flight measurement principle. To this end, infrared intensity-modulated light 14 is emitted by a light source 12. The modulated IR light has a wavelength comprised in the wavelength range from 0.7 to 20 μm. The modulated light source 12 emits infrared intensity-modulated light 14 into the scene 20. A part of this light is scattered back to the imaging device 2 and deviated by the scanning device 18 in direction of the range detector 4. The range detector 4 includes a lock-in light sensor 50. The received part of intensity-modulated light 16 is mapped by the scanning device 18 on the lock-in sensor 50 through a range detector filter 8a, which filters out light of undesired wavelengths, and through a range detector lens 6a focusing light on the lock-in sensor 50. The time-of-flight measurement principle involves knowing the relative positions of the modulated light source 12, the scanning device 18, the range detector lens 6a and the lock-in sensor 50. The lock-in sensor 50 is synchronized with the modulated light source to detect the difference in modulation phase between emitted and received light. The range data allow computing three-dimensional

images (i.e. images having rows and columns of pixels, wherein each pixel contains distance information).

[0021] To obtain thermographic data, the thermographic sensor 22 includes an infrared light sensor 26. This sensor 26 is sensitive to the mid- and long-wavelength infrared range, about 5 to 14 μm, A part of the thermal radiations 24 emitted from objects or living beings within the scene 20 are deviated by the scanning device 18 on the thermographic sensor 22. The thermal radiations 24 are mapped by the scanning device 18 on the light sensor 26 through a thermal sensor filter 8b, which filters out light of undesired wavelengths, and through a thermal sensor lens 6b focusing on the infrared light sensor 26. Each thermographic data point is associated to a point in the scene 20 based on the position of the scanning device 18 relatively to the infrared light sensor 26. On the basis of range and thermographic data, the microprocessor 58 can compute three-dimension images and thermographic images. The processor 58 can use these images separately to achieve automatic recognition according to shape and dimension or according to temperature. An improved solution combines these two kinds of images with the help of the processor 58 for ensuring extremely reliable recognition, especially for human beings.

[0022] In the embodiment of Fig. 1, the range detector 4 and the thermographic sensor 22 operate at different wavelengths. Range detector filter 8a is thus used to filter out, inter alia, most of the thermal radiation originating from objects or living beings in the scene. Likewise, thermal sensor filter 8b filters out, inter alia, the wavelength of the intensity-modulated light emitted by the modulated light source.

[0023] Intensity-modulated light backscattered from the scene 16 and thermal radiation 24 are mapped in a time-division multiplexed manner on both the lock-in light sensor 50 and the infrared light sensor 26. The imaging device 2 achieves the scan of the scene 20 by means of a scanning device 18. The scanning device 18 comprises a resonance-type micro-mechanical mirror 30.

[0024] An example of a resonance-type micro-mechanical mirror 30 is shown in more detail in Fig. 3. The actuator (36, see Fig. 1) drives the resonance-type micro-mechanical mirror 30, which includes a mobile reflecting surface 66. The reflecting surface is mounted on first torsion bars 32, 32', which define a first tilting axis 42. The first torsion bars 32, 32' connect the micro-mechanical mirror 30 to an intermediate

frame 74, which is itself mounted on second torsion bars 38, 38'. The second torsion bars 38, 38' define a second tilting axis 40, which is preferably orthogonal to the first tilting axis 42. The second torsion bars 38, 38' connect the intermediate frame 74 to an outer frame 76. The micro-mechanical mirror 30, the intermediate and outer frames 74,76 and the torsion bars 32, 32', 38, 38' are preferably formed from the same substrate. The actuator 36 and the micro-mechanical mirror 30 comprise electromagnetic elements (e.g. coils or conductor loops, or capacitor plates) and possibly also permanent-magnetic elements to exert forces and torques onto the micro-mechanical mirror 30, causing the latter to leave its equilibrium position, in which the sum of mechanical forces (here: the force of torsion bars 32, 32', 38, 38') acting thereon cancels. In operation, the actuator 36 thus applies oscillating signals to the electromagnetic elements, which create periodically inverting electric and/or magnetic forces and torques that act on the micro-mechanical mirror 30 and cause it to tilt to and fro about the first axis 42. Simultaneously, the actuator 6 causes the intermediate frame to tilt to and fro about the second tilting axis 40 under the action of electric and/or magnetic forces and torques. As a result, the micro-mechanical mirror 30 carries out a movement in two dimensions corresponding to the superposition of two simple oscillatory movements. The actuator 36 is controlled and/or configured to drive both movements at or close to their respective resonance frequency in order to achieve optimal excursion of the micro-mechanical mirror 30 in both directions at low power consumption. The two-dimensional scanning curve (43, see Fig. 4) described by the micro-mechanical mirror 30 is a Lissajou curve.

[0025] It should be noted that in the embodiment of Fig. 1, the scene is illuminated as a whole. Preferably, however, the scene is illuminated by a light beam that is swept through the scene via the scanning mirror and that illuminates only the spot in the scene that is currently seen by the range detector, because this reduces the overall needed power of light. Such embodiments of the invention are shown in Figs. 8 and 9 and described hereinafter.

[0026] Fig. 2 shows a second embodiment of a computer vision system 256 with a processor 258 connected to an imaging device 202. The system 256 is configured for recognizing and localizing targets 260, such as objects and living beings, present in a scene 220, based on size, shape, position in the scene 220 and temperature. The

imaging device 202 provides data including range measurement data and thermographic measurement data to the processor 258. The processor 258 uses these data to build images of the targets 260. The imaging device 202 interacts with the processor 258 by means of a controller 252. To ensure smooth and efficient operation, the controller 252 coordinates a scanning device 218 and a range detector 204 with the processor 258.

[0027] To obtain range data, the range detector 204 functions according to the time-of-flight measurement principle. The infrared intensity-modulated light 214 emitted by the source 212 has a wavelength in the mid- and long-wavelength infrared range, with wavelengths from about 5 to about 14 μm. The modulated light source 212 emits infrared intensity-modulated light 214 onto the scene 220. Part of this light is backscattered to the imaging device 202 and, more specifically, deviated by the scanning device 218 onto the range detector 204. The range detector 204 includes a light sensor 250 of the lock-in type sensitive to the specific wavelength of the modulated light. The scanning device 218 reflects light onto the lock-in sensor 250 through a range detector filter 208a, which filters out light of undesired wavelengths, and through a range detector lens 206a focusing on the lock-in sensor 250. The lock-in sensor 250 is synchronized with the modulated light source 212 to detect the difference in modulation phase between emitted and received light. The range data allow computing three-dimensional images (i.e. images having rows and columns of pixels, wherein each pixel contains distance information).

[0028] Since, according the embodiment of Fig. 2, the range detector 204 comprises a lock-in sensor 250 that is sensitive to infrared light in the mid- and long-wavelength infrared range, it is itself configured to acquire thermographic data in addition to the range data. Thermal radiation 224 from the scene 220 thus reaches the range detector 204 in the same manner as the modulated light that is backscattered from the scene. Accordingly, in the system 256, the scanning device 218 redirects both thermal radiation 224 and modulated light backscattered from the scene 220 onto the range detector 204, more specifically onto the lock-in sensor 250.

[0029] On the basis of range data and thermographic data obtained via the same lock-in sensor 250, the microprocessor 258 can compute three-dimensional images and/or thermographic images. The processor 258 uses these images to achieve

automatic target recognition according to shape and dimension or according to temperature, preferably by combining the two kinds of image.

[0030] Basically the intensities of thermal radiations 224 and of the backscattered intensity-modulated light 216 are additively superposed (see Fig. 5). The lock-in light sensor 250 thus receives light, which, in terms of intensity, corresponds to the sum of the intensity of the thermal background radiation and the intensity of the backscattered modulated light. Undesired wavelengths are filtered out by the filter 208a. The temperature information may be retrieved from the thermal background (indicated by reference number 80 in Fig. 5). The controller extracts the thermal background intensity 80 using the following relation:

$$I_{ij}(t) = A_{ij} \cdot \sin(\omega t + \varphi) + B_{ij}$$

where :

t represents time;

i and j indicate the position of a specific point in the scene 220;

$I_{ij}(t)$ is the overall intensity of the light received at the lock-in light sensor 250 ($I_{ij}(t)$ is indicated by reference number 78 in Fig. 5);

A_{ij} is the amplitude of the modulation at reception;.

ω is the modulation frequency

φ is the phase corresponding to the time needed by the intensity-modulated light 214 to travel from the range detector to a point in the scene and back; and

B_{ij} is an offset equal to the sum of background intensity and modulation amplitude.

[0031] Intensity-modulated light scattered in the scene 216 and thermal radiations 224 are mapped in a time-division multiplexed manner on the lock-in light sensor 250.

[0032] The imaging device 202 achieves a time-multiplexed scan of the scene 220 by means of a scanning device 218. In the second embodiment, the scanning device 218 comprises two distinct single-axis resonance-type micro-mechanical mirrors 230,

262, driven by a first actuator 236 and a second actuator 246 respectively. The two micro-mechanical mirrors 230, 262 are schematically shown in Fig. 6 and in Fig. 7, respectively. As seen in Fig.2, an intermediary mirror 264 is arranged in the light path of light reflected by the second micro-mechanical mirror 262 in order to redirect light onto the first micro-mechanical mirror 230.

[0033] The first resonance-type micro-mechanical mirror 230 provides a mobile reflecting surface 268 driven by the first actuator 236 and arranged to direct light onto the lock-in sensor 250. The first resonance-type micro-mechanical mirror 230 has one set of torsion bars 232, 232' that define a first single tilting axis 242 e.g. a horizontal axis. Similarly, in the second micro-mechanical mirror 262 seen in Fig. 7, the mobile reflecting surface 270 is also mounted on a single set second torsion bars 238, 238' that define a second single tilting axis 240, e.g. a vertical axis. The second actuator 246 drives the second micro-mechanical mirror 262, whose mobile reflecting surface 270 directs light, via the intermediary mirror 264 onto the first micro-mechanical mirror 230. The mirrors 230, 262 are preferably arranged and configured in such a way that their individual tilting axes 242 are orthogonal to each other. In each mirror, the torsion bars 232, 232'; 238, 238' respectively connect the reflecting surface 268; 270 to a respective outer frame 276; 277. Also, the torsion bars 232, 232'; 238, 238', the reflecting surface 268; 270 and the outer frame 276; 277 are preferably formed from the same substrate.

[0034] The actuators 236, 246 respectively comprise electromagnetic elements (e.g. coils or conductor loops, or capacitor plates – not shown) and possibly also permanent-magnetic elements, to exert forces and torques onto the torsion bars 232, 232'; 238, 238' so as to cause the reflecting surface 268; 270 to tilt to and fro about the first and the second axis 242, 240 respectively. During operation of the two micro-mechanical mirrors 230; 262, the reflecting surfaces 268; 270 oscillate in resonance simultaneously about their respective tilting axis. The controller 252 accordingly operates the actuators 236, 246 and actuates the mirrors 230; 262 at or close to their respective resonance frequency. The linear combination of the synchronous oscillatory movements of the two micro-mechanical mirrors 230; 262 provides the scanning curve used to map the scene 220 onto the range detector 204. In order to obtain a two-dimensional image in similar manner to the first embodiment, the two

mirrors 230, 262 of the scanning device 218 of Fig.2 thus also map the scanned scene 220 in time-multiplexed manner onto the range detector 204. The resulting scanning curve is also a Lissajou curve as illustrated in Fig.5.

[0035] The differing features of the first and second embodiments may also be combined vice-versa, e.g. with the independent thermal and lock-in sensors of Fig. 1 in combination with the independent single-axis mirrors of Fig. 2, or with a common thermal and range detection sensor of Fig. 2 combined with a two-axis micro-mechanical mirror of Fig. 1. As will be appreciated, either combination warrants the main improvement of achieving more reliable target recognition.

[0036] Fig. 8 shows a schematic layout of an imaging device 802 according to a third preferred embodiment of the invention. The imaging device of Fig. 8 is a combined 3D and thermographic imager. Its range imager comprises a laser source 812 as a source of intensity modulated light and a light sensor 810. The laser 812 emits a pencil beam 813 (i.e. a narrow beam having little divergence) into the scene 820 to be imaged via an oscillating scanning mirror 818 arranged in the light path of the laser beam 813. The laser beam thus successively illuminates punctiform spots 815 in the scene 820 as it is swept there through. Between the laser source 812 and the scanning mirror 818, the pencil beam 813 passes an opening 819 arranged in a static deflection and focussing mirror 864, which directs light that is scattered back from the scene onto the light sensor 810. When in operation, the scanning mirror 818 thus simultaneously sweeps the punctiform illuminated spot 815 and the field of view of the light sensor 810 through the scene 820. The light sensor 810 is arranged in such a way that the centre of its field of view essentially corresponds to the punctiform spot 815 in the scene (independently of the position of the scanning mirror). The sweeping is preferably effected according to a Lissajou pattern, as discussed hereinabove with reference to Fig. 4.

[0037] To obtain range data, the range detector operates according to the time-of-flight measurement principle. To this end, the intensity-modulated laser beam 813 (e.g. a sinusoidally modulated or pulsed laser beam) is emitted by the laser source 812. The wavelength of the laser is comprised in the wavelength range from 0.7 to 20 μm. A part of the intensity-modulated light is scattered back to the imaging device 802 and deviated via the scanning mirror 818 in direction of the light sensor 810. The

light sensor may e.g. be a lock-in light sensor, as disclosed, for instance, in T. Spirig's doctoral thesis "Smart CDD/CMOS Based Image Sensors with Programmable Real-Time, Temporal and Spatial Convolution Capabilities for Applications in Machine Vision and Optical Metrology" (Diss ETH 11993, 1997). Alternatively, especially in case of a pulsed laser beam, the light sensor could be a photosensitive gate to which a time-to-digital converted is operatively connected.

[0038] The imaging device of Fig. 8 also comprises a thermographic sensor 822 arranged in such a way that it sees the scene 820 via the deflection mirror 864 and the scanning mirror 818 under at most a slightly different angle than the light sensor 810. The thermographic sensor 822 is thus arranged with respect to the scanning mirror 828 in such a way that it receives thermal radiation via the scanning mirror.

[0039] As the scanning mirror 818 scans the fields of view of both the light sensor 810 and the thermographic sensor 822 through the scene 820, the scene 820 is mapped onto the light sensor 810 and the thermographic sensor 822, respectively, in a time-division multiplexed manner.

[0040] The imaging device 802 comprises a microcontroller 853 that controls and coordinates operation of the scanning mirror 818, the laser source 812, the light sensor 810 and the thermographic sensor 822.

[0041] In Fig. 8, a single scanning mirror 818 is shown. This is preferably a resonance-type micro-mechanical mirror as shown in Fig. 3. Alternatively, one could also use two distinct single-axis resonance-type micro-mechanical mirrors (as explained with reference to Figs. 2, 6 and 7), driven by a first actuator and a second actuator, respectively.

[0042] The imaging device 802 of Fig. 8 could e.g. be used to replace the imaging device of the computer vision system of Fig. 1.

[0043] Fig. 9 shows a schematic layout of an imaging device 902 according to a fourth preferred embodiment of the invention. The imaging device 902 is a combined 3D and thermographic imager. It comprises a laser source 912 as a source of intensity modulated light and a light sensor 910. The laser 912 emits a pencil beam 913 into the scene 920 to be imaged by means of an oscillating scanning mirror 918 arranged in the light path of the laser beam 913. The laser beam 913 thus

successively illuminates punctiform spots 915 in the scene 920 as it is swept there through. Between the laser source 912 and the scanning mirror 918 , the pencil beam 913 passes an opening 919 arranged in a static deflection and focussing mirror 964, which directs light that is scattered back from the scene 920 onto the light sensor 910. When in operation, the scanning mirror 918 thus simultaneously sweeps the puntiform illuminated spot 915 and the field of view of the light sensor 910 through the scene 920. The light sensor 910 is arranged in such a way that the centre of its field of view essentially corresponds to the punctiform spot 915 in the scene 920 (independently of the position of the scanning mirror). The sweeping is preferably effected according to a Lissajou pattern, as discussed hereinabove with reference to Fig. 5.

[0044] To obtain range data, the range detector operates according to the time-of-flight measurement principle. To this end, the intensity-modulated laser beam 913 (e.g. a sinusoidally modulated or pulsed laser beam) is emitted by the laser source 912. The wavelength of the laser is preferably comprised in the wavelength range from 5 to 14 μm. A part of the intensity modulated light is scattered back to the imaging device 902 and deviated via the scanning mirror 918 in direction of the light sensor 910. The light sensor 910 is preferably a lock-in light sensor, as disclosed, for instance, in T. Spirig's doctoral thesis "Smart CDD/CMOS Based Image Sensors with Programmable Real-Time, Temporal and Spatial Convolution Capabilities for Applications in Machine Vision and Optical Metrology" (Diss ETH 11993, 1997). Alternatively, especially in case of a pulsed laser beam, the light sensor could be a photosensitive gate to which a time-to-digital converted is operatively connected.

[0045] The light sensor is sensitive to infrared light at the wavelength of the laser light. It is configured to acquire thermographic data in addition to range data. Thermal radiation from the scene reaches the light sensor 910 in the same manner as the modulated laser light that is backscattered from the scene 920. The thermal radiation and the reflected laser light are additively superposed at the light sensor as explained hereinabove with reference to Fig. 5. The measurements carried out with the light sensor 910 allow separating the thermal radiation (background) from the reflected modulated laser light.

[0046] As the scanning mirror scans the fields of view of the light sensor 910 through the scene 920, the scene 920is mapped onto the light sensor in a time-division multiplexed manner.

[0047] The imaging device 902 comprises a microcontroller 952 that controls and coordinates operation of the scanning mirror 918, the laser source 912 and the light sensor 910.

[0048] In Fig. 9, a single scanning mirror 918 is shown. This is preferably a resonance-type micro-mechanical mirror as shown in Fig. 3. Alternatively, one could also use two distinct single-axis resonance-type micro-mechanical mirrors (as explained with reference to Figs. 2, 6 and 7), driven by a first actuator and a second actuator, respectively.

[0049] The imaging device of Fig. 9 could e.g. be used to replace the imaging device of the computer vision system of Fig. 2.

[0050] While specific embodiments have been described in detail, those with ordinary skill in the art will appreciate that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.

Legend:

2/202/802/902	Imaging device
4/204	Range detector
6a/206a	Range detector lens
6b	Thermal sensor lens
8a/208a	Range detector filter
8b	Thermal sensor filter
10/210/810/910	Light sensor
12/212/812/912	Modulated light source
14/214	Intensity-modulated light
16/216	Received part of intensity-modulated light
18/218/818/918	Scanning device
20/220/820/920	Scene
22/822	Thermographic sensor
24/224	Thermal radiations
26	Infrared light sensor
30	Resonance-type micro-mechanical mirror
230	First resonance-type micro-mechanical mirror
32/32'/232/232'	First torsion bar
42/242	First tilting axis
36/236	Actuator
38/38'/238/238'	Second torsion bar
40/240	Second tilting axis
43	Two-dimensional scanning curve
262	Second resonance-type micro-mechanical mirror
246	Second actuator
264	Intermediary mirror
50/250	Lock-in light sensor
52/252/852/952	Controller
56/256	Computer vision system
58/258	Processor
60/260	Objects
66	Reflecting surface of the resonance-type micro-mechanical mirror

268	Reflecting surface of the first resonance-type micro-mechanical mirror
270	Reflecting surface of the second resonance-type micro-mechanical mirror
272	Reflecting surface of the intermediary mirror
74	Intermediary frame
76	Outer frame of the resonance-type micro-mechanical mirror
276	Outer frame of the first resonance-type micro-mechanical mirror
277	Outer frame of the second resonance-type micro-mechanical mirror
78	Common signal
80	Background signal
82	Sampling points
84/86	Dotted boxes
88/90	Resampled stereoscopic half-images
813/913	Pencil beam
815/915	Punctiform spot
819/919	Opening
864/964	Deflection and focussing mirror

Claims

1. Imaging device (2, 202) for imaging a scene (20, 220) comprising
a range detector (4, 204) configured for operating according to the time-of-flight measurement principle, said range detector (4, 204) including a modulated light source (12, 212) configured to emit intensity-modulated light (14, 214) into said scene (20, 220) and a light sensor (10, 210) configured to receive a part of said intensity-modulated light (16, 216) scattered within a field of view thereof and to carry out range measurements based on said received part of intensity-modulated light (16, 216); and
a scanning device (18, 218) arranged with respect to said light sensor (10, 210) to scan the field of view of said light sensor (10, 210) through said scene (20, 220) in such a way as to map said scene (20, 220) onto said light sensor (10, 210) in a time-division multiplexed manner,
characterized in that said imaging device (2, 202) comprises a thermographic sensor (22) configured to carry out thermographic measurements based on thermal radiation (24, 224) received from said scene (20, 220), said thermographic sensor (22) being arranged with respect to said scanning device (18, 218) in such a way that said thermographic sensor (22) receives said thermal radiation (24, 224) via said scanning device (18, 218) and that said scene (20, 220) is mapped onto said thermographic sensor (22) in a time-division multiplexed manner as said scanning device (18, 218) scans said scene (20, 220).

2. Imaging device (2, 202) according to claim 1, wherein said thermographic sensor (22) comprises an infrared light sensor (26), such as e.g. a pyroelectric sensor or an infrared photodiode or a thermopile.

3. Imaging device (2, 202) according to claim 1 or 2, wherein said received part of intensity-modulated light (16, 216) comprises a thermal radiation (24, 224) background and wherein said range detector (4, 204) implements said thermographic sensor (22) by being configured to carry out measurements of said thermal radiation (24, 224) background.

4. Imaging device (2, 202) according to any one of claims 1 to 3, wherein said scanning device (18, 218) comprises a resonance-type micro-mechanical (30, 230) mirror mounted on first torsion bars (32, 32', 232, 232') defining a first tilting axis (42, 242) and an actuator (36, 236) for driving said micro-mechanical mirror (30, 230) in angular oscillatory motion about said first tilting axis (42, 242).

5. Imaging device (2, 202) according to claim 4, wherein said micro-mechanical mirror (30) and said first torsion bars (32, 32') are mounted on second torsion bars (38, 38') defining a second tilting axis (40), and wherein said actuator (36) is configured for driving said micro-mechanical mirror (30) in a two-dimensional angular oscillatory motion about said first tilting axis (42) and said second tilting axis (40) to achieve a two-dimensional scanning curve (43).

6. Imaging device (2, 202) according to claim 4, wherein said scanning device (18, 218) comprises a second resonance-type micro-mechanical mirror (262) mounted on second torsion bars (238, 238'), said second torsion bars (238, 238') defining a second tilting axis (240), and a second actuator (246) configured for driving said second micro-mechanical mirror (262) in angular oscillatory motion about said second tilting axis (240), and wherein said first and second tilting axes (242, 240) are chosen relative to one another such that said micro-mechanical mirrors (230, 262) jointly achieve a two-dimensional scanning curve (43) when driven by their respective actuators (236, 246).

7. Imaging device (2, 202) according to claim 6, wherein said scanning device (18, 218) comprises an intermediary mirror (264) arranged in a light path between said micro-mechanical mirrors (230, 262).

8. Imaging device according to any one of claims 5 to 6, wherein said two-dimensional scanning curve corresponds to a Lissajou curve.

9. Imaging device (2, 202) according to any one of claims 1 to 8, wherein said light sensor (10, 210) comprises at least one lock-in light sensor (50, 250) synchronized with said modulated light source (12, 212), said lock-in sensor (50, 250) being configured to carry out said range measurement based on phase-sensitive detection of said received part of intensity-modulated light (16, 216).

10. Imaging device (2, 202) according to any one of claims 1 to 9, comprising a controller (52, 252) operatively connected to said range detector (4, 204) and to said scanning device (18, 218) for controlling operation thereof.

11. Imaging device (2, 202) according to claim 10, said controller (52, 252) being configured to compute a range image of said scene (20, 220) by associating each range measurement with a corresponding position within said scene (20, 220).

12. Imaging device (2, 202) according to claim 10 or 11, wherein said controller (52, 252) is configured to compute a thermographic image of said scene (20, 220) by associating each thermographic measurement with a corresponding position within said scene (20, 220).

13. Imaging device (2, 202) according to claim 3 in combination with claim 10 or 11, wherein said controller (52, 252) is configured to compute a thermographic image of said scene (20, 220) by associating each thermal radiation (24, 224) background measurement with a corresponding position within said scene (20, 220).

14. Computer vision system (56, 256) comprising an imaging device (2, 202) according to any one of claims 1 to 13 as well as a processor (58, 258) operatively connected to said imaging device (2, 202) for receiving measurement data including range measurement data, and possibly thermographic measurement data, said processor (58, 258) being configured for recognizing objects (60, 260) and/or positions of objects (60, 260) in said scene (20, 220) based on said measurement data.

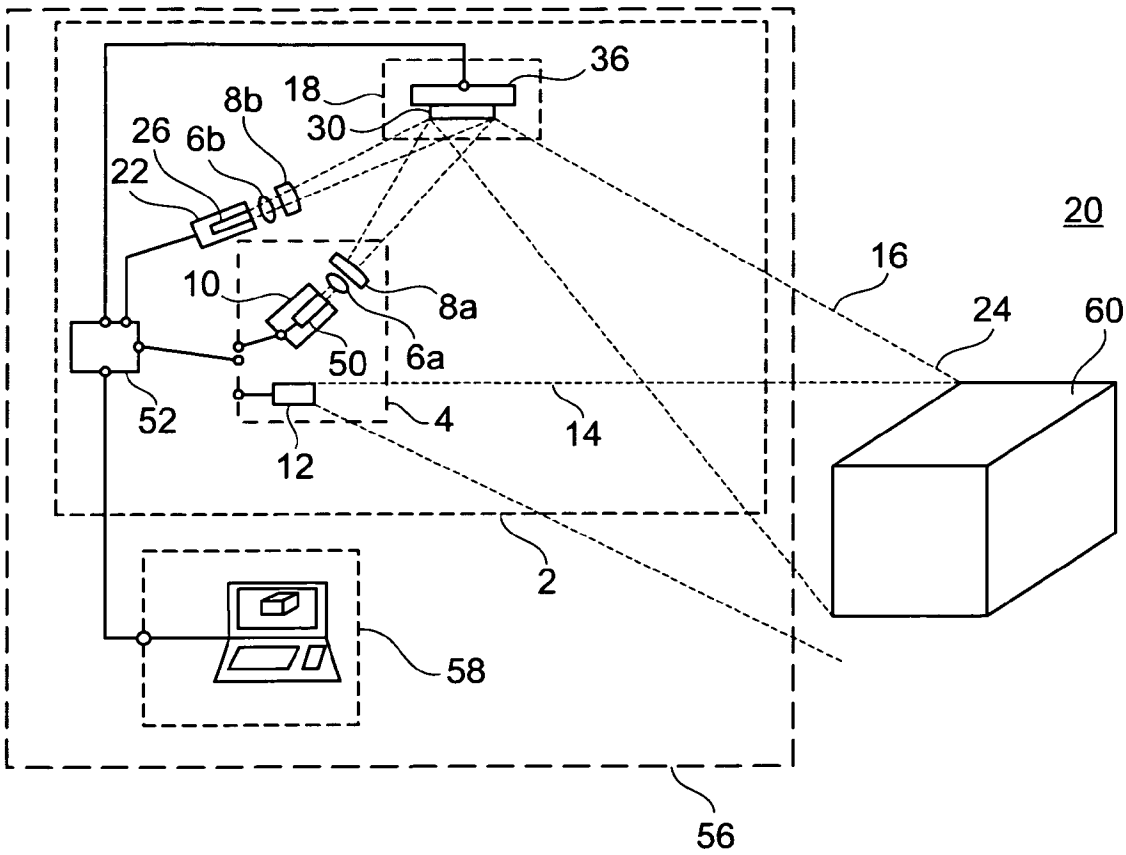


Fig. 1

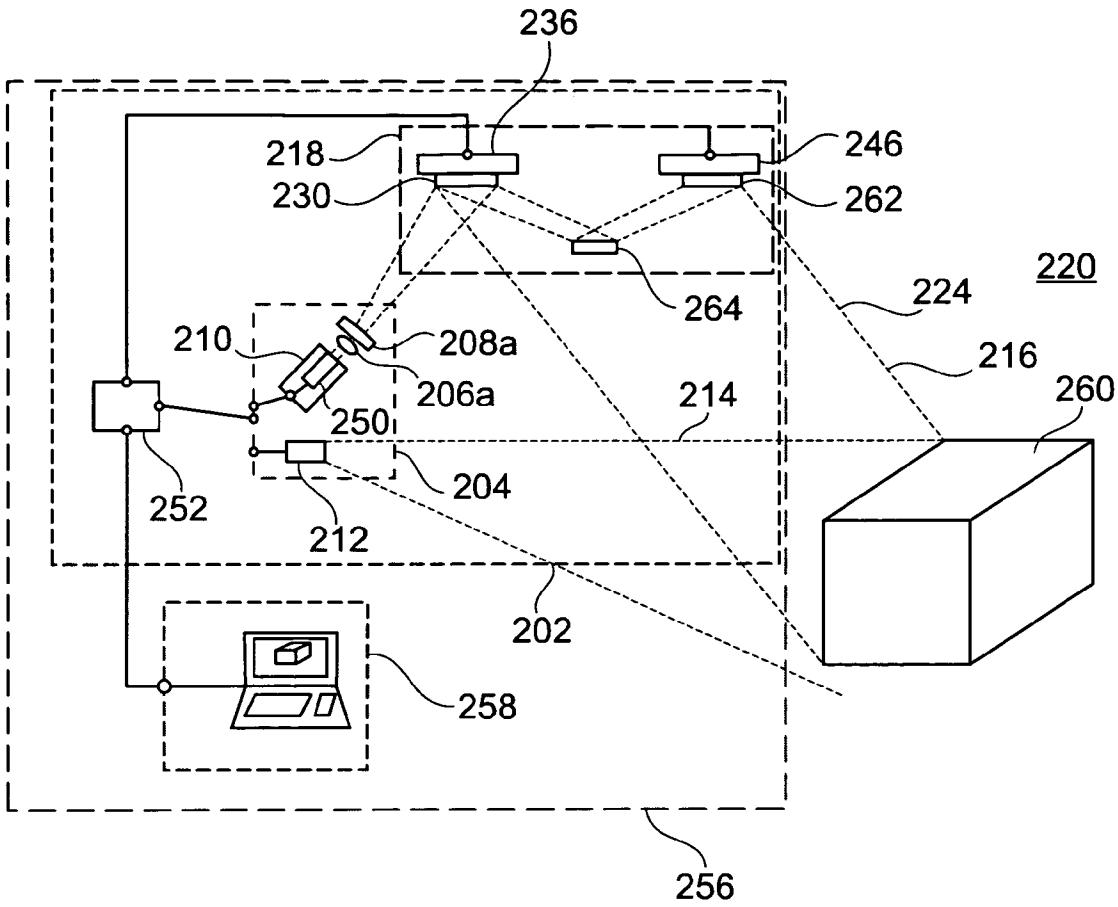

236
218
246
230
262
264
220
224
210
208a
216
206a
214
260
250
252
204
212
202
258
256

Fig. 2

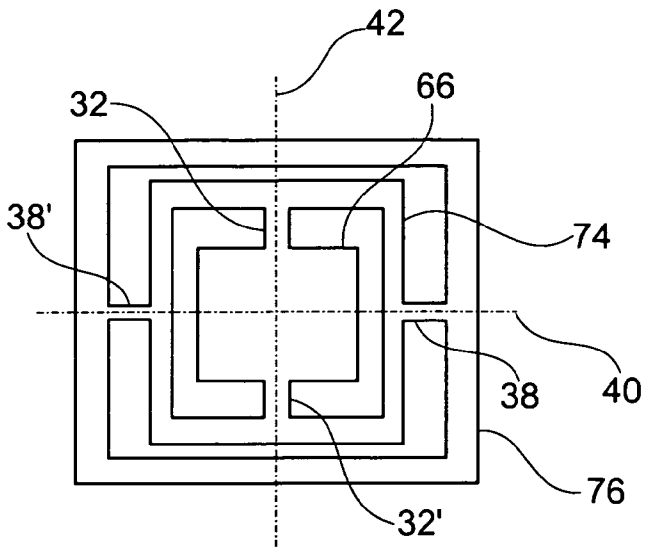

42
66
32
38'
74
40
38
76
32'

Fig. 3

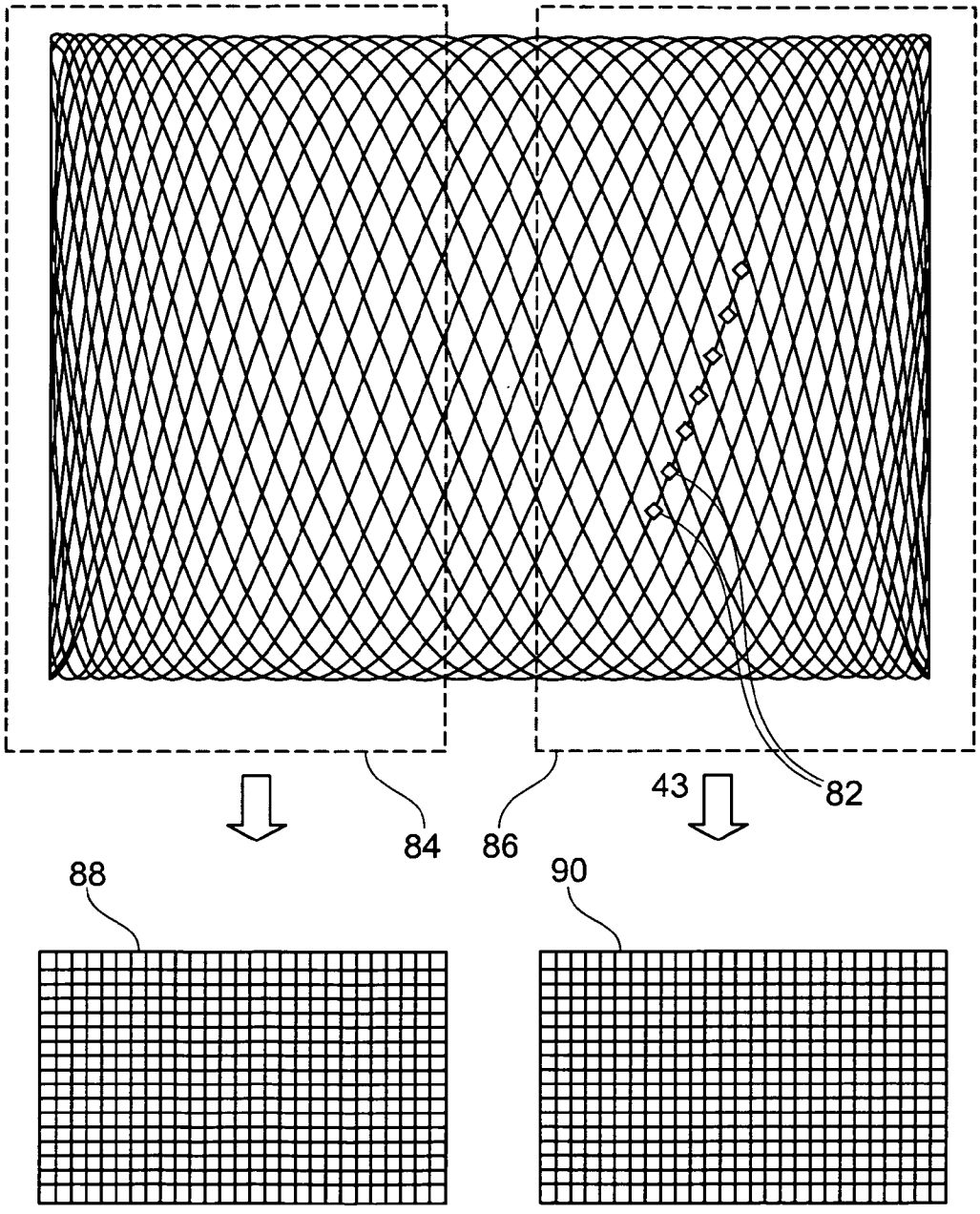


Fig. 4

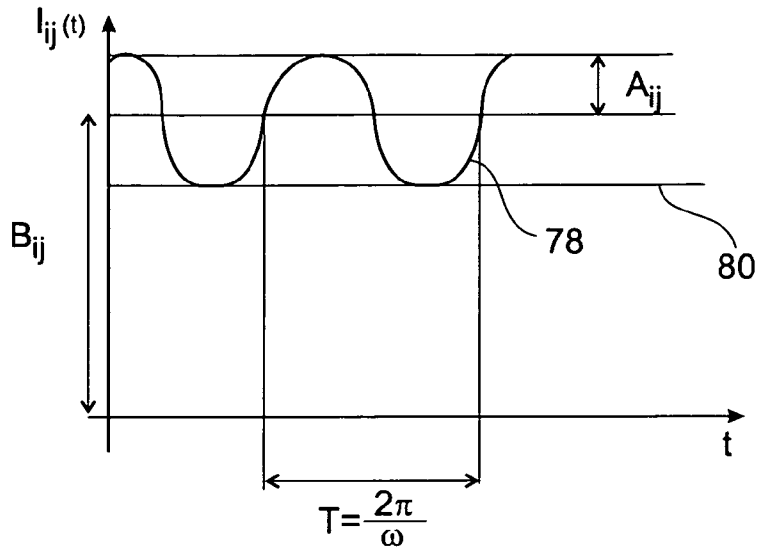


Fig. 5

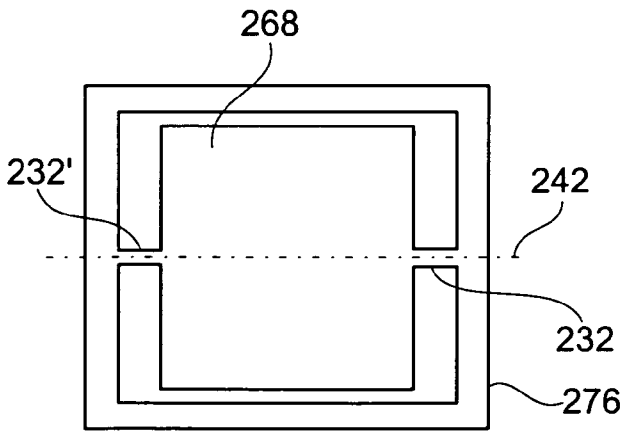


Fig. 6

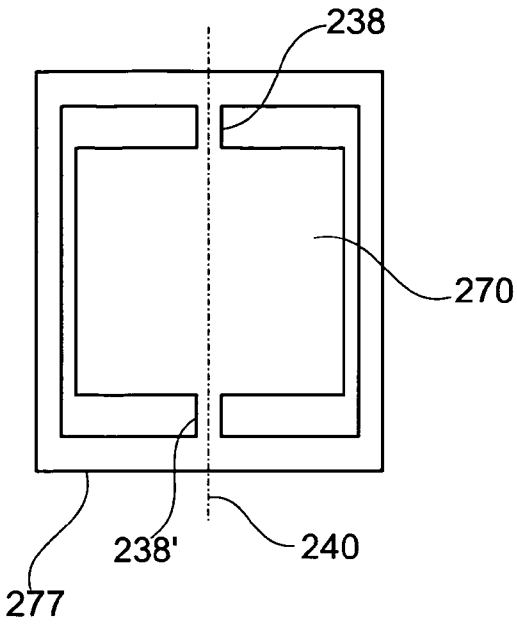


Fig. 7

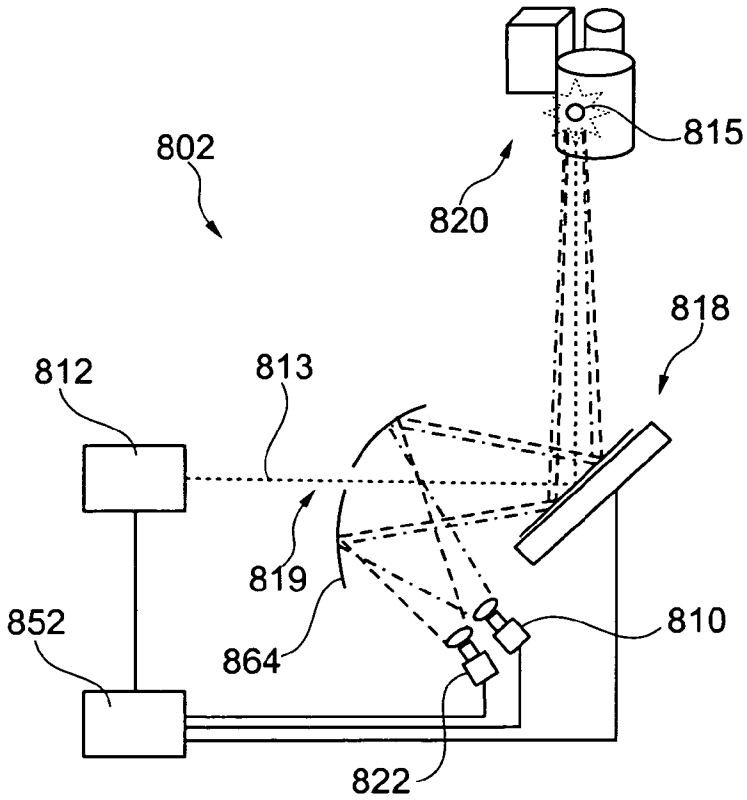


Fig. 8

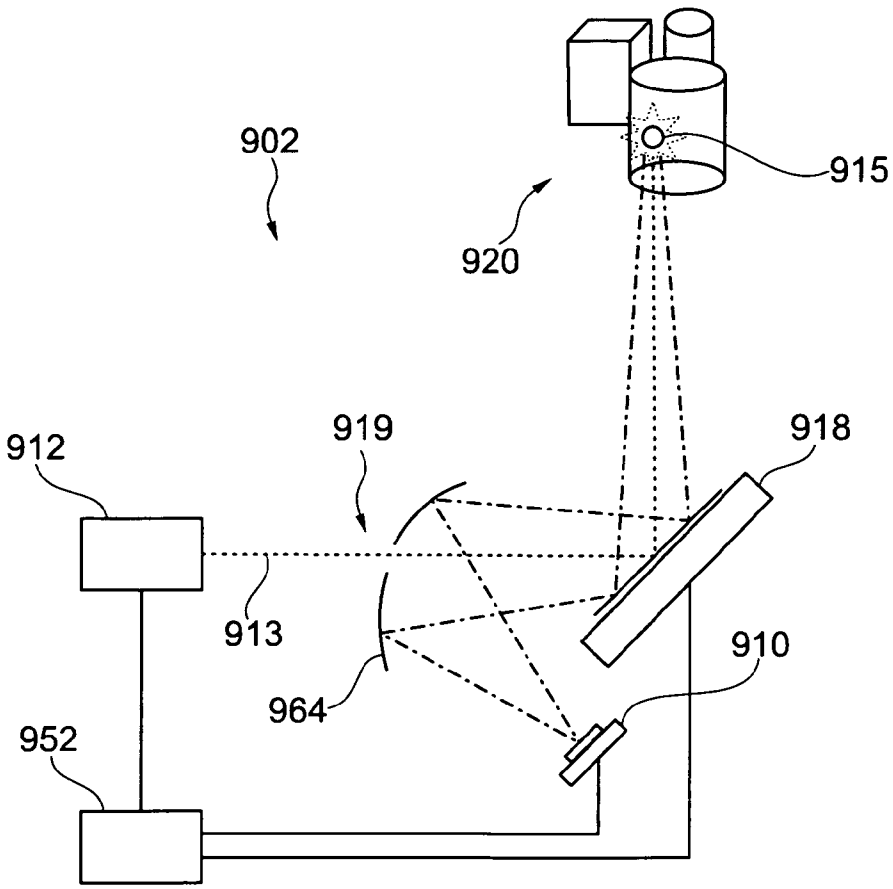


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/057241

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B11/24 G01S7/481 G01S17/36 G01S17/42 G01S17/89
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)
G01B 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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/001357 A2 (REAL IMAGING LTD [IL]; ARNON ISRAEL BOAZ [IL]) 31 December 2008 (2008-12-31)	1-4, 10-14
Y	abstract; figures 15-17,23a-b page 41 - pages 44,53	5-9

X	US 2006/132752 A1 (KANE DAVID M [US]) 22 June 2006 (2006-06-22)	1,10-14
Y	abstract; figures 1-3,6-10 paragraph [0157] - paragraph [0207]	2-9

Y	US 5 535 047 A (HORNBECK LARRY J [US]) 9 July 1996 (1996-07-09) the whole document	4-8

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

[X] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 June 2011	28/06/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Stanciu, C

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/057241

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	"Amplitude-modulated laser range finder for 3D imaging with multi-sensor data integration capabilities", SPIE, PO BOX 10 BELLINGHAM WA 98227-0010 USA, 1 January 2005 (2005-01-01), XP040206463, the whole document	9
Y	EP 1 903 299 A1 (IEE SARL [LU]) 26 March 2008 (2008-03-26) cited in the application the whole document	9
Y	EP 1 746 438 A2 (NORTHROP GRUMMAN CORP [US]) 24 January 2007 (2007-01-24) abstract; figures 1-3 paragraph [0021] - paragraph [0037]	2,3

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2011/057241

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009001357 A2	31-12-2008	CA 2691595 A1	31-12-2008
		CN 101854846 A	06-10-2010
		EP 2164385 A2	24-03-2010
		JP 2010531198 T	24-09-2010
		US 2010135550 A1	03-06-2010
US 2006132752 A1	22-06-2006	NONE	
US 5535047 A	09-07-1996	CA 2173637 A1	19-10-1996
		CN 1160218 A	24-09-1997
		DE 69634222 D1	03-03-2005
		DE 69634222 T2	05-01-2006
		EP 0738910 A2	23-10-1996
		JP 3851679 B2	29-11-2006
		JP 8334709 A	17-12-1996
EP 1903299 A1	26-03-2008	CN 101517355 A	26-08-2009
		EP 2074377 A1	01-07-2009
		WO 2008034738 A1	27-03-2008
		JP 2010504509 T	12-02-2010
		US 2010045966 A1	25-02-2010
EP 1746438 A2	24-01-2007	AU 2006202955 A1	01-02-2007
		CA 2550644 A1	12-01-2007
		SG 129382 A1	26-02-2007
		US 2007221849 A1	27-09-2007