necessary to combine the distance information obtained from the ranging step with angular information to fix the remaining two spatial coordinates. A camera comprising a pixel array and suitably arranged optics can be used to provide the additional angular information, by identifying the pixel in which the reflection is detected.

Embodiments of the present invention are based on the further insight of the inventors that in order to be able to use spot patterns generated by solid-state light sources in a LIDAR system at the desired ranges, a way to circumvent the optical power limitations is needed. The inventors have found that by prolonging the pulse duration and by integrating the reflected energy of multiple VCSEL-generated light pulses within at least two semiconductor sensor wells or within at least two pixels, followed by a single read-out of the integrated charge, a solid-state LIDAR system can be obtained with a significantly greater operating range than is currently possible with solid-state implementations. Hereinafter, the term "storage" will be used to designate the well or the pixel in which charge is accumulated in response to the detection of photons.

It is an advantage of the present invention that the solid-state light source and the solid-state sensor (such as a CMOS sensor, a CCD sensor, SPAD array or the like) may be integrated on the same semiconductor substrate. The solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern.

Moreover, by assessing the reflected light energy detected in two consecutive time windows, and normalizing for the total accumulated charge in the two consecutive windows, the impact of varying reflectivity of the object under study and the contribution of ambient light can adequately be accounted for in the distance calculation algorithm.

The present invention is further based on the insight of the inventors that the range of the system can be improved by splitting up the sensing of the full range over multiple frames (i.e., multiple sequences of pulses), each of which "sees" a different range by virtue of operating with different timing parameters (the first predetermined time window and the second predetermined time window).

A judicious choice of these operating parameters can ensure that in each frame, the number of reflected photons expected to be detected for the maximal distance of the desired range corresponds to an amount of charge that can be reliably read out from the charge storage well. On the other hand, the nearest point at which accurate measurements can be carried out is determined by the number of photons that will saturate the capactity of the pixels. The ratio between the minimal detectable number of photons and the maximal number of photons that can be received without saturation determines the distance range that can be spanned in a single frame.

In an embodiment of the system according to the present invention, each of the plurality of picture elements comprises at least two sets of charge storage wells, the detecting of said first amount of light and the detecting of the second amount of light occurring at respective ones of the at least two sets of charge storage wells; and each of the sets of charge storage wells is configured as a cascade.

The term "charge storage well" designates a storage provided in the semiconductor substrate, e.g. a capacitor, that stores electrical charges generated by the conversion of photons impinging on the pixel.

In the picture elements, charge representative of the impinging light is accumulated at well level. An advantage of charge accumulation at the well level is that read-out noise is minimized, leading to a better signal-to-noise ratio.

It is an advantage of the cascade-based arrangement that the total amount of charge to be accumulated is distributed over multiple wells, which allows for a greater total charge storage capacity while maintaining an accurate reading of the total charge level.

The increase in the total charge storage capacity is of particular importance at the end of the operating range where large number of photons - and hence, large amounts of charge - are received by the system; this is the case at short range (because the intensity of the light in function of distance follows an inverse-square law) or when surfaces with an unusually high reflectance are present in the field of view of the sensor. In conditions where a single well would tend to be saturated, a cascade-based arrangement allows the excess charge to be stored in a subsequent storage well, without losing the possibility of accurately determining the total amount of charge.

The total number of capacities in the cascade can be selected in function of the desired operating range and accuracy, and the general requirement to keep the Poisson noise as low as possible. The latter condition is inherently linked to the application of range gating, where Poisson noise is detrimental to the accuracy of the distance determination. A low level of Poisson noise allows a continuous photon-charge response, regardless of whether the charge is stored in one or more capacities of the cascade.

In an embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a serially arranged cascade. In another embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a parallelly arranged cascade.

It is an advantage of these embodiments that they provide easy to implement arrangements to obtain the desired cascade effect of the storage wells.

In an embodiment of the system according to the present invention, for each of said at least two consecutive sequences of pulses said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back, and a total storage capacity of said picture elements configured to detect said first amount of light is larger than a total storage capacity of said picture elements configured to detect said second amount of light.

It is an advantage of this embodiment that it helps to avoid saturation of the charge storage elements due to an overload of reflected photons. This problem is most prominent at nearby distances. At short ranges, the total number of reflected photons will be higher, due to the inverse square law, while most of the reflected signal will arrive within the first time window and thus be stored in the corresponding set of charge storage wells. Hence, it is useful to dimension the set of charge storage wells corresponding to the first time window so as to be able to deal with a larger amount of charge.

According to an aspect of the present invention, there is provided a vehicle, comprising: a system as described above arranged to operatively cover at least a part of an area surrounding said vehicle .

The system according to the present invention is particularly advantageous in a vehicle with ADAS or autonomous driving control unit such as but not limited to ECU (electrical control unit) . The vehicle may further comprise a vehicle control unit, adapted for receiving measurement information from the system and for using the information for ADAS control or autonomous driving decision taking. The part of an area surrounding the vehicle may include a road surface ahead of, beside, or behind the vehicle. Accordingly, the system may provide road profile information of the surface ahead of the car, to be used for active suspension or semi-active suspension .

According to an aspect of the present invention, there is provided a camera, the camera comprising a system as described above, whereby the system is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

According to an aspect of the present invention, there is provided a method for determining a distance to an object, the method comprising: using a solid-state light source to project a pattern of spots of laser light towards the object in a sequence of pulses; using a detector comprising a plurality of picture elements to detect light representing the pattern of spots as reflected by the object in synchronization with the sequence of pulses; and calculating the distance to the object as a function of exposure values generated by the pixels in response to the detected light; wherein the picture elements generate the exposure values by accumulating, for each pulse of the sequence, a first amount of electrical charge representative of a first amount of light reflected by the object during a first predetermined time window and a second amount of electrical charge representative of a second amount of light reflected by the object during a second predetermined time window, the second predetermined time window occurring after the first predetermined time window; and wherein the projecting and the detecting are repeated for at least two consecutive sequences of pulses, each of the sequences being operated with a different duration of the first predetermined time window and the second predetermined time window.

In an embodiment of the method according to the present invention, for each of the at least two consecutive sequences of pulses the first predetermined time window and the second predetermined time window are of substantially equal duration and occur back-to-back.

In an embodiment of the method according to the present invention, each of the plurality of picture elements comprises at least two charge storage wells, and the detecting of the first amount of light and the detecting of the second amount of light occurs at respective ones of the at least two charge storage wells.

According to an aspect of the present invention, there is provided a computer program product comprising code means configured to cause a processor to carry out the method as described above.

The technical effects and advanta ges of embodiments of the camera, the vehicle, the method, and the computer program product according to the present inventio n correspond, *mutatis mutandis*, to those of the corresponding emb odiments of the system according to the present invention.

Brief Description of the Figures

These and other aspec ts and advantages of the present invention will now be described in more detail with reference to the accompanying drawings , in which:

Figure 1 represents a flow chart of an embodiment of the method according to the present invention;

Figure 2 schematically represents an embodiment of the system according to the present invention;

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention;

Figure 4 provides diagrams of exemplary pixel output in function of incident light power as obtained by logarithmic tone mapping (top) and multilinear tone mapping (bottom) ;

Figure 5 provides a diagram of exemplary pixel outputs in function of incident light power as obtained by a high dynamic range multiple output pixel;

Figure 6 schematically illustrates the structure of a high-dynamic range pixel for use in embodiments of the present invention;

Figure 7 schematically illustrates an embodiment of a pixel architecture with two charge wells (bins) with each a separate transfer gate for use in embodiments of the present invention;

Figure 8 schematically illustrates a first exemplary optical arrangement for use in embodiments of the present invention;

Figure 9 schematically illustrates a second exemplary optical arrangement for use in embodiments of the present invention;

Figure 10 schematically illustrates a third exemplary optical arrangement for use in embodiments of the present invention;

Figure 11 schematically illustrates a fourth exemplary optical arrangement for use in embodiments of the present invention;

Figure 12 schematically illustrates a fifth exemplary optical arrangement for use in embodiments of the present invention; and

Figure 13 schematically illustrates a sixth exemplary optical arrangement .

Detailed Description of Embodiments

The surround sensing systems of the type disclosed in international patent application publication WO 2015/004213 A1, in the name of the present applicant, have the advantage of observing an extensive scene while illuminating that scene simultaneously or partially simultaneously only in a number of discrete and well-defined spots, in particular a predefined spot pattern. By using VCSEL lasers with an outstanding bundle quality and a very narrow output spectrum, it is possible to obtain a detection range with a limited amount of output power, even in the presence of daylight. The actual ranging performed in the system of WO 2015/004213 A1 relies on displacement detection, in particular triangulation, which was understood to be the only method practically available in the context of the long (quasi-stationary) pulse durations that were necessary in view of the power budget. To date, it had not been possible to achieve the same power/performance characteristics with a compact, semiconductor based time-of-f light based system.

The present invention overcomes this limitation by radically changing the way the time-of-f light based system operates. The invention increases the total amount of light energy emitted for each time-of-f light measurement (and thus, the number of photons available for detection at the detector for each time-of-f light measurement) by increasing the duration of individual pulses and by producing a virtual "composite pulse", consisting of a sequence of a large number of individual pulses. This bundling of extended pulses allowed the inventors to obtain the required amount of light energy (photons) for the desired operational range with low-power VCSELs.

Where an individual pulse of pre-existing LIDAR systems may have a duration of 1 ns, the systems according to the present invention benefit from a substantially longer pulse duration to partially compensate for the relatively low power level of semiconductor lasers such as VCSELs; in embodiments of the present invention, individual pulses within a sequence may have an exemplary duration of 1 μs (this is one possible value, chosen here to keep the description clear and simple; more generally, in embodiments of the present invention, the pulse duration may for example be 500 ns or more, preferably 750 ns or more, most preferably 900 ns or more) . In an exemplary system according to the present invention, a sequence may consist of 1000 pulse cycles, thus adding up to a duration of 1 ms. Given the fact that light would need approximately 0.66 μs to travel to a target at a distance of 100 m and back to the detector, it is possible to use composite pulses of this duration for ranging at distance of this order of magnitude; the skilled person will be able to adjust the required number of pulse cycles in function of the selected pulse width and the desired range. The detection of the sequence preferably comprises detecting the individual pulses in synchronization with the VCSEL-based light source, and accumulating the charges generated in response to the incoming photons at the pixel well level for the entire sequence prior to read-out. The term "exposure value" is used hereinafter to designate the value representative of the charge (and thus of the amount of light received at the pixel) integrated over the sequence. The sequence emission and detection may be repeated periodically.

The present invention operates by using range gating. Range gated imagers integrate the detected power of the reflection of the emitted pulse for the duration of the pulse. The amount of temporal overlap between the pulse emission window and the arrival of the reflected pulse depends on the return time of the light pulse, and thus on the distance travelled by the pulse. Thus, the integrated power is correlated to the distance travelled by the pulse. The present invention uses the principle of range gating, as applied to the sequences of pulses described hereinabove. In the following description, the integration of individual pulses of a sequence at the level of a picture element to obtain a measurement of the entire sequence is implicitly understood.

Figure 1 represents a flow chart of an embodiment of the method according to the present invention. Without loss of generality, the ranging method is described with reference to a range gating algorithm. In a first time window **10**, the method comprises projecting **110** a pattern of spots of laser light (e.g. a regular or an irregular spatial pattern of spots) from a light source comprising a solid-state light source **210** onto any objects in the targeted area of the scenery. The spatial pattern is repeatedly projected in a sequence of pulses.

As indicated above, the solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern. In order for the system to operate optimally, even at long ranges and with high levels of ambient light (e.g., in daylight) , a VCSEL for use in embodiments of the present invention is preferably arranged to emit a maximum optical power per spot per unit of area. Thus, lasers with a good beam quality (low M2-factor) are preferred. More preferably, the lasers should have a minimal wavelength spread; a particularly low wavelength spread can be achieved with monomode lasers. Thus, substantially identical pulses can reproducibly be generated, with the necessary spatial and temporal accuracy.

During the same time window in which a pulse is emitted, or in a substantially overlapping time window, a first amount of light representing the pattern of spots as reflected by the object of interest is detected **120** at a detector, which is preferably arranged as near as possible to the light source. The synchronicity or near synchronicity between the projection **110** of the spot pattern and the first detection **120** of its reflection, is illustrated in the flow chart by the side-by-side arrangement of these steps. In a subsequent second predetermined time window **20**, a second amount of light representing the reflected light spot is detected **130** at the detector. During this second window **20**, the solid-state light source is inactive. The distance to the object can then be calculated **140** as a function of the first amount of reflected light and the second amount of reflected light.

The first predetermined time window **10** and the second predetermined time window **20** are preferably back-to-back windows of substantially equal duration, to facilitate noise and ambient light cancellation by subtracting one of the detected amounts from the other one. An exemplary timing scheme will be described in more detail below in conjunction with Figure 3.

The detector comprises a plurality of picture elements, i.e. it consists of a picture element array with adequate optics arranged to project an image of the scenery (including the illuminated spots) onto the picture element. The term "picture element" as used herein may refer to an individual light-sensitive area or well of a pixel, or to an entire pixel (which may comprise multiple wells, see below) . For every given projected spot, the detecting **120** of the first amount of light and the detecting **130** of the second amount of light occurs at the same one or the same group of the plurality of picture elements.

Without loss of generality, each of the picture elements may be a pixel comprising at least two charge storage wells **221, 222,** such that the detecting **120** of the first amount of light and the detecting **130** of the second amount of light can occur at the respective charge storage wells **221, 222** of the same pixel or pixel group.

Figure 2 schematically represents an embodiment of the system according to the present invention, in relation to an object **99** in the scenery of interest. The system **200** comprises a solid-state light source **210** for projecting a pattern of a sequence of spots, which may be repeated periodically, onto the object **99.** A detector **220** is arranged near the light source and configured to detect light reflected by the object.

The light beam bouncing off the object **99** is illustrated as an arrow in dashed lines, travelling from the light source **210** to the object **99** and back to the detector **220.** It should be noted that this representation is strictly schematic, and not intended to be indicative of any actual relative distances or angles.

A synchronization means **230,** which may include a conventional clock circuit or oscillator, is configured to operate the solid-state light source **210** so as to project the pattern of spots onto the object during first predetermined time windows **10** and to operate the detector **220** so as to detect a first amount of light representing the light spot(s) reflected by the object **99** at substantially the same time. It further operates the detector **220** to detect a second amount of light representing the light spots reflected by the object **99,** during respective subsequent second predetermined time windows **20.** Appropriate processing means **240** are configured to calculate the distance to the object as a function of the first amount of reflected light and the second amount of reflected light.

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention. For clarity reasons, only a single pulse of a single pulse sequence of Figure 1 is illustrated, which consists of a first time window **10** and a second time window **20**. According to the present invention, at least two sequences are transmitted consecutively, using different durations of the first time window **10** and the second time window **20** in the first sequence than in the second sequence.

As can be seen in Figure 3a, during the first time window **10**, the solid-state light source **210** is in its "ON" state, emitting the pattern of light spots onto the scenery. During the second time window **20**, the solid-state light source **210** is in its "OFF" state.

The arrival of the reflected light at the detector **220** is delayed relative to the start of the projection by an amount of time that is proportional to the distance travelled (approximately 3.3 ns/m in free space) . Due to this delay, only a part of the reflected light will be detected at the first well or cascaded set of wells **221** of the detector **220**, which is only activated during the first time window **10**. Thus, the charge accumulated in this first well during its period of activation (the first time window **10**) consists of a part representing only the noise and the ambient light impinging on the pixel prior to the arrival of the reflected pulse, and a part representing the noise, the ambient light, and the leading edge of the reflected pulse.

The latter part of the reflected pulse will be detected at the second well or cascaded set of wells **222** of the detector **220**, which is only activated during the second time window **20**, which preferably immediately follows the first time window **10**. Thus, the charge accumulated in this second well during its period of activation (the second time window **20**) consists of a part representing the noise, the ambient light, and the trailing edge of the reflected pulse, and a part representing only the noise and the ambient light impinging on the pixel after the arrival of the reflected pulse.

The greater the distance between the reflecting object **99** and the system **200**, the smaller the proportion of the pulse that will be detected in the first well or cascaded set of wells **221** and the larger the proportion of the pulse that will be detected in the second well or cascaded set of wells **222**.

If the leading edge of the reflected pulse arrives after the closing of the first well or cascaded set of wells **221** (i.e., after the end of the first time window **10**), the proportion of the reflected pulse that can be detected in the second well or cascaded set of wells **222** will decrease again with increasing time of flight delay.

The resulting amounts of charge A, B in each of the respective wells or cascaded sets of wells **221**, **222** for varying distances of the object **99** is shown in Figure 3b. To simplify the representation, the effect of the attenuation of light with distance, according to the inverse square law, has not been taken into account in the diagram. It is clear that for time of flight delays up to the combined duration of the first time window **10** and the second time window **20**, the time of flight delay can in principle unambiguously be derived from the values of A and B:

- For time of flight delays up to the duration of the first time window **10**, B is proportional to the distance of the object **99**. To easily arrive at a determination of the absolute distance, the normalized value B/(B+A) may be used, removing any impact of non-perfect reflectivity of the detected object and of the inverse square law.
- For time of flight delays exceeding the duration of the first time window **10**, A consists of daylight and noise contributions only (not illustrated), and C–B is substantially proportional (after correcting for the inverse

square law) to the distance of the object **99**, where **C** is an offset value.

While Figures 3a and 3b illustrate the principle of the invention in relation to a single pulse emitted in the time window **10**, it shall be understood that the illustrated pulse is part of a sequence of pulses as defined above. Figure 3c schematically illustrates exemplary timing characteristics of a single sequence. As illustrated, the illumination scheme **40** consists of a repeated emission of a sequence **30** of individual pulses **10**. The width of the individual pulses **10** is determined by the maximal operating range. The entire sequence may be repeated at a frequency of, for example, 60 Hz.

Figure 3d schematically illustrates how the individual frames in the sequence of Figure 3c, which may fail to cover the entire targeted range of distances $[Z_{min}, Z_{max}]$ as a result of the constraints imposed by N_{max} (maximal number of electrons that can be stored without saturating the pixel) and N_{min} (minimum number of pixels required for accurate read-out), can be broken down into sequences with different timing parameters, each covering a portion of the targeted range $[z_{min}(i), z_{max}(i)]$ that can more easily be covered within the same constraints on the number of photons.

With reference to the symbols introduced above and used in Figure 3d, the corresponding electron amounts $n_{min}(i)$ and $n_{max}(i)$ of the subranges are defined by:

- The maximum allowable number of electrons (using "FPC" for the full pixel capacity, which corresponds to full well capacity in case there are no additional capacities):
  $n_{max} = N_{min} \times \left(\frac{z(i)}{z(i+1)}\right) \leq FPC$, with $z(0) = Z_{max}$
- The minimum required accuracy level: $n_{min} = N_{min}$
- $Z_{max}(i) = Z_{min}(i-1)$

Additionally, the pulse characteristics can be determined as follows:

- the pulsewidth $\tau(i) = \frac{2x_{max}(i)}{c}$
- the total "on" time is reduced proportionally to $\frac{N_{max}}{N_{min}}$ to respect the limits imposed by the full pixel capacity and the accuracy level.

The above principles may be further clarified by the following non-limiting numerical example.

A Lambertian reflecting surface with 10% reflectivity at a distance of 150m must provide 1000 electrons to obtain an accuracy of 1,6%. At the same distance, a 100% reflecting surface will generate 10000 electrons. With a full well capacity of 200000 electrons, the following multi-frame solution is proposed:

	Sub-range	Pulse Width	Total "on" time
Frame 1	150m - 33m	1 µs	1 ms
Frame 2	7.4m - 33m	22 ns	50 µs
Frame 3	1.65m - 7.4m	4.9 ns	2.5 µs
Frame 4	0.37m - 1.65m	1.1 ns	0.125 µs

It should be noted that for robustness reasons, it may be advantageous to provide an overlap in the subranges .

For assuring the same 3D resolution, it may be advantageous to use a faster camera: e.g., a camera operating at 180Hz with 3-frame interleaving gives the same data speed as a 60Hz with single frame operation .

As indicated in the text above, the charge storage elements **221, 222** may each consist of a cascade of charge storage wells. A judicious design of the cascades ensures a smooth transition between the capacities to assure extremely high accuracy levels. The storage capacities are preferably designed around each pixel, to ensure that there is sufficient space for the cascade while to optimizing the charge transfer from the area where the impinging photons are converted to electrical charges . The capacities are preferably dimensioned so as to provide an accurate read-out of the lowest level of light that must be detectable (e.g. 1000 photons), for the specific subrange applicable to each sequence of pulses and the corresponding timing parameters.

Reflections of light by objects at a short distances are more likely to cause pixel saturation, because the attenuation of such a reflection will be much less than that of a reflection originating from a more distant object (due to the inverse-square law of light attenuation over distance) . As certain applications, such as automotive applications, require accurate system operation up to relatively long distances, a large photon span must be covered between the nearest distances of operation and the farthest distances of operation. With these constraints, pixel saturation at short range is a very real risk, in particular at the first set of wells (which receives the bulk of the reflection at short range) . The inventors have found that for given total pixel space, the saturation problem can be mitigated by using an asymmetric well arrangement, in which the photon capacity represented by the first set of wells is increased, and the photon capacity represented by the second set of wells is decreased. If the increase and decrease are balanced, an increase of the dynamic range can be obtained at no additional pixel surface cost.

Blooming is a phenomenon that happens when the charge in a pixel exceeds the saturation level of that specific pixel. Consequently, the charge starts to overflow and causes nuisance in adjacent pixels. This creates inaccurate data in the neighboring pixels. Preferably, the pixels of the system according to the present invention are provided with anti-blooming electronics, to bleed off the excess charge before it saturates the relevant set of wells and spills over to the wells of adjacent pixels. In particular when the information from neighboring spots is used for the elimination of background light, it is of great importance to have an accurate estimation of the background light which is obtained independently (and without contamination from) neighboring pixels.

Embodiments of the present invention may employ correlated double sampling to correct the samples for the thermal noise related to the capacity of the wells (also designated as "kTC noise"). To this end, the electronics of the pixel may be designed to carry out a differential measurement between the reset voltage (V_{reset}) and the signal voltage (V_{signal}), for example by measuring V_{reset} at the beginning of the frame and measuring V_{signal} at the end of the frame. As an alternative to an electronic (in-pixel) implementation, correlated double sampling may also be implemented by digitally subtracting the read-out signals $(V_{signal} - V_{reset})$ in a processor.

To increase the amount of light that reaches the photosensitive elements (in particular diodes) in the pixel structure, embodiments of the present invention may use backside illumination; in that case, the pixel circuitry is behind the photosensitive layer, thus reducing the number of layers that must be traversed by the impinging photons to read the photosensitive elements.

The ranging system according to the present invention may be integrated with a triangulation-based system in accordance with WO 2015/004213 A1. If miniaturization is aimed for, the triangulation-based system will end up having a relatively small distance between its projector and its detector, thus leaving it with a reduced operating range. However, it is precisely at short range that the combination presents its benefit, because the triangulation-based system can cover the distances at which the time-of-flight based system cannot operate sufficiently accurately.

The entire ranging process may be repeated iteratively, so as to monitor the distance to the detected object or objects over time. Thus, the result of this method can be used in processes that require information about the distance to detected objects on a continuous basis, such as advanced driver assistance systems, vehicles with an active suspension, or autonomous vehicles.

In order for all elements of the system as described to operate optimally, the system has to be thermally stable. Thermal stability avoids, among other things, undesired wavelength shifts of the optical elements (thermal drift), which would otherwise impair the proper functioning of the optical filters and other elements of the optical chain. Embodiments of the system according to the present invention achieves thermal stability by their design, or by active regulation by means of a temperature control loop with a PID-type controller.

WO 2015/004213 A1 discloses various techniques to minimize the amount of ambient light that reaches the pixels during the detection intervals, thus improving the accuracy of the detection of the patterned laser spots. While these techniques have not been disclosed in the context of a LIDAR system, the inventors of the present invention have found that several such techniques yield excellent results when combined with embodiments of the present invention. This is particularly true for the use of narrow bandpass filters at the detector, and the use of adequate optical arrangements to ensure nearly perpendicular incidence of the reflected light onto the filters. The details of these arrangements as they appear in WO 2015/004213 A1 are hereby incorporated by reference. Further features and details are provided hereinafter.

While various techniques known from WO 2015/004213 A1 may be applied to embodiments of the present invention to minimize the amount of ambient light that reaches the pixels during the detection intervals, a certain amount of ambient light cannot be avoided. In a multi-pixel system, only some of the pixels will be illuminated by reflected spots, while others will be illuminated by residual ambient light only. The signal levels of the latter group of pixels can be used to estimate the contribution of the ambient light to the signals in the pixels of interest, and to subtract that contribution accordingly. Additionally or alternatively, background light or ambient light may be subtracted from the detected signal at pixel level. This requires two exposures, one during the arrival of the laser pulse and one in the absence of a pulse.

In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient discrimination of intensity levels in the darkest part of the scene, is an advantage of the use of such a sensor; it allows for a sensor that has a very long range and yet remains capable of detection objects at short distance (where the reflected light is relatively intense) without undergoing saturation. The inventors have found that the use of a true high dynamic range sensor is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression (see Figure 4). However, this non-linear compression necessitates relinearisation of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor as presented in Figure 5. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US 2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention.

Embodiments of the present invention use a high dynamic range pixel. This can be obtained by a sizeable full-well capacity of the charge reservoir or by designs limiting the electronic noise per pixel or by usage of CCD gates that do not add noise at charge transfer, or through a design with a large detection quantum efficiency (DQE) (e.g., in the range of 50% for front illumination or 90% in case of back illumination, also known as back thinning), or by a special design such as shown in Figure 6 (see below), or by any combination of the listed improvements. Furthermore, the dynamic range can be further enlarged by adding an overflow capacity to the pixel in overlay at its front side (this implementation requires back thinning). Preferably, the pixel design implements an anti-blooming mechanism.

Figure 6 presents a schematic illustration of an advantageous implementation of a pixel with high dynamic range. The example in this figure makes use of two storage gates 7, 8, connected to the floating diffusion. After exposure, the electron generated by the scene AND the laser pulse, is transferred on the floating diffusion using the transfer gate 11. Both Vgate1 and Vgate2 gate voltages are set high. The charges are then spread over both capacitors, realizing a significant Full Well. Once this high full-well data is read via connection to the amplifier, the voltage Vgate2 is set low. The electrons reflow towards capacitor 7, increasing the total pixel gain. The data can be read through the amplifier. It is further possible to achieve an even higher gain by applying later a low voltage on Vgate1. The electrons reflow towards the floating diffusion 2.

Figure 7 represents a possible dual-well or dual-bin implementation of an envisaged pixel to be used in CMOS technology. The impinging signal is distributed over two charge storages. Each reservoir has a separate transfer gate controlled by an external pulse which is synchronized with the pulse of the laser sources.

The charge storage elements shown in the designs of Figure 6 and Figure 7 may be replicated to obtain a cascade of charge storage in embodiments of the present invention.

Figures 8-10 illustrate cameras that may be used in embodiments of the invention, where the light radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter and optics arranged so as to modify an angle of incidence onto said narrow bandpass filter, to confine said angle of incidence to a predetermined range around a normal of a main surface of said narrow bandpass filter, said optics comprising an image-space telecentric lens. The term "camera" is used herein as a combination of a sensor and associated optics (lenses, lens arrays, filter) . In particular, in Figure 9, the optics further comprise a minilens array arranged between the image-space telecentric lens and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

These examples all result in radiation travelling a substantially equal length through the filter medium or in other words in that the incident radiation is substantially orthogonal to the filter surface, i.e. it is confined to an angle of incidence within a predetermined range around the normal of the filter surface, thus allowing in accurate filtering within a narrow bandwidth to e.g. filter the daylight, the sunlight and in order to for the spots to surpass the daylight.

The correction of the angle of incidence is of particular importance in embodiments of the present invention where the entire space around a vehicle is to be monitored with a limited number of sensors, for instance 8 sensors, such that the incident rays may extend over a solid angle of for example 1 x 1 rad. Figure 8 schematically illustrates a first optical arrangement of this type. It comprises a first lens **1030** and a second lens **1040**, with approximately the same focal length *f*, in an image space telecentric configuration. That means that all chief rays (rays passing through the center of the aperture stop) are normal to the image plane. An exemplary numerical aperture of 0.16 corresponds to a cone angle of 9.3° (half cone angle). The maximum incidence angle on the narrow bandpass filter 1060, arranged between the lens system **1030-1040** and the sensor **102**, would thus be 9.3°.

As illustrated in Figure 9, the preferred design consists of a tandem of two lenses **1130**, **1140** with approximately the same focal length *f*, in an image-space telecentric configuration (the configuration is optionally also object-space telecentric), a planar stack of mini-lens array **1150**, a spectral filter **1160** and a CMOS detector **102**. Since the center O of the first lens **1130** is in the focus of the second lens **1140**, every ray that crosses O will be refracted by the second lens **1140** in a direction parallel to the optical axis. Consider now a particular laser spot S **1110** located at a very large distance as compared to the focal length of the first lens **1130**. Thus the image of this spot **1110** by the first lens **1130** is a point P located close to the focal plane of this lens, thus exactly in the middle plane of the second lens **1140**. The light rays that are emitted from the spot S **1110** and captured by the first lens **1130** form a light cone that converges towards the point P in the second lens **1140**. The central axis of this light cone crosses the point O and is refracted parallel the optical axis and thus perpendicular to the spectral filter **1160** so as to achieve optimal spectral sensitivity. Hence, the second lens **1140** acts as a correcting lens for the angle of the incident light beam. The other rays of the cone can also be bent in a bundle of rays parallel to the optical axis by using a small convex mini-lens **1150** behind the second lens **1140** in such a way that the point P is located in the focal point of the mini-lens **1150**. In this way all the imaging rays of the spot S **1110** are bent in a direction nearly perpendicular to the spectral filter. This can now be done in front of every pixel of the CMOS detector separately by using an array of mini-lenses positioned in front of every pixel. In this configuration, the minilenses have an image-telecentric function. The main advantage is that the pupil of the first lens **1030** can be enlarged, or the aperture can be eliminated while compensating for the increase in spherical aberration by a local correction optics in the mini-lens **1150.** In this way the sensitivity of the sensor assembly can be improved. A second mini-lens array (not shown in Figure 11) may be added between the spectral filter **1160** and the CMOS pixels **102,** to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor.

For the first and second lenses **1130, 1140,** commercially available lenses may be used. The skilled person will appreciate that lenses typically used in other smart phone cameras or webcams of comparable quality can also be used. The aforementioned iSight camera has a 6 x 3 mm CMOS sensor with 8 megapixels, 1.5 μm pixel size, a very large aperture of f/2.2, an objective focal length of about f = 7 mm, and a pupil diameter about 3.2 mm. The viewing angle is of the order of 1 rad x 1 rad. If we assume that the resolution of the camera is roughly the pixel size (1.5 micron), we can conclude (from Abbe's law) that the aberrations of the lens are corrected for all the rays of the viewing angle selected by the aperture.

Figure 10 illustrates a variation of the arrangement of Figure 11, optimized for manufacturing in a single lithographic process. The first lens **1230** is similar to the first lens **1130** of the previous embodiment, but the angle-correcting second lens **1140** is replaced by a Fresnel lens **1240** with the same focal length f and the mini-lens arrays **1150** by Fresnel lens arrays **1250.** The advantage is that they are completely flat and can be produced by nano-electronics technology (with discrete phase zones) . A second mini-lens array **1270** may be added between the spectral filter **1260** and the CMOS pixels **102,** to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor. Thus the camera is essentially a standard camera as the iSight but in which the CMOS sensor is replaced by a specially designed multi-layer sensor in which all the components are produced in one integrated block within the same lithographic process. This multilayer sensor is cheap in mass production, compact, robust and it need not be aligned. Each of these five layers **1240, 1250, 1260, 1270, 102** has its own function to meet the requirements imposed by the present invention.

As the minimal angle of a cone generated by a lens of diameter *d* is of the order of λ/d, with λ the wavelength of the light, the minimal cone angle is 1/10 radian for a mini-lens diameter d = 8.5 μm and λ = 850 nm. With a good quality spectral interference filter this corresponds to a spectral window of about 3 nm.

In the arrangements of Figures 8-10, the characteristics of the optics will result in a non-planar focal plane. To compensate this effect, the picture elements of the detector may be arranged on a substrate having a curvature that follows the focal plane of the optics. As a result, the reflected and filtered spots will be in focus, regardless of where they reach the detector. The desired curvature of the substrate of the detector can be obtained by using flex-chip technology, or by composing the substrate by combining differently oriented tiles. This solution is schematically illustrated in Figure 11, which shows telecentric optics **1330,** followed by a narrow band-pass filter **1360,** and a curved pixel layer **102,** the curvature of which is adapted to follow the shape of the focal plane of the telecentric optics **1330.**

When it is not possible (or not desirable) to arrange the optics in such a way as to ensure that light rays following different paths all pass through the narrow bandpass filter under the same (perpendicular) angle, the problem of having different filter characteristics with different angles of incidence may be resolved at the source. In particular, the VCSEL array may be configured such that different spots have different respective wavelengths. This configuration may be obtained by using a tiled laser array, or by providing means for modulating the wavelength of individual VCSELs in the VCSEL array. This solution is schematically illustrated in Figure 12, which shows a narrow band-pass filter **1460** arranged before the optics **1430** and the sensor array **102**. For clarity purposes and without loss of generality, two different angles of incidence with different respective wavelengths (λ_1, λ_2) have been indicated on the Figure. The different wavelengths (λ_1, λ_2) of the light sources are chosen to correspond to the maximum of the passband of the narrow bandpass filter under their respective angles of incidence.

Figure 13 illustrates an alternative optical arrangement, comprising a dome **1510** (e.g., a bent glass plate) with the narrow bandpass filter **1520** disposed on its inside (as illustrated) or outside (not illustrated) . The advantage of disposing the filter **1520** on the inside of the dome **1510**, is that the dome **1510** protects the filter **1520** from outside forces. The dome **1510** and the filter **1520** optically cooperate to ensure that incident light passes through the filter **1520** along a direction that is substantially normal to the dome's surface. Fish-eye optics **1530** are provided between the dome-filter assembly and the sensor **102**, which may be a CMOS or a CCD sensor or SPAD array. The fish-eye optics **1530** are arranged to guide the light that has passed through the dome-filter assembly towards the sensitive area of the sensor .

Optionally, further fish-eye optics are provided at the projector. In a specific embodiment, a plurality of VCSELs are mounted in a 1 x n or a m x n configuration, whereby an exit angle of the laser beam can be realized over a spatial angle of m x 1 rad in height and n x 1 rad in width.

In some embodiments of the present invention, the intensity of the spots can be kept substantially constant over the full depth range, by applying a stepped or variable attenuation filter at the detector. Alternatively or in addition, also a non-symmetrical lens pupil can be provided for weakening the intensity of spots closer to the detector, while the intensity of the spots further away from the detector are received at full intensity. In this way clipping of the detector is avoided and the average intensity can be made substantially the same for all spots.

In some embodiments, the radiation source can be a VCSEL that can be split in different zones, whereby the laser ON time is controlled for the different zones. The images of the spots can thus be controlled to have a constant intensity, e.g. 2/3rd of the A/D range. Alternatively the driving voltage can be driven over the array of spots as function of the height, again to obtain a constant intensity. Such controlling can be referred to as a saturation avoidance servoing loop. The different VCSELs within the array can be controlled individually for intensity, varying the intensity of the individual VCSELs in the pattern while projected simultaneously.

In some other embodiments of the present invention, a micro prism matrix can be used in front of the narrow bandwidth filter, such that the radiation is incident within an angle of incidence between +9° and -9° on the filter. This allows to obtain narrow bandwidth filtering. The prism matrix can for example be made by plastic moulding.

In embodiments of the present invention, e.g. where active suspension vehicle applications are envisaged, the projection of the spot pattern is advantageously directed downwards, i.e. towards the road.

A system according to the invention may include an implementation of steps of the methods described above in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA), programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component(s) may also include other functions. The present invention also pertains to a computer program product comprising code means implementing the steps of the methods described above, which product may be provided on a computer-readable medium such as an optical, magnetic, or solid-state carrier.

The present invention also pertains to a vehicle comprising the system described above.

Embodiments of the present invention may be used advantageously in a wide variety of applications, including without limitation automotive applications, industrial applications, gaming applications, and the like, and this both indoor and outdoor, at short or long range. In some applications, different sensors according to embodiments of the present invention may be combined (e.g., daisy-chained) to produce panoramic coverage, preferably over a full circle (360° field of view).

While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system, respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A system (200) for determining a distance to an object comprising :

- a solid-state light source (210) arranged for projecting a pattern of discrete spots of laser light towards said object in a sequence of pulses;
- a detector (220) comprising a plurality of picture elements, said detector (220) being configured for detecting light representing said pattern of discrete spots as reflected by said object in synchronization with said sequence of pulses; and
- processing means (240) configured to calculate said distance to said object as a function of exposure values generated by said picture elements in response to said detected light;

wherein said picture elements (220) are configured to generate said exposure values by accumulating, for all of the pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window (10) and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10);

wherein said system is configured to perform said projecting and said detecting for at least two consecutive sequences of pulses, each of said sequences being operated with a different duration of said first predetermined time window and said second predetermined time window.

2. The system according to claim 1, wherein each of said plurality of picture elements comprises at least two sets of charge storage wells, said detecting of said first amount of light and said detecting of said second amount of light occurring at respective ones of said at least two sets of charge storage wells; and wherein each of said sets of charge storage wells is configured as a cascade.

3. The system according to claim 2, wherein each of said sets of charge storage wells is configured as a serially arranged cascade.

4. The system according to claim 2, wherein each of said sets of charge storage wells is configured as a parallelly arranged cascade .

5. The system according to any of the preceding claims, wherein for each of said at least two consecutive sequences of pulses said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back, and wherein a total storage capacity of said picture elements configured to detect said first amount of light is larger than a total storage capacity of said picture elements configured to detect said second amount of light.

6. A vehicle comprising a system (100) according to any of the previous claims arranged to operatively cover at least a part of an area surrounding said vehicle.

7. A camera, the camera comprising a system (100) according to any of claims 1 to 5, whereby the system (100) is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

8. A method for determining a distance to an object, the method comprising :

- using a solid-state light source (210) to project (110) a pattern of spots of laser light towards said object in a sequence of pulses;
- using a detector (220) comprising a plurality of picture elements to detect (120; 130) light representing said pattern of spots as reflected by said object in synchronization with said sequence of pulses; and

- calculating (140) said distance to said object as a function of exposure values generated by said pixels in response to said detected light;

wherein said picture elements (220) generate said exposure values by accumulating, for each pulse of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window (10) and a second amount of electrical charge representative of a second amount of light reflected by said object during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10); and

wherein said projecting (110) and said detecting (120; 130) are repeated for at least two consecutive sequences of pulses, each of said sequences being operated with a different duration of said first predetermined time window and said second predetermined time window.

9. The method according to claim 8, wherein for each of said at least two consecutive sequences of pulses said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back.

10. The method according to claim 8 or claim 9, wherein each of said plurality of picture elements comprises at least two charge storage wells, and wherein said detecting of said first amount of light and said detecting of said second amount of light occurs at respective ones of said at least two charge storage wells.

11. A computer program product comprising code means configured to cause a processor to carry out the method according to any of claims 8-10.

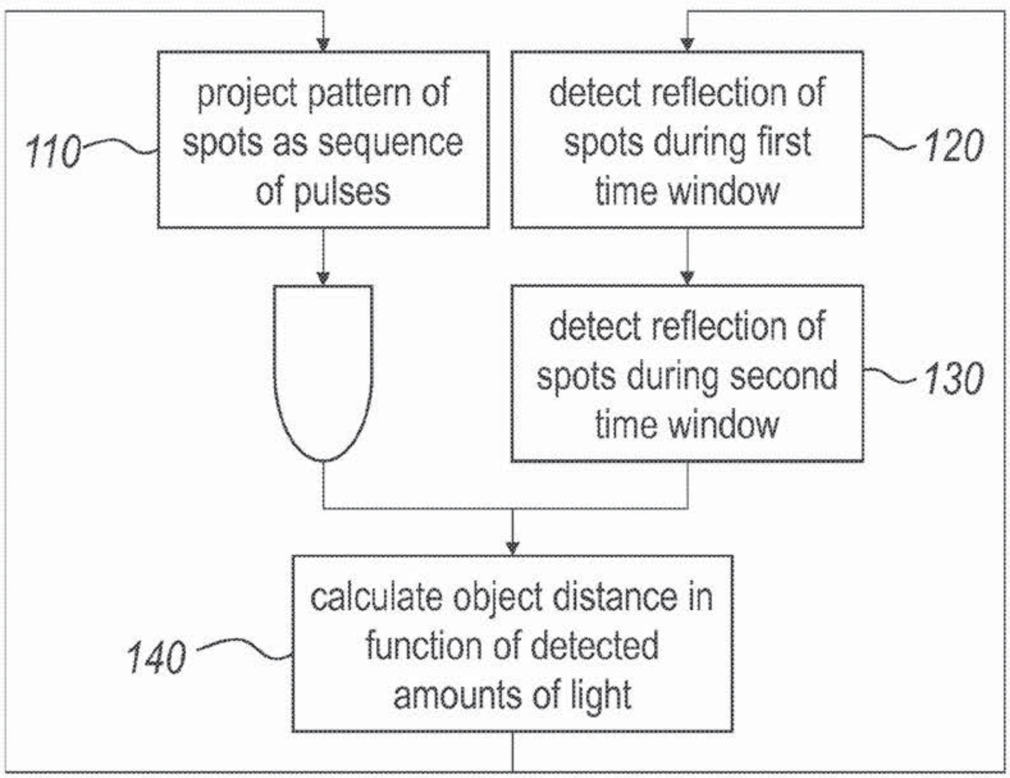
project pattern of spots as sequence of pulses
110
detect reflection of spots during first time window
120
detect reflection of spots during second time window
130
calculate object distance in function of detected amounts of light
140

Fig. 1

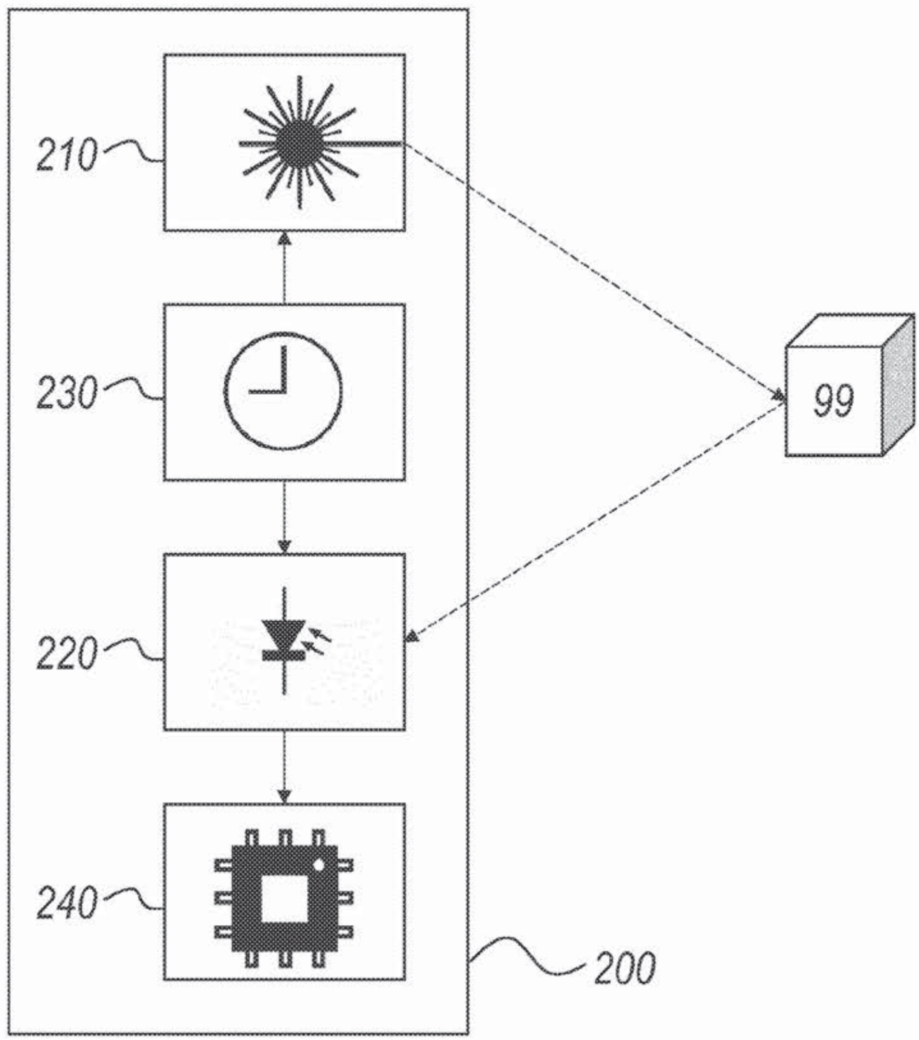

Fig. 2

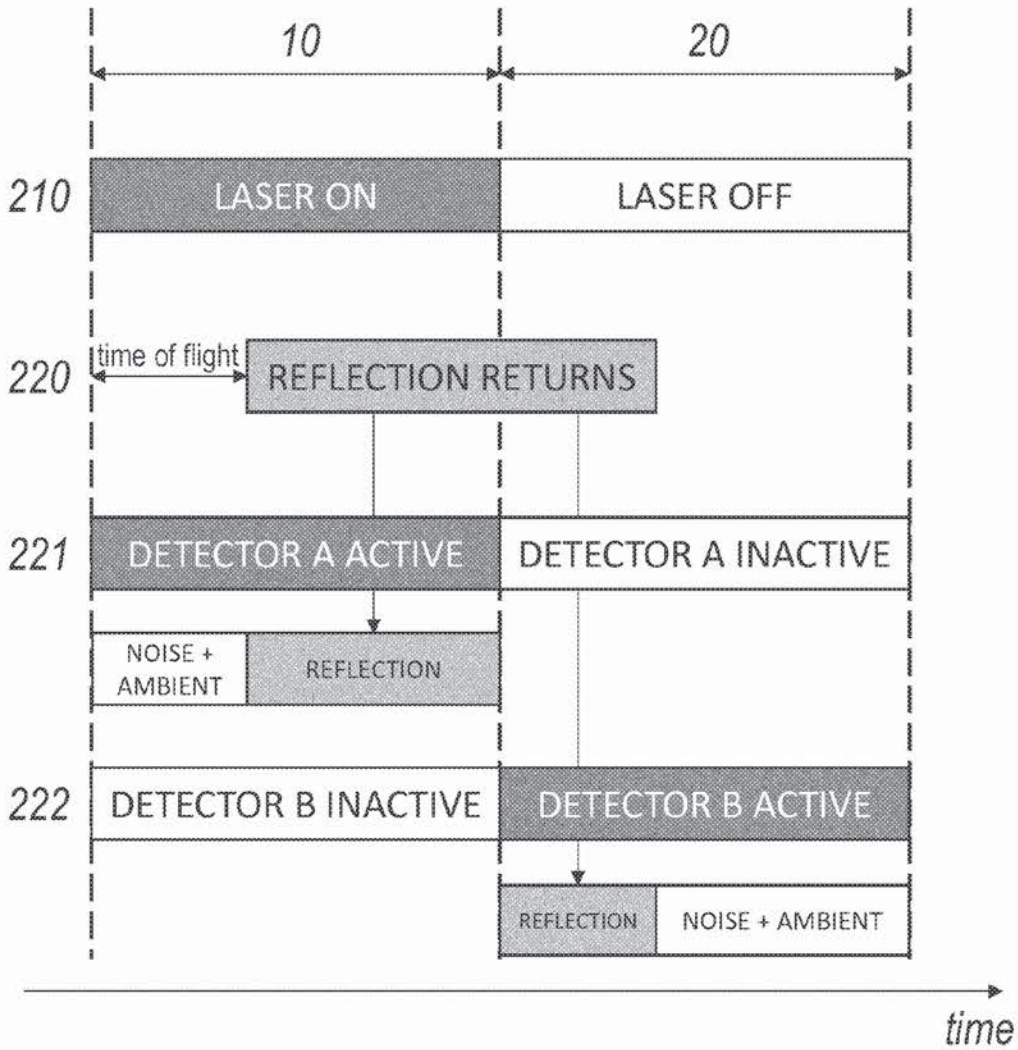
10
20
210
LASER ON
LASER OFF
220
time of flight
REFLECTION RETURNS
221
DETECTOR A ACTIVE
DETECTOR A INACTIVE
NOISE + AMBIENT
REFLECTION
222
DETECTOR B INACTIVE
DETECTOR B ACTIVE
REFLECTION
NOISE + AMBIENT
time

Fig. 3a

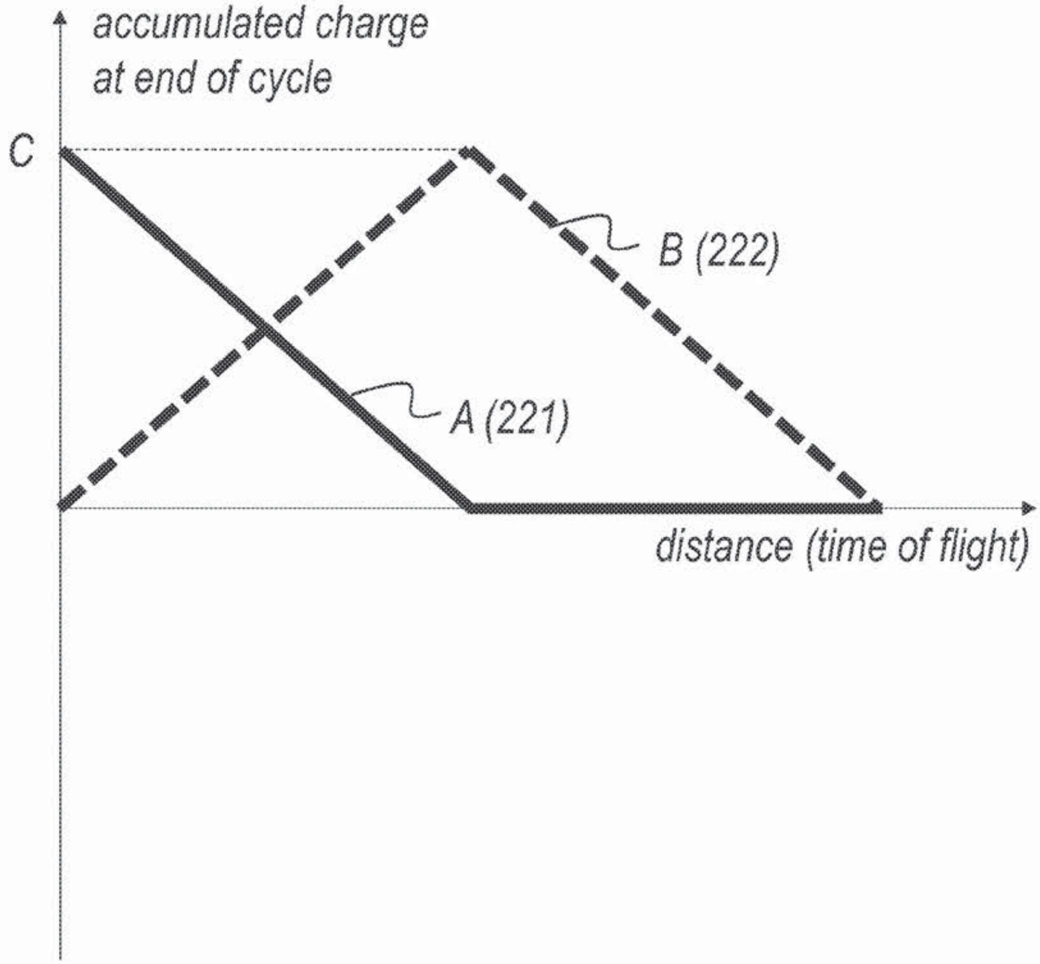
accumulated charge
at end of cycle
C
B (222)
A (221)
distance (time of flight)

Fig. 3b

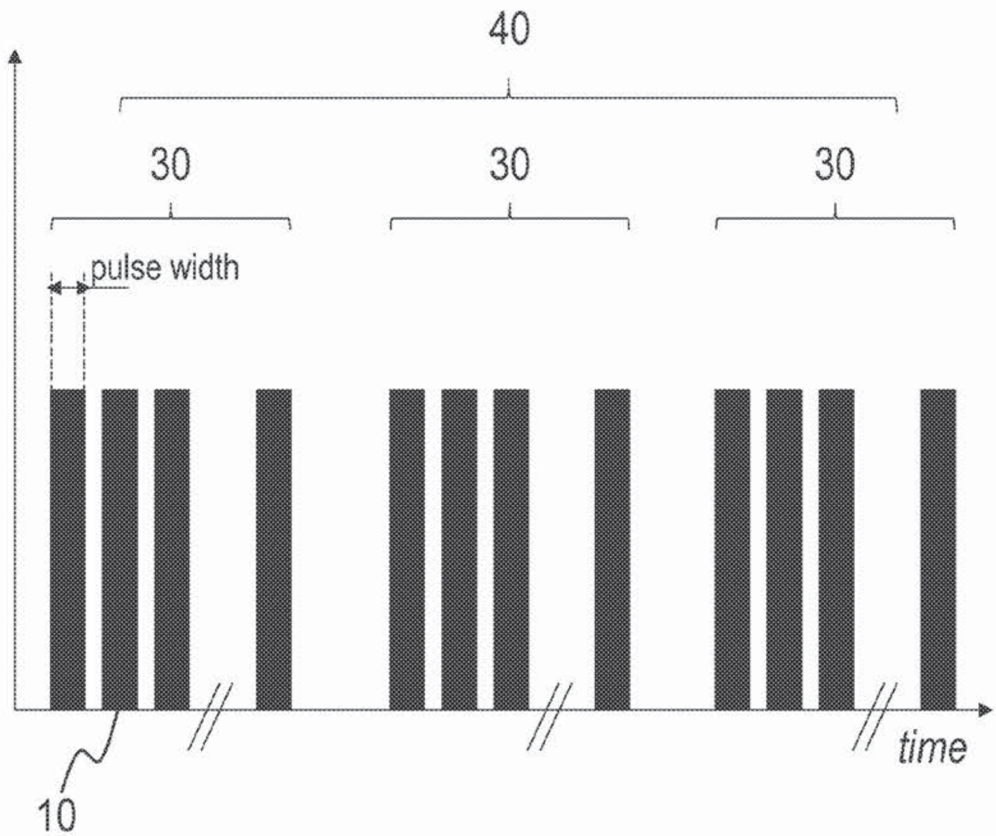

Fig. 3c

6/14

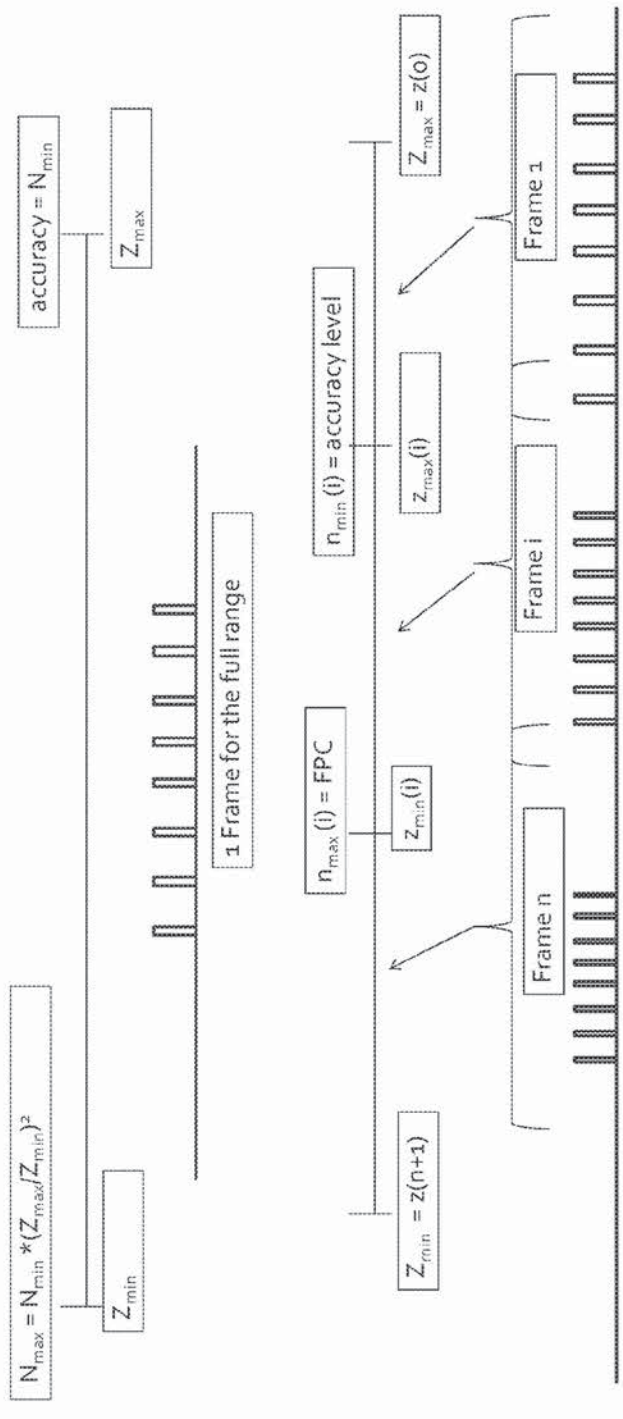
accuracy = N_{min}
Z_{max}
$N_{max} = N_{min} * (Z_{max}/Z_{min})^2$
Z_{min}
1 Frame for the full range
n_{min} (i) = accuracy level
n_{max} (i) = FPC
Z_{max} = z(o)
Z_{max}(i)
Z_{min}(i)
Z_{min} = z(n+1)
Frame 1
Frame i
Frame n

Fig. 3d

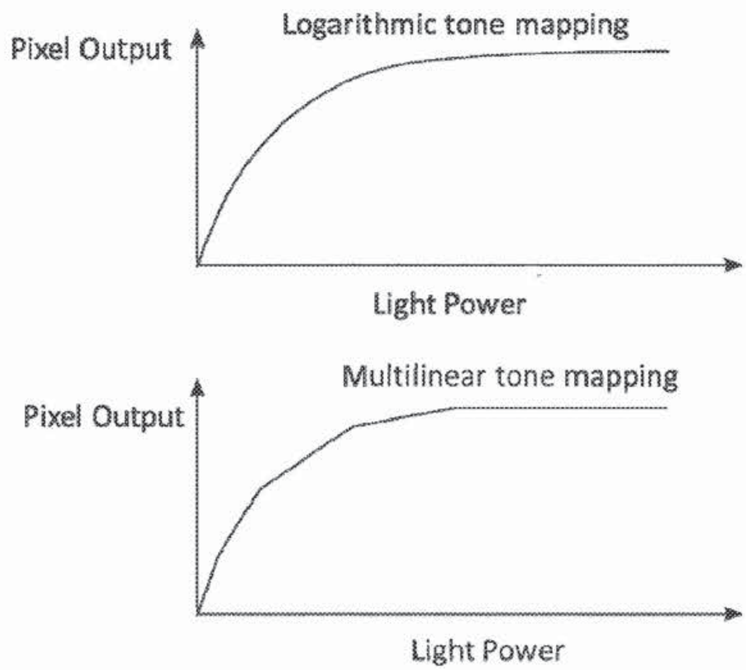
Logarithmic tone mapping
Pixel Output
Light Power
Multilinear tone mapping
Pixel Output
Light Power

Fig. 4

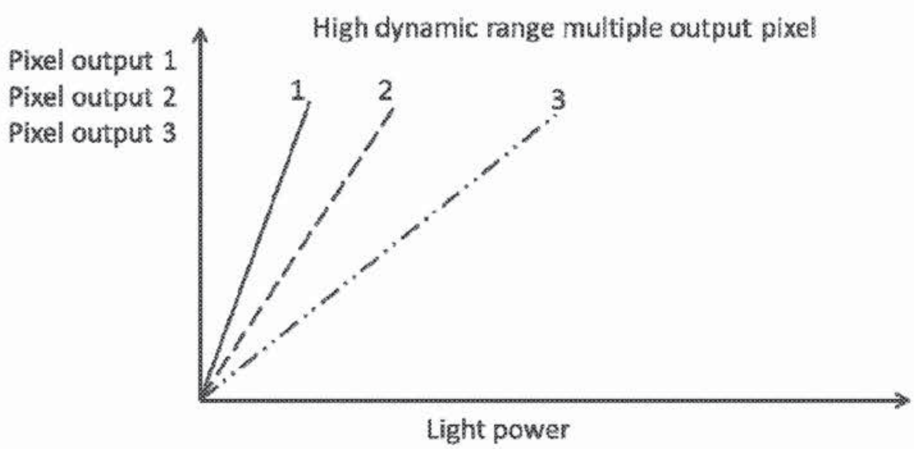
High dynamic range multiple output pixel
Pixel output 1
Pixel output 2
Pixel output 3
1
2
3
Light power

Fig. 5

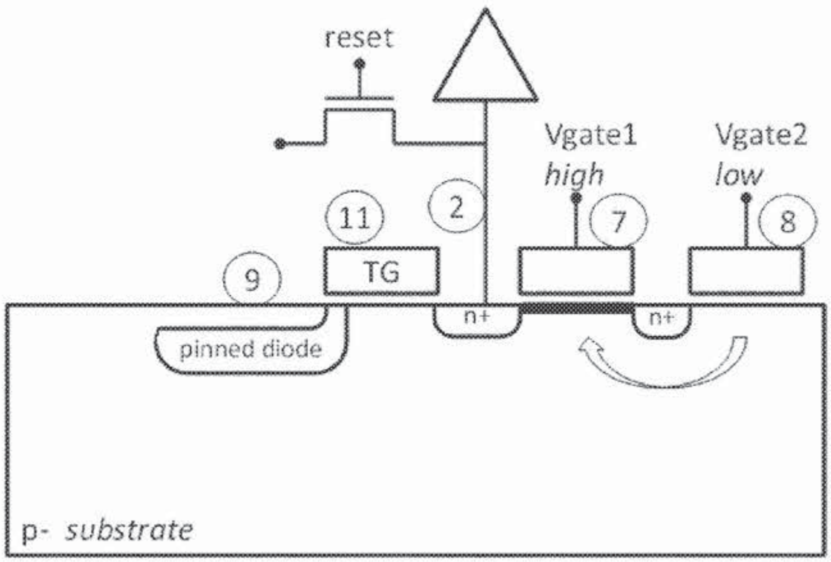
reset
Vgate1
high
Vgate2
low
11
2
7
8
9
TG
n+
n+
pinned diode
p- substrate

Fig. 6

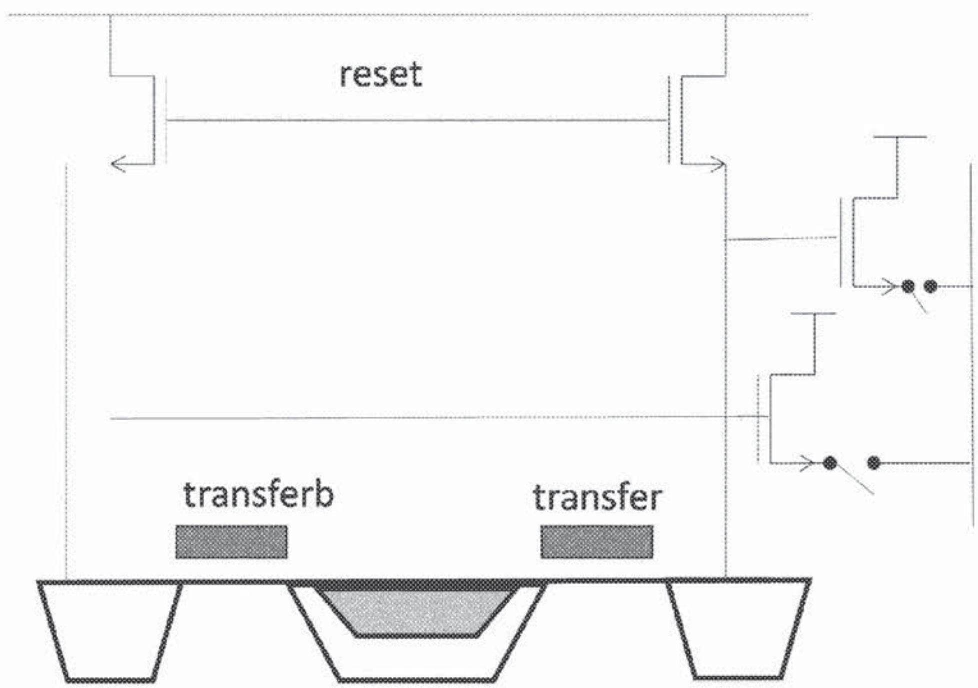

Fig. 7

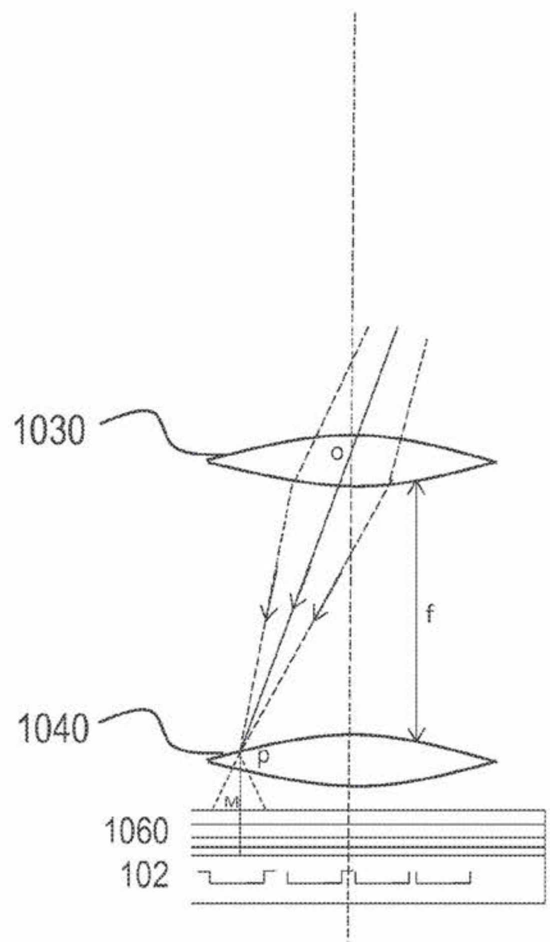

Fig. 8

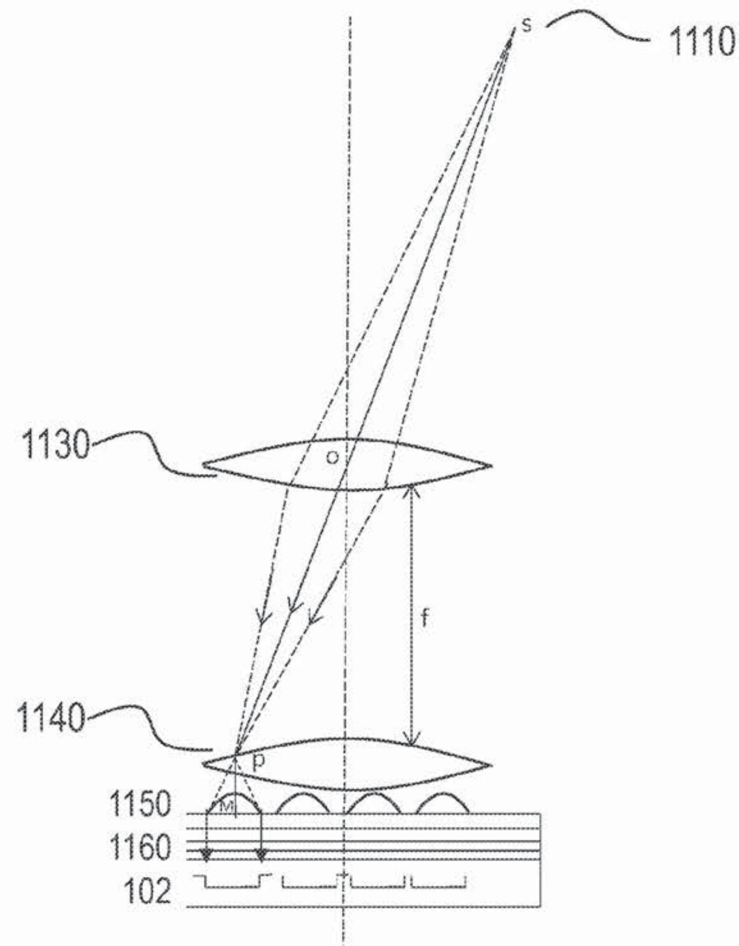

Fig. 9

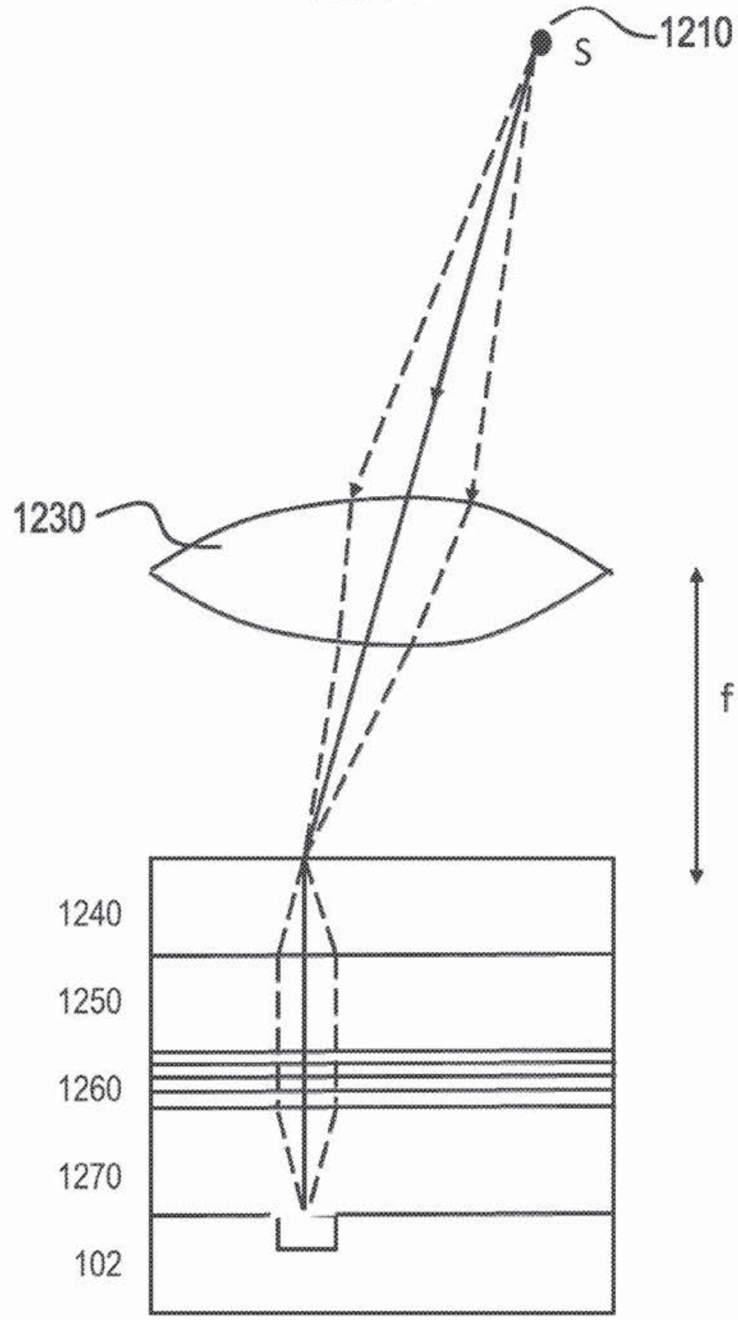

Fig. 10

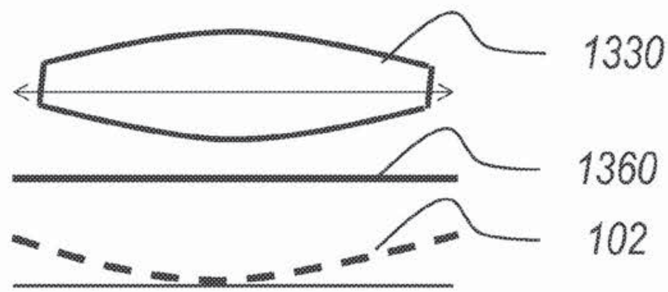
1330
1360
102

Fig. 11

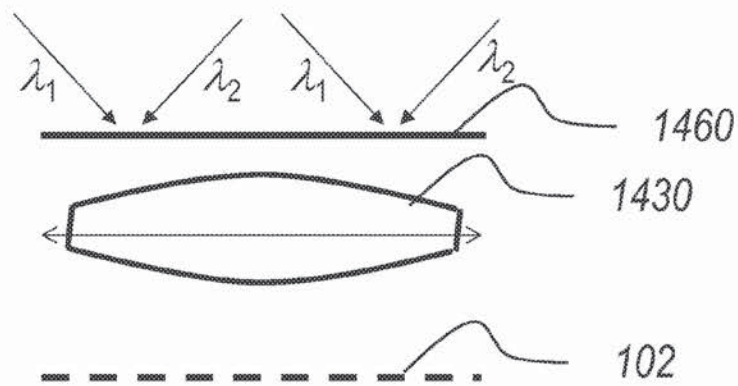
λ_1
λ_2
λ_1
λ_2
1460
1430
102

Fig. 12

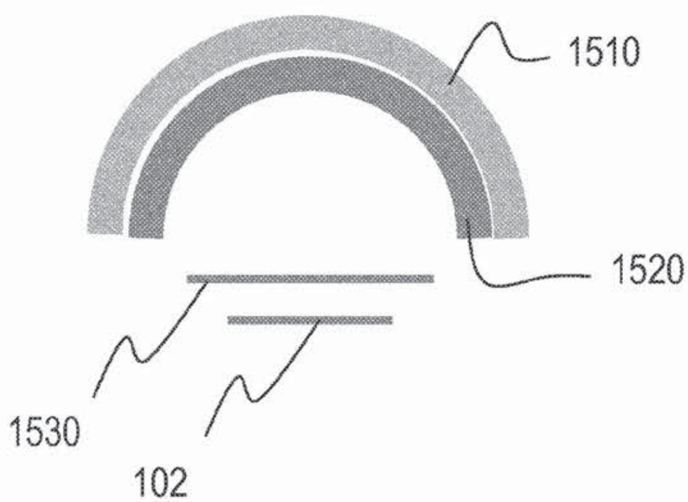

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075096

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/89 G01S17/93 G01S17/10 G01S7/481 G01S7/486
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, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/148102 A1 (OGGIER THIERRY [CH]) 13 June 2013 (2013-06-13) paragraphs [0002], [0008], [0017] - [0028], [0031], [0033], [0035], [0039]; figures 1,2,5b,7 -----	1-11
Y	BUTTGEN B ET AL: "Pseudonoise Optical Modulation for Real-Time 3-D Imaging with Minimum Interference", IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS I: REGULAR PAPERS, IEEE, US, vol. 54, no. 10, 1 October 2007 (2007-10-01), pages 2109-2119, XP011194105, ISSN: 1549-8328, DOI: 10.1109/TCSI.2007.904598 abstract paragraph [0001] -----	1-11

-/--

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

[X] 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

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"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	Date of mailing of the international search report
19 January 2018	26/01/2018

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	Metz, Carsten

1

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010/231891 A1 (MASE MITSUHITO [JP] ET AL) 16 September 2010 (2010-09-16) paragraphs [0093] - [0101], [0129] - [0135], [0198] - [0211]; figures 9,6,10,24 -----	2-4,8,10
Y	WO 2015/004213 A1 (XENOMATIX BVBA [BE]) 15 January 2015 (2015-01-15) page 4, line 26 - page 5, line 5 -----	6

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/075096

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP 2187237 A1	19-05-2010
		JP 5171158 B2	27-03-2013
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		US 2010231891 A1	16-09-2010
		WO 2009025373 A1	26-02-2009
WO 2015004213 A1	15-01-2015	CN 105393083 A	09-03-2016
		EP 3019824 A1	18-05-2016
		JP 2016530503 A	29-09-2016
		KR 20160029845 A	15-03-2016
		US 2016018526 A1	21-01-2016
		WO 2015004213 A1	15-01-2015

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G01S 17/93 (2006.01)

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(30) Priority Data:
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(54) Title: SYSTEM FOR DETERMINING A DISTANCE TO AN OBJECT

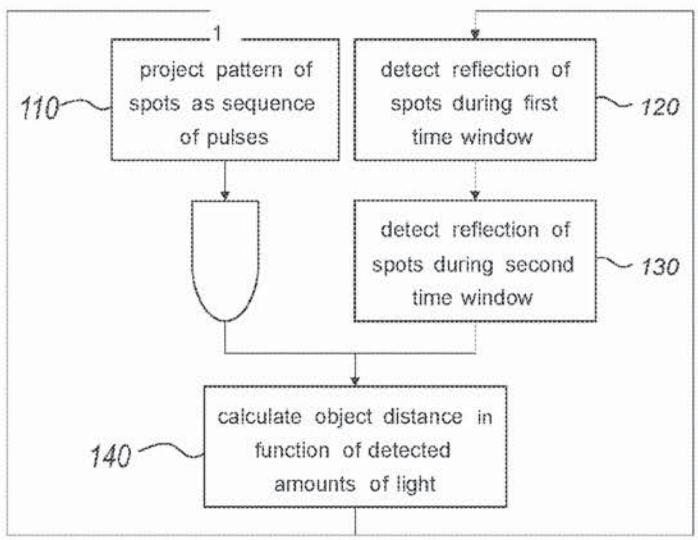

Fig. 1

(57) Abstract: The invention pertains to a system for determining a distance, comprising: a light source for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising picture elements, for detecting light representing the pattern as reflected by the object in synchronization with the sequence of pulses; and processing means to calculate the distance to the object as a function of exposure values generated by said picture elements. The picture elements generate the exposure values by accumulating a first amount of electrical charge representative of a first amount of light reflected during a first time window and a second electrical charge representative of a second amount of light reflected during a second time window, the second time window occurring after the first time window. The picture elements comprise at least two sets of charge storage wells, each configured as a cascade.

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System for determining a distance to an object

Field of the Invention

The present invention pertains to the field of systems for determining a distance to an object, in particular to time-of-flight based sensing systems to be used for the characterization of a scene or a part thereof.

Background

In the field of remote sensing technology, mainly in the usage of making high-resolution maps of the surroundings, to be used in many control and navigation applications such as but not limited to the automotive and industrial environment, gaming applications, and mapping applications, it is known to use time-of-f light based sensing to determine the distance of objects from a sensor. Time-of-flight based techniques include the use of RF modulated sources, range gated imagers, and direct time-of-f light (DToF) imagers. For the use of RF modulated sources and range gated imagers, it is necessary to illuminate the entire scene of interest with a modulated or pulsed source. Direct time-of-f light systems, such as most LIDARs, mechanically scan the area of interest with a pulsed beam, the reflection of which is sensed with a pulse detector.

In order to be able to correlate an emitted RF modulated signal with the detected reflected signal, the emitted signal must meet a number of constraints. In practice, these constraints turn out to make the RF modulated systems highly impractical for use in vehicular systems: the attainable range of detection is very limited for signal intensities that are within conventional safety limits and within the power budget of regular vehicles.

A direct TOF (DToF) imager, as used in most LIDAR systems, comprises a powerful pulsed laser (operating in a nanosecond pulse regime) , a mechanical scanning system to acquire from the ID point measurement a 3D map, and a pulse detector. Systems of this type are presently available from vendors including Velodyne Lidar of Morgan Hill, California. The Velodyne HDL-64E, as an example of state-of-the-art systems, uses 64 high-power lasers and 64 detectors (avalanche diodes) in a mechanically rotating structure at 5 to 15 rotations per second. The optical power required by these DToF LIDAR systems is too high to be obtained with semiconductor lasers, whose power is in the range of five to six orders of magnitude lower. In addition, the use of mechanically rotating elements for scanning purposes limits the prospects for miniaturization, reliability, and cost reduction of this type of system.

United States Patent application publication no. 2015/0063387 in the name of Trilumina discloses a VCSEL delivering a total energy of 50 mW in a pulse having a pulse width of 20 ns. The commercially available Optek OPV310 VCSEL delivers a total energy of 60 mW in a pulse having a duration of 10 ns and it can be estimated by extrapolation to have a maximum optical output power of 100 mW. This value is only realized under very stringent operating conditions, meaning optimal duty cycle and short pulse width so as to avoid instability due to thermal problems. Both the Trilumina disclosure and the Optek system illustrate that continuous-wave VCSEL systems are reaching their physical limits with respect to optical peak power output, due to thermal constraints inherently linked to the VCSEL design. At these pulse energy levels, and using ns pulses as presently used in DToF applications, the mere number of photons that can be expected to be usefully reflected by an object at a distance of 120 m is so low that it defeats detection by means of conventional semiconductor sensors such as CMOS or CCD or SPAD array. Thus, increasing the VCSEL power outputs by 5 or 6 orders of magnitude, as would be required to extend the range of the known DToF systems, is physically impossible.

Even the use of avalanche diodes (AD or SPAD), which are theoretically sufficiently sensitive to capture the few returning photons, cannot be usefully deployed in the known LIDAR system architectures. A solid state implementation of an array of SPADs must be read out serially. A high number of SPADs is required to achieve the desired accuracy. The serial read-out constraints of the solid state implementation limit the bandwidth of the system turning it inappropriate for the desired accuracy. For accuracies such as that of the Velodyne system (0.02 m to 0.04 m, independent of distance), the required read-out data rate exceeds the practically achievable bandwidth in case of today's IC implementation. For operation at 120 m, a SPAD array of 500x500 pixels is required, which, in an IC-based implementation, must be read-out serially. For the same precision as the aforementioned Velodyne system, it would require 1000 pulses per millisecond and hence 1000 frames per millisecond, translating into a readout rate of 250 Gigapixels per second. This is believed to be technically unfeasible in the context of current SPAD IC technology.

The paper by Neil E. Newman et al., "High Peak Power VCSELs in Short Range LIDAR Applications", *Journal of Undergraduate Research in Physics*, 2013, http://www.jurp.org/2 013/12 017EXR.pdf, describes a VCSEL-based LIDAR application. The paper states that the maximum output power of the described prototype system was not great enough to do wide-field LIDAR at a range greater than 0.75 m. With a relatively focused beam (0.02 m spot size at 1 m distance), the authors were able to range a target object at a distance of up to 1 m.

The above examples clearly indicate that the optical power emitted by present semiconductor lasers cannot meet the power requirements necessary for operations in the known LIDAR systems to be of practical use in automotive applications (e.g. for ranges up to 120 m).

United States patent no. 7,544,945 in the name of Avago Technologies General IP (Singapore) Pte. Ltd., discloses vehicle-based LIDAR systems and methods using multiple lasers to provide more compact and cost-effective LIDAR functionality. Each laser in an array of lasers can be sequentially activated so that a corresponding optical element mounted with respect to the array of lasers produces respective interrogation beams in substantially different directions. Light from these beams is reflected by objects in a vehicle's environment, and detected so as to provide information about the objects to vehicle operators and/or passengers. The patent provides a solid state projector in which the individual lasers are consecutively activated in order to replace the known mechanical scanning in the known DToF LIDAR systems.

A high-accuracy medium-range surround sensing system for vehicles that does not use time-of-flight detection, is known from international patent application publication WO 2015/004213 A1 in the name of the present applicant. In that publication, the localization of objects is based on the projection of pulsed radiation spots and the analysis of the displacement of detected spots with reference to predetermined reference spot positions. More in particular, the system of the cited publication uses triangulation . However, the accuracy that can be achieved correlates with the triangulation base, which limits the further miniaturization that can be achieved.

US patent application publication no. US 2012/0038903 A1 discloses methods and systems for adaptively controlling the illumination of a scene. In particular, a scene is illuminated, and light reflected from the scene is detected. Information regarding levels of light intensity received by different pixels of a multiple pixel detector, corresponding to different areas within a scene, and/or information regarding a range to an area within a scene, is received. That information is then used as a feedback signal to control levels of illumination within the scene. More particularly, different areas of the scene can be provided with different levels of illumination in response to the feedback signal.

European patent application publication no. EP 2 322 953 A1 discloses a distance image sensor capable of enlarging the distance measurement range without reducing the distance resolution. A radiation source provides first to fifth pulse trains which are irradiated to the object as radiation pulses in the first to fifth frames arranged in order on a time axis. In each of the frames, imaging times are prescribed at points of predetermined time from the start point of each frame, also the pulses are shifted respectively by shift amounts different from each other from the start point of the first to fifth frames. A pixel array generates element image signals each of which has distance information of an object in distance ranges different from each other using imaging windows A and B in each of five frames. A processing unit generates an image signal by combining the element image signals. Since five times-of-f light measurement are used, the width of the radiation pulse does not have to be increased to obtain distance information of the object in a wide distance range, and the distance resolution is not reduced.

European patent application publication no. EP 2 290 402 A1 discloses a range image sensor which is provided on a semiconductor substrate with an imaging region composed of a plurality of two-dimensionally arranged units, thereby obtaining a range image on the basis of charge quantities output from the units. One of the units is provided with a charge generating region (region outside a transfer electrode) where charges are generated in response to incident light, at least two semiconductor regions which are arranged spatially apart to collect charges from the charge generating region, and a transfer electrode which is installed at each periphery of the semiconductor region, given a charge transfer signal different in phase, and surrounding the semiconductor region.

The article by Shoji Kawahito et al., "A CMOS Time-of-Flight Range Image Sensor With Gates-on-Field-Oxide Structure", *IEEE Sensors Journal*, Vol. 7, no. 12, p. 1578-1586, discloses a type of CMOS time-of-flight (TOS) range image sensor using single-layer gates on field oxide structure for photo conversion and charge transfer. This structure allows the realization of a dense TOF range imaging array with 15 x 15 μm^2 pixels in a standard CMOS process. Only an additional process step to create an n-type buried layer which is necessary for high-speed charge transfer is added to the fabrication process. The sensor operates based on time-delay dependent modulation of photocharge induced by back reflected infrared light pulses from an active illumination light source. To reduce the influence of background light, a small duty cycle light pulse is used and charge draining structures are included in the pixel. The TOF sensor chip fabricated measures a range resolution of 2.35 cm at 30 frames per second an improvement to 0.74 cm at three frames per second with a pulse width of 100 ns.

European patent application no. EP15191288.8 in the name of the present applicant, which has not been published at the filing date of the present application, describes some aspects of a system and method for determining a distance to an object.

There is a continuing need to obtain extreme miniaturization and/or longer-range in complex vehicular surround sensing applications, such as ADAS (autonomous driving assistance system) applications and autonomous driving applications, and this at a reasonable cost and in a compact, semiconductor-integrated form factor.

Summary of the Invention

It is an objective of embodiments of the present invention to provide a further miniaturized and longer-range alternative for displacement-based vehicular surround sensing systems. Furthermore, it is an objective of embodiments of the present invention to provide a full solid-state alternative for the known LIDAR systems.

According to an aspect of the present invention, there is provided a system for determining a distance to an object comprising: a solid-state light source arranged for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising a plurality of picture elements, the detector being configured for detecting light representing the pattern of discrete spots as reflected by the object in synchronization with the sequence of pulses; and processing means configured to calculate the distance to the object as a function of exposure values generated by the picture elements in response to the detected light; wherein the picture elements are configured to generate the exposure values by accumulating, for all of the pulses of the sequence, a first amount of electrical charge representative of a first amount of light reflected by the object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by the object during a second predetermined time window, the second predetermined time window occurring after the first predetermined time window; wherein each of the plurality of picture elements comprises at least two sets of charge storage wells, the detecting of said first amount of light and the detecting of the second amount of light occurring at respective ones of the at least two sets of charge storage wells; and wherein each of the sets of charge storage wells is configured as a cascade.

The term "charge storage well" designates a storage provided in the semiconductor substrate, e.g. a capacitor, that stores electrical charges generated by the conversion of photons impinging on the pixel.

The present invention relies on the same physical principles as direct time-of-f light based ranging systems, viz. the fact that light always takes a certain amount of time to travel a given distance. However, the present invention uses range gating to determine the distance travelled by a light pulse that has been transmitted and subsequently reflected by a target object. The present invention is *inter alia* based on the insight of the inventors that by combining range gating, an at least partially simultaneous spot pattern projection (based on a novel illumination scheme) and a low-power semiconductor light source, a substantially miniaturized, full solid state and energy-efficient long-range distance detection method can be obtained. The term "pattern" as used herein refers to a spatial distribution of simultaneously projected spots. In order to determine the position of the detected spot reflection in three-dimensional space, it is necessary to combine the distance information obtained from the ranging step with angular information to fix the remaining two spatial coordinates. A camera comprising a pixel array and suitably arranged optics can be used to provide the additional angular information, by identifying the pixel in which the reflection is detected.

Embodiments of the present invention are based on the further insight of the inventors that in order to be able to use spot patterns generated by solid-state light sources in a LIDAR system at the desired ranges, a way to circumvent the optical power limitations is needed. The inventors have found that by prolonging the pulse duration and by integrating the reflected energy of multiple VCSEL-generated light pulses within at least two sets of semiconductor sensor wells, followed by a single read-out of the integrated charge, a solid-state LIDAR system can be obtained with a significantly greater operating range than is currently possible with solid-state implementations. Hereinafter, the term "storage" will be used to designate the well or the pixel in which charge is accumulated in response to the detection of photons.

It is an advantage of the present invention that the solid-state light source and the solid-state sensor (such as a CMOS sensor, a CCD sensor, SPAD array or the like) may be integrated on the same semiconductor substrate. The solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern.

Moreover, by assessing the reflected light energy detected in two consecutive time windows, and normalizing for the total accumulated charge in the two consecutive windows, the impact of varying reflectivity of the object under study and the contribution of ambient light can adequately be accounted for in the distance calculation algorithm.

The transmission and detection of the sequence of pulses may be repeated periodically.

In the picture elements, charge representative of the impinging light is accumulated at well level. An advantage of charge accumulation at the well level is that read-out noise is minimized, leading to a better signal-to-noise ratio.

It is an advantage of the cascade-based arrangement that the total amount of charge to be accumulated is distributed over multiple wells, which allows for a greater total charge storage capacity while maintaining an accurate reading of the total charge level.

The increase in the total charge storage capacity is of particular importance at the end of the operating range where large number of photons - and hence, large amounts of charge - are received by the system; this is the case at short range (because the intensity of the light in function of distance follows an inverse-square law) or when surfaces with an unusually high reflectance are present in the field of view of the sensor. In conditions where a single well would tend to be saturated, a cascade-based arrangement allows the excess charge to be stored in a subsequent storage well, without losing the possibility of accurately determining the total amount of charge.

The total number of capacities in the cascade can be selected in function of the desired operating range and accuracy, and the general requirement to keep the Poisson noise as low as possible. The latter condition is inherently linked to the application of range gating, where Poisson noise is detrimental to the accuracy of the distance determination. A low level of Poisson noise allows a continuous photon-charge response, regardless of whether the charge is stored in one or more capacities of the cascade.

In an embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a serially arranged cascade. In another embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a parallelly arranged cascade.

It is an advantage of these embodiments that they provide easy to implement arrangements to obtain the desired cascade effect of the storage wells.

In an embodiment of the system according to the present invention, the first predetermined time window and the second predetermined time window are of substantially equal duration and occur back-to-back, and a total storage capacity of the set of charge storage wells configured to detect the first amount of light is larger than a total storage capacity of the set of charge storage wells configured to detect the second amount of light.

It is an advantage of this embodiment that it helps to avoid saturation of the charge storage elements due to an overload of reflected photons. This problem is most prominent at nearby distances. At short ranges, the total number of reflected photons will be higher, due to the inverse square law, while most of the reflected signal will arrive within the first time window and thus be stored in the corresponding set of charge storage wells. Hence, it is useful to dimension the set of charge storage wells corresponding to the first time window so as to be able to deal with a larger amount of charge.

According to an aspect of the present invention, there is provided a vehicle, comprising: a system as described above arranged to operatively cover at least a part of an area surrounding said vehicle .

The system according to the present invention is particularly advantageous in a vehicle with ADAS or autonomous driving control unit such as but not limited to ECU (electrical control unit). The vehicle may further comprise a vehicle control unit, adapted for receiving measurement information from the system and for using the information for ADAS control or autonomous driving decision taking. The part of an area surrounding the vehicle may include a road surface ahead of, beside, or behind the vehicle. Accordingly, the system may provide road profile information of the surface ahead of the car, to be used for active suspension or semi-active suspension.

According to an aspect of the present invention, there is provided a camera, the camera comprising a system as described above, whereby the system is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

The technical effects and advantages of embodiments of the camera and the vehicle according to the present invention correspond, *mutatis mutandis*, to those of the corresponding embodiments of the system according to the present invention.

Brief Description of the Figures

These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings, in which:

Figure 1 represents a flow chart of an embodiment of the method according to the present invention;

Figure 2 schematically represents an embodiment of the system according to the present invention;

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention;

Figure 4 provides diagrams of exemplary pixel output in function of incident light power as obtained by logarithmic tone mapping (top) and multilinear tone mapping (bottom);

Figure 5 provides a diagram of exemplary pixel outputs in function of incident light power as obtained by a high dynamic range multiple output pixel;

Figure 6 schematically illustrates the structure of a high-dynamic range pixel for use in embodiments of the present invention;

Figure 7 schematically illustrates an embodiment of a pixel architecture with two charge wells (bins) with each a separate transfer gate for use in embodiments of the present invention;

Figure 8 schematically illustrates a first exemplary optical arrangement for use in embodiments of the present invention;

Figure 9 schematically illustrates a second exemplary optical arrangement for use in embodiments of the present invention;

Figure 10 schematically illustrates a third exemplary optical arrangement for use in embodiments of the present invention;

Figure 11 schematically illustrates a fourth exemplary optical arrangement for use in embodiments of the present invention;

Figure 12 schematically illustrates a fifth exemplary optical arrangement for use in embodiments of the present invention; and

Figure 13 schematically illustrates a sixth exemplary optical arrangement.

Detailed Description of Embodiments

The surround sensing systems of the type disclosed in international patent application publication WO 2015/004213 A1, in the name of the present applicant, have the advantage of observing an extensive scene while illuminating that scene simultaneously or partially simultaneously only in a number of discrete and well-defined spots, in particular a predefined spot pattern. By using VCSEL lasers with an outstanding bundle quality and a very narrow output spectrum, it is possible to obtain a detection range with a limited amount of output power, even in the presence of daylight. The actual ranging performed in the system of WO 2015/004213 A1 relies on displacement detection, in particular triangulation, which was understood to be the only method practically available in the context of the long (quasi-stationary) pulse durations that were necessary in view of the power budget. To date, it had not been possible to achieve the same power/performance characteristics with a compact, semiconductor based time-of-f light based system.

The present invention overcomes this limitation by radically changing the way the time-of-f light based system operates. The invention increases the total amount of light energy emitted for each time-of-f light measurement (and thus, the number of photons available for detection at the detector for each time-of-f light measurement) by increasing the duration of individual pulses and by producing a virtual "composite pulse", consisting of a sequence of a large number of individual pulses. This bundling of extended pulses allowed the inventors to obtain the required amount of light energy (photons) for the desired operational range with low-power VCSELs.

Where an individual pulse of pre-existing LIDAR systems may have a duration of 1 ns, the systems according to the present invention benefit from a substantially longer pulse duration to partially compensate for the relatively low power level of semiconductor lasers such as VCSELs; in embodiments of the present invention, individual pulses within a sequence may have an exemplary duration of 1 μs (this is one possible value, chosen here to keep the description clear and simple; more generally, in embodiments of the present invention, the pulse duration may for example be 500 ns or more, preferably 750 ns or more, most preferably 900 ns or more). In an exemplary system according to the present invention, a sequence may consist of 1000 pulse cycles, thus adding up to a duration of 1 ms. Given the fact that light would need approximately 0.66 µs to travel to a target at a distance of 100 m and back to the detector, it is possible to use composite pulses of this duration for ranging at distance of this order of magnitude; the skilled person will be able to adjust the required number of pulse cycles in function of the selected pulse width and the desired range. The detection of the sequence preferably comprises detecting the individual pulses in synchronization with the VCSEL-based light source, and accumulating the charges generated in response to the incoming photons at the pixel well level for the entire sequence prior to read-out. The term "exposure value" is used hereinafter to designate the value representative of the charge (and thus of the amount of light received at the pixel) integrated over the sequence. The sequence emission and detection may be repeated periodically.

The present invention operates by using range gating. Range gated imagers integrate the detected power of the reflection of the emitted pulse for the duration of the pulse. The amount of temporal overlap between the pulse emission window and the arrival of the reflected pulse depends on the return time of the light pulse, and thus on the distance travelled by the pulse. Thus, the integrated power is correlated to the distance travelled by the pulse. The present invention uses the principle of range gating, as applied to the sequences of pulses described hereinabove. In the following description, the integration of individual pulses of a sequence at the level of a picture element to obtain a measurement of the entire sequence is implicitly understood.

Figure 1 represents a flow chart of an embodiment of the method according to the present invention. Without loss of generality, the ranging method is described with reference to a range gating algorithm. In a first time window **10**, the method comprises projecting **110** a pattern of spots of laser light (e.g. a regular or an irregular spatial pattern of spots) from a light source comprising a solid-state light source **210** onto any objects in the targeted area of the scenery. The spatial pattern is repeatedly projected in a sequence of pulses.

As indicated above, the solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern. In order for the system to operate optimally, even at long ranges and with high levels of ambient light (e.g., in daylight) , a VCSEL for use in embodiments of the present invention is preferably arranged to emit a maximum optical power per spot per unit of area. Thus, lasers with a good beam quality (low M2-factor) are preferred. More preferably, the lasers should have a minimal wavelength spread; a particularly low wavelength spread can be achieved with monomode lasers. Thus, substantially identical pulses can reproducibly be generated, with the necessary spatial and temporal accuracy.

During the same time window in which a pulse is emitted, or in a substantially overlapping time window, a first amount of light representing the pattern of spots as reflected by the object of interest is detected **120** at a detector, which is preferably arranged as near as possible to the light source. The synchronicity or near synchronicity between the projection **110** of the spot pattern and the first detection **120** of its reflection, is illustrated in the flow chart by the side-by-side arrangement of these steps. In a subsequent second predetermined time window **20,** a second amount of light representing the reflected light spot is detected **130** at the detector. During this second window **20,** the solid-state light source is inactive. The distance to the object can then be calculated **140** as a function of the first amount of reflected light and the second amount of reflected light.

The first predetermined time window **10** and the second predetermined time window **20** are preferably back-to-back windows of substantially equal duration, to facilitate noise and ambient light cancellation by subtracting one of the detected amounts from the other one. An exemplary timing scheme will be described in more detail below in conjunction with Figure 3.

The detector comprises a plurality of picture elements, i.e. it consists of a picture element array with adequate optics arranged to project an image of the scenery (including the illuminated spots) onto the picture element. The term "picture element" as used herein may refer to an individual light-sensitive area or well of a pixel, or to an entire pixel (which may comprise multiple wells, see below). For every given projected spot, the detecting **120** of the first amount of light and the detecting **130** of the second amount of light occurs at the same one or the same group of the plurality of picture elements.

Without loss of generality, each of the picture elements may be a pixel comprising at least two charge storage wells **221, 222,** such that the detecting **120** of the first amount of light and the detecting **130** of the second amount of light can occur at the respective charge storage wells **221, 222** of the same pixel or pixel group.

Figure 2 schematically represents an embodiment of the system according to the present invention, in relation to an object **99** in the scenery of interest. The system **200** comprises a solid-state light source **210** for projecting a pattern of a sequence of spots, which may be repeated periodically, onto the object **99.** A detector **220** is arranged near the light source and configured to detect light reflected by the object.

The light beam bouncing off the object **99** is illustrated as an arrow in dashed lines, travelling from the light source **210** to the object **99** and back to the detector **220.** It should be noted that this representation is strictly schematic, and not intended to be indicative of any actual relative distances or angles.

A synchronization means **230,** which may include a conventional clock circuit or oscillator, is configured to operate the solid-state light source **210** so as to project the pattern of spots onto the object during first predetermined time windows **10** and to operate the detector **220** so as to detect a first amount of light representing the light spot(s) reflected by the object **99** at substantially the same time. It further operates the detector **220** to detect a second amount of light representing the light spots reflected by the object **99**, during respective subsequent second predetermined time windows **20**. Appropriate processing means **240** are configured to calculate the distance to the object as a function of the first amount of reflected light and the second amount of reflected light.

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention. For clarity reasons, only a single pulse of the pulse sequence which is repeated periodically of Figure 1 is illustrated, which consists of a first time window **10** and a second time window **20**.

As can be seen in Figure 3a, during the first time window **10**, the solid-state light source **210** is in its "ON" state, emitting the pattern of light spots onto the scenery. During the second time window **20**, the solid-state light source **210** is in its "OFF" state.

The arrival of the reflected light at the detector **220** is delayed relative to the start of the projection by an amount of time that is proportional to the distance travelled (approximately 3.3 ns/m in free space) . Due to this delay, only a part of the reflected light will be detected at the first set of wells **221** of the detector **220**, which is only activated during the first time window **10**. Thus, the charge accumulated in this first well during its period of activation (the first time window **10**) consists of a part representing only the noise and the ambient light impinging on the pixel prior to the arrival of the reflected pulse, and a part representing the noise, the ambient light, and the leading edge of the reflected pulse.

The latter part of the reflected pulse will be detected at the second set of wells **222** of the detector **220**, which is only activated during the second time window **20**, which preferably immediately follows the first time window **10**. Thus, the charge accumulated in this second well during its period of activation (the second time window **20**) consists of a part representing the noise, the ambient light, and the trailing edge of the reflected pulse, and a part representing only the noise and the ambient light impinging on the pixel after the arrival of the reflected pulse.

The greater the distance between the reflecting object **99** and the system **200**, the smaller the proportion of the pulse that will be detected in the first set of wells **221** and the larger the proportion of the pulse that will be detected in the second set of wells **222**.

If the leading edge of the reflected pulse arrives after the closing of the first set of wells **221** (i.e., after the end of the first time window **10**), the proportion of the reflected pulse that can be detected in the second set of wells **222** will decrease again with increasing time of flight delay.

The resulting amounts of charge A, B in each of the respective sets of wells **221, 222** for varying distances of the object **99** is shown in Figure 3b. To simplify the representation, the effect of the attenuation of light with distance, according to the inverse square law, has not been taken into account in the diagram. It is clear that for time of flight delays up to the combined duration of the first time window **10** and the second time window **20**, the time of flight delay can in principle unambiguously be derived from the values of A and B:

- For time of flight delays up to the duration of the first time window **10**, B is proportional to the distance of the object **99**. To easily arrive at a determination of the absolute distance, the normalized value B/(B+A) may be used, removing any impact of non-perfect reflectivity of the detected object and of the inverse square law.

- For time of flight delays exceeding the duration of the first time window **10**, **A** consists of daylight and noise contributions only (not illustrated), and **C–B** is substantially proportional (after correcting for the inverse square law) to the distance of the object **99**, where **C** is an offset value.

While Figures 3a and 3b illustrate the principle of the invention in relation to a single pulse emitted in the time window **10**, it shall be understood that the illustrated pulse is part of a sequence of pulses as defined above. Figure 3c schematically illustrates exemplary timing characteristics of such a sequence. As illustrated, the illumination scheme **40** consists of a repeated emission of a sequence **30** of individual pulses **10**. The width of the individual pulses **10** is determined by the maximal operating range. The entire sequence may be repeated at a frequency of, for example, 60 Hz.

The sets of wells **221**, **222** each consist of a cascade of charge storage wells. A judicious design of the cascades ensures a smooth transition between the capacities to assure extremely high accuracy levels.

The storage capacities are preferably designed around each pixel, to ensure that there is sufficient space for the cascade while optimizing the charge transfer from the area where the impinging photons are converted to electrical charges.

The capacities are preferably dimensioned so as to provide an accurate read-out of the lowest level of light that must be detectable (e.g. 1000 photons). It is advantageous to design the cascade in such a way that the maximum amount of charge n_{max} that can be stored in any given stage of the cascade equals the minimum amount of charge n_{min} that can be reliably read out from the next stage.

Reflections of light by objects at a short distances are more likely to cause pixel saturation, because the attenuation of such a reflection will be much less than that of a reflection originating from a more distant object (due to the inverse-square law of light attenuation over distance) . As certain applications, such as automotive applications, require accurate system operation up to relatively long distances, a large photon span must be covered between the nearest distances of operation and the farthest distances of operation. With these constraints, pixel saturation at short range is a very real risk, in particular at the first set of wells (which receives the bulk of the reflection at short range) . The inventors have found that for given total pixel space, the saturation problem can be mitigated by using an asymmetric well arrangement, in which the photon capacity represented by the first set of wells is increased, and the photon capacity represented by the second set of wells is decreased. If the increase and decrease are balanced, an increase of the dynamic range can be obtained at no additional pixel surface cost.

Blooming is a phenomenon that happens when the charge in a pixel exceeds the saturation level of that specific pixel. Consequently, the charge starts to overflow and causes nuisance in adjacent pixels. This creates inaccurate data in the neighboring pixels. Preferably, the pixels of the system according to the present invention are provided with anti-blooming electronics, to bleed off the excess charge before it saturates the relevant set of wells and spills over to the wells of adjacent pixels. In particular when the information from neighboring spots is used for the elimination of background light, it is of great importance to have an accurate estimation of the background light which is obtained independently (and without contamination from) neighboring pixels.

Embodiments of the present invention may employ correlated double sampling to correct the samples for the thermal noise related to the capacity of the wells (also designated as "kTC noise") . To this end, the electronics of the pixel may be designed to carry out a differential measurement between the reset voltage (V_{reset}) and the signal voltage (V_{signal}), for example by measuring V_{reset} at the beginning of the frame and measuring V_{signal} at the end of the frame. As an alternative to an electronic (in-pixel) implementation, correlated double sampling may also be implemented by digitally subtracting the read-out signals (V_{signal} - V_{reset}) in a processor .

To increase the amount of light that reaches the photosensitive elements (in particular diodes) in the pixel structure, embodiments of the present invention may use backside illumination; in that case, the pixel circuitry is behind the photosensitive layer, thus reducing the number of layers that must be traversed by the impinging photons to read the photosensitive elements .

The ranging system according to the present invention may be integrated with a triangulation-based system in accordance with WO 2015/004213 A1. If miniaturization is aimed for, the triangulation-based system will end up having a relatively small distance between its projector and its detector, thus leaving it with a reduced operating range. However, it is precisely at short range that the combination presents its benefit, because the triangulation-based system can cover the distances at which the time-of-flight based system cannot operate sufficiently accurately .

The entire ranging process may be repeated iteratively, so as to monitor the distance to the detected object or objects over time. Thus, the result of this method can be used in processes that require information about the distance to detected objects on a continuous basis, such as advanced driver assistance systems, vehicles with an active suspension, or autonomous vehicles.

In order for all elements of the system as described to operate optimally, the system has to be thermally stable. Thermal stability avoids, among other things, undesired wavelength shifts of the optical elements (thermal drift), which would otherwise impair the proper functioning of the optical filters and other elements of the optical chain. Embodiments of the system according to the present invention achieves thermal stability by their design, or by active regulation by means of a temperature control loop with a PID-type controller.

WO 2015/004213 A1 discloses various techniques to minimize the amount of ambient light that reaches the pixels during the detection intervals, thus improving the accuracy of the detection of the patterned laser spots. While these techniques have not been disclosed in the context of a LIDAR system, the inventors of the present invention have found that several such techniques yield excellent results when combined with embodiments of the present invention. This is particularly true for the use of narrow bandpass filters at the detector, and the use of adequate optical arrangements to ensure nearly perpendicular incidence of the reflected light onto the filters. The details of these arrangements as they appear in WO 2015/004213 A1 are hereby incorporated by reference. Further features and details are provided hereinafter.

While various techniques known from WO 2015/004213 A1 may be applied to embodiments of the present invention to minimize the amount of ambient light that reaches the pixels during the detection intervals, a certain amount of ambient light cannot be avoided. In a multi-pixel system, only some of the pixels will be illuminated by reflected spots, while others will be illuminated by residual ambient light only. The signal levels of the latter group of pixels can be used to estimate the contribution of the ambient light to the signals in the pixels of interest, and to subtract that contribution accordingly. Additionally or alternatively, background light or ambient light may be subtracted from the detected signal at pixel level. This requires two exposures, one during the arrival of the laser pulse and one in the absence of a pulse.

In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient discrimination of intensity levels in the darkest part of the scene, is an advantage of the use of such a sensor; it allows for a sensor that has a very long range and yet remains capable of detection objects at short distance (where the reflected light is relatively intense) without undergoing saturation. The inventors have found that the use of a true high dynamic range sensor is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression (see Figure 4). However, this non-linear compression necessitates relinearisation of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor as presented in Figure 5. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US 2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention.

Embodiments of the present invention use a high dynamic range pixel. This can be obtained by a sizeable full-well capacity of the charge reservoir or by designs limiting the electronic noise per pixel or by usage of CCD gates that do not add noise at charge transfer, or through a design with a large detection quantum efficiency (DQE) (e.g., in the range of 50% for front illumination or 90% in case of back illumination, also known as back thinning), or by a special design such as shown in Figure 6 (see below), or by any combination of the listed improvements. Furthermore, the dynamic range can be further enlarged by adding an overflow capacity to the pixel in overlay at its front side (this implementation requires back thinning). Preferably, the pixel design implements an anti-blooming mechanism.

Figure 6 presents a schematic illustration of an advantageous implementation of a pixel with high dynamic range. The example in this figure makes use of two storage gates 7, 8, connected to the floating diffusion. After exposure, the electron generated by the scene AND the laser pulse, is transferred on the floating diffusion using the transfer gate 11. Both Vgate1 and Vgate2 gate voltages are set high. The charges are then spread over both capacitors, realizing a significant Full Well. Once this high full-well data is read via connection to the amplifier, the voltage Vgate2 is set low. The electrons reflow towards capacitor 7, increasing the total pixel gain. The data can be read through the amplifier. It is further possible to achieve an even higher gain by applying later a low voltage on Vgate1. The electrons reflow towards the floating diffusion 2.

Figure 7 represents a possible dual-well or dual-bin implementation of an envisaged pixel to be used in CMOS technology. The impinging signal is distributed over two charge storages. Each reservoir has a separate transfer gate controlled by an external pulse which is synchronized with the pulse of the laser sources.

The charge storage elements shown in the designs of Figure 6 and Figure 7 may be replicated to obtain a cascade of charge storage wells as required by the present invention.

Figures 8-10 illustrate cameras that may be used in embodiments of the invention, where the light radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter and optics arranged so as to modify an angle of incidence onto said narrow bandpass filter, to confine said angle of incidence to a predetermined range around a normal of a main surface of said narrow bandpass filter, said optics comprising an image-space telecentric lens. The term "camera" is used herein as a combination of a sensor and associated optics (lenses, lens arrays, filter) . In particular, in Figure 9, the optics further comprise a minilens array arranged between the image-space telecentric lens and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

These examples all result in radiation travelling a substantially equal length through the filter medium or in other words in that the incident radiation is substantially orthogonal to the filter surface, i.e. it is confined to an angle of incidence within a predetermined range around the normal of the filter surface, thus allowing in accurate filtering within a narrow bandwidth to e.g. filter the daylight, the sunlight and in order to for the spots to surpass the daylight.

The correction of the angle of incidence is of particular importance in embodiments of the present invention where the entire space around a vehicle is to be monitored with a limited number of sensors, for instance 8 sensors, such that the incident rays may extend over a solid angle of for example 1 x 1 rad. Figure 8 schematically illustrates a first optical arrangement of this type. It comprises a first lens **1030** and a second lens **1040**, with approximately the same focal length *f*, in an image space telecentric configuration. That means that all chief rays (rays passing through the center of the aperture stop) are normal to the image plane. An exemplary numerical aperture of 0.16 corresponds to a cone angle of 9.3° (half cone angle) . The maximum incidence angle on the narrow bandpass filter 1060, arranged between the lens system **1030-1040** and the sensor **102,** would thus be 9.3°.

As illustrated in Figure 9, the preferred design consists of a tandem of two lenses **1130, 1140** with approximately the same focal length *f*, in an image-space telecentric configuration (the configuration is optionally also object-space telecentric), a planar stack of mini-lens array **1150,** a spectral filter **1160** and a CMOS detector **102.** Since the center 0 of the first lens **1130** is in the focus of the second lens **1140,** every ray that crosses 0 will be refracted by the second lens **1140** in a direction parallel to the optical axis. Consider now a particular laser spot S **1110** located at a very large distance as compared to the focal length of the first lens **1130.** Thus the image of this spot **1110** by the first lens **1130** is a point P located close to the focal plane of this lens, thus exactly in the middle plane of the second lens **1140.** The light rays that are emitted from the spot S **1110** and captured by the first lens **1130** form a light cone that converges towards the point P in the second lens **1140.** The central axis of this light cone crosses the point 0 and is refracted parallel the optical axis and thus perpendicular to the spectral filter **1160** so as to achieve optimal spectral sensitivity. Hence, the second lens **1140** acts as a correcting lens for the angle of the incident light beam. The other rays of the cone can also be bent in a bundle of rays parallel to the optical axis by using a small convex mini-lens **1150** behind the second lens **1140** in such a way that the point P is located in the focal point of the mini-lens **1150.** In this way all the imaging rays of the spot S **1110** are bent in a direction nearly perpendicular to the spectral filter. This can now be done in front of every pixel of the CMOS detector separately by using an array of mini-lenses positioned in front of every pixel. In this configuration, the minilenses have an image-telecentric function. The main advantage is that the pupil of the first lens **1030** can be enlarged, or the aperture can be eliminated while compensating for the increase in spherical aberration by a local correction optics in the mini-lens **1150.** In this way the sensitivity of the sensor assembly can be improved. A second mini-lens array (not shown in Figure 11) may be added between the spectral filter **1160** and the CMOS pixels **102**, to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor.

For the first and second lenses **1130**, **1140**, commercially available lenses may be used. The skilled person will appreciate that lenses typically used in other smart phone cameras or webcams of comparable quality can also be used. The aforementioned iSight camera has a 6 x 3 mm CMOS sensor with 8 megapixels, 1.5 μm pixel size, a very large aperture of f/2.2, an objective focal length of about f = 7 mm, and a pupil diameter about 3.2 mm. The viewing angle is of the order of 1 rad x 1 rad. If we assume that the resolution of the camera is roughly the pixel size (1.5 micron), we can conclude (from Abbe's law) that the aberrations of the lens are corrected for all the rays of the viewing angle selected by the aperture.

Figure 10 illustrates a variation of the arrangement of Figure 11, optimized for manufacturing in a single lithographic process. The first lens **1230** is similar to the first lens **1130** of the previous embodiment, but the angle-correcting second lens **1140** is replaced by a Fresnel lens **1240** with the same focal length f and the mini-lens arrays **1150** by Fresnel lens arrays **1250**. The advantage is that they are completely flat and can be produced by nano-electronics technology (with discrete phase zones) . A second mini-lens array **1270** may be added between the spectral filter **1260** and the CMOS pixels **102**, to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor. Thus the camera is essentially a standard camera as the iSight but in which the CMOS sensor is replaced by a specially designed multi-layer sensor in which all the components are produced in one integrated block within the same lithographic process. This multilayer sensor is cheap in mass production, compact, robust and it need not be aligned. Each of these five layers **1240**, **1250**,

1260, **1270**, **102** has its own function to meet the requirements imposed by the present invention.

As the minimal angle of a cone generated by a lens of diameter d is of the order of λ/d, with λ the wavelength of the light, the minimal cone angle is 1/10 radian for a mini-lens diameter $d = 8.5$ μm and $\lambda = 850$ nm. With a good quality spectral interference filter this corresponds to a spectral window of about 3 nm.

In the arrangements of Figures 8-10, the characteristics of the optics will result in a non-planar focal plane. To compensate this effect, the picture elements of the detector may be arranged on a substrate having a curvature that follows the focal plane of the optics. As a result, the reflected and filtered spots will be in focus, regardless of where they reach the detector. The desired curvature of the substrate of the detector can be obtained by using flex-chip technology, or by composing the substrate by combining differently oriented tiles. This solution is schematically illustrated in Figure 11, which shows telecentric optics **1330**, followed by a narrow band-pass filter **1360**, and a curved pixel layer **102**, the curvature of which is adapted to follow the shape of the focal plane of the telecentric optics **1330**.

When it is not possible (or not desirable) to arrange the optics in such a way as to ensure that light rays following different paths all pass through the narrow bandpass filter under the same (perpendicular) angle, the problem of having different filter characteristics with different angles of incidence may be resolved at the source. In particular, the VCSEL array may be configured such that different spots have different respective wavelengths. This configuration may be obtained by using a tiled laser array, or by providing means for modulating the wavelength of individual VCSELs in the VCSEL array. This solution is schematically illustrated in Figure 12, which shows a narrow band-pass filter **1460** arranged before the optics **1430** and the sensor array **102**. For clarity purposes and without loss of generality, two different angles of incidence with different respective wavelengths (λ_1, λ_2) have been indicated on the Figure. The different wavelengths (λ_1, λ_2) of the light sources are chosen to correspond to the maximum of the passband of the narrow bandpass filter under their respective angles of incidence.

Figure 13 illustrates an alternative optical arrangement, comprising a dome **1510** (e.g., a bent glass plate) with the narrow bandpass filter **1520** disposed on its inside (as illustrated) or outside (not illustrated) . The advantage of disposing the filter **1520** on the inside of the dome **1510,** is that the dome **1510** protects the filter **1520** from outside forces. The dome **1510** and the filter **1520** optically cooperate to ensure that incident light passes through the filter **1520** along a direction that is substantially normal to the dome's surface. Fish-eye optics **1530** are provided between the dome-filter assembly and the sensor **102,** which may be a CMOS or a CCD sensor or SPAD array. The fish-eye optics **1530** are arranged to guide the light that has passed through the dome-filter assembly towards the sensitive area of the sensor.

Optionally, further fish-eye optics are provided at the projector. In a specific embodiment, a plurality of VCSELs are mounted in a 1 x n or a m x n configuration, whereby an exit angle of the laser beam can be realized over a spatial angle of m x 1 rad in height and n x 1 rad in width.

In some embodiments of the present invention, the intensity of the spots can be kept substantially constant over the full depth range, by applying a stepped or variable attenuation filter at the detector. Alternatively or in addition, also a non-symmetrical lens pupil can be provided for weakening the intensity of spots closer to the detector, while the intensity of the spots further away from the detector are received at full intensity. In this way clipping of the detector is avoided and the average intensity can be made substantially the same for all spots.

In some embodiments, the radiation source can be a VCSEL that can be split in different zones, whereby the laser ON time is controlled for the different zones. The images of the spots can thus be controlled to have a constant intensity, e.g. 2/3rd of the A/D range. Alternatively the driving voltage can be driven over the array of spots as function of the height, again to obtain a constant intensity. Such controlling can be referred to as a saturation avoidance servoing loop. The different VCSELs within the array can be controlled individually for intensity, varying the intensity of the individual VCSELs in the pattern while projected simultaneously.

In some other embodiments of the present invention, a micro prism matrix can be used in front of the narrow bandwidth filter, such that the radiation is incident within an angle of incidence between +9° and -9° on the filter. This allows to obtain narrow bandwidth filtering. The prism matrix can for example be made by plastic moulding.

In embodiments of the present invention, e.g. where active suspension vehicle applications are envisaged, the projection of the spot pattern is advantageou sly directed downwards, i.e. towards the road.

A system according to the invention may include an implementation of steps of the methods described above in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA) , programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component (s) may also include other functions. The present invention also pertains to a computer program product comprising code means implementing the steps of the methods described above, which product may be provided on a computer-readable medium such as an optical, magnetic, or solid-state carrier.

The present invention also pertains to a vehicle comprising the system described above.

Embodiments of the present invention may be used advantageously in a wide variety of applications, including without limitation automotive applications, industrial applications, gaming applications, and the like, and this both indoor and outdoor, at short or long range. In some applications, different sensors according to embodiments of the present invention may be combined (e.g., daisy-chained) to produce panoramic coverage, preferably over a full circle (360° field of view).

While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system, respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A system (200) for determining a distance to an object comprising :

- a solid-state light source (210) arranged for projecting a pattern of discrete spots of laser light towards said object in a sequence of pulses;
- a detector (220) comprising a plurality of picture elements, said detector (220) being configured for detecting light representing said pattern of discrete spots as reflected by said object in synchronization with said sequence of pulses; and
- processing means (240) configured to calculate said distance to said object as a function of exposure values generated by said picture elements in response to said detected light;

wherein said picture elements (220) are configured to generate said exposure values by accumulating, for all of the pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window (10) and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10);

wherein each of said plurality of picture elements comprises at least two sets of charge storage wells, each set of charge storage wells being configured as a cascade so as to form a greater total charge storage capacity, said detecting of said first amount of light and said detecting of said second amount of light occurring at respective ones of said cascades.

2. The system according to claim 1, wherein each of said sets of charge storage wells is configured as a serially arranged cascade.

3. The system according to claim 1, wherein each of said sets of charge storage wells is configured as a parallelly arranged cascade .

4. The system according to any of the preceding claims, wherein said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back, and wherein a total storage capacity of said set of charge storage wells configured to detect said first amount of light is larger than a total storage capacity of said set of charge storage wells configured to detect said second amount of light.

5. A vehicle comprising a system (100) according to any of the previous claims arranged to operatively cover at least a part of an area surrounding said vehicle.

6. A camera, the camera comprising a system (100) according to any of claims 1 to 4, whereby the system (100) is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

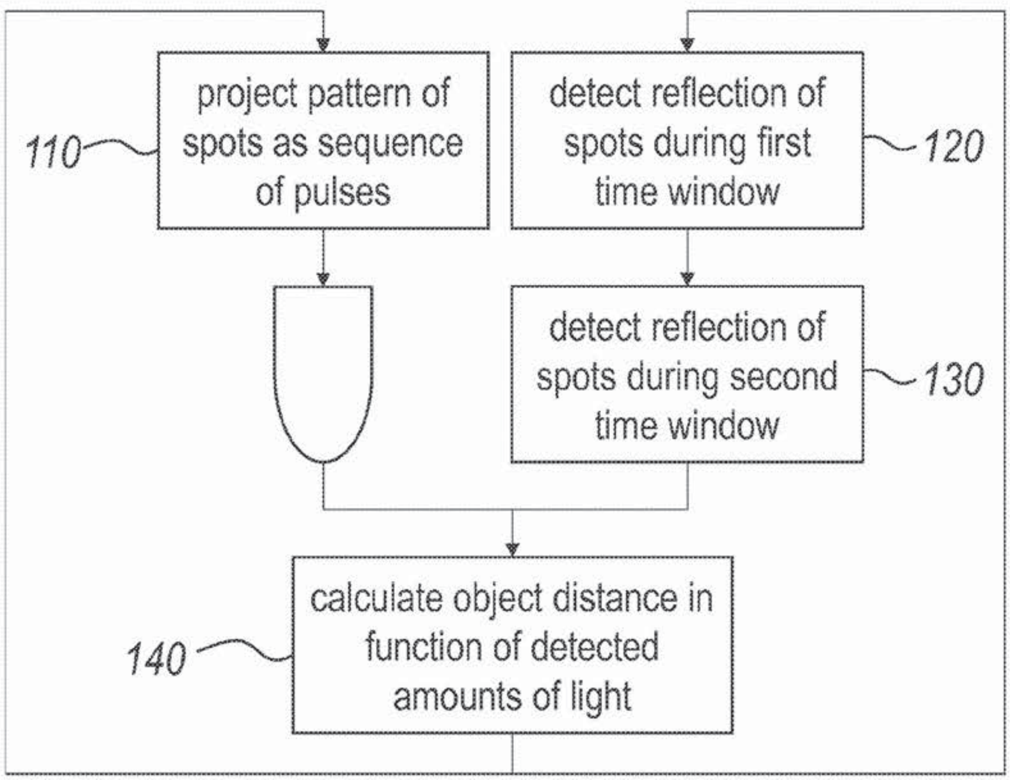
project pattern of spots as sequence of pulses
110
detect reflection of spots during first time window
120
detect reflection of spots during second time window
130
calculate object distance in function of detected amounts of light
140

Fig. 1

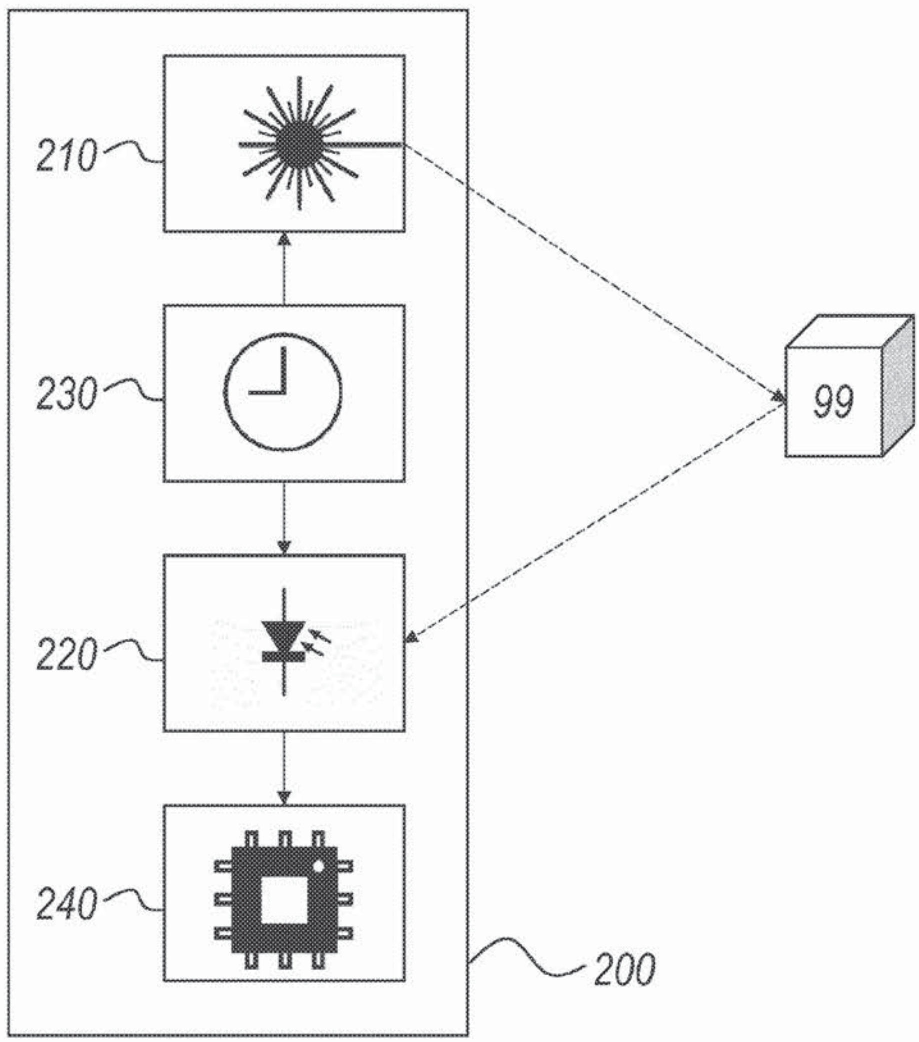

Fig. 2

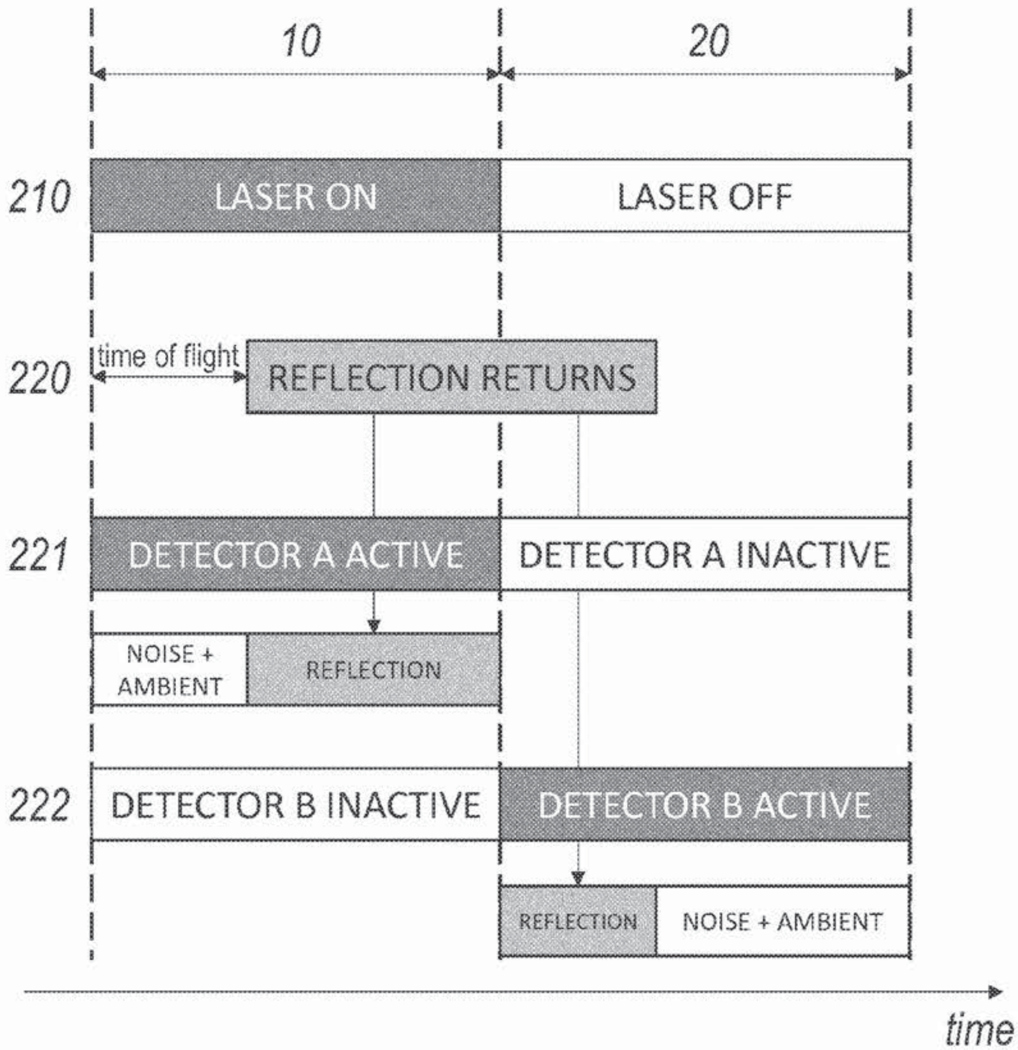
10
20
210
LASER ON
LASER OFF
220
time of flight
REFLECTION RETURNS
221
DETECTOR A ACTIVE
DETECTOR A INACTIVE
NOISE + AMBIENT
REFLECTION
222
DETECTOR B INACTIVE
DETECTOR B ACTIVE
REFLECTION
NOISE + AMBIENT
time

Fig. 3a

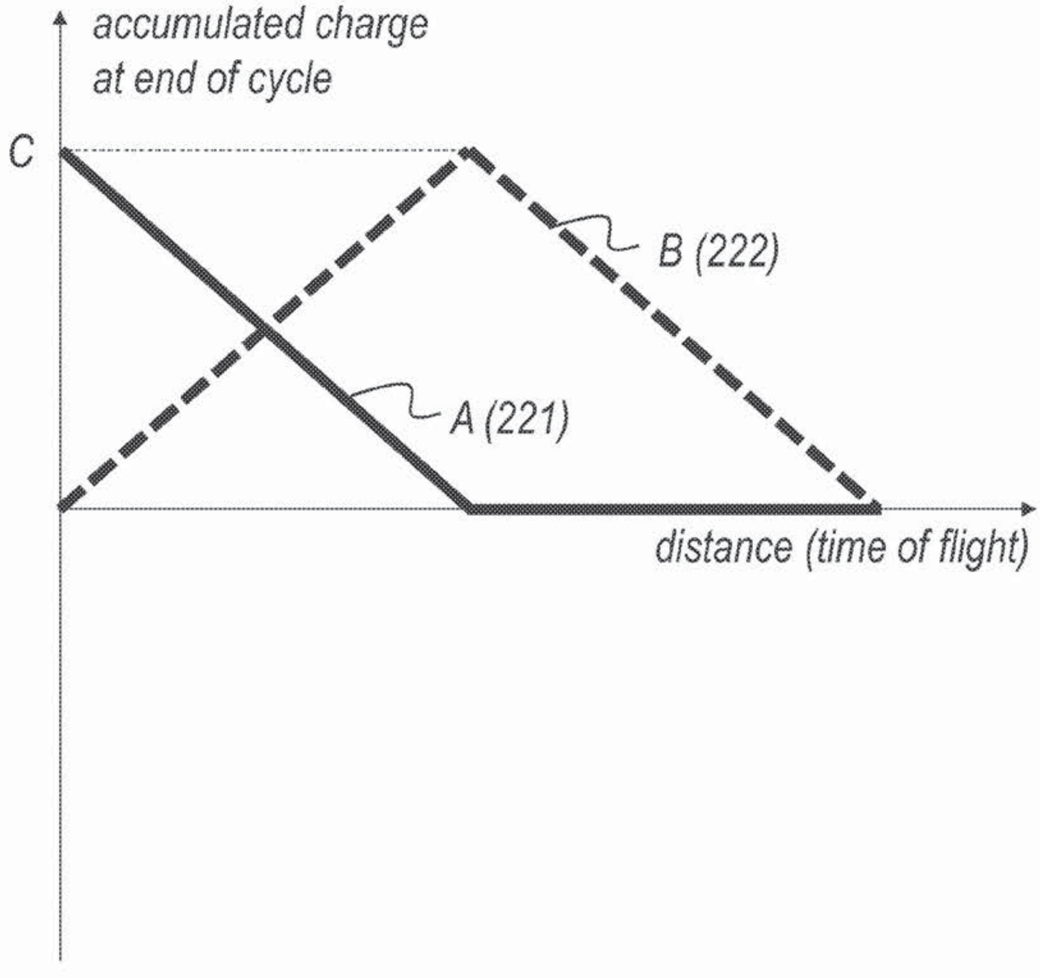
accumulated charge
at end of cycle
C
B (222)
A (221)
distance (time of flight)

Fig. 3b

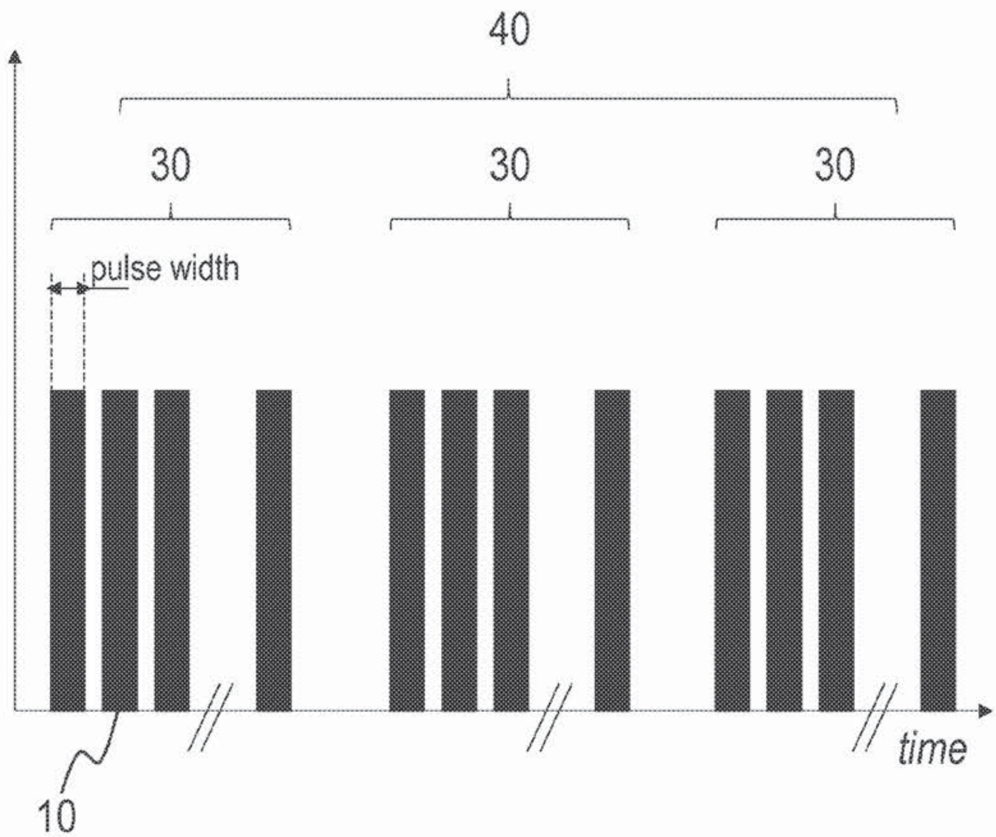

Fig. 3c

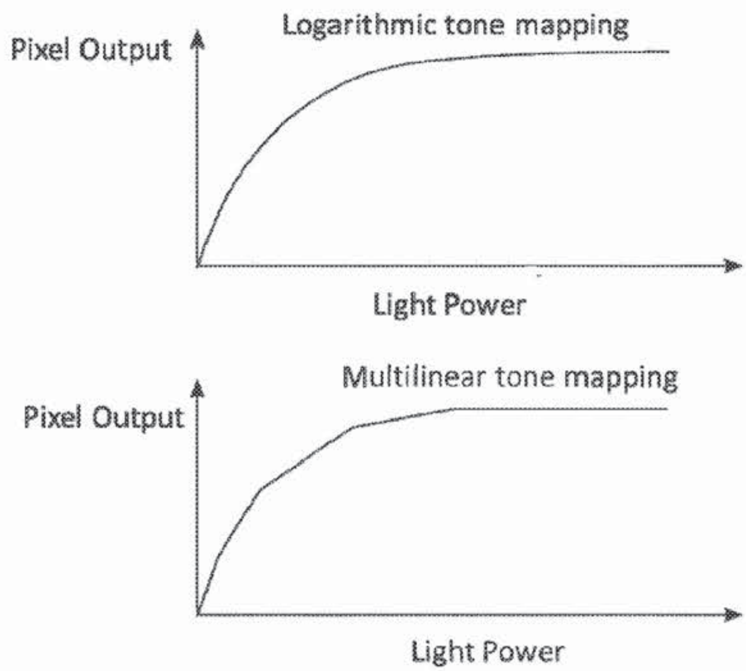
Logarithmic tone mapping
Pixel Output
Light Power
Multilinear tone mapping
Pixel Output
Light Power

Fig. 4

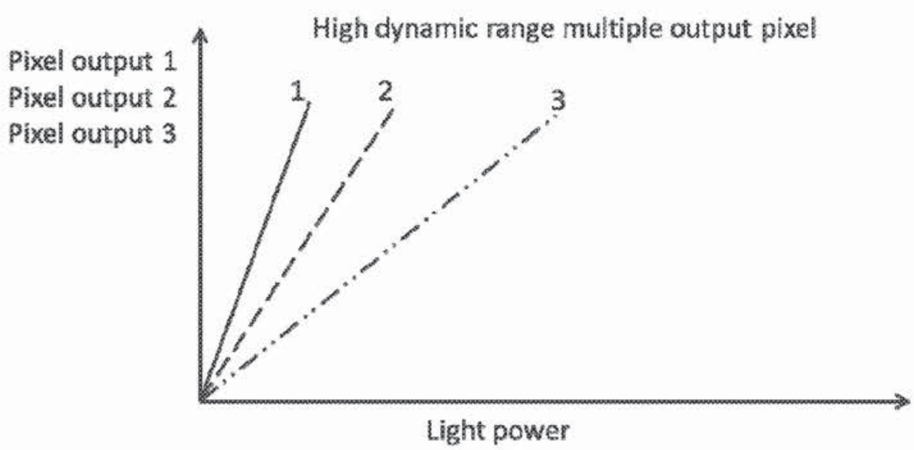
High dynamic range multiple output pixel
Pixel output 1
Pixel output 2
Pixel output 3
1
2
3
Light power

Fig. 5

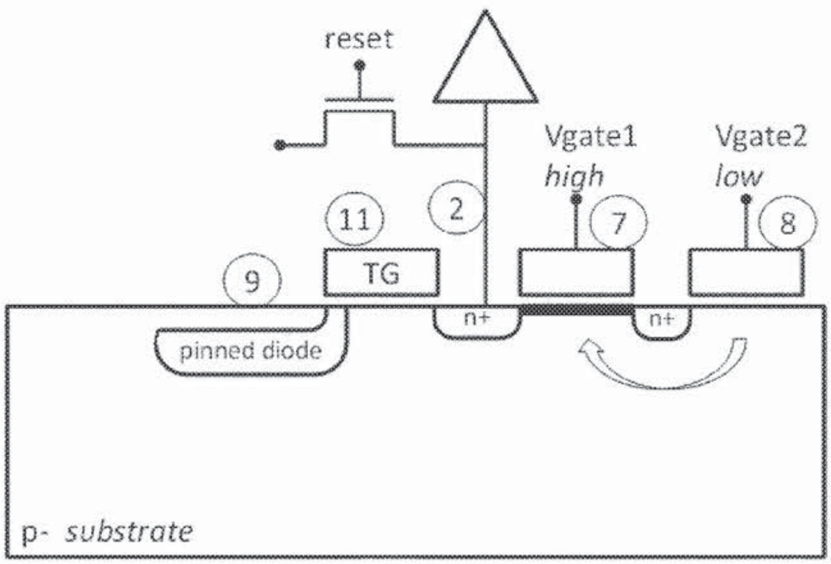
reset
Vgate1
high
Vgate2
low
11
2
7
8
9
TG
n+
n+
pinned diode
p- substrate

Fig. 6

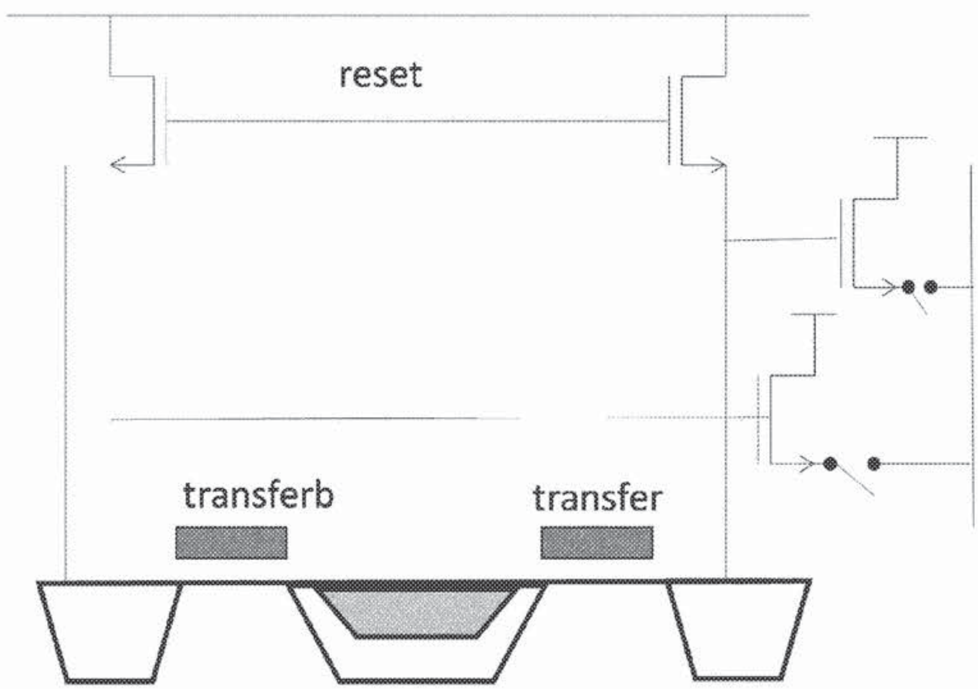

Fig. 7

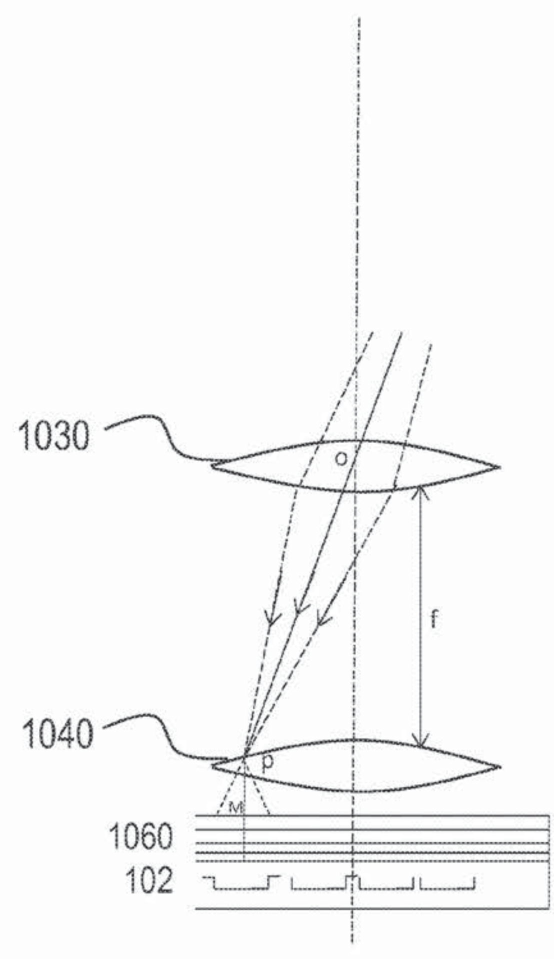

Fig. 8

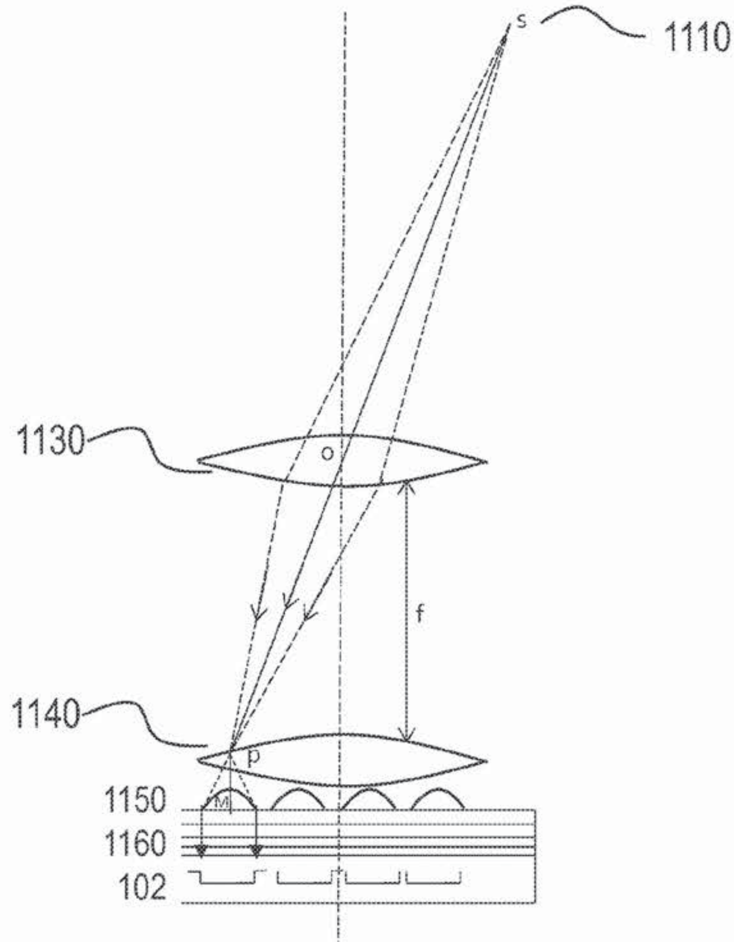

Fig. 9

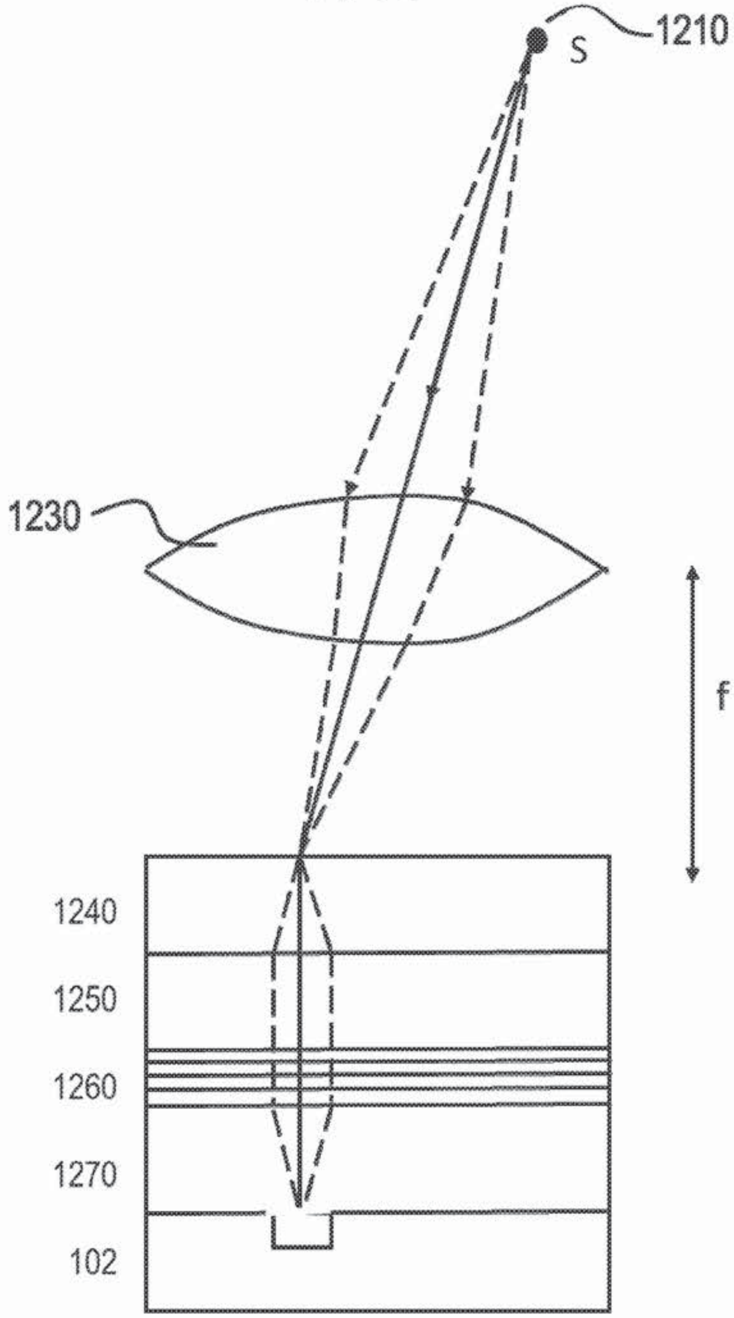

Fig. 10

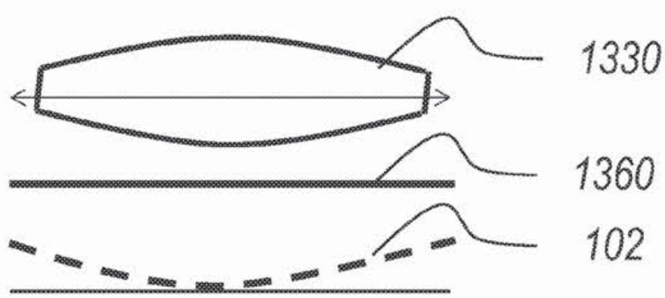

Fig. 11

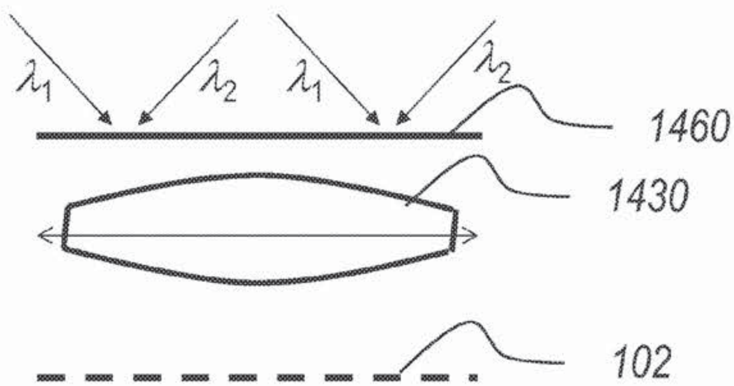

Fig. 12

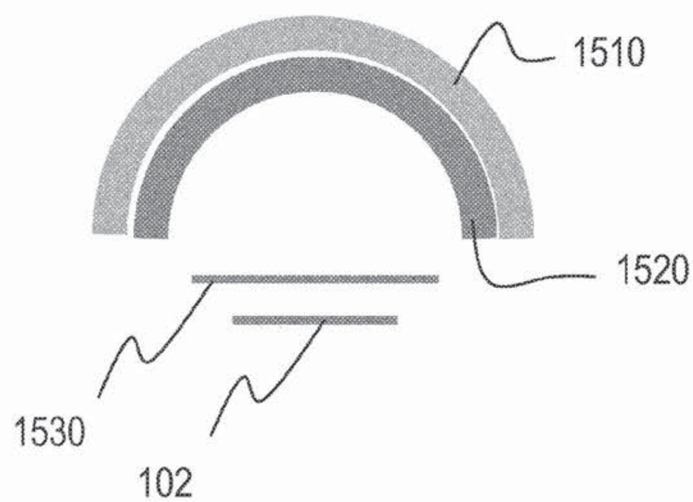

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075094

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/10 G01S17/89 G01S17/93 G01S7/481 G01S7/486
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 , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/148102 A1 (OGGIER THIERRY [CH]) 13 June 2013 (2013-06-13) paragraphs [0002], [0008], [0016] - [0028], [0014], [0031], [0033], [0035], [0039]; figures 1,2,5b,7 -----	1-6
Y	US 2010/231891 A1 (MASE MITSUHITO [JP] ET AL) 16 September 2010 (2010-09-16) paragraphs [0093] - [0101], [0129] - [0135], [0198] - [0211], [0125] - [0128], [0069]; figures 6,9,10,24 -----	1-6

☐ 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 application or patent 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

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"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	Date of mailing of the international search report
19 January 2018	29/01/2018

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	Metz, Carsten

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/075094

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013148102 AI	13-06-2013	NONE	
US 2010231891 AI	16-09-2010	CN 101784911 A	21-07-2010
		EP 2187237 AI	19-05-2010
		JP 5171158 B2	27-03-2013
		JP 2009047662 A	05-03-2009
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		US 2010231891 AI	16-09-2010
		Wo 2009025373 AI	26-02-2009

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G01S 17/89 (2006.01) *G01S 7/481* (2006.01)

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(30) **Priority Data:**
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(74) **Agent: IPLODGE BVBA;** Technologielaan 9, B-3001 Heverlee (BE).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, 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.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) **Title:** SYSTEM FOR DETERMINING A DISTANCE TO AN OBJECT

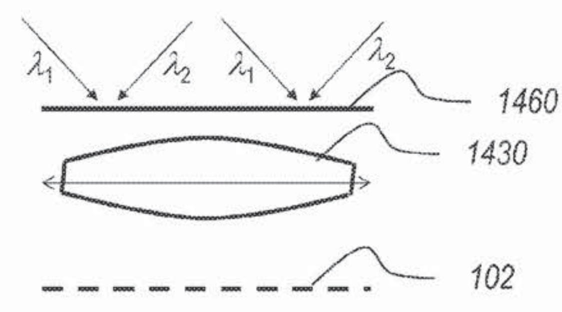

Fig. 12

WO 2018/065428 A3

(57) **Abstract:** The invention pertains to a system for determining a distance, comprising: a light source for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising picture elements, for detecting light representing the pattern as reflected by the object in synchronization with the sequence of pulses; and processing means to calculate the distance to the object as a function of exposure values generated by said picture elements. The picture elements generate exposure values by accumulating a first amount of electrical charge representing a first amount of light reflected during a first time window and a second electrical charge representating a second amount of light reflected during a second time window. The solid-state radiation source emits substantially monochromatic light having a wavelength spread of less than ±20 nm and the detector is equipped with a corresponding narrow bandpass filter.

[Continued on next page]

Declarations under Rule 4.17:
- *of inventorship (Rule 4.17(iv))*

Published:
- *with international search report (Art. 21(3))*
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INTERNATIONAL SEARCH REPORT

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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 , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/148102 A1 (OGGIER THIERRY [CH]) 13 June 2013 (2013-06-13) paragraphs [0002], [0008], [0017] - [0028], [0014], [0016], [0031], [0033], [0035], [0039]; figures 1,5b, 7,2	1-13
Y	WO 2015/004213 A1 (XENOMATIX BVBA [BE]) 15 January 2015 (2015-01-15) page 5, line 28-page 6, line 24 and page 4, line 26 - page 5, line 5	1-3, 11- 13
Y	US 2007/177841 A1 (DANZIGER YOCHAY [IL]) 2 August 2007 (2007-08-02)	2
A	paragraph [0084]; figure 13	1,3, 11-13

-/-

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

[X] 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

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"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

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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
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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2007/177011 A1 (LEWIN ANDREW C [GB] ET AL) 2 August 2007 (2007-08-02) paragraphs [0081], [0109], [0115], [0116], [0148], [0158]; figure 2 -----	2 1,3, 11-13
Y A	US 2015/260830 A1 (GHOSH CHUNI LAL [US] ET AL) 17 September 2015 (2015-09-17) paragraphs [0019], [0078], [0087], [0089], [0108]; figures 8,13 -----	2,3 1,11-13
Y A	US 2010/231891 A1 (MASE MITSUHITO [JP] ET AL) 16 September 2010 (2010-09-16) paragraphs [0093] - [0101], [0129] - [0135], [0198] - [0211]; figures 6,10,24 -----	12 1-3,11, 13
Y	MICHAEL C Y HUANG ET AL: "Monolithic Integrated Piezoelectric MEMS-Tunable VCSEL", IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 13, no. 2, 1 March 2007 (2007-03-01), pages 374-380, XP011179412, ISSN: 1077-260X, DOI: 10.1109/JSTQE.2007.894056 pages 374-378, paragraph III; figures 1-2 -----	4,5
Y	US 8 742 325 B1 (DROZ PIERRE-YVES [US] ET AL) 3 June 2014 (2014-06-03) col. 2, line 13-col. 8, line 4; claim 1; figures 1-4 -----	6-10
Y	EP 3 045 936 A1 (XENOMATIX BVBA [BE]) 20 July 2016 (2016-07-20) paragraph [0037] -----	9,10
A	Anonymous: "Laser linewidth - Wikipedia, the free encyclopedia", , 14 November 2011 (2011-11-14), XP055426729, Retrieved from the Internet: URL:https://web.archive.org/web/20111114232732/https://en.wikipedia.org/wiki/Laser_linewidth [retrieved on 2017-11-20] the whole document -----	1-3, 11-13

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2017/075095

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 11-13

An optical wavelength division multiplex system illuminating different spots by individually different respective wavelengths, which are selectively received by the detector.
Solved technical problem underlying the claimed invention (see page 11, lines 9-18): Projecting spots as monochromatic light, and filtering the light to be detected to a narrow band around the wavelength of the projected spots, thus reducing the amount of sunlight to be dealt with to the light present in the relevant band.

---

2. claims: 4, 5

Means to adapt the emission wavelength of individual VCSELs within the a VCSEL array light source for an optical distance determining system.
Solved technical problem underlying the claimed invention (see page 10, lines 1-7): The emission wavelength is tuned to the detector such that is at the maximum of the passband of the detectors narrow bandpass filter under different angles of incidence.

---

3. claims: 6-8

The implementation of an image-space telecentric optics and an angle of incident changing optics for an optical distance determining system.
Solved technical problem underlying the claimed invention (see page 12, lines 29- page 12, line 5): To allow the narrowband filter to obtain satisfactory results over a wider field of view.

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4. claims: 9, 10

A minilens array optics for an optical distance determining system.
Solved technical problem underlying the claimed invention (see page 29, lines 3-4): To improve the sensitivity of the sensor assembly.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/075095

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2013148102	A1	13-06-2013	NONE			
WO 2015004213	A1	15-01-2015	CN	105393083	A	09-03-2016
			EP	3019824	A1	18-05-2016
			JP	2016530503	A	29-09-2016
			KR	20160029845	A	15-03-2016
			US	2016018526	A1	21-01-2016
			WO	2015004213	A1	15-01-2015
US 2007177841	A1	02-08-2007	AT	481653	T	15-10-2010
			EP	1813964	A2	01-08-2007
			IL	181030	A	30-04-2012
			US	2007177841	A1	02-08-2007
US 2007177011	A1	02-08-2007	CA	2556996	A1	15-09-2005
			EP	1721189	A2	15-11-2006
			JP	2007527007	A	20-09-2007
			US	2007177011	A1	02-08-2007
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			US	2015260830	A1	17-09-2015
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			EP	2187237	A1	19-05-2010
			JP	5171158	B2	27-03-2013
			JP	2009047662	A	05-03-2009
			KR	20100062975	A	10-06-2010
			US	2010231891	A1	16-09-2010
			WO	2009025373	A1	26-02-2009
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			EP	3028067	A1	08-06-2016
			JP	2016535269	A	10-11-2016
			KR	20160035055	A	30-03-2016
			US	8742325	B1	03-06-2014
			US	2015034809	A1	05-02-2015
			WO	2015017213	A1	05-02-2015
EP 3045936	A1	20-07-2016	EP	3045936	A1	20-07-2016
			US	2016200161	A1	14-07-2016

Form PCT/ISA/210 (patent family annex) (April 2005)

(19) Europäisches Patentamt
European Patent Office
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Technologielaan 9
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(54) **VEHICULAR SYSTEM FOR MEASURING A DISTANCE TO AN OBJECT AND METHOD OF INSTALLING SAME**

(57) The invention pertains to a system (100), in a vehicle (200) having a windshield (250), for measuring a distance to an object outside said vehicle (200). The system comprises: a light source (110) for projecting a light pattern in a first direction onto said object; a detector (120) for detecting at least a partial reflection of said light pattern, arriving from said object in a second direction; and processing means (130) configured to determine a position and/or a distance of said object on the basis of said detected reflection. It further comprises a transparent prism (140), shaped in such a way that it can be placed with a first side in contact with the windshield (250) and a second side directed to the light source (110) and the detector (120), whereby the second side presents a smaller angle of incidence towards the first and second direction than the windshield (250).

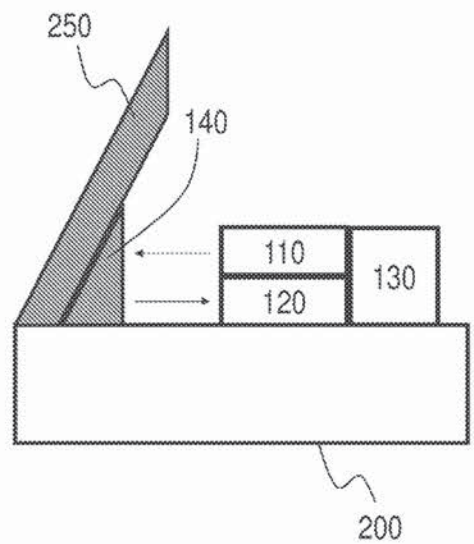

Figure 1

EP 3 316 000 A1

Printed by Jouve, 75001 PARIS (FR)

Description

Field of the Invention

[0001] The present invention pertains to the field of vehicular systems for determining a distance to an object in the vicinity or the path of a vehicle, including time-of-flight based sensing systems and triangulation-based sensing systems. The present invention also pertains to a method for installing such a system in a vehicle.

Background

[0002] Vehicular distance measurement systems are known and used in applications such as park assist, active suspension systems, advanced driver assistance systems, and self-driving cars.

[0003] A specific type of detection system is disclosed in detail in international patent application publication no. WO 2015/004213 A1 in the name of the present applicant.

[0004] Another specific type of detection system is described for example in the unpublished international patent application no. PCT/EP2016/075589 in the name of the present applicant.

[0005] It is clear from both cited applications, that it is extremely important to detect the largest possible proportion of the reflected light at the detector of such a system, to obtain the desired operating range and accuracy. The known systems have not been deployed inside vehicles, because the necessary passage of projected and reflected light beams through the vehicle's windshield is believed to attenuate the light beams to such an extent that sufficiently accurate detection would no longer be possible.

[0006] Hence, there is a need for systems of the above mentioned type that can be deployed inside vehicles.

Summary

[0007] According to an aspect of the present invention, there is provided a system, mountable in the interior of a vehicle having a windshield, the system being configured for measuring a distance to an object outside the vehicle, the system comprising: a light source for projecting a light pattern in a first direction onto the object; a detector for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction; and processing means configured to determine a position and/or a distance of the object on the basis of the detected reflection; wherein the system further comprises a transparent prism which is shaped in such a way that it can be placed with a first side in contact with an inner surface of the windshield and a second side directed to the light source and the detector, whereby the second side presents a smaller angle of incidence towards the first direction and the second direction than the windshield.

[0008] The present invention is based *inter alia* on the insight of the inventor that the range and accuracy of a vehicular ranging system, mounted inside a vehicle, can be improved by reducing the attenuation caused by the repeated traversal of the air/glass interfaces by the light beams. The present invention is further based on the insight of the inventor that such a reduction in attenuation can be obtained by modifying the angle of incidence at the interior interface. It is an advantage of the present invention that the angle of incidence at the interior interface is reduced by the presence of a judiciously shaped and positioned prism that modifies the angle of incidence at the air/glass interface on the internal side. It should be noted that the terms "internal side" and "external side" are used herein to designate the inside and the outside of the vehicle, and not of the prism.

[0009] The term "transparent prism" is used herein to denote a transparent solid body having at least two sides, forming non-parallel material/air interfaces.

[0010] The prism may be made of glass or a transparent polymer (e.g. polycarbonate or polymethylmethacrylate). Glass is preferred because it has a refractive index that is close to that of the windshield and excellent mechanical properties for the purposes of the present invention.

[0011] In an embodiment of the system according to the present invention, the second side is substantially perpendicular to the first direction and the second direction.

[0012] It is an advantage of this embodiment that the angle of incidence at the internal side is reduced to the maximum extent.

[0013] In an embodiment of the system according to the present invention, a refractive index of the prism is in the range of 1.48 to 1.52.

[0014] It is an advantage of this embodiment that the refractive index of the prism is close to that of a typical windshield, thus approaching the desired situation where the windshield and the prism form an optical continuum.

[0015] In an embodiment, the system according to the present invention further comprises a layer of adhesive arranged on the first side for attaching the prism to the windshield, the layer of adhesive having a refractive index in the range of 1.48 to 1.52.

[0016] It is an advantage of this embodiment that the refractive index of the adhesive layer is close to that of a typical windshield, thus approaching the desired situation where the windshield and the adhesive layer form an optical continuum.

[0017] According to an aspect of the present invention, there is provided a vehicle comprising a system as described above, the vehicle having a windshield, the prism being arranged with the first side in contact with an inner surface of the windshield, and the light source and the detector being arranged such that their optical paths pass through the first side and the second side of the prism, the optical paths having a smaller angle of incidence onto the second side than onto the windshield.

[0018] In an embodiment of the vehicle according to the present invention, the windshield is provided with an anti-reflective coating, having a smaller refractive index than the windshield.

[0019] According to an aspect of the present invention, there is provided a method for installing a detection system in a vehicle having a windshield, the detection system comprising: a light source for projecting a light pattern in a first direction onto an object outside the vehicle; a detector for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction; and processing means configured to determine a position and/or a distance of the object on the basis of the detected reflection; the method comprising: arranging a transparent prism with a first side in contact with an inner surface of a windshield of the vehicle; and arranging the light source and the detector such that their optical paths pass through the first side and the second side of the prism, whereby the second side presents a smaller angle of incidence towards the first direction and the second direction than the windshield.

[0020] In an embodiment of the method according to the present invention, the arranging of the transparent prism comprises providing a layer of adhesive on the first side for attaching the prism to the windshield, the layer of adhesive having a refractive index in the range of 1.48 to 1.52.

[0021] The technical effects and advantages of embodiments of the vehicle and the method according to the present invention correspond, *mutatis mutandis*, to those of the corresponding embodiments of the system according to the present invention.

Brief Description of the Figures

[0022] These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings, in which:

- Figure 1 schematically illustrates a system according to an embodiment of the present invention;
- Figure 2 schematically clarifies a principle of operation of the present invention; and
- Figure 3 provides a flow chart of a method according to an embodiment of the present invention.

Detailed Description of Embodiments

[0023] Figure 1 schematically illustrates a system **100** according to an embodiment of the present invention.

[0024] The system **100** is mountable in the interior of a vehicle **200** having a windshield **250**, and it is configured for measuring a distance to an object outside the vehicle **200**; in particular, the distance measurement is performed through the windshield **250**. The system **100** comprises a light source **110** for projecting a light pattern in a first direction onto the object, which may for example comprise a laser source arranged to project a pattern of spots (e.g., a VCSEL array, or a laser/grating combination). The system **100** further comprises a detector **120** for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction, which may for example comprise a CMOS sensor array. The system **100** further comprises processing means **130** configured to determine a position and/or a distance of the object on the basis of the detected reflection. The processing means **130** may be implemented in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA), programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component(s) may also include other functions.

[0025] The light source **110**, the detector **120**, and the processing means **130** may cooperate to obtain a distance measurement in a variety of ways that are known to the skilled person. Without limitation, the distance measurement may be obtained by analyzing in the processing means **130** the displacement of individual laser spots in a pattern projected by the light source **110** and detected by the detector **120**, as disclosed in detail in international patent application publication no. WO 2015/004213 A1 in the name of the present applicant. Still without limitation, the distance measurement may also be obtained by assessing in the processing means **130** the round-trip time-of-flight of a light (e.g., laser) pulse projected by the light source **110** and detected by the detector **120**, as described for example in the unpublished international patent application no. PCT/EP2016/075589 in the name of the present applicant. It is clear from both cited applications, that it is extremely important to detect the largest possible proportion of the reflected light at the detector **120**. The arrangements envisaged by the present invention have in common that the light is projected from inside the vehicle **200**, through the windshield **250**, onto a target scenery outside the vehicle **200**, and the reflections are again measured inside the vehicle **200** after passing once again through the windshield **250**. These systems may be used in automotive applications such as park assist, active suspension systems, advanced driver assistance systems, and self-driving cars.

[0026] The system **100** further comprises a transparent prism **140** which is shaped in such a way that it can be placed with a first side in contact with an inner surface of the windshield **250** and a second side directed to the light source **110** and the detector **120**. In other words, the transparent prim **140** is placed between the source/detector combination **110/120** and the windshield **250**, in the optical path of the projected and reflected light beams. The shape and the arrangement of the transparent prism **140** is such that its second side presents a smaller angle of incidence towards the first direction and the second direction than the windshield **250**. As a result, the projected and reflected beams pass through the prism/air interface at an angle that is closer to the perpendicular than the angle that they would present at the windshield/air interface in the absence of the prism. Accordingly, the beams undergo less refraction, and the amount of attenuation is reduced.

[0027] Thus, in a vehicle **200** equipped with the system **100** according to an embodiment of the present invention, the prism **140** is arranged with the first side in contact with an inner surface of the windshield **250**, and the light source **110** and the detector **120** are arranged such that their optical paths pass through the first side and the second side of the prism **140**, the optical paths having a smaller angle of incidence onto the second side than onto the windshield **250**. The windshield **250** may be provided with an anti-reflective coating **260**, having a smaller refractive index than the windshield. The refractive index and the thickness of the anti-reflective coating **260** may be selected by the skilled person to minimize the attenuation of a light beam having a given wavelength traversing the interface under a given angle.

[0028] Preferably, the second side - i.e. the side facing the source/detector combination **110/120** - is substantially perpendicular to the first direction and the second direction, so as to minimize the refraction effects.

[0029] The refractive index of the prism **140** is preferably in the range of 1.48 to 1.52. To optimize the system, the refractive index of the prism **140** may be chosen as close as possible to the refractive index of the windshield **250**, to approach the situation where the combination of the windshield **250** and the prism **140** form an optical continuum.

[0030] A layer of adhesive **150** may be arranged on the first side for attaching the prism **140** to the windshield **250**. The layer of adhesive **150** preferably has a refractive index in the range of 1.48 to 1.52. To optimize the system, the refractive index of the adhesive **150** may be chosen as close as possible to the refractive index of the windshield **250**, to approach the situation where the combination of the windshield **250** and the adhesive **150** form an optical continuum.

[0031] Figure 2 schematically clarifies a principle of operation of the present invention.

[0032] The top half of Figure 2 illustrates the situation of a light beam traversing the glass/air interfaces on the exterior side and the interior side of a windshield **250**. As the respective interfaces are parallel planes, and as the air on both sides has the same refractive index, identical angles of incidence can be observed on both sides. As the light typically travels to and from objects on the road in front of the vehicle, the angle of incidence on the exterior side will necessarily be very large - as a result, in this arrangement, the corresponding angle of incidence on the interior side will be equally large, which is undesirable.

[0033] Applying the Fresnel equations using standard values for the refractive indices of air ($n = 1$) and glass ($n = 1.55$), it may be calculated that the optical power of a light beam that travels a round-trip through the windshield (4 interface transitions) at angles of incidence of 65° will be reduced to 57%. At angles of incidence of 80°, the optical power of such a light beam will even be reduced to a mere 13%. Such a loss of optical power is detrimental to the range and accuracy of ranging systems as described above.

[0034] The bottom half of Figure 2 illustrates the situation of a light beam traversing the glass/air interfaces on the exterior side and the interior side of a windshield **250**, in the presence of a prism **140**, arranged in accordance with the present invention. The windshield/prism combination **250/140** is assumed to form an optical continuum. Hence, the respective interfaces traversed by the light beams are no longer parallel planes, such that different angles of incidence can be observed on both sides. By a judicious choice of the shape and arrangement of the prism **140**, the light that travels to and from objects on the road in front of the vehicle, is refracted in such a way that the angle of incidence on the interior side is small, preferably close to the perpendicular.

[0035] Applying the Fresnel equations again using the same values for the refractive indices of air ($n = 1$) and glass ($n = 1.55$), it may be calculated that the optical power of a light beam that travels a round-trip through the windshield (4 interface transitions) at angles of incidence of 65° (exterior) and 0° will be reduced to 69%. At angles of incidence of 80° (exterior) and 0° (interior), the optical power of such a light beam will be reduced to 33%. Hence, a much larger portion of the emitted light remains available for detection by the ranging systems thanks to the presence of the prism **140**, allowing a longer detection range and higher accuracy.

[0036] Figure 3 provides a flow chart of a method according to an embodiment of the present invention. While the steps of the method are illustrated as consecutive steps, this is done for clarification purposes only, and the illustrated order is not limiting. For consistency, reference numbers relating to elements illustrated in Figure 1 will also be included in the following description. Details and options of the system disclosed hereinabove in the context of Figure 1 apply to the following description as well, and will not be repeated.

[0037] The purpose and effect of the illustrated method is to install a detection system **100** in a vehicle **200** having a windshield **250**. The detection system **100** comprises a light source **110** for projecting a light pattern in a first direction onto an object outside the vehicle **200**, a detector **120** for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction; and processing means **130** configured to determine a position and/or a distance of the object on the basis of the detected reflection. The method comprises arranging **310** a transparent prism **140** with a first side in contact with an inner surface of a windshield **250** of the vehicle **200**, and arranging **320** the light source **110** and the detector **120** such that their optical paths pass through the first side and the second side of the prism **140**. This is done in such a way that the second side of the prism **140** presents a smaller angle of incidence towards the first direction and the second direction than the windshield **250.**

[0038] The arranging **310** of the transparent prism **140** may comprise providing a layer of adhesive **150** on the first side for attaching the prism to the windshield **250,** the layer of adhesive **150** having a refractive index in the range of 1.48 to 1.52.

[0039] While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system, respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A system (100), mountable in the interior of a vehicle (200) having a windshield (250), the system (100) being configured for measuring a distance to an object outside said vehicle (200), said system comprising:

   - a light source (110) for projecting a light pattern in a first direction onto said object;
   - a detector (120) for detecting at least a partial reflection of said light pattern, arriving from said object in a second direction; and
   - processing means (130) configured to determine a position and/or a distance of said object on the basis of said detected reflection;

   characterized in that said system (100) further comprises a transparent prism (140) which is shaped in such a way that it can be placed with a first side in contact with an inner surface of said windshield (250) and a second side directed to said light source (110) and said detector (120), whereby said second side presents a smaller angle of incidence towards said first direction and said second direction than said windshield (250).

2. The system (100) according to claim 1, whereby said second side is substantially perpendicular to said first direction and said second direction.

3. The system (100) according to claim 1 or claim 2, wherein a refractive index of said prism (140) is in the range of 1.48 to 1.52.

4. The system (100) according to any of the preceding claims, further comprising a layer of adhesive (150) arranged on said first side for attaching said prism (140) to said windshield (250), said layer of adhesive (150) having a refractive index in the range of 1.48 to 1.52.

5. A vehicle (200) comprising a system (100) according to any of the preceding claims, said vehicle (200) having a windshield (250), said prism (140) being arranged with said first side in contact with an inner surface of said windshield (250), and said light source (110) and said detector (120) being arranged such that their optical paths pass through said first side and said second side of said prism (140), said optical paths having a smaller angle of incidence onto said second side than onto said windshield (250).

6. The vehicle (200) according to claim 5, wherein said windshield (250) is provided with an anti-reflective coating (260), having a smaller refractive index than said windshield.

7. A method for installing a detection system (100) in a vehicle (200) having a windshield (250), said detection system (100) comprising:

   - a light source (110) for projecting a light pattern in a first direction onto an object outside said vehicle (200);
   - a detector (120) for detecting at least a partial reflection of said light pattern, arriving from said object in a second direction; and
   - processing means (130) configured to determine a position and/or a distance of said object on the basis of said detected reflection;

   said method comprising:

   - arranging (310) a transparent prism (140) with a first side in contact with an inner surface of a windshield of said vehicle; and
   - arranging (320) said light source (110) and said detector (120) such that their optical paths pass through said first side and said second side of said prism (140),

   whereby said second side presents a smaller angle of incidence towards said first direction and said second direction than said windshield (250).

8. The method according to claim 7, wherein said arranging (310) of said transparent prism (140) comprises providing a layer of adhesive (150) on said first side for attaching said prism to said windshield (250), said layer of adhesive (150) having a refractive index in the range of 1.48 to 1.52.

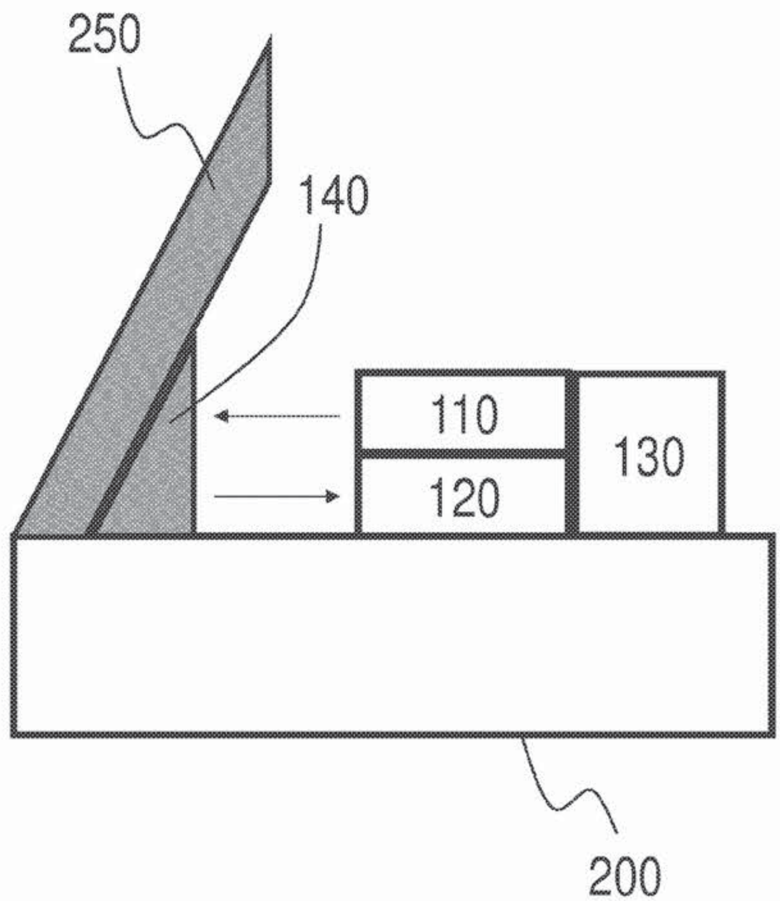

Figure 1

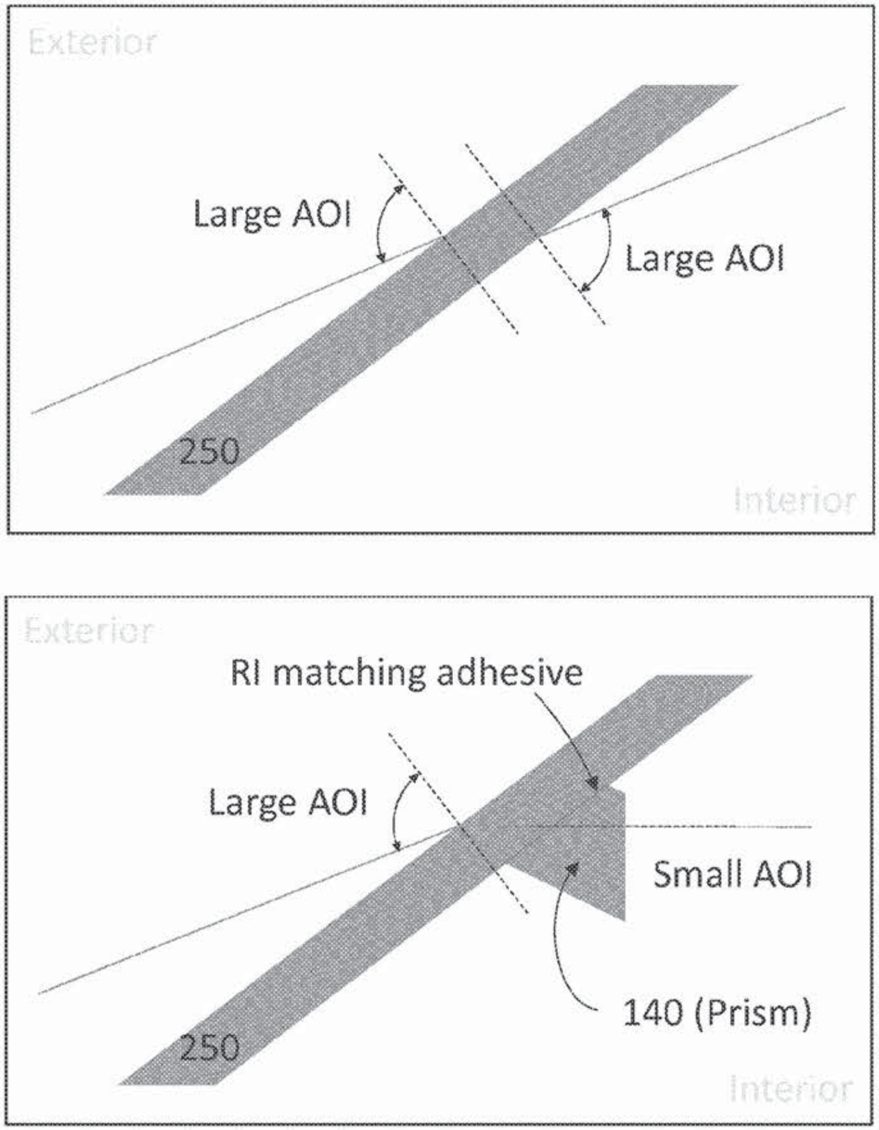
Exterior
Large AOI
Large AOI
250
Interior
Exterior
RI matching adhesive
Large AOI
Small AOI
140 (Prism)
250
Interior

Figure 2

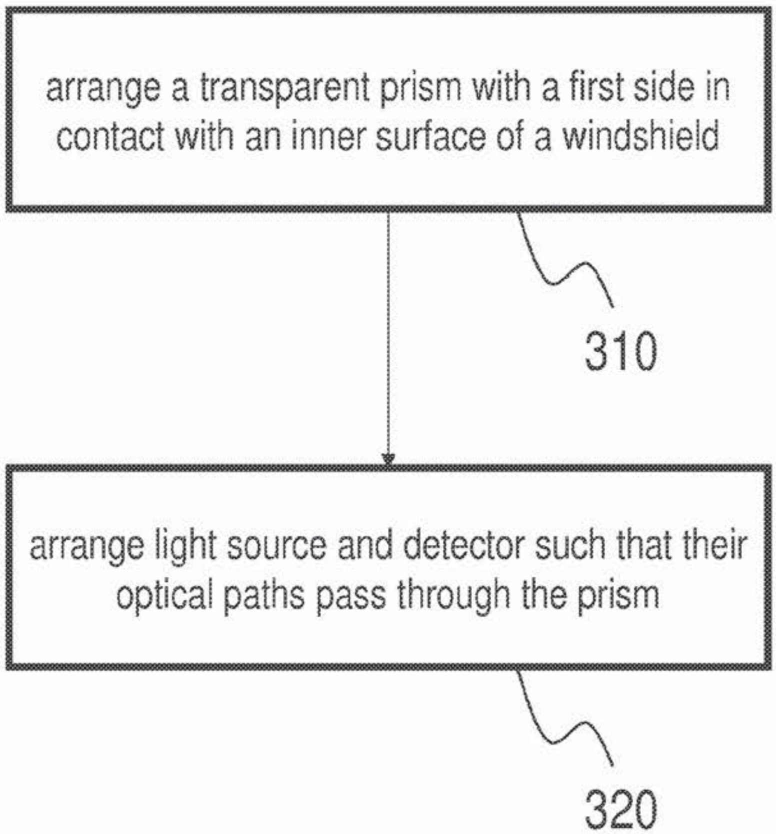
arrange a transparent prism with a first side in contact with an inner surface of a windshield
310
arrange light source and detector such that their optical paths pass through the prism
320

Figure 3

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EUROPEAN SEARCH REPORT

Application Number
EP 16 19 6456

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 94/19705 A1 (SHACHTER ISRAEL [IL]; SILICON HEIGHTS LTD [IL]; YAVNAYI AMOTZ [IL]; GA) 1 September 1994 (1994-09-01) * abstract; figures 1,2a,16-18 * * page 11, lines 8-28 * * page 26, line 12 - page 27, line 15 * * claims 24-26 * -----	1-8	INV. G01S17/93 G01S7/481 ADD. G01S17/46
A	US 2011/128525 A1 (MIZUNO TAMOTSU [JP] ET AL) 2 June 2011 (2011-06-02) * abstract; figures 1-3 * * paragraphs [0043] - [0048], [0059] - [0077] * -----	1-8	
A	US 2003/156291 A1 (TSUNETOMO KEIJI [JP] ET AL) 21 August 2003 (2003-08-21) * abstract; figures 1,9,17 * -----	1-8	
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			G01S

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	27 April 2017	Lupo, Emanuela

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 16 19 6456

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27-04-2017

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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- EP 2016075589 W **[0004] [0025]**

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(11) EP 3 045 935 A1

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(54) Surround sensing system with dome-filter assembly

(57) The invention pertains to a system (100) for detecting a characteristic of an object, comprising: a source (101) to generate a pulsed radiation pattern; a detector (102); a processor (103) to process data from the detector (102) when radiation from the radiation source is reflected by an object; a synchronization means (104) interfacing between the detector (102) and the radiation source (101); wherein: the detector (102) is synchronized with the source (101) so that radiation is detected only during the pulses, the processor (103) determines a characteristic of the object by determining displacement of spots with reference to reference positions, the source emits monochromatic light and the detector is equipped with a corresponding filter (1320) arranged on a dome (1310), wherein fish-eye optics (1330) arranged between said filter (1320) and said detector (102) guide light that has passed through said filter (1320) towards a light-sensitive area of said detector (102).

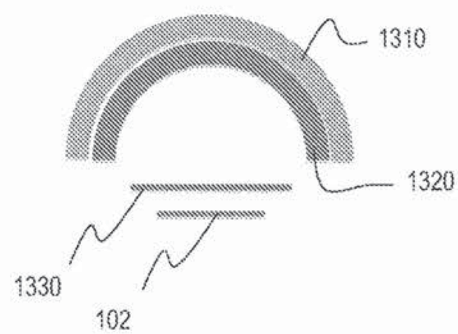

Fig. 13

EP 3 045 935 A1

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Description

Field of the invention

[0001] The invention relates to the field of characterising a scene or part thereof. More specifically it relates to systems and methods for detecting the characteristic, e.g. a profile or property, of an object or person, in particular in the vicinity of a vehicle.

Background of the invention

[0002] There are a large number of applications where knowledge of the 3D profile of an object is relevant. Different techniques exist for scanning the profile of an object. Basically they can be subdivided into radar based systems, ultrasound based systems and optical sensing systems.

[0003] Radar based systems have the advantage that they can sense a long range but have the disadvantage that they have a poor angular and depth resolution with regard to certain applications (e.g. for tracking the profile in a road).

[0004] Ultrasound based systems can be useful for short range sensing but their narrow bandwidth limits the depth sensitivity and the sampling resolution and the strong absorption in air limits the range to a few meter.

[0005] Optical sensing based methods can be subdivided in different types measuring the distance through time of flight measurements or by triangulation.

[0006] In time of flight methods the object is illuminated by a light source. From the delay between the emission and the detection the distance travelled by the light can be determined. The time of flight methods can make use of pulsed illumination.

[0007] In triangulation based systems, the unknown position of an object is calculated using trigonometry. An example of such a system is the Kinect system of Microsoft described in US8320621. In this system structured infra-red light (e.g. circles) is projected and viewed with a 3D camera. This system, which is primarily intended for indoor gaming and entertainment applications, is not suitable for outdoor use, due to the intensity of the sunlight.

[0008] In stereovision the distance to an object is determined from the local shift between corresponding parts in the images obtained by two cameras under different viewing angles or by one stereo camera with two lenses. Stereovision based systems can make use of existing set-ups and algorithms from robot vision, can operate using ambient illumination, and do not require projection. On the other hand stereovision based systems have the disadvantage that calibrated cameras with sufficient distance are required. Furthermore, sufficient structure in the images is required to enable cross correlation for parallax, it is difficult to detect flat surfaces and water, a sufficient number of pixels is required, the depth sensitivity is limited, and typical cameras have insufficient dynamic range to cope with various light conditions. The biggest hurdle seems to be that stereovision based systems cannot work if there is insufficient structure in the object being scanned.

[0009] US 2005/195383 A1 discloses a method for obtaining information about objects in an environment around a vehicle in which infrared light is emitted into a portion of the environment and received and the distance between the vehicle and objects from which the infrared light is reflected is measured. An identification of each object from which light is reflected is determined and a three-dimensional representation of the portion of the environment is created based on the measured distance and the determined identification of the object. Icons representative of the objects and their position relative to the vehicle are displayed on a display visible to the driver based on the three-dimensional representation. Additionally or alternatively to the display of icons, a vehicular system can be controlled or adjusted based on the relative position and optionally velocity of the vehicle and objects in the environment around the vehicle to avoid collisions.

[0010] US 2007/177011 A1 relates to a movement control system which can be used to control moving platforms such as vehicles or robotic arms. It especially applies to a driving aid for vehicles and to a parking aid capable of self-parking a vehicle. A three-dimensional camera is located on the platform, say a car and arranged to view the environment around the platform. A processor uses the three-dimensional information to create a model of the environment which is used to generate a movement control signal. Preferably the platform moves relative to the environment and acquires a plurality of images of the environment from different positions.

[0011] US 2012/038903 A1 provides methods and systems for adaptively controlling the illumination of a scene. In particular, a scene is illuminated, and light reflected from the scene is detected. Information regarding levels of light intensity received by different pixels of a multiple pixel detector, corresponding to different areas within a scene, and/or information regarding a range to an area within a scene, is received. That information is then used as a feedback signal to control levels of illumination within the scene. More particularly, different areas of the scene can be provided with different levels of illumination in response to the feedback signal.

[0012] The systems mentioned above are not capable of operating sufficiently accurately at a high vehicle speed for a long detection range.

[0013] Therefore there is still room for improvement of surround sensing scan systems that can be used in outdoor situations scanning the profile of objects over a large range with a high resolution and with a high speed.

[0014] An improved system is described in European patent application no. 13175826.0 and international patent application no. PCT/EP2014/064769 (unpublished at the date of filing of the present application) in the name of the present applicant. The present application discloses further improvements relating to the capturing and detection of images, which can be used in systems such as the one of the aforementioned patent applications.

Summary of the invention

[0015] It is an object of embodiments of the present invention to provide good systems and methods for determining the profile of an object.

[0016] It is an advantage of embodiments of the present invention that it is robust against the variation in light conditions that can occur in an outdoor environment, such as daylight and/or rain. Moreover, it is an advantage of embodiments of the current invention that it is robust against the light of other vehicles.

[0017] It is an advantage of embodiments of the present invention that scanning is possible over a range from 1 to 15 m, in some embodiments even over a range from 1 to 30 m, and in some embodiments up to 200 m. By providing ranges up to 200 m, embodiments of the present invention are particularly suited for use in autonomous vehicles. The maximal range can be improved by using better cameras and lasers. Use can be made of the benefits of using semiconductor technology for manufacturing such components. The profiling precision is depending on the range to be scanned. In embodiments according to the present invention, a precision of 1/1000 of the range can be obtained.

[0018] Precision here means precision in distance between the car and the road. The vertical precision "local height of the road" can even be 10 times better.

[0019] It is an advantage of the embodiments of the present invention that a viewing angle of 1 radian horizontally and 1 radian vertically can be obtained. Depending on the application, one can choose for different horizontal and vertical angles. Furthermore, if larger viewing angles are required, more systems can be combined.

[0020] It is an advantage of embodiments of the present invention that they are robust against vibrations. It is an advantage of embodiments of the present invention that components used in systems according to embodiments of the present invention typically have a long lifetime.

[0021] It is an advantage of embodiments of the present invention that the average radiation power is below 1 mW per spot. In case a radiation pattern of 100x100 spots is used this results in an overall average radiation of 10 W. The power threshold is in agreement with commonly applied safety regulations. Furthermore, it is an advantage of embodiments of the present invention that the power consumption of systems according to embodiments of the present invention is low. This is of particular importance in a vehicular environment, where the vehicle's power system must not be overly burdened by the sensing system.

[0022] It is an advantage of embodiments of the present invention that they can be easily installed and that the alignment is easy and may even be automated. The initial alignment can e.g. be done by scanning a flat plane and recording the positions of the projected spots as initial reference. A possible change in relative position between projector and detector can easily be detected by observing the projected pattern as a whole.

[0023] It is an advantage of embodiments of the present invention that a low-weight and compact system can be provided. It is an advantage of embodiments of the present invention that a low cost system can be obtained, as e.g. it can be based on components that can be made using standard processing techniques. It is an advantage of at least some embodiments of the present invention that no mechanical scanning of the object under study is required resulting in a mechanically less complex system. It thereby is an advantage that the basic components can be available components such as for example CMOS and CCD cameras and laser arrays. These components are readily available or can be customized based on the invention requirements.

[0024] When multiple cameras are used in a system, use can be made of one or more radiation splitter such as a semi-transparent mirror, a beam splitter, a beam splitting cube, etc. for aligning the different cameras.

[0025] For the basic components such as CMOS and CCD cameras and laser arrays we profit for the steady increase in performance and decrease in cost.

[0026] It is an advantage of embodiments of the current invention that the performance is scalable.

[0027] It is an advantage of embodiments of the present invention that the system's design and component selection can make it reliably functioning independent of the weather conditions, e.g. whether the system is functioning at night, in rain, in fog, independent of the road quality, independent of the used surface material, etc. Systems according to embodiments of the present invention are very robust providing reliable operation in many different environmental conditions. Operation may be substantially independent of the road surface, the material type, the weather, day or night, etc.

[0028] It is an advantage of embodiments of the present invention that the sensed and/or processed data is used for saving energy and/or optimizing use of energy in the characterization system, e.g. the active suspension system.

[0029] Without changing the basic principles of the method the performance is increased by just using newer versions of camera and lasers. For instance, regarding only the resolution as a performance indicator, in 3 years CMOS cameras increase from 1 megapixel to 4 megapixel and the same cost.

[0030] There are different tradeoffs that can be tuned depending on the application requirements (e.g. tradeoff between power and field of view), resulting in optimum characteristics for particular applications.

[0031] In at least some embodiments according to the present invention, the object for which a characteristic, e.g. a profile or property, is to be determined is the road in front of a vehicle. In some embodiments according to the present invention, information of the road in front of the vehicle is used for controlling the suspension system of the vehicle. It is an advantage of embodiments of the present invention, specifically when applied in automotive applications, that they are still working up to speeds of 50 m/s.

[0032] It is an advantage of embodiments of the current invention that besides information of the monitored object such as a profile, also several other parameters can be derived. For example, when applied in an automotive environment, also the 3D orientation of a car, the speed of the car, the presence of approaching cars or other objects, the presence of water on the road surface, etc. can be obtained.

[0033] The above objective is accomplished by a method and device according to the present invention.

[0034] According to an aspect of the present invention, there is provided a vehicle-mountable system for detecting a characteristic of an object, the system comprising: a radiation source adapted to generate a simultaneously pulsed radiation pattern composed of radiation spots; at least one detector having a plurality of pixels; a processor adapted to process data from the at least one detector when radiation from the radiation source is reflected by an object and detected by the at least one detector; a synchronization means interfacing between the at least one detector and the radiation source; wherein the synchronization means is adapted for synchronizing the at least one detector with the radiation source so that detection by the detector of radiation to be processed is detected only during the radiation pulses, the processor is adapted for determining a characteristic of the object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions; and the radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter arranged on a dome, the system further comprising fish-eye optics arranged between the narrow bandpass filter and the at least one detector to guide light that has passed through the narrow bandpass filter towards a light-sensitive area of said at least one detector.

[0035] Known vehicle-mounted object detection systems have to be able to detect the reflections of the projected pattern, i.e. the projected spots, over a potentially intense "background radiation" consisting of sunlight in the order of 500 W/m^2. An approach to overcome this problem, is to filter the light to be detected to a narrow band around the wavelength of the projected spots, thus reducing the amount of sunlight to be dealt with to the light present in the relevant band. However, known optical systems do not deliver the incoming radiation at a sufficient perpendicular angle onto the narrowband filter to obtain satisfactory results. The inventors have found that extremely accurate filtering can be obtained by combining a specific optical arrangement with a narrowband filter arranged on a dome, operating on the light before it reaches the sensor. The phrase "arranged on a dome" is used to indicate that the surface of the filter follows the surface of the (transparent) dome, i.e., it has substantially the same curvature. The filter may be arranged on the inside or the outside of the dome. It is an advantage of the invention that accurate detection of radiation spots becomes possible at longer ranges and/or with reduced output power.

[0036] As used herein, monochromatic light is understood to include laser light as produced by common semiconductor laser devices. The monochromatic light may have a wavelength spread of less than ± 5 nm, preferably less than ± 3 nm, most preferably less than ± 1 nm. Accordingly, the narrow bandpass filter preferably has a passband bandwidth in the range of 1-3 nm The radiation source may be adapted to generate laser light in the spectrum of 700-1500 nm, preferably 800-1000 nm. In a specific embodiment, the optics further comprise a minilens array arranged between the narrow bandpass filter and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

[0037] According to an embodiment of the present invention, the at least one detector comprises a CMOS sensor or a CCD sensor having a dynamic range of at least 90 dB, preferably more than 120 dB.

[0038] Known vehicle-mounted object detection systems are not always accurate, especially at longer ranges. The inventors have discovered that this is in part due to the highly variable lighting conditions in which such systems may be used. Indeed, it turns out that the background light intensity may vary over many orders of magnitude between different pixels of the same sensor at the same time, for instance because of the occurrence of bright sunlight and deep shadows in the same scenery, or a because a generally dark scenery (at night) is only partially lit by the vehicle's headlights. In such cases, it is common to attempt to avoid pixel saturation in the brighter areas by reducing the overall intensity of the light arriving at the detector. However, that approach may lead to blind spots in areas where the projected spots are already particularly weak (long range). It is therefore an advantage of the present invention, that improved operation of the vehicle-mounted object detection system is obtained at long ranges in situations with highly variable lighting. The inventors have found that this advantage can be obtained with a sensor having a dynamic range of at least 90 dB, a range that may be spanned by a digital representation of 16 bits (this dynamic range covers the intensity ratio between a spot at a distance of 1 m and a similar spot at a distance of 150 m, leaving margin for environmental variations and object variations such as varying surface reflectivity). The advantage is even more pronounced with a sensor having a dynamic range of at least 120 dB.

[0039] According to an embodiment of the present invention, the at least one detector comprises a CMOS sensor or a CCD sensor configured to subtract background illumination from the radiation from the radiation source by comparing a signal sensed during an on-phase of said pulsed radiation pattern with a signal sensed during an off-phase of said pulsed radiation pattern.

[0040] Known vehicle-mounted object detection systems have to be able to detect the reflections of the projected pattern, i.e. the projected spots, over a potentially intense "background radiation" consisting of sunlight in the order of 500 W/m^2. An approach to overcome this problem, is to emit the radiation pattern at a very high intensity, i.e. an intensity which exceeds the intensity of the sun light in the relevant spectral band. This becomes a challenge, especially at long ranges. The inventors have found that the power requirement of the projection system can be reduced by performing a differential measurement at the sensor. As the projected pattern is emitted in a pulsed manner, and the timing of each pulse is known, it is possible to compare the detected level of incident light during the on-phase of the pulse with the detected level of incident light during the off-phase of the pulse, whereby the magnitude of the difference is indicative of the presence of a projected spot. The inventors have found that it is possible to perform this subtraction at the level of individual pixels. It is an advantage of this embodiment that accurate detection of radiation spots becomes possible at longer ranges and/or with reduced output power.

[0041] In a specific embodiment, the comparing is performed at individual pixels of said at least one detector. It is advantage of this specific embodiment, that the subtraction can be performed on the basis of signals that have a very low noise content. In such an embodiment, the pixels adapted to perform the comparing may be pixels with an increased dynamic range (i.e., at least 90 dB, or preferably at least 120 dB) as described above.

[0042] The predetermined reference spot positions may for example be determined in a calibration phase. The pulsed nature of the pattern implies that the radiated spots are intermittently switched on and off. The duration of the "on" phase may be much shorter than the pulsation frequency. For example, the pattern may be switched on every 16.6 ms (60 Hz frequency), but the duration of illumination within each period may be an order of magnitude shorter. The radiation source may be composed of a plurality of devices. The determining of the displacement may be performed with sub-pixel accuracy by multipixel fitting the detected spots.

[0043] The radiation source may be adapted to project light at an intensity of 10 W/m^2, optionally at least 100 W/m^2, optionally even at least 500 W/m^2, and is operated at a pulse width and a pulse frequency which are determined so as to keep the average emitted power per spot below 1 mW. The relevant light intensity is the intensity at the intersection of the object and the emitted light. It is an advantage of this embodiment that the brightness of the projected spots exceeds the expected brightness of sunlight. The stated intensity criterion is preferably met up to a range of 30 m when projecting obliquely downwards (for road inspection) and preferably up to 200 m when project forward (for obstacle detection).

[0044] The radiation source may comprise a VCSEL array with a low beam divergence, the VCSEL array being configured to simultaneously transmit individual spots of the radiation pattern.

[0045] In particular, the system may further comprise micro array optics configured to focus and/or orient each laser spot of the VCSEL array. Alternatively, the system may further include a macroscopic optical system to project the light emitted by the VCSEL array into the desired spot pattern.

[0046] The at least one radiation source may comprise at least one laser radiation source for generating laser spots constituting the pulsed radiation pattern.

[0047] The processor may be adapted for processing the detected data based on triangulation. The at least one radiation source may comprise a phase grating for simultaneously generating the combination of radiation spots. It is an advantage of embodiments of the present invention that efficient phase gratings can be obtained, the gratings comprising a system of grooves with a specific depth in a specific transparent material. In an advantageous embodiment, a set of horizontal and vertical grooves can be applied. The design furthermore is flexible so that it can be optimized with respect to the target specifications. The phase grating may be a discrete phase grating such as but not limited to a dammann grating.

[0048] The at least one radiation source may be constructed to generate the radiation pattern as a combination of radiation spots and whereby groups of the radiation spots are generated sequentially in time, each group comprising simultaneously pulsed spots.

[0049] The at least one radiation source may comprise a MEMS-scanner. The detector may comprise a MEMS-scanner and the system may comprise a synchronization device for synchronizing the MEMS-scanner of the radiation source with a MEMS-scanner of the detector.

[0050] The system may comprise a shutter whereby the shutter, when closed, blocks radiation from arriving at the detector and whereby the synchronization means is adapted for synchronising the pulses of the at least one radiation source with the opening and closing of the shutter.

[0051] The obtained data can be used as an input for a more refined model based fitting of a characteristic, e.g. a profile or property, of the road or object, such as spline fitting and even to more sophisticated models for the motion of the object.

[0052] The at least one radiation source may be conceived for generating monochromatic radiation in the near infrared spectrum.

[0053] The at least one radiation source may comprise a semiconductor laser.

[0054] The at least one radiation source may comprise a single VCSEL source or a VCSEL array. The at least one detector may be a plurality of detectors, e.g. two detectors or more detectors. In addition to the triangulation principle based on a single detector, embodiments of the present invention also may make use of a parallax between different detectors. Furthermore embodiments of the present invention optionally also may be combined with stereovision.

[0055] The at least one radiation source and the shutter may be adapted for pulsing with pulse widths in the microsecond range.

[0056] The system may comprise an interface for outputting obtained information.

[0057] The system may further comprise means for modifying an intensity of respective ones of said radiation spots in function of their distance from said system so as to equalize their perceived intensity, the means operating in conjunction with said radiation source or with said at least one detector. It is an advantage of such embodiments that clipping (detector saturation) of the detected spots can be avoided (for the spots that would otherwise have the highest intensity), such that the accurate spatial detection of the spot is not impaired (in particular, the image size analysis using multipixel fitting). In particular, the means for modifying the intensity may comprise an aperture placed in the optical path of said at least one detector, the aperture having an asymmetric shape relative to any horizontal plane. Hence, the aperture is a non-symmetrical lens pupil that modulates the intensity of the received light in function of its angle of incidence, such that reflections from a nearby road area are more strongly attenuated relative to reflections from far away areas. Additionally or alternatively, the projector may project blocks of spots or individual spots with mutually different intensities, or different duration, so as to reduce the intensity or duration of nearby spots relative to faraway spots. Additionally or alternatively, the processor may perform software-based post-processing to remove the effects of clipping (saturation) from the detected spot profiles.

[0058] The system may further be adapted to perform the detecting in a range between 1 m and 30 m. This is the range that is preferably covered for the purpose of inspecting the road profile.

[0059] The system may further be adapted to perform the detecting in a range between 0 m and 200 m. This is the range that is preferably covered for the purpose of detecting obstacles and/or when the system is applied in autonomous vehicles.

[0060] The present invention also relates to a vehicle with controllable suspension, the vehicle comprising a system as described above, a suspension system, and a control system, whereby the control system is adapted for receiving profile information of the system for determining a characteristic of an object and is adapted for using the characteristic, e.g. a profile or property, of the object for controlling the suspension system.

[0061] The present invention also relates to a camera, the camera comprising a system as described above whereby the system is adapted to add 3D information to the camera image making it possible to create a 3D image.

[0062] According to an aspect of the present invention, there is provided a method for detecting a characteristic of an object, the method comprising the following steps: emitting a pulsed radiation pattern composed of radiation spots on the object using a radiation source, detecting the reflected pattern using at least one detector having a plurality of pixels, whereby the detection is synchronized with the pulsed radiation pattern for detecting radiation to be processed only during the radiation pulses, and processing the data from the detector for determining a characteristic of an object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions, wherein said emitting uses monochromatic light and said at least one detector is equipped with a corresponding narrow bandpass filter arranged on a dome, wherein fish-eye optics arranged between said narrow bandpass filter and said at least one detector guide light that has passed through said narrow bandpass filter towards a light-sensitive area of said at least one detector.

[0063] Further optional features of embodiments of the system according to the present invention may be applied *mutatis mutandis* to embodiments of the method according to the present invention to obtain the corresponding effects and advantages.

[0064] The present invention also relates to the use of a system as described above for detecting a characteristic of an object in a vicinity of a vehicle, the use taking place in an outdoor environment. In particular, the use may be for measuring a characteristic, e.g. a profile or property, of the road in front of a car, or for controlling autonomous vehicles.

[0065] The present invention also relates to a computer program product comprising code means adapted to cause a processor to perform the determining of said characteristic of the method described above.

[0066] Particular and preferred aspects of the invention are set out in the accompanying independent and dependent claims. Features from the dependent claims may be combined with features of the independent claims and with features of other dependent claims as appropriate and not merely as explicitly set out in the claims.

[0067] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

Brief description of the drawings

[0068]

FIG. 1 gives a schematic overview of different components and their interactions in an exemplary system according to embodiments of the present invention.

FIG. 2 illustrates a schematic representation of an exemplary method for obtaining a characteristic, according to an embodiment of the present invention.

FIG. 3 illustrates a schematic representation of a triangulation principle as can be used in an embodiment of the present invention.

FIG. 4 provides diagrams of exemplary pixel output in function of incident light power as obtained by logarithmic tone mapping (top) and multilinear tone mapping (bottom).

FIG. 5 provides a diagram of exemplary pixel outputs in function of incident light power as obtained by a high dynamic range multiple output pixel.

FIG. 6 schematically illustrates the structure of a high-dynamic range pixel for use in embodiments of the present invention.

FIG. 7 schematically illustrates further aspects of the operation of a high-dynamic range pixel for use in embodiments of the present invention.

FIG. 8 schematically illustrates an embodiment of a sensor for use in embodiments of the present invention, the sensor including a pixel area having pixels that provide a differential output (target light- background light) in hardware.

FIG. 9 schematically illustrates the structure of a pixel that provides a differential output (target light-background light).

FIG. 10 schematically illustrates a first exemplary optical arrangement.

FIG. 11 schematically illustrates a second exemplary optical arrangement.

FIG. 12 schematically illustrates a third exemplary.

FIG. 13 schematically illustrates a fourth exemplary optical arrangement for use in embodiments of the present invention.

[0069] The drawings are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. Any reference signs in the claims shall not be construed as limiting the scope.

Detailed description of illustrative embodiments

[0070] The present invention will be described with respect to particular embodiments and with reference to certain drawings but the invention is not limited thereto but only by the claims. The drawings described are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. The dimensions and the relative dimensions do not correspond to actual reductions to practice of the invention.

[0071] Furthermore, the terms first, second and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

[0072] Moreover, the terms top, under and the like in the description and the claims are used for descriptive purposes and not necessarily for describing relative positions. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other orientations than described or illustrated herein.

[0073] It is to be noticed that the term "comprising", used in the claims, should not be interpreted as being restricted to the means listed thereafter; it does not exclude other elements or steps. It is thus to be interpreted as specifying the presence of the stated features, integers, steps or components as referred to, but does not preclude the presence or addition of one or more other features, integers, steps or components, or groups thereof. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

[0074] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments.

[0075] Similarly it should be appreciated that in the description of exemplary embodiments of the invention, various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the detailed description are hereby expressly incorporated into this detailed description, with each claim standing on its own as a separate embodiment of this invention. Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

[0076] In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the invention may be practiced without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding of this description.

[0077] Where in embodiments of the current invention reference is made to an object, reference is made to any objects that are stationary or moving relative to the vehicle, which may include the road; road signage; humans using the road as pedestrians, cyclists, etc.; animals; other vehicles; substances on the surface of the road, such as water, sand, mud, leaves, snow, ice, dirt, debris and the like; in agricultural applications, crops, cut grass or hay (baled or loose) on the ground.

[0078] Where in embodiments of the current invention reference is made to a vehicle, reference is made to cars, trucks, trains, fork lifts, etc., regardless of whether they are propelled by an internal combustion engine, an electrical motor, or the like, and regardless of the interface with the ground.

[0079] Where in embodiments of the current invention reference is made to the near infrared region reference is made to radiation with wavelength between 700 and 1500 nm, in particular between 800 and 1000 nm.

[0080] Where in embodiments according to the present invention reference is made to a radiation pattern, the radiation pattern is physically or logically composed of radiation spots characterized by their spot size and intensity. According to the invention, the radiation pattern comprises simultaneously radiated spots or groups of spots, which are turned on and off in a pulsed manner.

[0081] Where in embodiments according to the present invention reference is made to triangulation, reference is made to the use of observation of an object under an angle and determining the distance to the spot based on a shift between a reference position and an observed position of a corresponding spot in the image viewed by the camera. Where in embodiments of the present invention reference is made to a MEMS scanner reference is made to a MEMS scanning micro-mirror whereby the mirror can oscillate in at least one dimension.

[0082] The present invention relates to a system for detecting a characteristic, e.g. a profile or property, of an object. A schematic overview of different components which are comprised in the system according to embodiments of the present invention are illustrated in FIG. 1. FIG. 1 shows a radiation source **101** for generating a pulsed radiation pattern. The radiation pattern advantageously is spot pattern. The system may be mounted at any suitable position. If e.g. the system is mounted to a vehicle, this can be at the top thereof, the side thereof or may be integrated in existing cavities and openings, such as for example in cavities for the head lights or back lights or in the head or back lights themselves, at or near the number plate, etc.

[0083] The radiation pattern is reflected by the object under study and captured by a detector **102** also shown in FIG. 1. The radiation source **101** and the detector **102** are synchronized by a synchronization means **104.** In embodiments according to the present invention also a shutter **105** might be present whereby the shutter **105** is also synchronized by the synchronization means **104** such that it blocks radiation from the detector **102** as long as no radiation pattern is being transmitted. Alternatively, the detector may be oversampled and only the samples corresponding with time slots wherein pulses are given are considered. Systems according to embodiments of the present invention may comprise one or more radiation sources. The processor **103** in FIG. 1 processes the data coming from the detector **102** thereby revealing profile information of the object under study. The processing advantageously can be based on triangulation. The processor may be adapted for determining a characteristic of an object by determining a displacement of detected spots, the spots being detected with the at least one detector with reference to predetermined reference spot positions. The triangulation principle used in embodiments of the present invention is illustrated by way of example in FIG. 3. The triangulation method used can be based on a single detector, although the invention should not be considered limited to systems comprising only a single detector. In addition to spot shift calculations (triangulation), the system may also analyze the intensity, size, and shape of the reflected spots, to detect further characteristics of the surface from which the spots are reflected.

[0084] By way of illustration, embodiments of the present invention not being limited thereto, the different elements of an exemplary system according to an embodiment of the present invention will further be discussed.

[0085] In embodiments of the current invention the at least one radiation source **101** is designed to generate radiation, e.g. monochromatic radiation or radiation from a particular wavelength range, in the near infrared region. The near infrared region has the advantage that it is invisible to humans and that CMOS or CCD sensors are still sufficiently sensitive for radiation with a wavelength in this region. In this way, the user is not disturbed by the radiation. The at least one radiation source **101** typically is adapted for extending over the complete object to be monitored. Optical elements therefore may be provided or may be part of the at least one radiation source. In embodiments according to the present invention this object is a viewing scene in front of a car.

[0086] The object to be monitored is irradiated using a radiation pattern. In some embodiments according to the present invention this pattern is a regular or irregular array of spots, e.g. sharp spots. The size of the spots may be of the order of 1/1000 of the range. Thus 1 cm at a distance of 10 meter.

[0087] According to embodiments of the present invention, the radiation pattern may be an m x n pattern, wherein m is at least 1 and n is at least 1. The spots may be of any geometrical form such as for example an oval, a line, a circle, a disc. The radiation pattern may be regular, i.e. a full matrix, or may be irregular. The radiation pattern may be repetitive, random, etc. The arrangement of the spots in the radiation pattern may be selected as function of the application.

[0088] The irradiation is performed during short periods of time, i.e. in a pulsed manner. This has the advantage that a lot of irradiation power can be generated - in pulsed irradiation the momentaneous intensity can be significantly higher than in continuous wave - but that meanwhile the average radiation power can be kept low. In the particular example wherein a spot-like pattern is used for irradiating, the intensity is local on particular positions on the object, which also reduces the total amount of power required by the radiation source **101** to surpass the intensity of the daylight. Advantageously, the spot size may be selected in relationship to the pixel size of the detector **102.**

[0089] In embodiments according to the present invention irradiation pattern may be induced using laser beams. It is an advantage of embodiments of the present invention that laser beams can yield a very large depth of focus with simple optics.

[0090] The irradiation pattern can be irradiated simultaneously. Alternatively, different parts of the irradiation pattern can be irradiated sequentially, such that over time the irradiation pattern is built up, but the irradiation pattern is not provided in a single illumination pulse. According to some embodiments of the present invention, where a plurality of m x n beams is used, the system may be equipped with an optical element, such as for example a prism based microlens, for grouping the beams into an a x b pattern thus increasing the spot intensity at the point of incidence by a factor of a * b compared to a single beam. Individual parts of the irradiation pattern may be, in one embodiment, may be obtained by positioning a MEMS scanner after the radiation source **101** for deflecting the laser beam in the wanted direction and thus irradiating the object in a scanning manner.

[0091] In some embodiments according to the present invention, the irradiation source comprises one or more semiconductor lasers. These semiconductor lasers have a very good cost/performance relationship.

[0092] In some embodiments according to the present invention where individual spots of a radiation pattern are transmitted simultaneously different alternatives exist to realize the radiation pattern. A single laser may be used in combination with a diffractive grating for inducing an array of spots. The laser must have sufficient power.

[0093] In some embodiments, micro array optics can be used for focusing each laser spot of the laser, e.g. VCSEL.

[0094] The peak power of the laser must be sufficient (order of 0.1 to 2 kilowatt) so that the intensity in every spot of the projected pattern surpasses the daylight in the relevant spectral band. For a projected array of 100x100 spots and a range of 10 m the total peak power of the complete laser must be of the order of 250 Watt. But the average

[0095] (continuous) power of the individual spots may not surpass the safety requirements of 1 mW. Thus for a pattern of 100x100 spots the total average power of the single laser may not exceed 10 Watt. This high peak power versus low average power can be realised by using short pulse times.

[0096] Another requirement for practical use is that the electric power of the laser does not exceed 50 Watts. But with an average optical power of 10 watts this requirement can easily be met for semiconductors lasers which have a large efficiency.

[0097] The power budget can be improved by emitting spots with a very narrow spectral width and detecting them with a sensor that is equipped with a filter that has a corresponding very narrow pass band. Additionally or alternatively, the power budget can be improved by performing differential detection, i.e. by detecting the presence of the spot in the portion of the image detected by a given pixel by comparing the measured intensity at a point in time when the spots are not being projected with the measured intensity at point in time when the spots are being projected. This comparison may be performed in appropriately adapted hardware or in software.

[0098] In case we use a VCSEL laser array instead of a single laser the power requirements of the single laser have to be met by the array as a whole.

[0099] The laser may be a surface edge emitting laser. The irradiation source also may comprise a diffraction grating for generating a grid or other irradiation pattern. Different types of diffractive gratings could be used. For efficiency a phase grating in a transparent material can be used. Ease of manufacturing (simple and cheap) is enhanced if the phase grating has linear grooves in two orthogonal directions. The depth of the grooves typically may corresponds with a phase shift of 180°. The width of the grooves can be calculated such that the intensity envelope matches the required field of view. The FOV of source and detector is both of the order of 1 radian horizontally and 1 radian vertically

[0100] In other embodiments according to the present invention, where individual spots of the radiation pattern are transmitted simultaneously, a VCSEL array is used as radiation source **101.** Such a VCSEL array may be an array with a low beam divergence. The size of the VCSEL may be 10x10, but may be larger. It is an advantage of embodiments using VSCEL arrays that the geometry of the array and the shape of the spots can be tuned depending on the application. The principle may be combined with scanning irradiation as will be discussed later, such that subsequently an array of spots is transmitted.

[0101] In some embodiments, at least two radiation sources, also referred to as projectors, may be included, one projector being fixed and another projector being steerable over at least one axis and preferably steerable over two axis for operating in a smaller field of view angle than the fixed projector. The steerable projector may thus be suitable for zooming. Such a function may be used for detecting with more detail certain objects such as for examples holes, birds, children, etc. Additionally or alternatively, the detector **102**, described hereunder, may be steerable or include steerable components. The steering of the detector components may occur at the sensor level, or at the level of individual optical components, or even at the level of pixel-specific components (such as microlenses forming an array, which may be steered by means of MEMS).

[0102] The detector **102** may be a CMOS or CCD detector. After the object under study is irradiated by the at least one radiation source **101**, the reflected radiation is detected by the detector **102**. In order to avoid interference from daylight different precautions can be taken. In embodiments according to the present invention a small band spectral filter can be positioned in front of the detector **102**. The small band filter only passes through radiation in the specific wavelength range emitted and blocks the rest of the daylight spectrum.

[0103] In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient resolution in the darkest part of the scene, is an advantage of the present invention. The inventors have found that the use of a true high dynamic range sensor is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression (see Figure 4). However this nonlinear compression necessitates relinearisation of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor as presented in Figure 5. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US 2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention.

[0104] Figure 6 presents a schematic illustration of an advantageous implementation of a pixel with high dynamic range. The example in this figure makes use of two storage gates 7, 8, connected to the floating diffusion. After exposure, the electron generated by the scene AND the laser pulse, is transferred on the floating diffusion using the transfer gate 11. Both *Vgate1* and *Vgate2* gate voltages are set high. The charges are then spread over both capacitors, realizing a significant Full Well. Once this high full-well data is read via connection to the amplifier, the voltage *Vgate2* is set low. The electrons reflow towards capacitor **7**, increasing the total pixel gain. The data can be read through the amplifier. It is further possible to achieve an even higher gain by applying later a low voltage on *Vgate1*. The electrons reflow towards the floating diffusion **2**. Figure 7 schematically illustrates how to achieve multiple gains using the same technique.

[0105] In embodiments according to the present invention, a synchronization means may be provided that synchronizes the detection with the pulses, resulting in the fact that unwanted irradiation on the detector outside the pulse time of the radiation source can be avoided. This can be implemented in a plurality of ways, e.g. by oversampling by the detector and only taking into account samples wherein a reply on the pulse is expected. Alternatively, a shutter **105** can be used in front of the detector **102**. The synchronization means **104** then opens the shutter **105** during the time window the reflected radiation arrives at the detector **102**. Therefore the synchronization means **104** gets its synchronization input signal from the radiation source **101**. The time window is dependent on the pulse width and on the object range.

[0106] In some embodiments, the above said detector may be able to subtract the background light from the scene and sense only the required signal, i.e. the laser beam information. An example of such a detector is schematically presented in Figure 8, with further details on the pixel structure being shown in Figure 9. With reference to Figure 9, the pixel comprises a photodiode that can be read with 2 transfer gates controlled by *transfer* and *transferb* signals. The transfer signals are synchronized with the laser pulse emission as follows:

- When *transferb* is on, the electrons generated in the photodiode by the scene AND the laser pulse are transferred to a particular storage node, CCD1.
- When *transfer* is on, the electrons generated in the photodiode by the scene WITHOUT the laser pulse are transferred to a particular storage node, CCD2.

[0107] In a particular embodiment, the storage element can be manufactured using a CCD gate, in an adequate CCD/CMOS process. This implementation is advantageous because the consecutive accumulation of charges due to multiple transfers remains in the charge domain, without detrimental noise accumulation.

[0108] Once the frame information has been acquired, after one or several transfer activations, the pixel data can be read using *read1* and *read2*. The conversion of charge to voltage happens at this moment, on the floating diffusion. Both data are then read via two different channels using the *Select1* and *Select2* switches. Outside the pixel array, both voltages are subtracted to retrieve only the desired laser pulse data.

[0109] This embodiment is advantageous because it allows CDS operation on both floating diffusions, reducing the readout noise. The removal of the scene illumination from the actual data further allows maximizing voltage dynamic usage by applying analog gain after background subtraction.

[0110] In embodiments according to the present invention, the detector **102** optics may be focused to the largest range so as to resolve the spots at that distance and to match it with the pixel size. However because the depth of focus is much smaller than the range, the images of the spots will be broadened at shorter distances. On the other hand the intensity of the spots increases with decreasing distance so that the accuracy in the determination of the position increases. Calculations show that this easily compensates the increased spot size. In embodiments according to the present invention the distance between the spots is chosen such that overlap of spots at the detector **(102)** side is avoided. In an exemplary embodiment the distance between the spots is equal to ten times the diameter of the spots.

[0111] In embodiments according to the present invention the detector **102** may have a number of pixels NxN and the detector **102** optics are selected to match this large number of pixels with the angular resolution (1/N = 1 millirad). Moreover the radiation source **101** and accompanying projection optics can be selected to have the same angular resolution (so that the spot size matches the pixel size).

[0112] In embodiments of the present invention, large ranges can be bridged. For example radiation spots can surpass the daylight intensity over a large range by a sufficient factor for accurate measurements hereby keeping the individual laser beams below the safety guidelines of 1 mW continuous. Such a range may e.g. be between 1m and 15m, or even between 1m and 30 m.

[0113] In embodiments according to the present invention, the system also comprises a processor **103** for processing the data received by the detector **102.** The detected radiation pattern may for example be analyzed trough triangulation. For example if a spot pattern is used, the spot pattern is observed under a different angle with a detector, e.g. high resolution CMOS or CCD megapixel camera. The distance travelled by a light ray, being part of the radiation pattern, to a particular spot can then be determined by triangulation from the shift between the theoretical and observed position of the corresponding spot in the image viewed by the camera.

[0114] The position of a spot can be determined by image processing in which one calculates the weighted center of intensity of the pixels (cfr. center of mass). The calculation of a center of intensity is very simple and can be done in real time with simple and cheap hardware. If the angular resolution of the radiation source **101** and the detector **102** are worse than 1/N then the observed spot size in the image is larger than one pixel. But since the spot profile is known, one can in principle obtain sub pixel accuracy by multipixel fitting of the whole spot. In an embodiment according to the present invention the theoretical resolution can be calculated using the following formulas. In the embodiment a pattern of light spots is generated by a radiation source **101** and the monitored object is the road in front of a car whereby:

- *D* is the distance between the radiation source **101** and the detector **102**
- *Z* is the range over which the road is monitored
- *N* the number of pixels of the detector **102** in both directions
- The angular resolution of the projection and of the detection are 1/*N*
- The opening angle of the detector an optional lenses is 1 steradian
- H is the height of the projector above the road

[0115] The obtainable resolution can be subdivided in:

- *d:* the distance resolution
- v: the vertical resolution

[0116] The theoretical distance resolution can be calculated as:

$$d = \frac{Z^2}{D.N}$$

[0117] The theoretical vertical resolution in the profile of the road can be calculated as:

$$v = \frac{Z.H}{D.N}$$

[0118] Thus for a 4 Megapixel detector 101 (N=2000) *D* = 2 m *H* = 1 m and Z = 20 m a distance resolution of 10 cm (0.5 %) and a vertical resolution of 5 mm can be obtained.

[0119] At a distance of 1 m the distance resolution is 0.5 mm and the vertical resolution is also 0.5 mm.

[0120] As can be seen in the formulas, both the distance resolution and the vertical resolution are inversely proportional to the distance D between the radiation source **101** and the detector **102.** Since this distance can be made much larger than the distance between the lenses in a 3D camera, the depth resolution is then also proportionally better for the same illumination.

[0121] In one example, a spot profile design is used wherein an interspot distance of 10 spot diameters is present. This then corresponds with a grid of N/10 x N/10 spots. For a 1 Megapixel camera the grid then consists of 100x100 points. With a frame rate of 100 Hz we then efficiently sample the road in front of the tires with a vertical resolution of about 1 mm at a lateral sampling distance of 1 cm. The sampling distance in the moving direction depends on the speed of the vehicle.

[0122] At the maximal speed of 50m/sec the sampling distance in the moving direction is of the order of 5 mm. This is quite sufficient for most applications that one can envisage which makes the concept very generic.

[0123] The maximal continuous power of 100x100 spots (at the safety level of lmilliwatt) is then 10 watt which is within all realistic requirements.

[0124] In embodiments of the current invention processing the data from the detector **102** can be done on binarized images. It is an advantage of embodiments of the current invention that the required processing power of the processor **103** for processing the data is limited.

[0125] For projecting a grid of 100x100 points at a repetition rate of 100 Hz a peak power of the order of 100 Watt and an average power of 10 Watt is required, as also discussed above. A first estimation shows that even with an isotropic reflection coefficient of 1/1000 the total number of detected photons per pixel is above the detection sensitivity of the camera. For triangulation, the radiation source **101**, the detector **102**, and the object under study form a triangle. The line between the detector and the radiation source **101** is known. The radiation angle is known, allowing to determine distances.

[0126] In some embodiments according to the present invention, instead of simultaneously projecting the individual spots of the radiation pattern, the individual spots or groups of spots of the radiation pattern are transmitted sequentially by the radiation source **101**. This can be realized by projecting a pulsed laser beam on a scanner, e.g. a micro-machined scanner, the micro-machined scanner having two degrees of freedom. In embodiments according to the present invention a complete image of 1000x1000 spots can be projected with a repetition rate of 30 Hz or more.

[0127] In one embodiment, at the receiving side, a CMOS or CCD detector **102** captures the pulsed radiation source **101** after it was reflected by the object under study. At the receive side, similar embodiments can be realized as is the case for simultaneous projection of the radiation pattern. The radiation source **101** and the detector **102** are synchronized such that each transmit angle can be associated with a detection spot on the detector 102.

[0128] In an embodiment, the receive side also comprises a micro-machined scanner with 2 degrees of freedom. The scanner can track the reflected radiation, by synchronously moving with the micro-machined scanner at the transmit side.

[0129] The radiation captured by the micro-machined scanner is projected on to a photodetector (an analog linear photosensitive detector). In this way, an optical scanner with a high dynamic range can be realized. A radiation pattern comprising 1000x1000 spots can be transmitted and detected with a repetition rate of 30 Hz or more (for example, with a repetition rate of 60 Hz) using such an embodiment.

[0130] In embodiments according to the present invention a characteristic, e.g. a profile or property, of the monitored object is determined or reconstructed through triangulation on the received radiation pattern knowing the transmitted radiation pattern. The radiation pattern can be transmitted sequentially or simultaneously. In order to surpass daylight interference the power of the transmitted radiation pattern is increased keeping the average power constant by decreasing the transmitting pulse width.

[0131] The following non-limiting example concerns the application of a system 100, according to an embodiment of the present invention, on a vehicle for monitoring a characteristic, e.g. a profile or property, of the road in front of the vehicle.

[0132] To have a large range of visibility the radiation power should be sufficiently high.

[0133] For a laser beam with divergence d the area S of the laser beam at a distance Z and measured perpendicular to the beam is of the order of $S = (Z^*d)^2$. If the projector is positioned at a height H from the road the area Sp of the projected laser spot is $Sp=(Z/H)^*(Z^*d)^2$.

[0134] For the values $Z = 30$ m, $d = 1$ mrad, $H = 1$ m, this yields $Sp = 270$ cm^2.

[0135] A typical value for the power of daylight is 500 W/m^2 (the actual value depends on the geographical location and atmospheric conditions).

[0136] Thus if one wants the projected spot intensity to be of the same order as the daylight, one needs a power of 500 W/m^2. And for an area of 270 cm^2 one thus needs an optical power of 13.5 W. If we use monochromatic light and a spectral filter, one can gain a factor of 150. Thus one needs an optical power of 0.09 W per spot (hereinafter rounded to 0.1 W per spot). For safety reasons, the average power of the laser cannot exceed 1 mW. Thus the duty cycle of the laser can not exceed 0.001/0.1= 1/100. This can be realized by pulsing the laser in synchronization with the CMOS detector. If we use a CMOS detector at 60 Hz, the frame time is 16 ms. And then the pulse time is 16 ms/100 = 160 μs.

[0137] The following non-limiting example concerns the application of a system 100, according to an embodiment of the present invention, on a vehicle for use as an autonomous sensor. The objects to be sensed are assumed for this example to have a typical reflectivity of 10%; accordingly 10% of the incident intensity is reflected back isotropically over the relevant half of the space (over 2π sr). Absorption by air is neglected. Thus, the total reflected energy for an exemplary spot at a power of 20 mW (resulting for example from a total electric peak power of 120 W divided over 3000 VCSEL lasers with 50% efficiency), integrated over a pulse duration of 100 μs and reflected at 10%, is 2×10^{-7} J. Due to physical limitations, the maximum effective opening angle of the lens is of the same order as the area of the CMOS sensor chip **102**, which is assumed to be about 25 mm^2 for the purposes of the present example. Thus, the solid angle as seen from the reflecting point is about 2.5×10^{-9} sr, and the fraction of the reflected pulse that is captured by the camera is then 2.5×10^{-9} sr / 2π sr = 4.0×10^{-10}, which leads to a captured energy of 8.0×10^{-17} J, which represents approximately 160 photons (assuming infrared light at 850 nm, with 2.3 eV per photon). In a 1 megapixel camera with a viewing angle of 1 rad × 1 rad, with a conservative hypothetical beam divergence of 3 mrad, a spot would cover about 10 pixels, such that each pixel receives at most about 16 photons, without considering the further reduction due to the fill factor. This example illustrates that it is of particular importance in such cases to use a sensor with a very low noise level, preferably down to 10 electrons per pixel. The detector **102** only captures incoming radiation when radiation pulses are arriving. Therefore the detector is synchronized with the radiation source 101 through the synchronization means **104.**

[0138] In case of a camera of 1 Megapixel the number of measurements per second is also of the order of 1 million. When the vehicle moves at a speed of 50 m/s and the road has a width of 20 m the road will be sampled with a resolution of 3x3 cm.

[0139] For time of flight based systems, monitoring the same range of 30 m, a radiation beam requires 0.2 μs to travel the whole distance back and forth. During this time the detector **102** is open monitoring the complete field of view. This means that with a fixed average power of 10 Watt illumination over only 1/100 of a second is possible. It also means that with a required detector opening time of 0.2 μs only 10000 measurements per second can be achieved. Therefore embodiments according to the present invention can monitor at measurement rates which are a factor 20 better than time of flight based systems.

[0140] In some embodiments, the system may be adapted for eliminating or minimizing reflection of sun light and/or for reducing direct reflection of sunlight in reflective surfaces such as water. One or more of the at least one radiation source, the detector and/or the processor may be adapted therefore. In one embodiment, the at least one radiation source may be adapted for generating radiation with one or more predetermined polarization states and the at least one detector may be adapted for receiving only radiation of that one or more predetermined polarization states. The latter may be obtained by providing a polarization filter before the at least one detector for selecting the one or more predetermined polarization states. In another embodiment, the at least one radiation source may be adapted for generating radiation of one or more predetermined wavelengths, which may be in or out of the water spectrum, and the detector may be adapted, e.g. using wavelength filters, to limit the detection substantially to the one or more predetermined wavelengths. Alternatively, these wavelengths may be selected at the level of the processor from images recorded with a larger wavelength spectrum. Another alternative is that the at least one radiation source is not specifically adapted but that the at least one detector filters one or more predetermined wavelengths from the image, which may be in or out of the water spectrum. The filtering also may be performed at the level of the processor from images recorded with a larger wavelength spectrum. In yet another embodiment, the processor used may be adapted for eliminating the daylight or sunlight from a picture by image processing, e.g. by correcting image frame(s) with a fitted reference contribution for daylight/sunlight, thus eliminating the daylight/sunlight.

[0141] In some embodiments, the at least one radiation source may be adapted for radiation with at least two different wavelengths thus creating a multispectral radiation source. The latter may be advantageous for detecting certain objects, such as for example detecting organic material, detecting ice, water, snow, etc. Similar as for blocking sunlight, the detector typically also may be adapted with a filter for filtering the corresponding wavelengths emitted by the radiation source to work selectively. In some embodiments, a corresponding filter may be provided for each wavelength. The predetermined wavelengths may be detected each separately or in a single detection. In one embodiment, the processor also or alternatively may be adapted for filtering these wavelengths from an image recorded in a broader wavelength range. The information recorded at specific wavelengths thus may be used for selective detecting certain objects which are more sensitive to these specific wavelengths.

[0142] In some embodiments, the processor may be adapted for calculating a relation between consecutive frames. The frames thereby do not need to be directly subsequent frames, in other words, some frames may be skipped. Calculating the relation may be based on correlation, least square fitting, etc. but is not limited thereto. Such a relation may serve to determining a property of the moving object, e.g. vehicle, for example for determining a dynamic property. The relation may for example be used for determining a speed, a pitch, a roll, a yaw, etc. of a moving object. Such a relation also may be used for determining a height measurement of complete surfaces of the object or parts of the object. The object thereby may be in relative movement or may be stationary.

[0143] In some embodiments, the processor may alternatively or in addition to other tasks be configured for interpreting image or pixel information for different applications. Such different applications may be - but are not limited to - pavement detection, road detection, road inspection, inspection of the state of the pavement, detection of obstacles such as for example living or non-living creatures, moving or stationary obstacles, etc. Also detection of objects in relationship to their environment may be envisaged.

[0144] In some embodiments, the present invention also relates to a system comprising a plurality of systems as described above. The latter may allow to cover a larger field of view. The plurality of systems thereby comprises as much systems as required to cover the field of view one is interested in. The plurality of systems thereby may be mounted such that they cover the field of view of interest. This may be a system that covers 360° horizontally and 180° vertically to obtain surround viewing. Alternatively, any other field of view size may be obtained by appropriately selecting the number of systems and their position. Advantageously, the field of view realized by multiplicating the system at different physical locations may be organized specifically for certain applications such as for example but not limited to autonomous cars, warehouse transport, inspection vehicles, etc. Alternatively or in addition thereto, one or more systems or components thereof may be adjustable to cover different fields of view. The latter may be obtained by making one or more systems moveable to different positions, e.g. to different positions around a car in vehicle applications, by tilting the system under different angles, e.g. change the mounting angle, by making a system steerable, by creating overlap between the system's field of view or a combination thereof.

[0145] In some embodiments, the system may be adapted for covering a field of view from near the vehicle to the radar range. Consequently, the system may be combined with radar sensing as to extend the range for certain applications, such as pedestrian detection, collision avoidance or other safety and autonomous vehicle related applications or so as to provide additional and/or complementary measurement data serving the application. More generally, the system can be combined with additional sensors such as radar(s), infrared camera sensor(s), etc. In particular, the system may be used to determine the presence and speed of other vehicles or objects, and that information may in turn be used to control direction and speed of the vehicle, e.g. to avoid collisions, or to maintain a safe and substantially fixed distance to the vehicle ahead (smart cruise control).

[0146] In some embodiments, the system may be adapted for performing egomotion related applications. The processor may be adapted to supply data usable for egomotion related applications. The projector, i.e. the radiation source, and/or the detector also may be arranged for creating/recording relevant data for egomotion related applications. In one particular example, egomotion related data may be based on a vehicle's motion based on its motion relative to lines on the road or relative to street signs as observed from the vehicle itself. Egomotion related information may for example be used in autonomous navigation applications.

[0147] In some embodiments, the system may be adapted for providing odometry information. The processor may be adapted for determining equivalent odometry information using sequential detector images for estimating distances travelled. The latter may for example be used for enhanced navigational accuracy in robots or vehicles using any type of locomotion on any type of surface.

[0148] In some embodiments, a spot pattern may be introduced, whereby some spots, some groups of spots or each spot is addressable and configurable in intensity, spot size,... This allows grouping of spots, introducing irregularities for example in order to render the image processing easier, changing the distance between the lines i.e. making the distance variable, ...

[0149] In some particular embodiments, the intensity of the VCSEL's may be controlled, such that the spots all have the same shape, the same intensity independent of the distance or the location in the projected spot pattern,. The latter enhances the data processing and allows to obtain a more accurate measurement e.g. to avoid clipping of pixel charge and allow multipixel fitting for all spots in the spot pattern. It also allows to fit a curve between profiles that have about the same geometry.

[0150] In some embodiments, the radiation source, e.g. VCSEL, may be split in several zones and the different zones may be driven differently to compensate for example for an intensity decrease for spots imaged further away from the source and/or detector. For example, different zones may be driven with a different power or ON time so as to partially or fully compensate for the different intensity loss for the different spots, depending on the position where they are imaged. The latter thus allows that the spots positioned further from the detector are driven at a higher power than the spots closer to the detector. The latter also allows to optimally make use of A/D conversion ranges, where required. In one example, control of one or more spot properties also may be performed for compensating for differently reflecting objects, which otherwise could result in substantially different geometries of the reflected spot. For example, white lines for guiding traffic on the road have a substantially different reflectivity than other parts of the roads. The system can be adapted for compensating geometry changes of the reflected spot caused thereby.

[0151] The above control may be referred to as intensity servoing.

[0152] In some embodiments, the wavelength of the radiation source used may be controlled (thermal servoing) such that it optimally fits filters, e.g. bandpass filters, used. The wavelength shift may for example be performed using a peltier or heating element. A good fit between the wavelength of the radiation source and the filters used may result in the possibility to reduce and/or minimize the influence of environmental disturbing radiation such as daylight.

[0153] Figures 10-12 illustrate exemplary cameras that may be used in systems, where the radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter and optics arranged so as to modify an angle of incidence onto said narrow bandpass filter, to confine said angle of incidence to a predetermined range around a normal of a main surface of said narrow bandpass filter, said optics comprising an image-space telecentric lens. The term "camera" is used herein as a combination of a sensor and associated optics (lenses, lens arrays, filter). In particular, in Figure 8, the optics further comprise a minilens array arranged between the image-space telecentric lens and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

[0154] These examples all result in radiation travelling a substantially equal length through the filter medium or in other words in that the incident radiation is substantially orthogonal to the filter surface, i.e. it is confined to an angle of incidence within a predetermined range around the normal of the filter surface, thus allowing in accurate filtering within a narrow bandwidth to e.g. filter the daylight, the sunlight and in order to for the spots to surpass the daylight.

[0155] The correction of the angle of incidence is of particular importance in systems where the entire space around the vehicle is to be monitored with a limited number of sensors, for instance 8 sensors, such that the incident rays may extend over a solid angle of for example 1 x 1 rad.

[0156] Figure 10 schematically illustrates a first optical arrangement of this type. It comprises a first lens **1030** and a second lens **1040**, with approximately the same focal length *f*, in an image space telecentric configuration. That means that all chief rays (rays passing through the center of the aperture stop) are normal to the image plane. An exemplary numerical aperture of 0.16 corresponds to a cone angle of 9.3° (half cone angle). The maximum incidence angle on the narrow bandpass filter 1060, arranged between the lens system **1030-1040** and the sensor **102,** would thus be 9.3°.

[0157] As illustrated in Figure 11, the preferred design consists of a tandem of two lenses **1130, 1140** with approximately the same focal length *f*, in an image-space telecentric configuration (the configuration is optionally also object-space telecentric), a planar stack of mini-lens array **1150**, a spectral filter **1160** and a CMOS detector **102.** Since the center O of the first lens **1130** is in the focus of the second lens **1140,** every ray that crosses O will be refracted by the second lens **1140** in a direction parallel to the optical axis. Consider now a particular laser spot S **1110** located at a very large distance as compared to the focal length of the first lens **1130.** Thus the image of this spot **1110** by the first lens **1130** is a point P located close to the focal plane of this lens, thus exactly in the middle plane of the second lens **1140.** The light rays that are emitted from the spot S**1110** and captured by the first lens **1130** form a light cone that converges towards the point P in the second lens **1140.** The central axis of this light cone crosses the point O and is refracted parallel the optical axis and thus perpendicular to the spectral filter **1160** so as to achieve optimal spectral sensitivity. Hence, the second lens **1140** acts as a correcting lens for the angle of the incident light beam. The other rays of the cone can also be bent in a bundle of rays parallel to the optical axis by using a small convex mini-lens **1150** behind the second lens **1140** in such a way that the point P is located in the focal point of the mini-lens 1150. In this way all the imaging rays of the spot S**1110** are bent in a direction nearly perpendicular to the spectral filter. This can now be done in front of every pixel of the CMOS detector separately by using an array of mini-lenses positioned in front of every pixel. In this configuration, the minilenses have an image-telecentric function. The main advantage is that the pupil of the first lens **1030** can be enlarged, or the diaphragma can be eliminated while compensating for the increase in spherical aberration by a local correction optics in the mini-lens **1150.** In this way the sensitivity of the sensor assembly can be improved. A second mini-lens array (not shown in Figure 11) may be added between the spectral filter **1160** and the CMOS pixels **102,** to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor.

[0158] For the first and second lenses **1130, 1140,** commercially available lenses may be used, such as the lenses used in the iSight camera of the iPhone 6 smart phone from Apple Corp. The skilled person will appreciate that lenses typically used in other smart phone cameras or webcams of comparable quality can also be used. The aforementioned iSight camera has a 6 x 3 mm CMOS sensor with 8 megapixels, 1.5 µm pixel size, a very large aperture of f/2.2, an objective focal length of about f = 7 mm, and a pupil diameter about 3.2 mm. The viewing angle is of the order of 1 rad x 1 rad. If we assume that the resolution of the camera is roughly the pixel size (1.5 micron), we can conclude (from Abbe's law) that the aberrations of the lens are corrected for all the rays of the viewing angle selected by the diaphragma.

[0159] Figure 12 illustrates a variation of the arrangement of Figure 11, optimized for manufacturing in a single lithographic process. The first lens **1230** is similar to the first lens **1130** of the previous example, but the angle-correcting second lens **1140** is replaced by a Fresnel lens **1240** with the same focal length f and the mini-lens arrays **1150** by Fresnel lens arrays **1250.** The advantage is that they are completely flat and can be produced by nano-electronics technology (with discrete phase zones). A second mini-lens array **1270** may be added between the spectral filter **1260** and the CMOS pixels **102,** to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor. Thus the camera is essentially a standard camera as the iSight but in which the CMOS sensor is replaced by a specially designed multi-layer sensor in which all the components are produced in one integrated block within the same lithographic process. This multilayer sensor is cheap in mass production, compact, robust and it need not be aligned. Each of these five layers **1240, 1250, 1260, 1270, 102** has its own function to meet the requirements imposed by the present invention.

[0160] As the minimal angle of a cone generated by a lens of diameter d is of the order of λ/d, with λ the wavelength of the light, the minimal cone angle is 1/10 radian for a mini-lens diameter d = 8.5 μm and λ = 850 nm. With a good quality spectral interference filter this corresponds to a spectral window of about 3 nm.

[0161] Figure 13 illustrates an optical arrangement according to the present invention, comprising a dome **1310** (e.g., a bent glass plate) with the narrow bandpass filter **1320** disposed on its inside (as illustrated) or outside (not illustrated). The advantage of disposing the filter **1320** on the inside of the dome **1310**, is that the dome **1310** protects the filter **1320** from outside forces. The dome **1310** and the filter **1320** optically cooperate to ensure that incident light passes through the filter **1320** along a direction that is substantially normal to the dome's surface. Fish-eye optics **1330** are provided between the dome-filter assembly and the sensor **102**, which may be a CMOS or a CCD sensor. The fish-eye optics **1330** are arranged to guide the light that has passed through the dome-filter assembly towards the sensitive area of the sensor.

[0162] Optionally, further fish-eye optics are provided at the projector. In a specific embodiment, a plurality of VCSELs are mounted in a 1 x n or a m x n configuration, whereby an exit angle of the laser beam can be realised over a spatial angle of m x 1 rad in height and n x 1 rad in width.

[0163] In some embodiments of the present invention, the camera, the detector is slightly rotated relative to the projector or vice versa e.g. over an angle of 4°, allowing an improved image processing and facilitating the identification of the spots as the chance of overlap between the segments of the 2D projection on the image sensor of the 3D epipolar lines on which the spots are searched for is reduced.

[0164] In some embodiments of the present invention, the type of road can be determined from the spreading of the measured values and from the variation of the intensity, e.g. in a predetermined zone (advantageously the area where the tires will roll).

[0165] In some embodiments of the present invention, the intensity of the spots can be kept substantially constant over the full depth range, by applying a stepped or variable attenuation filter at the detector. Alternatively or in addition, also a non-symmetrical lens pupil can be provided for weakening the intensity of spots closer to the detector, while the intensity of the spots further away from the detector are received at full intensity. In this way clipping of the detector is avoided and the average intensity can be made substantially the same for all spots.

[0166] In some embodiments, the radiation source can be a VCSEL that can be split in different zones, whereby the laser ON time is controlled for the different zones. The images of the spots can thus be controlled to have a constant intensity, e.g. 2/3rd of the A/D range. Alternatively the driving voltage can be driven over the array of spots as function of the height, again to obtain a constant intensity. Such controlling can be referred to as a saturation avoidance servoing loop.

[0167] In some other embodiments of the present invention, a micro prism matrix can be used in front of the narrow bandwidth filter, such that the radiation is incident within an angle of incidence between +9° and -9° on the filter. This allows to obtain narrow bandwidth filtering. The prism matrix can for example be made by plastic moulding.

[0168] In embodiments of the present invention, e.g. where active suspension vehicle applications are envisaged, the projection of the spot pattern is advantageously directed downwards, i.e. towards the road.

[0169] In embodiments of the present invention, advantageously the distance between the detector and the projector is not too small, in order to allow for accurate image processing.

[0170] In a second aspect, the present invention relates to vehicles in which the detection system 100 is implemented for monitoring road conditions and as input for controlling the suspension system of the vehicle.

[0171] In embodiments according to the present invention, the system for detecting a characteristic, e.g. a profile or property, of an object is placed in front of a vehicle. The object under study is in that case the road in front of the vehicle. Ranges of 1m to 15 m, even 1m up to 30 m in front of the car can be monitored.

[0172] In advantageous embodiments, the detection system 100 interfaces with the suspension system through an interface or output means. The data may be communicated to a controller for controlling the active suspension system. The result is that the vehicle smoothly moves over the road, also referred to as "flying carpet".

[0173] Note that the image of the viewing scene is taken repeatedly with the frame rate of the camera. Thus the characteristic of the road is continuously updated and fed back to the active suspension system.

[0174] In one particular example, the controlling may include controlling of the suspension such that the roll vector lies in the same direction as the centrifugal force, so that passengers are pressed against their seats. In another example, the controlling may include active lifting of the chassis of the vehicle when a braking manoeuver so that a higher downforce on the vehicle and a higher friction force on the tires is obtained, resulting in a shorter braking distance. Yet another example of controlling is increasing the pitch of a vehicle maximally for collision damage control, resulting in an increased front side of the vehicle for restricting the risk of sliding under a truck. In other circumstances, the controlling may be such that fuel use is minimized by reducing the pitch of a vehicle and thus reducing the air resistance.

[0175] In some embodiments, compensation of the active suspension occurs based on the average height in a zone with a surface area as large as the surface of the contact area of the tire on the road. Such compensation may be performed about 50 to 100 ms before the event.

The distance of the relevant zone to monitor is a function of the speed of the vehicle. The lateral position (left - right) of the relevant zone is a function of the steering angle. The transformation to be performed for the three degrees of freedom (X, Y and theta) can be identified based on an optimal correlation between two consecutive images. This transformation is then used for determining a new set of height measurements. The roll and/or pitch of the vehicle can be identified based on the 6 degrees of freedom transformation of the coordinate system of the vehicle with respect to a least squares plane fitted through the measurement points. In embodiments according to the present invention, the depth information of the road in front of the car detected by the detection system can be used as a 3D component that can be added to the image of a color camera to render this image into a 3D image.

[0176] It is an advantage of embodiments of the present invention that the system can also be used for warning the driver for bad conditions, such as for example rain or snow.

[0177] In embodiments according to the present invention, a processor can also be used for deriving the speed of the car from the data coming from the detection system.

[0178] In embodiments according to the present invention, the orientation of the car with regard to the road can be derived from the data coming from the detection system. The orientation can then be expressed as the car making an angle with the central line of the road, or in any other suitable way. A processor adapted for deriving such information may be embedded in the detection system or in another system, e.g. control system of the car. In embodiments according to the present invention the presence and speed of approaching objects can also be detected using the detection system. A processor adapted for deriving such information may be embedded in the detection system or in another system, e.g. control system of the car.

[0179] The output of the detection system mounted on a vehicle can thus be used, not only for the suspension system, but as an input for several active components in a car enabling the car to be autonomously controlled.

[0180] It is an advantage of embodiments of the present invention that they can be combined with other techniques for extending the possibilities. For example, in one embodiment, the system may be extended with a radar system in order to extend the range that can be monitored.

[0181] Generally, when the system according to the invention is mounted to a vehicle, it may be arranged in such a way that the system can move relative to the vehicle, to select a desired field of view. The projector can have angular rotation relative to the detector or vice versa, e.g. over an angle of 4°, allowing an improved image processing and facilitating the identification of the spots as the chance of overlap between the segments of the 2D projection on the image sensor of the 3D epipolar lines on which the spots are searched for is reduced. To obtain a high accuracy in the spot shift analysis more specifically with respect to the vertical resolution, the detector is preferably placed at some distance from the projector. With

D is the distance between projector and detector

Z is the range over which e.g. the road is monitored

ϑ is the angular resolution (corresponding to a pixel, so for a 1 Megapixel camera and an angle of 1 rad this corresponds to 1mrad or 1/1000 rad)

H is height of the projector above the object

the distance resolution corresponds to

$$d = \vartheta * Z^2 / D$$

and the vertical resolution

$$v = d*(H/Z)$$

[0182] Thus in the conditions Z = 30 m and ϑ = 1/1000 and D = 1 m and H = 1 m following results are calculated

D = 90 cm

V = 3 cm

In case Z = 10 m other parameters equal

d = 10 cm

z = 1 cm

[0183] In order to realize a vertical resolution of 3cm at 30m and 1cm at 10m with a 1 Megapixel camera the distance between projector and detector/camera must be 1m.

[0184] Depending on the extent of the field of view required for a particular application, multiple projectors and detectors may be used, whereby ultimately a full 360° viewing angle could be obtained. In view of the scarcity of space for technical components in modern vehicles, the system according to the invention is preferably integrated in the vehicle using existing cavities or newly created spaces for seamless integration.

[0185] In a third aspect, the present invention relates to a method for detecting a characteristic, e.g. a profile or property, of an object. Such a method can advantageously be used in combination with a system as described in the first aspect, although embodiments of the present invention are not limited thereto. The method may advantageously be used for determining a characteristic such as a profile of a road. The method may be incorporated in a method for controlling a suspension of a car, the method comprising performing a method for detecting a characteristic, e.g. a profile or property, of a road and a step of using such information for actively controlling a suspension. Nevertheless, the method for detecting a characteristic, e.g. a profile or property, of an object also may be used outside automotive, for any other suitable application.

[0186] In a first step **201** a radiation pattern is emitted on the object under study using a radiation source. The radiation pattern can be emitted in one shot (i.e. simultaneously) or sequentially. In any case, the radiation pattern is emitted in a pulsed manner. The latter advantageously results in a better signal to noise resolution, as the amount of power that can be provided during the pulse can be higher, thus resulting in less disturbance of environmental light, such as e.g. daylight.

[0187] In a second step **202**, the reflected pattern is detected using a detector **102.** The detector has a plurality of pixels such that it can detect the complete reflected radiation pattern with a resolution that is sufficient to resolve the pattern. The detection is synchronized with the radiation through a synchronization means **104.**

[0188] In a third step **203**, the data from the detector **(102)** is processed using a processor **(103).** Triangulation based methods on the data allow to retrieve profile information from that data. The method may comprise an auto-calibration phase.

[0189] A schematic representation of a method according to embodiments of the present invention is shown in FIG. 2.

[0190] Whereas the above method has been described for detecting a characteristic in an object, e.g. a profile in a road, it will be clear to the skilled person that a number of other applications can be performed using the present system. Particular applications may be based on a particular interpretation of the measured raw data in combination with for example calibration datasets.

[0191] In a first example, as discussed in more detail above, the application envisaged is increasing driving comfort. Active suspension is steered based on the obtained measurements to adjust for road imperfections, to adjust for type of pavement, to adjust for road conditions such as ice, water, snow, grind, etc. (this can also be a safety application) to adjust for pitch, roll, etc.

[0192] Another example of an application is autonomous or assisted driving of vehicles. The system may for example be used for providing or assisting in a steering function. It may provide steering instructions for semi-autonomous or autonomous steering of vehicles of any means, for example in agriculture, for any type of transport, for road inspection, for a garbage collection truck, for pick and collect tasks in warehouses, for load applications, etc. The system thereby may perform one or more of speed calculation, determination of moving or stationary objects in relation to their environment, etc.

[0193] Another example of an application is the provision of safety information or the performance of safety actions. The system may be used for detecting traffic signs, moving objects, vicinity of objects, detection of any moving or stationary object in relation to its environment, road conditions, road types, etc.

Claims

1. A vehicle-mountable system (100) for detecting a characteristic of an object, the system comprising:

    - a radiation source (101) adapted to generate a simultaneously pulsed radiation pattern composed of radiation spots;
    - at least one detector (102) having a plurality of pixels;
    - a processor (103) adapted to process data from the at least one detector (102) when radiation from the radiation source is reflected by an object and detected by the at least one detector (102);
    - a synchronization means (104) interfacing between the at least one detector (102) and the radiation source (101);

    wherein:

    - the synchronization means (104) is adapted for synchronizing the at least one detector (102) with the radiation source (101) so that detection by the detector of radiation to be processed is detected only during the radiation pulses,
    - the processor (103) is adapted to determine a characteristic of the object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions, and
    - the radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter (1320) arranged on a dome (1310), said system further comprising fish-eye optics (1330) arranged between said narrow bandpass filter (1320) and said at least one detector (102) to guide light that has passed through said narrow bandpass filter (1320) towards a light-sensitive area of said at least one detector (102).

2. The system (100) according to claim 1, wherein the at least one detector comprises a CMOS sensor or a CCD sensor having a dynamic range of at least 90 dB, preferably more than 120 dB.

3. The system (100) according to claim 1 or claim 2, wherein the at least one detector comprises a CMOS sensor or a CCD sensor configured to subtract background illumination from the radiation from the radiation source by comparing a signal sensed during an on-phase of said pulsed radiation pattern with a signal sensed during an off-phase of said pulsed radiation pattern.

4. The system (100) according to any of the preceding claims, wherein said determining of said displace-

ment is performed with sub-pixel accuracy by multipixel fitting said detected spots.

5. A vehicle comprising the system (100) according to any of the preceding claims.

6. The vehicle according to claim 5, further comprising a suspension system, and a control system, whereby the control system is adapted for receiving profile information of the system for determining a characteristic of an object and is adapted for using the information for controlling the suspension system.

7. A camera, the camera comprising a system (100) according to any of claims 1 to 4, whereby the system (100) is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

8. A method for detecting a characteristic of an object, the method comprising the following steps:

- emitting (201) a pulsed radiation pattern composed of radiation spots on the object using a radiation source (101),
- detecting (202) the reflected pattern using at least one detector (102) having a plurality of pixels, whereby the detection is synchronized with the pulsed radiation pattern for detecting radiation to be processed only during the radiation pulses, and
- processing (203) the data from the detector (102) for determining a characteristic of an object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions,

wherein said emitting (201) uses monochromatic light and said at least one detector (102) is equipped with a corresponding narrow bandpass filter (1320) arranged on a dome (1310), and wherein fish-eye optics (1330) arranged between said narrow bandpass filter (1320) and said at least one detector (102) guide light that has passed through said narrow bandpass filter (1320) towards a light-sensitive area of said at least one detector (102).

9. The method according to claim 8, wherein the at least one detector comprises a CMOS sensor or a CCD sensor having a dynamic range of at least 90 dB, preferably more than 120 dB.

10. The method according to claim 8 or claim 9, wherein the at least one detector comprises a CMOS sensor or a CCD sensor configured to subtract background illumination from the radiation from the radiation source by comparing a signal sensed during an on-phase of said pulsed radiation pattern with a signal sensed during an off-phase of said pulsed radiation pattern.

11. The method according to any of claims 8-10, wherein said determining of said displacement is performed with sub-pixel accuracy by multipixel fitting said detected spots.

12. A computer program product comprising code means adapted to cause a processor to perform the determining of said characteristic of the method according to any of claims 8 to 11.

13. Use of a system (100) according to any of claims 1 to 4 for detecting a characteristic of an object in a vicinity of a vehicle, said use taking place in an outdoor environment.

14. Use according to claim 13 for measuring the profile of the road in front of a car or for controlling of autonomous vehicles.

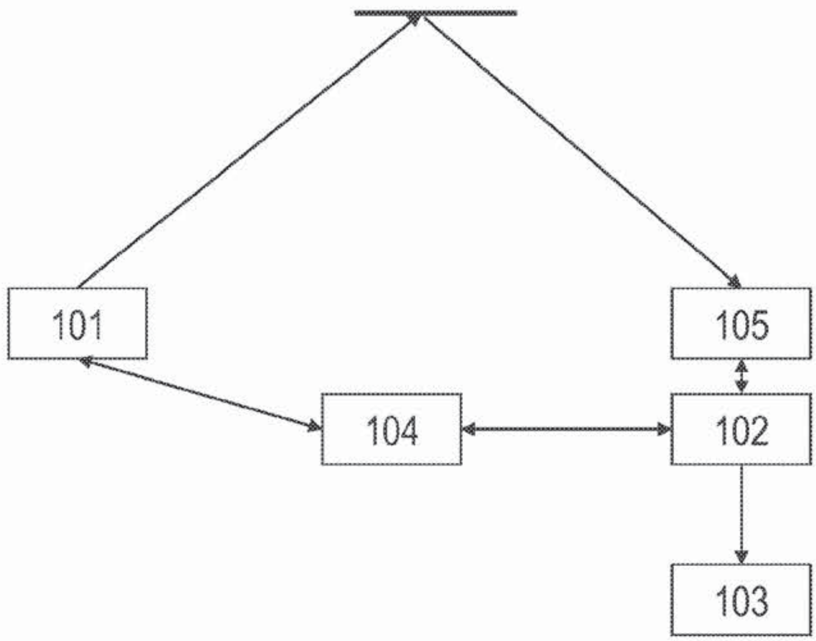

Fig. 1

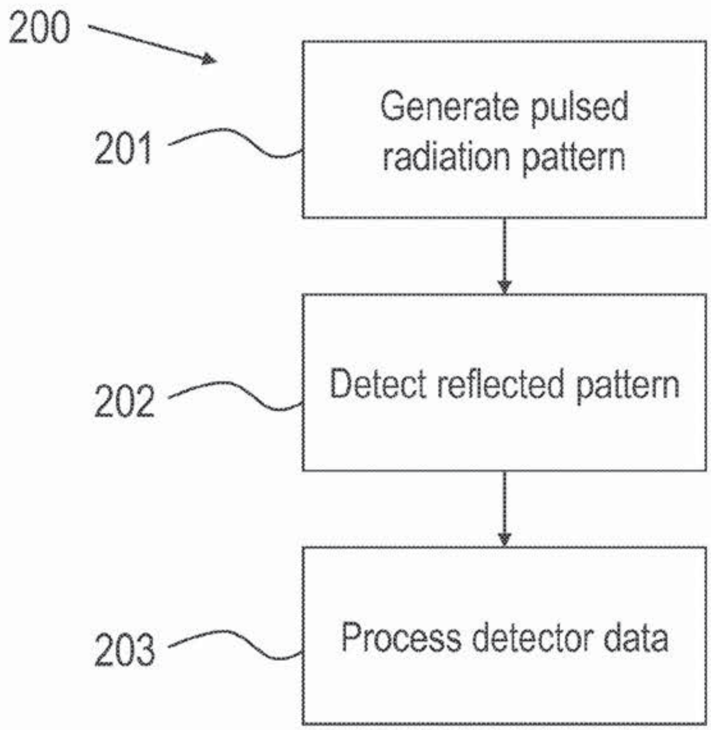
200
201
Generate pulsed radiation pattern
202
Detect reflected pattern
203
Process detector data

Fig. 2

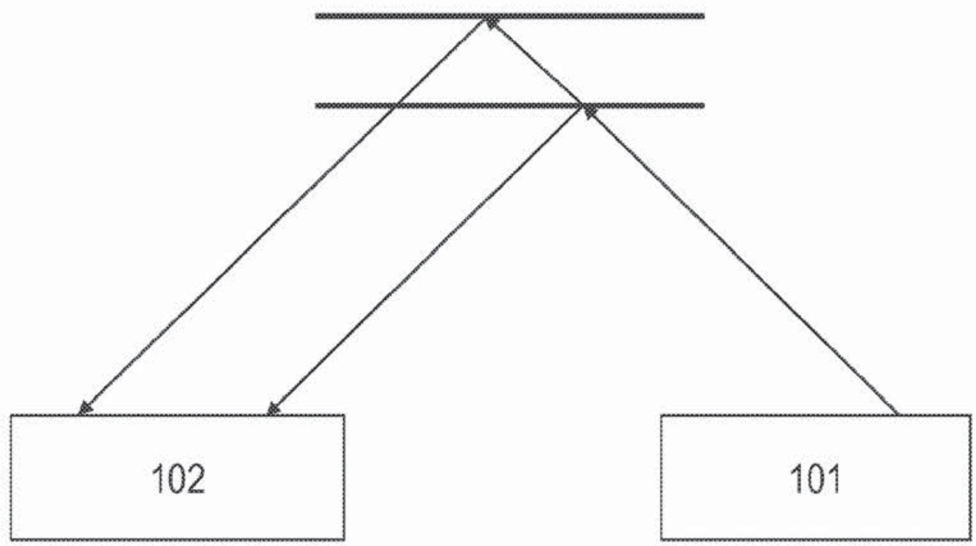

Fig. 3

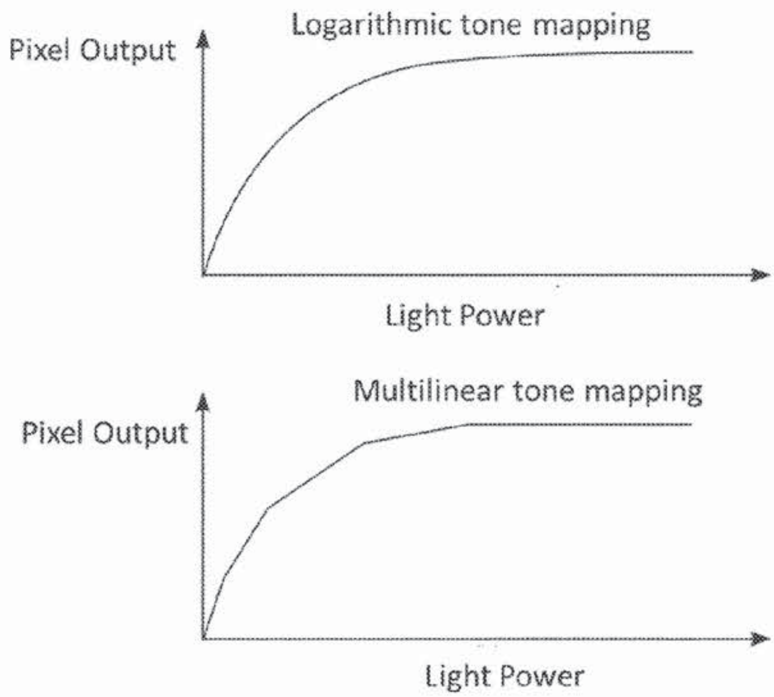
Logarithmic tone mapping
Pixel Output
Light Power
Multilinear tone mapping
Pixel Output
Light Power

Fig. 4

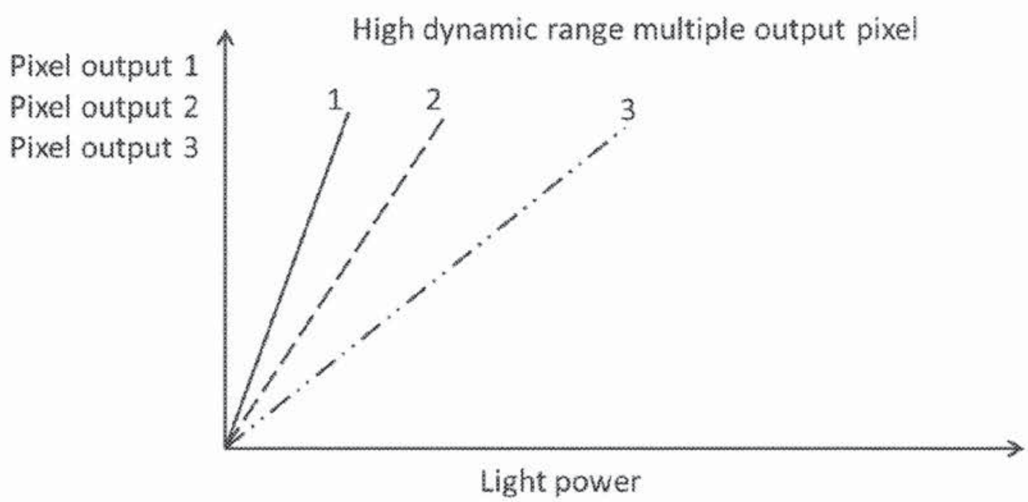
High dynamic range multiple output pixel
Pixel output 1
Pixel output 2
Pixel output 3
1
2
3
Light power

Fig. 5

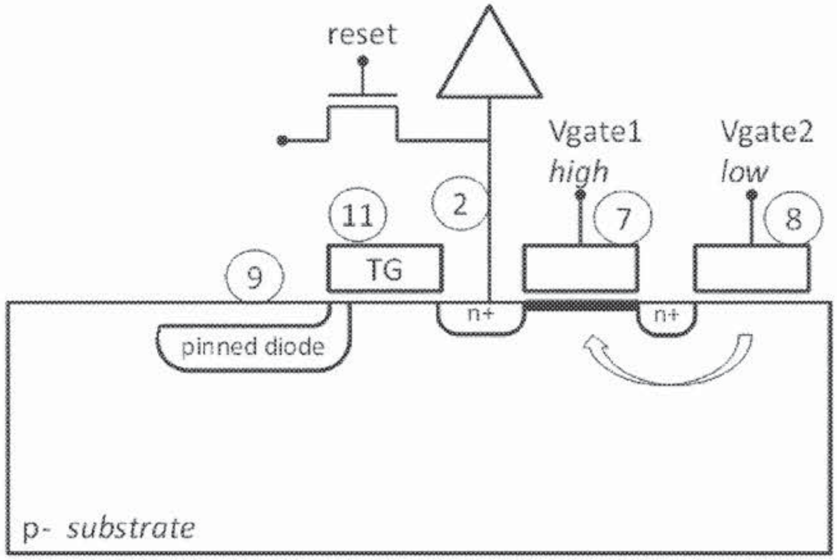
reset
Vgate1
high
Vgate2
low
11
2
7
8
9
TG
n+
n+
pinned diode
p- substrate

Fig. 6

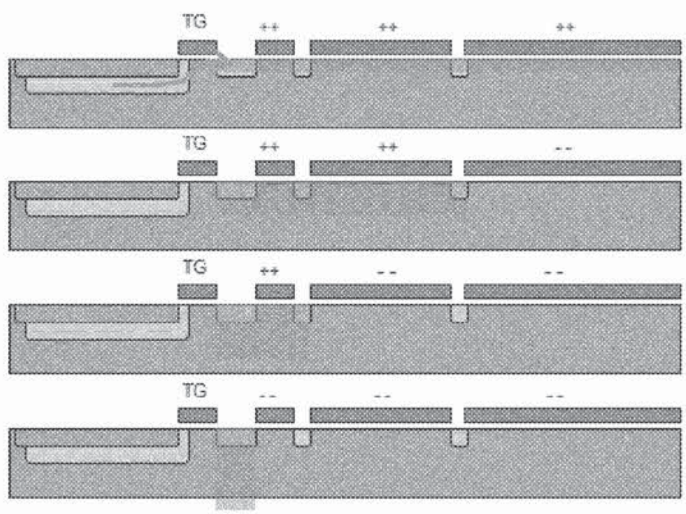
TG
++
++
++
TG
++
++
--
TG
++
--
--
TG
--
--
--

Fig. 7

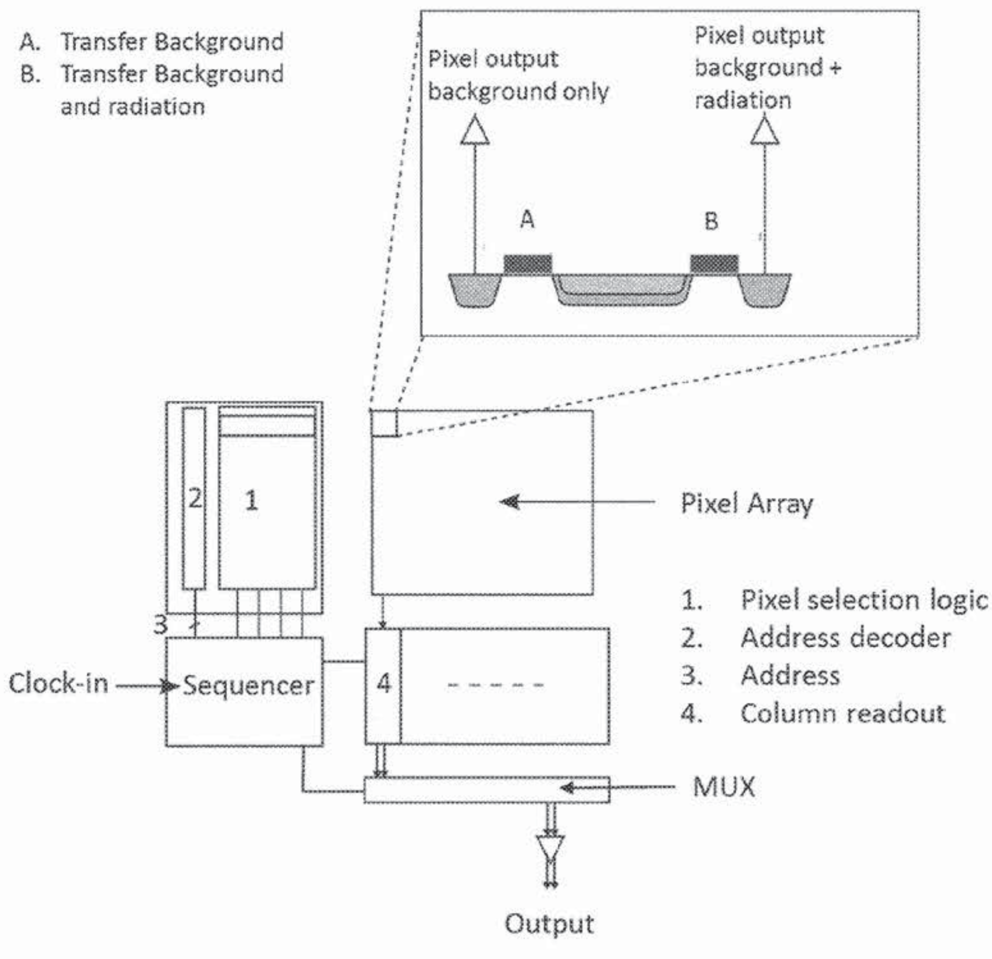
A. Transfer Background
B. Transfer Background and radiation
Pixel output background only
Pixel output background + radiation
A
B
2
1
3
Pixel Array
1. Pixel selection logic
2. Address decoder
3. Address
4. Column readout
Clock-in
Sequencer
4
MUX
Output

Fig. 8

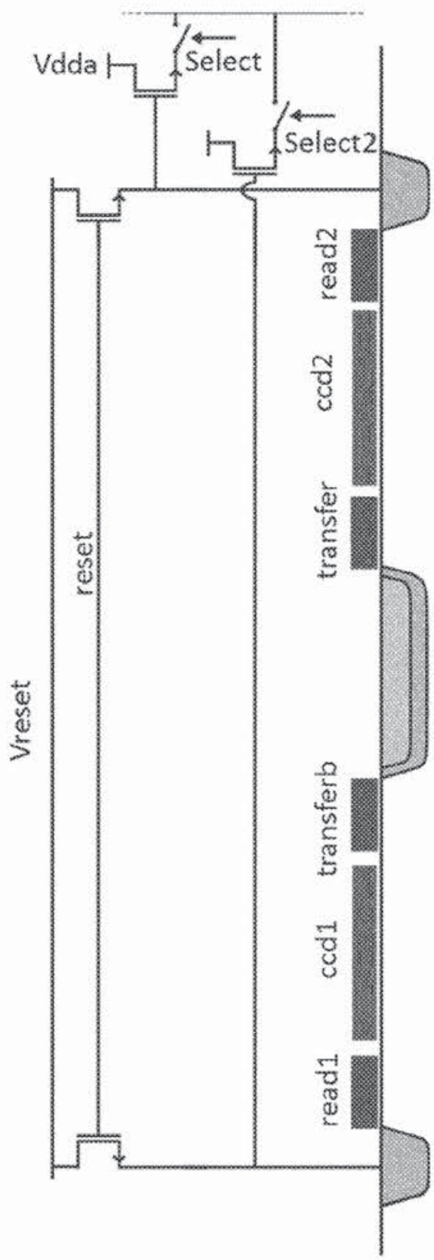
Vdda
Select
Select2
Vreset
reset
read2
ccd2
transfer
transferb
ccd1
read1

Fig. 9

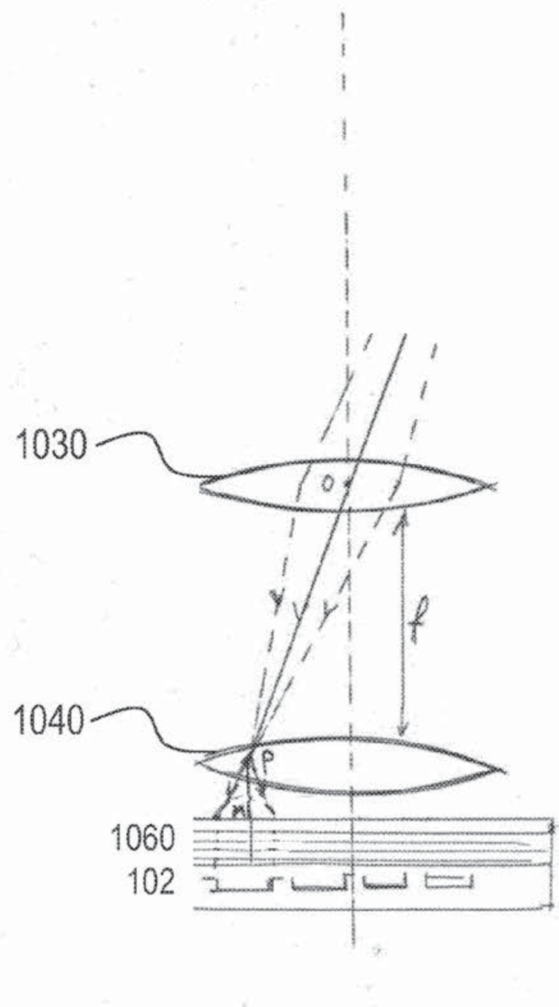

Fig. 10

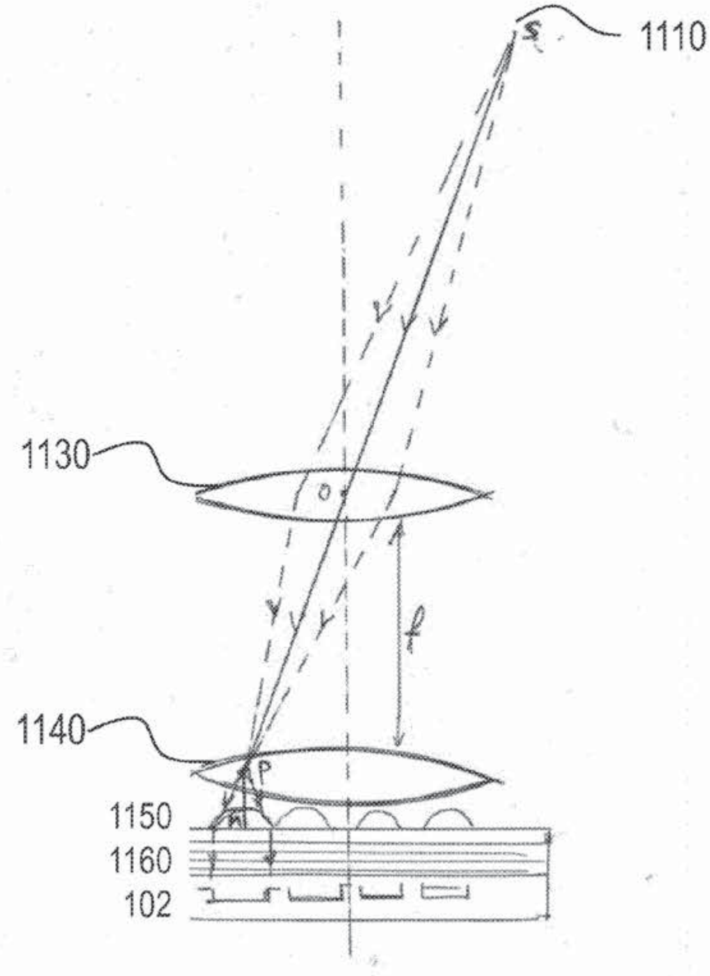

Fig. 11

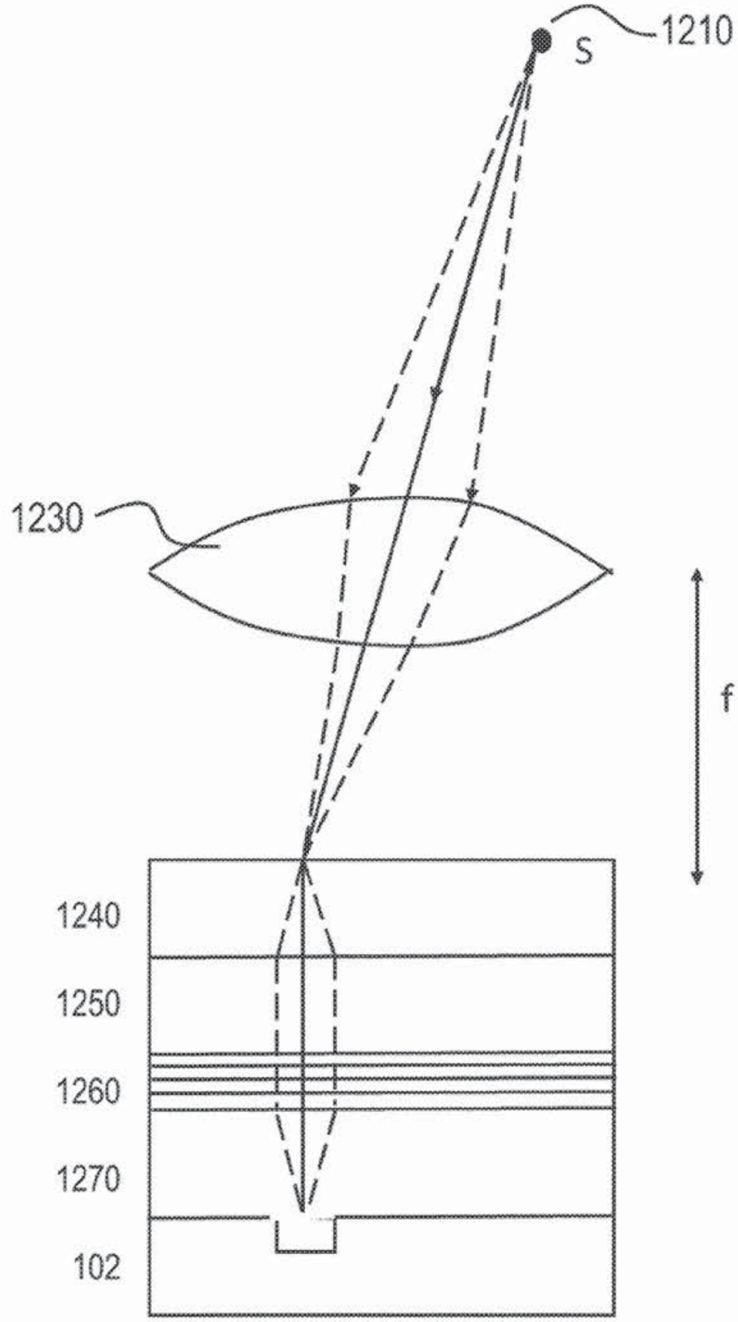

Fig. 12

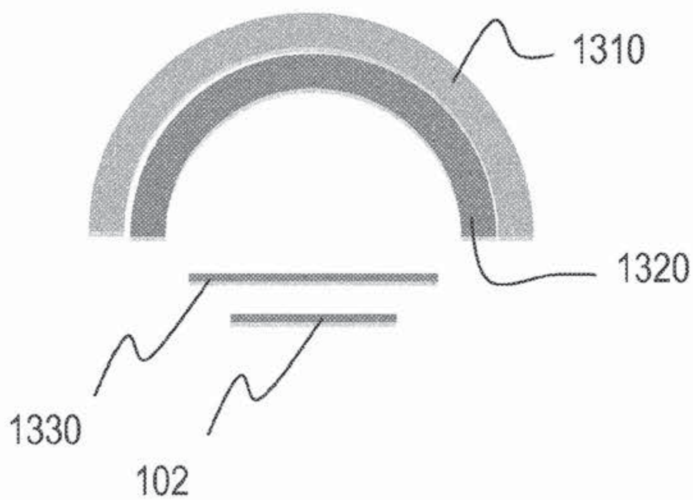

Fig. 13

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 15 15 1031

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 5 040 116 A (EVANS JR JOHN M [US] ET AL) 13 August 1991 (1991-08-13) * abstract; figure 1b * * column 2, line 15 - line 57 * * column 3, line 55 * * column 4, line 29 - line 40 * * column 7, line 35 - line 39 * -----	1-14	INV. G01S17/46 G01S17/89 G01S7/481
X	US 6 678 598 B1 (HILLEBRAND MATTHIAS [DE] ET AL) 13 January 2004 (2004-01-13) * abstract * * column 3, line 30 - line 54 * * column 4, line 37 - line 54 * * column 7, line 36 - line 64 * * claim 1 * -----	1-5,8-12	
X	DE 102 26 278 A1 (LUX PETER [DE]) 24 December 2003 (2003-12-24) * the whole document * -----	1-5,8-14	
A	US 2005/213082 A1 (DIBERNARDO ENRICO [US] ET AL) 29 September 2005 (2005-09-29) * paragraph [0046] * -----	1-14	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2011/060478 A1 (NICKOLAOU JAMES N [US]) 10 March 2011 (2011-03-10) * paragraph [0036] - paragraph [0038] * -----	6	G01S H04N G01F

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	25 June 2015	Beer, Mark

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 15 15 1031

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

25-06-2015

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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US 6678598	B1	13-01-2004	DE 59906278 D1	14-08-2003
			EP 1185442 A1	13-03-2002
			US 6678598 B1	13-01-2004
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US 2005213082	A1	29-09-2005	DE 112005000738 T5	26-04-2007
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			US 2011060478 A1	10-03-2011

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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- US 8320621 B **[0007]**
- US 2005195383 A1 **[0009]**
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- US 2012038903 A1 **[0011]**
- EP 13175826 A **[0014]**
- EP 2014064769 W **[0014]**
- US 2014353472 A1 **[0103]**

Electronic Acknowledgement Receipt

EFS ID:	35496723
Application Number:	16046643
International Application Number:	
Confirmation Number:	1720
Title of Invention:	OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS
First Named Inventor/Applicant Name:	Angus Pacala
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P001USC2-1096583
Receipt Date:	21-MAR-2019
Filing Date:	26-JUL-2018
Time Stamp:	19:11:54
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		IDS_transmittal-PTOSB08A-P001USC2.pdf	179301 9fe533bba08578bc21d62783da35bf1984e9c806	yes	4

	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Information Disclosure Statement (IDS) Form (SB08)		3	4	
	Transmittal Letter		1	2	
Warnings:					
Information:					
2	Foreign Reference	WO2018197441A1.pdf	11040325 45229720b9d42e35b24e89e99e2a98f45a3f9be8	no	48
Warnings:					
Information:					
3	Foreign Reference	WO2018122415A1.pdf	7512437 707b7a47354d2fb534286d505607a4d76bc9e482	no	29
Warnings:					
Information:					
4	Foreign Reference	WO2018065426A1.pdf	7734001 4f64e7b833f422a6be52c2c498b3b907251ef854	no	36
Warnings:					
Information:					
5	Foreign Reference	WO2018065429A1.pdf	11914118 6cc95ae8fa39bafa44221613de04ce4ca03d7b3b	no	56
Warnings:					
Information:					
6	Foreign Reference	WO2018065427A1.pdf	10574327 2959a07904507777945 71a536ff1a1a70c390506	no	50
Warnings:					
Information:					
7	Foreign Reference	WO2018065428A3.pdf	1945480 7d46bc3ec72c96580ce81fad869cd77734876d46	no	7
Warnings:					

Information:					
8	Foreign Reference	EP3316000A1.pdf	384972 8ba1196090a6b856858d44c58eecb940208970f4	no	11
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9	Foreign Reference	EP3045935A1.pdf	903626 6604f41934e60a5c14556fc9fab1f29af43b51ad	no	33
Warnings:					
Information:					
		Total Files Size (in bytes):	52188587		

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New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.
National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.
New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 16/046,643	Filing Date 07/26/2018	☐ To be Mailed

ENTITY: ☐ LARGE ☑ SMALL ☐ MICRO

APPLICATION AS FILED - PART I

	(Column 1)	(Column 2)		
FOR	NUMBER FILED	NUMBER EXTRA	RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	x $50 =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	x $230 =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1)		(Column 2)	(Column 3)		
AMENDMENT	04/02/2019	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 40	Minus	** 34	= 6	x $50 =	300
	Independent (37 CFR 1.16(h))	* 5	Minus	*** 4	= 1	x $230 =	230
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	530

		(Column 1)		(Column 2)	(Column 3)		
AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	x $0 =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x $0 =	
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.	LIE
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".	/SHEILA D CHAPMAN/
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".	
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.	

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

Angus Pacala, *et al.*

Application No.: 16/046,643

Filed: July 26, 2018

For: OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS

Customer No.: 20350

Confirmation No.: 1720

Examiner: Not yet assigned

Art Unit: 2414

PRELIMINARY AMENDMENT

Mail Stop: Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

Prior to examination of the above-referenced application, please enter the following amendments and remarks:

Amendments to the Claims are reflected in the listing of claims which begins on page 2 of this paper.

Remarks/Arguments begin on page 8 of this paper.

Amendments to the Claims

This listing of claims will replace all prior versions, and listings of claims in the application.

Listing of Claims:

1. (Currently Amended) An optical imaging system comprising:

a bulk ~~receiver~~ imaging optic having a focal plane;

an array of pixels; and

an aperture layer disposed between the bulk ~~receiver~~ imaging optic and the array of pixels, the aperture layer including a plurality of discrete apertures coincident with the focal plane, wherein the aperture layer and pixel layer are arranged to form a plurality of sense channels defining a plurality of discrete, non-overlapping fields of view beyond a threshold distance in a field external to the optical imaging system, each sense channel in the plurality of sense channels including a pixel from the array of pixels and an aperture from the plurality of apertures that defines the field of view for its respective pixel, and wherein a ~~sensing~~ pixel area of each pixel in the plurality of sense channels is larger than an area of its corresponding aperture in the plurality of apertures.

2. (Currently Amended) The optical imaging system of claim 1 wherein each pixel in the array of pixels comprises a plurality of subpixels distributed across its ~~sensing~~ pixel area.

3. (Original) The optical imaging system of claim 2 wherein the plurality of subpixels in each pixel is a plurality of SPADs.

4. (Currently Amended) The optical imaging system of claim 1 further comprising, within each channel in the plurality of sense channels, an optical filter disposed between the bulk ~~receiver~~ imaging optic and the array of pixels, the optical filter configured to receive light passed through the bulk ~~receiver~~ imaging optic and pass a narrow band of radiation while blocking radiation outside the band.

5. (Currently Amended) The optical imaging system of claim 1 further comprising:

a bulk transmitter optic; and

an illumination source comprising a plurality of lasers corresponding in number to the plurality of sense channels, each laser in the plurality of lasers configured to project a discrete illuminating beam at an operating wavelength through the bulk transmitter optic into a field of view that is substantially the same size and geometry as a field of view defined by the bulk ~~receiver~~ imaging optic and a corresponding aperture in the plurality of sense channels.

6. (Original) The optical imaging system of claim 5 wherein each laser in the plurality of lasers is a VCSEL.

7. (Original) The optical imaging system of claim 5 wherein a diameter of each discrete beam projected from the illumination source is substantially similar to a cross-section of the field of view of its respective channel at various distances from the bulk imaging optic.

8. (Currently Amended) The optical imaging system of claim 5 further comprising, within each channel in the plurality of sense channels, an optical filter disposed between the bulk ~~receiver~~ imaging optic and the array of pixels, the optical filter configured to receive light passed through the bulk ~~receiver~~ imaging optic and pass a narrow band of radiation that includes the operating wavelength of the plurality of lasers to the plurality of pixels while blocking radiation outside the band.

9. (Original) The optical imaging system of claim 8 further comprising, within each channel in the plurality of sense channels, a diffuser disposed within the channel between the aperture and the pixel.

10. (Currently Amended) The optical imaging system of claim 5 wherein each laser in the plurality of lasers is a VCSEL, each pixel in the array of pixels comprises a plurality of SPADs and an optical filter is disposed between the bulk ~~receiver~~ imaging optic and the array of pixels, the optical filter configured to receive light passed through the bulk ~~receiver~~

<u>imaging</u> optic and pass a narrow band of radiation that includes the operating wavelength of the plurality of VCSELs to the array of pixels while blocking radiation outside the band.

11. (Original) The optical imaging system of claim 1 further comprising a plurality of lenses, wherein each channel in the plurality of channels includes a lens from the plurality of lenses disposed between the aperture of the channel and its corresponding pixel.

12. (Original) The optical imaging system of claim 1 wherein adjacent apertures in the aperture layer are offset by an aperture pitch distance greater than a diameter of each aperture.

13. (Currently Amended) An optical imaging system comprising:

a bulk ~~receiver~~ <u>imaging</u> optic having a focal plane;

an array of pixels of substantially uniform ~~sensing~~ <u>pixel</u> area, each pixel in the array of pixels including a plurality of subpixels distributed across its ~~sensing~~ <u>pixel</u> area; and

an aperture layer disposed between the bulk ~~receiver~~ <u>imaging</u> optic and the array of pixels, the aperture layer including a plurality of discrete apertures of substantially uniform area formed coincident with the focal plane and stop regions interposed between adjacent apertures in the aperture layer, wherein the aperture layer and pixel layer are arranged to form a plurality of sense channels defining a plurality of discrete, non-overlapping fields of view beyond a threshold distance in a field external to the optical imaging system, each sense channel in the plurality of sense channels including an aperture from the plurality of apertures and a pixel from the array of pixels with the aperture of each channel defining the field of view for its respective pixel, and wherein the area of the aperture in each channel is smaller than the ~~sensing~~ pixel area of its respective pixel.

14. (Original) The optical imaging system of claim 13 wherein the plurality of subpixels in each pixel is a plurality of SPADs.

15. (Currently Amended) The optical imaging system of claim 13 further comprising:

a bulk transmitter optic; and

an illumination source comprising a plurality of lasers corresponding in number to the plurality of sense channels, each laser in the plurality of lasers configured to project a discrete illuminating beam at an operating wavelength through the bulk transmitter optic into a field of view that is substantially the same size and geometry as a field of view defined by the bulk ~~receiver~~ imaging optic and a corresponding aperture in the plurality of sense channels.

16. (Original) The optical imaging system of claim 15 wherein each aperture in the plurality of discrete apertures defines a field of view in the field coincident a discrete spot output by a corresponding laser in the plurality of lasers.

17. (Currently Amended) An optical imaging system comprising:

a bulk ~~receiver~~ imaging optic having a focal plane;

an optical assembly having a plurality of sense channels defining a plurality of discrete, non-overlapping fields of view beyond a threshold distance in a field external to the bulk ~~receiver~~ imaging optic, the optical assembly comprising:

an array of pixels of substantially uniform ~~sensing~~ pixel area, each pixel in the array of pixels including a plurality of subpixels distributed across its ~~sensing~~ pixel area;

an aperture layer disposed between the bulk receiver optic and the array of pixels, the aperture layer including a plurality of discrete apertures of substantially uniform area formed coincident with the focal plane and stop regions between adjacent apertures;

a lens layer including a plurality of lenses arranged to receive light passed through the aperture and pass the received light towards the array of pixels; and

an optical filter layer disposed between the bulk ~~receiver~~ imaging optic and the array of pixels, the optical filter layer configured to receive light passed through the bulk ~~receiver~~ imaging optic and pass a narrow band of radiation while blocking radiation outside that band;

wherein each sense channel in the optical assembly includes a pixel from the array of pixels, an aperture from the aperture layer that defines the field of view for its respective pixel and has an area that is smaller than a sensing area of its respective pixel, a lens from the lens layer and a filter from the optical filter layer.

18. (Original) The optical imaging system of claim 17 wherein adjacent apertures in the aperture layer are offset by an aperture pitch distance greater than a diameter of each aperture and substantially equal to a pitch between adjacent lenses in the lens layer.

19. (Original) The optical imaging system of claim 18 wherein the optical filter layer is disposed between the lens layer and the array of pixels and wherein each lens is configured to collimate light rays passed by its respective aperture so that light rays incident on the optical filter meet the optical filter at an angle of incidence of approximately 0 degrees.

20. (Currently Amended) The optical imaging system of claim 18 further comprising:

a bulk transmitter optic; and

an illumination source comprising a plurality of lasers corresponding in number to the plurality of sense channels, each laser in the plurality of lasers configured to project a discrete illuminating beam at an operating wavelength through the bulk transmitter optic into a field of view that is substantially the same size and geometry as a field of view defined by the bulk ~~receiver~~ <u>imaging</u> optic and a corresponding aperture in the plurality of sense channels.

21. (Original) The optical imaging system of claim 20 wherein the plurality of subpixels in each pixel is a plurality of SPADs and where the plurality of lasers in the illumination source is a plurality of VCSELs.

22. (Original) The optical imaging system of claim 21 wherein each aperture has a diameter of 200 microns or less.

23. (Original) The optical imaging system of claim 21 wherein each aperture has a diameter approaching the diffraction-limited diameter for the wavelength of light output by the plurality of lasers.

24. (Original) The optical imaging system of claim 21 wherein each aperture has a diameter less than the diffraction-limited diameter for the wavelength of light output by the plurality of lasers.

25. (Original) The optical imaging system of claim 21 wherein each aperture has a diameter matched to a dynamic range of its corresponding pixel.

26. (Original) The optical imaging system of claim 21 wherein the stop region surrounding each aperture blocks light rays reflected from a region of the surface outside the field of view of its corresponding aperture.

27. (Currently Amended) An optical imaging system comprising:

a bulk ~~receiver~~ imaging optic having a focal plane;

a plurality of pixels arranged in a pixel array in which adjacent pixels in the array are spaced apart from each other in a first dimension by a pixel pitch; and

an aperture layer disposed between the bulk ~~receiver~~ imaging optic and the plurality of pixels arranged in the pixel array, the aperture layer including a plurality of discrete apertures of substantially uniform size coincident with the focal plane and stop regions between adjacent apertures, wherein the plurality of discrete apertures are arranged in an aperture array in which adjacent apertures in the aperture array are spaced apart from each other in the first dimension by an aperture pitch and wherein the aperture array is aligned with the pixel array and a maximum linear dimension of each aperture in the aperture array is less than the pixel pitch; and

wherein the aperture layer and pixel layer are arranged to form a plurality of sense channels defining a plurality of discrete, non-overlapping fields of view beyond a threshold distance in a field external to the optical imaging system, each sense channel in the plurality of sense channels including a pixel from the array of pixels and an aperture from the plurality of apertures that defines the field of view for its respective pixel.

28. (Previously Presented) The optical imaging system of claim 27 wherein each aperture in the plurality of discrete apertures is a circular aperture of substantially uniform diameter.

29. (Previously Presented) The optical imaging system of claim 27 wherein the aperture pitch is substantially equal to the pixel pitch.

30. (Previously Presented) The optical imaging system of claim 27 wherein each pixel in the plurality of pixels comprises a plurality of subpixels distributed across a pixel area.

31. (Previously Presented) The optical imaging system of claim 29 wherein the plurality of subpixels in each pixel is a plurality of SPADs.

32. (Currently Amended) The optical imaging system of claim 27 further comprising, within each channel in the plurality of sense channels, an optical filter disposed between the bulk ~~receiver~~ imaging optic and the pixel within the channel, the optical filter configured to receive light passed through the bulk ~~receiver~~ imaging optic and pass a narrow band of radiation while blocking radiation outside the band.

33. (Currently Amended) The optical imaging system of claim 32 further comprising:

a bulk transmitter optic; and

an illumination source comprising a plurality of lasers corresponding in number to the plurality of sense channels, each laser in the plurality of lasers configured to project a discrete illuminating beam at an operating wavelength through the bulk transmitter optic into a field of view that is substantially the same size and geometry as a field of view defined by the bulk ~~receiver~~ imaging optic and a corresponding aperture in the plurality of sense channels; and

wherein the narrow band of radiation passed by the optical filter includes the operating wavelength.

34. (Previously Presented) The optical imaging system of claim 33 wherein each laser in the plurality of lasers is a VCSEL.

35. (New) An optical imaging system comprising:

a bulk imaging optic having a focal plane;

an array of pixels; and

an aperture layer disposed between the bulk imaging optic and the array of pixels, the aperture layer including a plurality of discrete apertures coincident with the focal plane, wherein the aperture layer and pixel layer are arranged to form a plurality of sense channels defining a plurality of discrete, non-overlapping fields of view beyond a threshold distance in a field external to the optical imaging system, each sense channel in the plurality of sense channels including a pixel from the array of pixels and an aperture from the plurality of apertures that defines the field of view for its respective pixel.

36. (New) The optical imaging system of claim 35 further comprising a plurality of lenses disposed between the aperture layer and the array of pixels with each lens in the plurality of lenses being characterized by a second focal length, and wherein each channel in the plurality of channels includes a lens from the plurality of lenses offset from the bulk receiver optic focal plane by the second focal length and aligned with a corresponding aperture in the channel.

37. (New) The optical imaging system of claim 36 further comprising, within each channel in the plurality of sense channels, an optical filter disposed between the bulk imaging optic and the array of pixels, the optical filter configured to receive light passed through the bulk imaging optic and pass a narrow band of radiation that includes the operating wavelength of the plurality of lasers to the plurality of pixels while blocking radiation outside the band.

38. (New) The optical imaging system of claim 36 wherein, within each channel, the lens from the plurality of lenses is disposed between an aperture and optical filter and is configured to collimate light rays passed by the aperture and to pass the collimated light rays into the optical filter.

39. (New) The optical imaging system of claim 35 wherein the pixel in each of the plurality of sense channels comprises a plurality of SPADs distributed across a pixel area of the pixel that is larger than an area of its corresponding aperture.

40. (New) The optical imaging system of claim 39 further comprising, within each channel in the plurality of sense channels, a diffuser disposed within the channel between the aperture and its corresponding pixel, the diffuser configured to spread light rays passed by the aperture across the plurality of SPADs distributed across the pixel area of the pixel.

REMARKS/ARGUMENTS

Upon entry of the present amendment, claims 1-40 will be pending in this application. Claims 1-2, 4-5, 8, 10, 13, 15, 17, 20, 27 and 32-33 have been amended, no claims have been canceled and new claims 35-40 have been added.

Applicants respectfully assert that the claims are all supported by the application as originally filed and that no new matter is added.

CONCLUSION

In view of the foregoing, Applicant believes all claims now pending in this Application are in condition for examination.

Except for the issue fees payable under 37 C.F.R. § 1.18, the Director is authorized to charge any additional fees during pendency of this application, including any required extension of time fees, or credit any overpayment to Deposit Account Number 20-1430. This paragraph is intended to be a constructive petition for extension of time in accordance with 37 C.F.R. § 1.136(a)(3).

If the Examiner believes a telephone conference would expedite prosecution of this application, please contact the undersigned at 858-350-6104 or WShaffer@kilpatricktownsend.com.

Respectfully submitted,

/ William L. Shaffer /

William L. Shaffer
Registration No. 37,234

KILPATRICK TOWNSEND & STOCKTON LLP

Electronic Acknowledgement Receipt

EFS ID:	35607174
Application Number:	16046643
International Application Number:	
Confirmation Number:	1720
Title of Invention:	OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS
First Named Inventor/Applicant Name:	Angus Pacala
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P001USC2-1096583
Receipt Date:	02-APR-2019
Filing Date:	26-JUL-2018
Time Stamp:	17:51:52
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		Second_Preliminary_Amendment-P001USC2.pdf	132912 9392f6909f9af17cdd6d55eb17f6dae153d663e4	yes	11

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Preliminary Amendment	1	1
	Claims	2	10
	Applicant Arguments/Remarks Made in an Amendment	11	11

Warnings:

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Total Files Size (in bytes):	132912

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16/046,643
	Filing Date	July 26, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2414
	Examiner Name	
	Attorney Docket Number	103033-1096583

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code 1	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	8836922	B1	Sep 16, 2014	Pennecot et al.	
	2.	9989406	B2	Jun 5, 2018	Pacala et al.	
	3.	6374024	B1	Apr 16, 2002	Iijima, Ryuta	

U.S. PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code 1	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	4.	20130229646	A1	Sep 5, 2013	Sakurai	
	5.	20150260830	A1	Sep 17, 2015	Ghosh et al.	

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number3	Country Code2	Kind Code4	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T5
	6	0095725	EP	A1	12-07-1983	Tokyo Shibaura Denki Kabushiki Kaisha		

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T5

EXAMINER SIGNATURE

Examiner Signature		Date Considered	

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16/046,643
	Filing Date	July 26, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2414
	Examiner Name	
	Attorney Docket Number	103033-1096583

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document.[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

Electronic Acknowledgement Receipt

EFS ID:	38466892
Application Number:	16046643
International Application Number:	
Confirmation Number:	1720
Title of Invention:	OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS
First Named Inventor/Applicant Name:	Angus Pacala
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P001USC2-1096583
Receipt Date:	31-JAN-2020
Filing Date:	26-JUL-2018
Time Stamp:	21:42:47
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		IDS-Transmittal-PTOSB08A-P001USC2.pdf	236300 0420538b415aee1c778c0d41d9478c59ecbca007	yes	4

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Transmittal Letter	1	2
	Information Disclosure Statement (IDS) Form (SB08)	3	4
Warnings:			
Information:			
	Total Files Size (in bytes):	236300	

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New Applications Under 35 U.S.C. 111
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New International Application Filed with the USPTO as a Receiving Office
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I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on January 31, 2020.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer-Johnson/

PATENT
Attorney Docket No.: 103033-1096583-P001USC2
Client Ref. No.: P001USC2

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 1720
Angus Pacala	Examiner:
Application No.: 16/046,643	Technology Center/Art Unit: 2414
Filed: July 26, 2018	
For: OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patents and U.S. Patent Application Publications are not provided. Copies of the references are not enclosed.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no

representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed before the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/ William L. Shaffer /

William L. Shaffer
Registration No. 37,234

KILPATRICK TOWNSEND & STOCKTON LLP

Attachment

Electronic Acknowledgement Receipt

EFS ID:	38730344
Application Number:	16046643
International Application Number:	
Confirmation Number:	1720
Title of Invention:	OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS
First Named Inventor/Applicant Name:	Angus Pacala
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P001USC2-1096583
Receipt Date:	28-FEB-2020
Filing Date:	26-JUL-2018
Time Stamp:	17:47:03
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Transmittal Letter	IDS_P001USC2.pdf	232559 0f03bc71335f4cbf924adb8635c2042507d5a90d	no	3

Warnings:

Information:	
Total Files Size (in bytes):	232559

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New Applications Under 35 U.S.C. 111
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New International Application Filed with the USPTO as a Receiving Office
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KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer-Johnson/

PATENT
Attorney Docket No.: 103033-1096583-P001USC2
Client Ref. No.: P001USC2

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 1720
Angus Pacala	Examiner: LEE, John R.
Application No.: 16/046,643	Technology Center/Art Unit: 2878
Filed: July 26, 2018	
For: OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patents and U.S. Patent Application Publications are not provided. Copies of the references are not enclosed.

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This Information Disclosure Statement is being filed before the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/ William L. Shaffer /

William L. Shaffer
Registration No. 37,234

KILPATRICK TOWNSEND & STOCKTON LLP

Attachment

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16/046,643
	Filing Date	July 26, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2414
	Examiner Name	
	Attorney Docket Number	103033-1096583

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	7433042	B1	10-07-2008	Cavanaugh	

U.S. PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	2.	20110228142	A1	09-22-2011	Brueckner, et al.	
	3.	20090236505	A1	09-24-2009	Pallaro, et al.	

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T[5]

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[5]

EXAMINER SIGNATURE

Examiner Signature		Date Considered	

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16/046,643
	Filing Date	July 26, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2414
	Examiner Name	
	Attorney Docket Number	103033-1096583

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code 1	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	8645810	B2	Feb 4, 2014	Sharon et al.	
	2	8762798	B2	Jun 24, 2014	Hu et al.	
	3	9281841	B2	Mar 8, 2016	Chen et al.	
	4	9866241	B2	Jan 9, 2018	Yen et al.	
	5	9992477	B2	Jun 5, 2018	Pacala et al.	
	6	10063849	B2	Aug 28, 2018	Pacala et al.	
	7	10291261	B2	May 14, 2019	Yen et al.	

U.S. PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code 1	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	8	20130038941	A1	Feb 14, 2013	Pesach et al.	
	9	20140267878	A1	Sep 18, 2014	Geelen et al.	
	10	20170299700	A1	Oct 19, 2017	Pacala et al.	
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	16	20070112679	KR		Nov 27, 2007	Samsung Sdi Co., Ltd.		
	17	2018057084	WO		Mar 29, 2018	Ouster, Inc.		

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16/046,643
	Filing Date	July 26, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2414
	Examiner Name	
	Attorney Docket Number	103033-1096583

	18	2017330180	AU		Oct 10, 2019	Ouster, Inc.		

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	19	15/276,532 , "Non-Final Office Action", December 15, 2017, 15 pages	
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	23	LE et al., "On the Use of Hard-Decision LDPC Decoders on MLC NAND Flash Memory", 15th International Multi-Conference on Systems, Signals & Devices (SSD), March 2018, 6 pages	
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*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document.[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

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전체 청구항 수 : 총 16 항

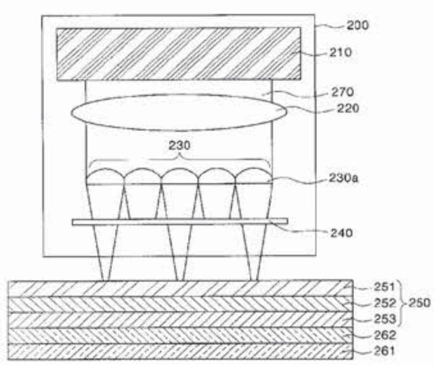
(54) 레이저 조사장치 및 그를 이용한 유기전계발광소자의제조방법

(57) 요 약

본 발명은 다양한 픽셀배치 방법을 실행할 수 있는 레이저 조사장치 및 그를 이용한 유기전계발광소자의 제조방법에 관한 것으로, 광원장치; 상기 광원장치 하부에 위치하는 시준렌즈(collimation lens); 상기 시준렌즈 하부에 위치하는 대칭 마이크로 렌즈 어레이(symmetrical microlens array); 및 상기 대칭 마이크로 렌즈 어레이 하부에 위치하는 마스크를 포함하는 것을 특징으로 하는 레이저 조사장치를 제공한다.

또한, 본 발명은 제 1 전극이 형성된 기판을 제공하고; 기재층, 상기 기재층 상에 광-열변환층 및 상기 광-열변환층 상에 전사층이 차례로 적층된 구조로 제조된 도너기판을 제공하고; 상기 전사층이 상기 기판과 대향하도록 서로 이격되어 배치하고; 광원장치, 시준렌즈, 대칭 마이크로 렌즈 어레이 및 마스크를 포함하는 레이저 조사장치를 이용하여 상기 기재층의 일부 영역에 레이저를 조사하여 상기 전사층의 전사를 수행하여 상기 기판 상에 유기막층 패턴을 형성하는 것을 포함하는 유기전계발광소자의 제조방법을 제공한다.

대표도 - 도3a



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특허청구의 범위

청구항 1

광원장치;

상기 광원장치 하부에 위치하는 시준렌즈(collimation lens);

상기 시준렌즈 하부에 위치하는 대칭 마이크로 렌즈 어레이(symmetrical microlens array); 및

상기 대칭 마이크로 렌즈 어레이 하부에 위치하는 마스크를 포함하는 것을 특징으로 하는 레이저 조사장치.

청구항 2

제 1 항에 있어서,

상기 대칭 마이크로 렌즈 어레이는 투명성 재질로 이루어진 복수의 대칭 마이크로 렌즈의 조합으로 이루어진 것을 특징으로 하는 레이저 조사장치.

청구항 3

제 1 항에 있어서,

상기 대칭 마이크로 렌즈 어레이는 상기 시준렌즈와 상기 마스크 사이를 상하로 이동 가능한 것을 특징으로 하는 레이저 조사장치.

청구항 4

제 1 항에 있어서,

상기 대칭 마이크로 렌즈의 초점거리는 10~300㎜ 인 것을 특징으로 하는 레이저 조사장치.

청구항 5

제 1 항에 있어서,

상기 대칭 마이크로 렌즈의 지름은 60~500㎛ 인 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 6

제 1 항에 있어서,

상기 마스크는 상기 대칭 마이크로 렌즈 어레이 중 일부 마이크로 렌즈를 통과한 레이저빔을 차단하는 것을 특징으로 하는 레이저 조사장치.

청구항 7

제 2 항에 있어서,

상기 투명성 재질은 유리 또는 투명성 플라스틱인 것을 특징으로 하는 레이저 조사장치.

청구항 8

제 1 전극이 형성된 기판을 제공하고;

기재층, 상기 기재층 상에 광-열변환층 및 상기 광-열변환층 상에 전사층이 차례로 적층된 구조로 제조된 도너 기판을 제공하고;

상기 전사층이 상기 기판과 대향하도록 서로 이격되어 배치하고;

광원장치, 시준렌즈, 대칭 마이크로 렌즈 어레이 및 마스크를 포함하는 레이저 조사장치를 이용하여 상기 기재층의 일부 영역에 레이저를 조사하여 상기 전사층의 전사를 수행하여 상기 기판 상에 유기막층 패턴을 형성하는 것을 포함하는 유기전계발광소자의 제조방법.

청구항 9

제 8 항에 있어서,

상기 도너기판은 상기 광-열변환층과 상기 비퍼층 사이에 가스생성층을 더욱 포함하는 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 10

제 8 항에 있어서,

상기 대칭 마이크로 렌즈 어레이는 투명성 재질로 이루어진 복수의 대칭 마이크로 렌즈의 조합으로 이루어진 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 11

제 8 항에 있어서,

상기 대칭 마이크로 렌즈 어레이는 상기 시준렌즈와 상기 마스크 사이를 상하로 이동 가능한 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 12

제 8 항에 있어서,

상기 대칭 마이크로 렌즈의 초점거리는 10~300㎜ 인 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 13

제 8 항에 있어서,

상기 대칭 마이크로 렌즈의 지름은 60~500㎛ 인 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 14

제 8 항에 있어서,

상기 대칭 마이크로 렌즈와 상기 도너기판과의 거리는 20/3~200㎜인 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 15

제 8 항에 있어서,

상기 유기막층 패턴의 크기는 20~500/3㎛ 인 것을 특징으로 하는 유기전계발광소자의 제조방법.

청구항 16

제 8 항에 있어서,

상기 레이저 조사장치는 멀티 스캔 방식으로 수행되는 것을 특징으로 하는 유기전계발광소자의 제조방법.

명 세 서

발명의 상세한 설명

발명의 목적

발명이 속하는 기술 및 그 분야의 종래기술

<6> 본 발명은 레이저 조사장치 및 그를 이용한 유기전계발광소자의 제조방법에 관한 것으로, 상세하게는 레이저 조사장치에서 패터닝하고자 하는 화소를 정의하는 대칭 마이크로 렌즈 어레이 및 다양한 픽셀배치 방법을 실행할 수 있는 마스크를 포함하는 레이저 조사장치 및 이를 이용한 유기전계발광소자의 제조방법에 관한 것이다.

<7> 일반적으로 평판표시소자인 유기전계발광소자는 애노드 전극과 캐소드 전극 그리고 상기 애노드 전극과 캐소드 전극 사이에 개재된 유기막층을 포함한다. 상기 유기막층은 적어도 유기발광층을 포함한다. 이러한 유기전계발광소자는 상기 유기발광층을 이루는 물질에 따라서 고분자 유기전계발광소자와 저분자 유기전계발광소자로 나누어진다.

<8> 이러한 유기전계발광소자에 있어 풀칼라화를 구현하기 위해서는 R, G, B의 삼원색을 나타내는 각각의 발광층을 패터닝해야 한다. 여기서 상기 발광층을 패터닝하기 위한 방법으로 저분자 유기전계발광소자의 경우 섀도우 마스크(shadow mask)를 사용하는 방법이 있고, 고분자 유기전계발광소자의 경우 잉크젯 프린팅(ink jet printing) 또는 레이저 열전사법(Laser Induced Thermal Imaging; 이하 LITI라 한다.)이 있다. 이중에서 상기 LITI는 상기 유기막층을 미세하게 패터닝할 수 있고, 대면적에 사용할 수 있으며 고해상도에 유리하다는 장점이 있을 뿐만 아니라, 상기 잉크젯 프린팅이 습식 공정인데 반해 이는 건식 공정이라는 장점이 있다.

<9> 도 1 은 종래의 레이저 조사장치를 이용한 유기전계발광소자의 제조방법을 설명한 모식도이다.

<10> 도 1을 참조하면, 제 1 전극(162)이 형성된 기판(161)을 제공한다. 상기 제 1 전극(162)과 상기 기판(161) 사이에 박막트랜지스터, 절연막 및 캐패시터 등을 포함할 수 있다.

<11> 이어서, 상기 기판(161) 상에 레이저 전사용 도너기판(150)을 라미네이션(lamination)한다. 여기서, 상기 도너기판(150)은 기재층(151), 상기 기재층(151) 상에 광-열변환층(152) 및 상기 광-열변환층(152) 상에 전사층(153)이 차례로 적층된 구조로 제공된다.

<12> 한편, 상기 기판(161)과 상기 도너기판(150)과는 별도로 레이저 조사장치(100)가 제공된다. 상기 레이저 조사장치(100)는 광원장치(110), 패터닝되어 있는 마스크(120) 및 프로젝션 렌즈(130)를 포함하고 있다.

<13> 이어서, 상기 광원장치(110)에서 발생한 레이저빔(140)은 패터닝되어 있는 상기 마스크(120)를 통과하고, 상기 통과한 레이저빔(140)은 상기 프로젝션 렌즈(130)에 의해 굴절되어 상기 기재층(151)의 일부 영역에 조사된다.

<14> 상기 기재층(151)의 일부 영역에 조사된 상기 레이저빔(140)은 상기 광-열변환층(152)에서 흡수되어 열에너지로 변환된다. 흡수된 열에너지에 의해 상기 광-열변환층(152)은 상기 전사층(153)을 상기 기판(161)상에 밀착시킨다. 이어서, 밀착된 상기 전사층(153)의 결합이 끊어지면서 상기 전사층(153)은 상기 기판(161) 상으로 전사되어 유기막층 패턴(미도시)을 형성한다.

<15> 도 2 는 종래의 레이저 조사장치를 이용하여 패터닝한 화소를 나타낸 평면도이다.

<16> 도 2를 참조하면, 상기 기판(161)의 각 픽셀에 레드(R), 블루(B), 그린(G) 등의 단위화소 중 하나인 레드 화소가 레이저 스캔방향으로 패터닝되어 있다.

<17> 그러나 종래의 레이저 조사장치는 레이저 스캔방향으로 각 픽셀에 레드(R), 블루(B), 그린(G)등의 단위화소들 중 하나의 단위화소만 패터닝을 해야하므로 같은 레이저 스캔방향으로는 다른 색의 단위화소를 패터닝 할 수 없고, 또한 스트라이프 형태로만 패터닝을 해야 하는 문제점이 있다.

발명이 이루고자 하는 기술적 과제

<18> 따라서 본 발명은 상기와 같은 문제점을 해결하기 위한 것으로 다양한 픽셀 배치 방법 등에 대응할 수 있는 레이저 조사장치 및 그를 이용한 유기전계발광소자의 제조방법을 제공함에 그 목적이 있다.

발명의 구성 및 작용

<19> 상기와 같은 목적을 달성하기 위하여, 본 발명은 다양한 픽셀 배치 방법에 대응할 수 있는 레이저 조사장치 및 그를 이용한 유기전계발광소자의 제조방법에 관한 것으로, 광원장치; 상기 광원장치 하부에 위치하는 시준렌즈(collimation lens); 상기 시준렌즈 하부에 위치하는 대칭 마이크로 렌즈 어레이(symmetrical microlens array); 및 상기 대칭 마이크로 렌즈 어레이 하부에 위치하는 마스크를 포함하는 것을 특징으로 하는 레이저 조사장치를 제공한다.

<20> 또한, 본 발명은 제 1 전극이 형성된 기판을 제공하고; 기재층, 상기 기재층 상에 광-열변환층 및 상기 광-열변환층 상에 전사층이 차례로 적층된 구조로 제조된 도너기판을 제공하고; 상기 전사층이 상기 기판과 대향하도록 서로 이격되어 배치하고; 광원장치, 시준렌즈, 대칭 마이크로 렌즈 어레이 및 마스크를 포함하는 레이저 조사장치를 이용하여 상기 기재층의 일부 영역에 레이저를 조사하여 상기 전사층의 전사를 수행하여 상기 기판

상에 유기막층 패턴을 형성하는 것을 포함하는 유기전계발광소자의 제조방법을 제공한다.

<21> 이하, 본 발명을 보다 구체적으로 설명하기 위하여 본 발명에 따른 바람직한 실시 예를 첨부된 도면을 참조하여 보다 상세하게 설명한다. 그러나 본 발명은 여기서 설명되어지는 실시 예에 한정되지 않고 다른 형태로 구체화될 수도 있다. 도면들에 있어서, 층이 다른 층 또는 기판 "상" 에 있다고 언급되어지는 경우에 그것은 다른 층 또는 기판 상에 직접 형성될 수 있거나 또는 그들 사이에 제 3의 층이 개재될 수도 있다. 명세서 전체에 걸쳐서 동일한 참조번호들은 동일한 구성요소를 나타낸다.

<22> 도 3a는 본 발명에 의한 레이저 조사장치 및 유기전계발광소자의 제조방법을 설명하는 모식도이다.

<23> 도 3a를 참조하면, 제 1 전극(262)이 형성되어 있는 기판(261)을 제공한다. 상기 기판(261)과 상기 제 1 전극(262) 사이에는 박막트랜지스터, 절연막 및 캐패시터 등이 포함 될 수도 있다.

<24> 한편, 상기 기판(261)과는 별도로 레이저 전사용 도너기판(250)을 제공한다. 상기 도너기판(250)은 기재층(251), 상기 기재층(251) 상에 광-열변환층(252) 및 상기 광-열변환층(252) 상에 전사층(253)이 적층되어 있는 구조이다. 또한, 상기 광-열변환층(252)과 상기 전사층(253) 사이에는 가스생성층(미도시)이 더욱 포함될 수도 있다.

<25> 상기 기재층(251)은 상기 광-열변환층(252)에 빛을 전달하기 위하여 투명성을 가져야 하며, 적당한 광학적 성질과 충분한 기계적 안정성을 가진 물질로 이루어질 수 있다. 예를 들면, 폴리에스테르, 폴리아크릴, 폴리에폭시, 폴리에틸렌 및 폴리스틸렌으로 이루어진 군에서 선택되는 하나 이상의 고분자 물질이거나 유리로 이루어질 수 있다. 더욱 바람직하게는 상기 기재층(251)은 폴리에틸렌테레프탈레이트일 수 있다. 상기 기재층(251)의 역할은 지지기판으로서의 역할을 수행하며 복합적인 다중계도 사용 가능하다.

<26> 상기 광-열변환층(252)은 적외선-가시광선 영역의 빛을 흡수하여 상기 빛의 일부분을 열로 변환시키는 층이며, 빛을 흡수하기 위한 광흡수성 물질을 포함하는 것이 바람직하나. 또한, 상기 광-열변환층(252)은 Al, Ag 및 이들의 산화물 및 황화물로 이루어진 금속막이거나 카본 블랙, 흑연 또는 적외선 염료를 포함하는 고분자로 이루어진 유기막으로 이루어질 수 있다. 여기서, 상기 금속막은 진공 증착법, 전자빔 증착법 또는 스퍼터링을 이용하여 형성할 수 있으며, 상기 유기막은 통상적인 필름 코팅 방법으로서, 그라비아(Gravure), 압출(extrusion), 스핀(spin) 및 나이프(knife) 코팅방법 중에 하나의 방법에 의해 형성될 수 있다.

<27> 상기 가스생성층(미도시)은 광 또는 열을 흡수하면 분해반응을 일으켜 질소 가스나 수소 가스 등을 방출함으로서 전사에너지를 제공하는 역할을 수행하며, 사질산펜타에리드리드(PETN), 드리니드로톨루엔(TNT)등으로 선택된 물질로 이루어진다.

<28> 상기 전사층(253)은 정공주입층, 정공수송층, 유기발광층, 정공억제층, 전자수송층 및 전자주입층으로 이루어진 군에서 선택되는 하나의 단층막 또는 하나 이상의 다층막으로 이루어질 수 있다.

<29> 상기 정공주입층은 유기전계발광소자의 유기발광층에 정공주입을 용이하게 하며 소자의 수명을 증가시킬 수 있는 역할을 한다. 상기 정공주입층은 아릴 아민계 화합물 및 스타버스터형 아민류등으로 이루어질 수 있다. 더욱 상세하게는 4,4',4"-트리스(3-메틸페닐아미노)트리페닐아미노(m-MTDATA), 1,3,5-트리스[4-(3-메틸페닐아미노)페닐]벤젠(m-MTDATB) 및 프탈로시아닌 구리(CuPc)등으로 이루어질 수 있다.

<30> 상기 정공수송층은 아릴렌 디아민 유도체, 스타버스트형 화합물, 스피로기를 갖는 비페닐디아민유도체 및 사다리형 화합물등으로 이루어질 수 있다. 더욱 상세하게는 N,N-디페닐-N,N'-비스(4-메틸페닐)-1,1'-바이페닐-4,4'-디아민(TPD)이거나 4,4'-비스[N-(1-나프틸)-N-페닐아미노]비페닐(NPB)일 수 있다.

<31> 상기 유기발광층은 적색발광재료인 Alq3(호스트)/DCJTB(형광도펀트), Alq3(호스트)/DCM(형광도펀트), CBP(호스트)/PtOEP(인광 유기금속 착체) 등의 저분자 물질과 PFO계 고분자, PPV계 고분자등의 고분자물질을 사용할 수 있으며, 녹색발광재료인 Alq3, Alq3(호스트)/C545t(도펀트), CBP(호스트)/IrPPY(인광 유기물 착체) 등의 저분자 물질과 PFO계 고분자, PPV계 고분자등의 고분자물질을 사용할 수 있다. 또한, 청색발광재료인 DPVBi, 스피로-DPVBi, 스피로-6P, 디스틸벤젠(DSB), 디스트릴아릴렌(DSA)등의 저분자 물질과 PFO계 고분자, PPV계 고분자 등의 고분자물질을 사용할 수 있다.

<32> 상기 정공억제층은 유기발광층내에서 전자이동도보다 정공이동도가 큰 경우 정공이 전자주입층으로 이동하는 것을 방지하는 역할을 한다. 여기 상기 정공억제층은 2-비페닐-4-일-5-(4-t-부틸페닐)-1,3,4-옥시디아졸(PBD), 스피로-PBD 및 3-(4'-t-부틸페닐)-4-페닐-5-(4'-비페닐)-1,2,4-트리아졸(TAZ)로 이루어진 군에서 선택된 하나

의 물질로 이루어질 수 있다.

<33> 상기 전자수송층은 전자가 잘 수용할 수 있는 금속화합물로 이루어지며, 캐소드 전극으로부터 공급된 전자를 안정하게 수송할 수 있는 특성이 우수한 8-하이드로퀴놀린 알루미늄염(Alq3)으로 이루어질 수 있다.

<34> 상기 전자주입층은 1,3,4-옥시디아졸 유도체, 1,2,4-트리아졸 유도체 및 LiF로 이루어진 군에서 선택되는 하나 이상의 물질로 이루어질 수 있다.

<35> 또한, 이와 같은 유기막은 압출, 스핀, 나이프 코팅방법, 진공 증착법, CVD등의 방법에 의해 형성될 수 있다.

<36> 상기 도너기판(250)은 상기한 층들뿐만 아니라 다양한 용도를 갖는 층들을 더욱 포함할 수 있으며, 그 용도에 따라서 적층 구조를 변경하여 사용할 수 있다.

<37> 이어서, 상기 기판(261)의 화소영역과 상기 도너기판의 전사층(253)이 서로 대향하도록 서로 이격되어 배치한 후, 균일하게 라미네이션(lamination)한다.

<38> 상기 라미네이션은 롤러, 기체 가압 또는 크라운 프레스를 사용하여 가압함으로써 이루어진다. 상기 라미네이션은 중앙에서 외곽으로 나가는 방향으로 진행할 수 있다. 또한, 상기 라미네이션은 단방향으로 진행할 수 있다.

<39> 상기 라미네이션을 중앙에서 외곽으로 나가는 방향으로 할 경우, 상기 도너기판(250)과 상기 기판(261) 사이의 버블이 효과적으로 방지 될 수 있으므로, 중앙에서 외곽으로 나가는 방향으로 라미네이션을 하는 것이 더욱 바람직하다.

<40> 한편, 상기 기판(261) 및 상기 도너기판(250)과는 별도로 레이저 조사장치(200)를 제공한다. 상기 레이저 조사장치(200)는 광원장치(210), 시준렌즈(collimation lens: 220), 대칭 마이크로 렌즈 어레이(symmetrical microlens array: 230) 및 마스크(240)를 포함한다.

<41> 상기 광원장치(210)는 상기 전사층(253)을 상기 도너기판(250)으로부터 분리하여 상기 기판(261)상에 전사시켜 소정의 패턴을 형성하는데 필요한 레이저빔(240)을 발생시킨다.

<42> 상기 시준렌즈(220)는 상기 광원장치(210)에서 출사된 레이저빔(270)을 평행화하는 역할을 한다.

<43> 상기 대칭 마이크로 렌즈 어레이(230)는 상기 시준렌즈(220)를 통과한 평행한 레이저빔으로부터 복수의 빔을 형성하고, 각 빔마다 초점을 결상시키는 광학 수단이며, 패터닝하고자 하는 화소를 정의하는 역할을 한다

<44> 상기 대칭 마이크로 렌즈 어레이(230)는 복수의 대칭 마이크로 렌즈(230a)의 조합으로 이루어져 있다. 이로 인하여, 상기 레이저 조사장치(200)는 동시에 동일색의 복수의 화소를 패턴할 수 있는 멀티 스캔 방식을 수행하여 유기전계발광소자를 제조할 수 있다.

<45> 상기 대칭 마이크로 렌즈 어레이(230)는 상기 시준렌즈(220)와 상기 마스크(240) 사이를 상하로 이동 가능하기 때문에 상기 대칭 마이크로 렌즈(230a)의 초점 거리를 조절할 수 있으므로 화소영역의 패턴크기를 자유자재로 조절할 수 있다.

<46> 상기 대칭 마이크로 렌즈 어레이(230)는 투명성 재질인 유리 또는 플라스틱으로 구성되는 것이 바람직하다.

<47> 도 3b는 본 발명에 의한 레이저 조사장치의 대칭 마이크로 렌즈와 단위화소 즉, 유기막 패턴과의 관계를 설명한 단면도이다.

<48> 도 3b를 참조하면, 상기 대칭 마이크로 렌즈(230a)의 피치를 P1, 상기 대칭 마이크로 렌즈(230a)의 지름을 S1, 상기 대칭 마이크로 렌즈(230a)의 초점거리를 f1, 상기 대칭 마이크로 렌즈(230a)와 적색(R), 녹색(G) 및 청색(B) 중의 어느 하나를 나타내는 단위 화소까지의 거리를 d, 상기 단위 화소의 너비를 S2, 상기 적색(R), 녹색(G) 및 청색(B) 각 단위 화소의 너비의 합을 P2 로 표기한다.

<49> 여기서, 상기 대칭 마이크로 렌즈의 초점거리(f1)의 범위는 10~300㎜ 이다. 상기 초점거리(f1)가 10㎜ 이하이면 패터닝이 실시 될 때 기판과 렌즈 사이에 도너기판 외에 기타 부수적인 장치가 들어갈 수 없는 공간을 확보할 수 없고 스캔을 할 때 이격 공간이 없어 작동이 원활하지 않을 수 있다. 또한, 300㎜이상이면 장치의 크기가 너무 커지는 문제점이 발생한다.

<50> 상기 대칭 마이크로 렌즈와 화소와의 거리(d)는 20/3~200㎜ 이다. 상기 마이크로 렌즈와 화소와의 거리(d)한정의 이유는 상기 대칭 마이크로 렌즈의 초점거리(f1)의 범위한정의 이유와 동일하다.

<51> 상기 화소를 대략 50~300ppi(pixel per inch)로 제작한다고 하면, 화소의 크기(P2)는 60~500㎛ 이나. 또한 상기 대칭 마이크로 렌즈의 지름(P1)은 화소(P2)의 크기와 같다. 상기 레드(R), 그린(G) 및 블루(B)중 어느 하나를 나타내는 단위화소(S2)의 크기는 20~500/3㎛이다.

<52> 이어서, 이를 간단한 수식으로 정리하면, 한 픽셀 당 R, G, B 3개의 칼라를 패터닝해야 하므로,

<53> P2:S2= 3:1 <----(1)

<54> 삼각형의 정리를 이용하면

<55> f1:f1-d=3:1 <----(2)

<56> f1:f1-d=S1:S2 <----(3)

<57> (2)식에서 d=2×f1/3 <----(4)

<58> (3)식에서 P1 과 S2는 같으므로

<59> (f1-d)×P1=f1×S2 <----(5)

<60> 윗식에 (4)을 대입하면

<61> S2=P1/3 <----(6) 으로 식이 주어진다.

<62> (실시 예)

<63> 17인치 UXGA를 제작할 때, 픽셀수는 1600×1200 이다. 픽셀 피치는 72×216 ㎛가 된다. 이때 레이저 조사장치를 설계해보면 다음과 같다.

<64> f1을 20cm 로 한다면, S2는 72㎛이다.

<65> (6)식을 도입하면, P1은 216㎛, d는 13.34cm 이다.

<66>

<67> 이어서, 도 3a를 다시 참조하면, 상기 마스크(240)는 상기 기판(261) 상에 패터닝 하고자 하는 픽셀 배치에 대응하도록 여러 가지 모양으로 패터닝된다. 상기 마스크(240)의 개구부의 배치 모양에 따라 예를 들면, 델타 방식으로 개구부가 배치되면 델타 방식으로 픽셀이 패터닝 될 수 있다.

<68> 이어서, 상기 레이저 조사장치(200)의 광원장치(210)에서 발생한 레이저빔(240)은 상기 시준렌즈(220)를 통과함으로서 평행화되고, 상기 평행화된 레이저빔(240)은 상기 대칭 마이크로 렌즈(230a)를 통과한다. 상기 대칭 마이크로 렌즈(230a)를 통과한 레이저빔은 화소영역을 정의할 수 있도록 패터닝됨으로서 자동적으로 상기 대칭 마이크로 렌즈(230a)에 의해 화소 영역의 패턴의 크기가 조절된다. 상기 패터닝된 레이저빔은 상기 마스크(240)를 통과한다. 상기 통과된 레이저빔은 상기 기재층(251)의 일부 영역을 조사하여 상기 전사층(253)을 상기 기판(261) 상에 전사를 수행하여 유기막층 패턴(미도시)을 형성한다.

<69> 여기서, 상기 레이저 조사장치(200)를 이용하여 유기막층 패턴을 형성하는 전사 공정은 $_2$N분위기에서 이루어질 수 있다. 이는 대기 중에 존재하는 산소에 의해 상기 유기막층 패턴의 산화를 방지하기 위함이다. 여기서$_2$ N분위기를 조성하기에 많은 시간과 비용을 투자해야 하므로, 상기 유기막층이 산소나 수분의 영향을 미치지 않는 조건을 고려하여 O_2 및 H_2O가 각각 100ppm이하의 분위기가 조성될 때까지 N_2를 충전하는 것이 바람직하다.

<70> 또한, 상기 전사 공정은 진공 분위기에서 이루어질 수 있는데, 상기 도너기판을 상기 기판 전면에 라미네이션하는 공정시 상기 도너기판과 상기 기판사이의 기포 발생을 억제할 수 있는 효과가 있다.

<71> 도 4 는 본 발명의 의한 레이저 조사장치로 패터닝한 화소의 평면도이다.

<72> 도 4를 참조하면, 상기 기판(261)에 형성된 각 픽셀에 레드(R), 블루(B), 그린(G) 등의 단위화소가 레이저 스캔 방향으로 다양하게 패터닝 되어 있다. 상기 레이저 조사장치(200)의 마스크(240)를 이용하여 불필요한 부분은 차단했기에 원하는 단위화소를 각 픽셀에 레이저 스캔 방향과 관계없이 패터닝 할 수 있다.

<73> 이상에서와 같이, 본 발명은 대칭 마이크로 렌즈 어레이 및 마스크를 구비한 레이저 조사장치를 이용하여 유기전계발광소자를 제조함으로써 다양한 픽셀배치 방법을 행할 수 있는 장점이 있다.

<74> 본 발명을 특정의 바람직한 실시 예에 관련하여 도시하고 설명하였지만, 본 발명이 그에 한정되는 것이 아니고, 이하의 특허청구범위에 의해 마련되는 본 발명의 정신이나 분야를 이탈하지 않는 한도 내에서 본 발명이 다양하게 개조 및 변화될 수 있다는 것을 당 업계에서 통상의 지식을 가진 자는 용이하게 알 수 있을 것이다.

발명의 효과

<75> 이상에서와 같이, 본 발명은 대칭 마이크로 렌즈 어레이 및 마스크를 구비한 레이저 조사장치를 이용하여 유기전계발광소자를 제조함으로써 다양한 픽셀 배치 방법을 수행할 수 있는 장점이 있다.

도면의 간단한 설명

<1> 도 1 은 종래의 레이저 조사장치를 이용한 유기전계발광소자의 제조방법을 설명하기 위한 모식도.

<2> 도 2 는 종래의 레이저 조사장치로 패터닝된 픽셀을 나타낸 평면도.

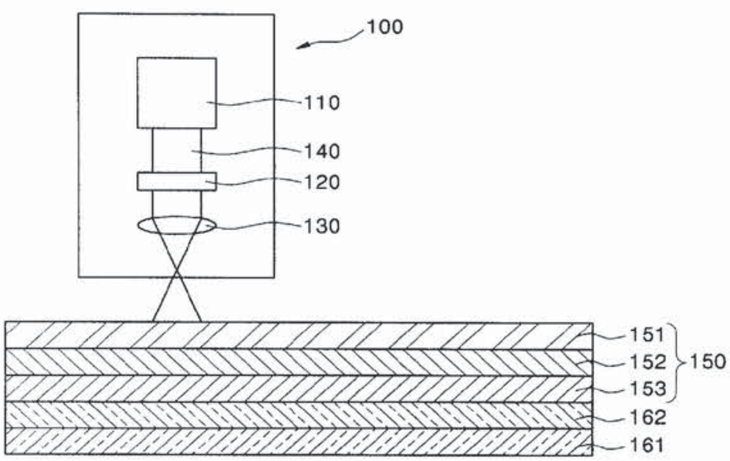
<3> 도 3a 는 본 발명의 일실시예에 따른 레이저 조사장치를 이용한 유기전계발광소자의 제조방법을 설명하기 위한 모식도.

<4> 도 3b 는 본 발명에 의한 레이저 조사장치의 대칭 마이크로 렌즈와 화소와의 관계를 설명한 단면도.

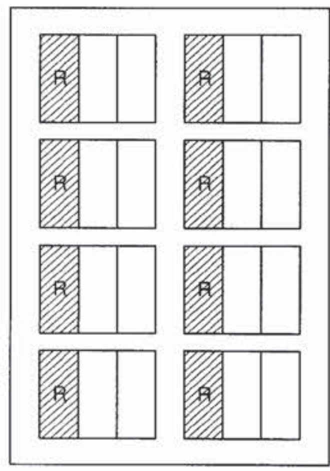
<5> 도 4 는 본 발명에 의한 레이저 조사장치로 패터닝된 픽셀을 나타낸 평면도.

도면

도면1



도면2


R
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R
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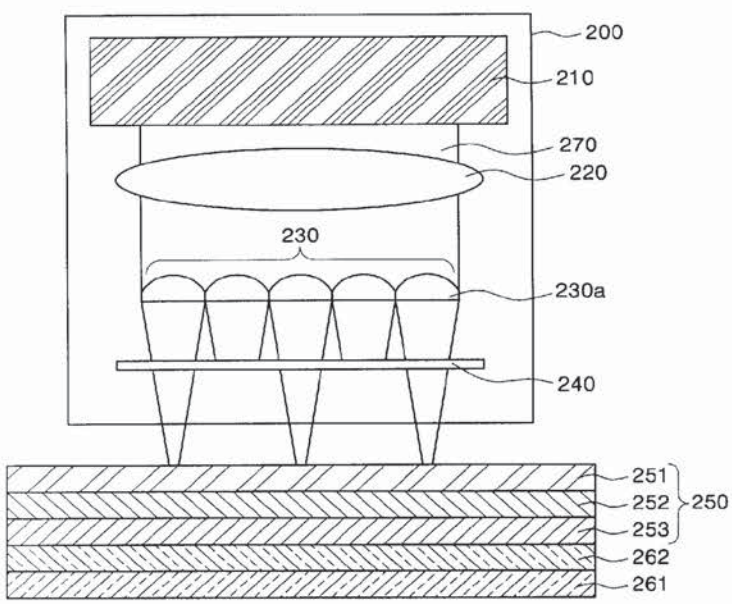
161

도면3a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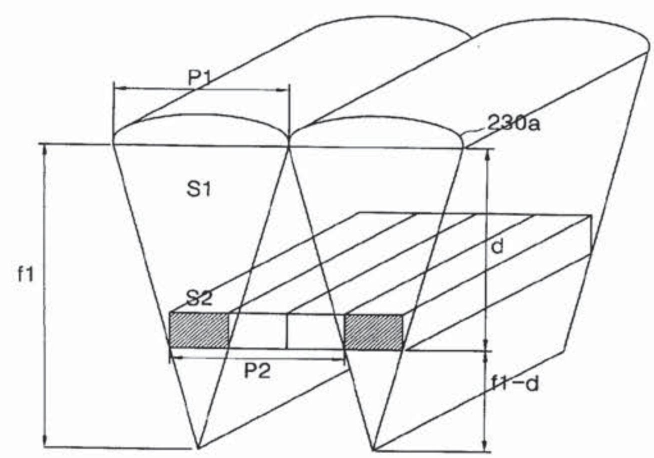
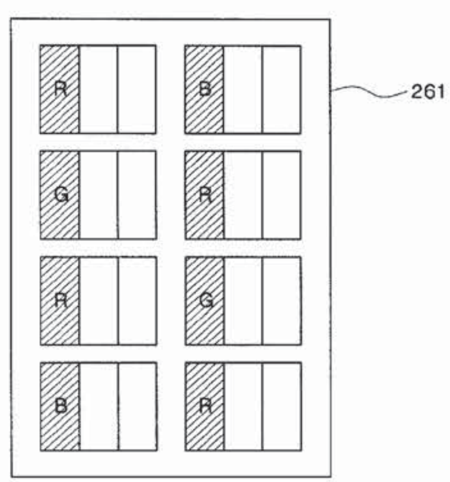
261

도면3b



도면4



Electronic Acknowledgement Receipt

EFS ID:	39280881
Application Number:	16046643
International Application Number:	
Confirmation Number:	1720
Title of Invention:	OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS
First Named Inventor/Applicant Name:	Angus Pacala
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P001USC2-1096583
Receipt Date:	27-APR-2020
Filing Date:	26-JUL-2018
Time Stamp:	21:43:55
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		IDS-P001US2.pdf	192113 da7ac5a377d7886dbbc1dbce6bf0a0b9ba5ff1b0	yes	5

	Multipart Description/PDF files in .zip description				
	Document Description		Start		End
	Transmittal Letter		1		2
	Information Disclosure Statement (IDS) Form (SB08)		3		5
Warnings:					
Information:					
2	Non Patent Literature	SwedishSearchReport.pdf	857938 77d136ca234a422c13d807ce6d3819bd47edd1eb	no	3
Warnings:					
Information:					
3	Foreign Reference	KR20070112679A.pdf	430647 b44d5c65c78f80b25a3d49ff9b724079d59f02d9	no	11
Warnings:					
Information:					
		Total Files Size (in bytes):	1480698		

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<u>New Applications Under 35 U.S.C. 111</u>
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.
<u>National Stage of an International Application under 35 U.S.C. 371</u>
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.
<u>New International Application Filed with the USPTO as a Receiving Office</u>
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on April 27, 2020.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer-Johnson/

PATENT
Attorney Docket No.: 103033-1096583-P001USC2
Client Ref. No.: P001USC2

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 1720
Angus Pacala	Examiner: LEE, John R.
Application No.: 16/046,643	Technology Center/Art Unit: 2878
Filed: July 26, 2018	
For: OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patents and U.S. Patent Application Publications are not provided. Copies of the references are enclosed.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no

representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed *before* the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/ William L. Shaffer /

William L. Shaffer
Registration No. 37,234

KILPATRICK TOWNSEND & STOCKTON LLP

Attachment

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16/046,643
	Filing Date	July 26, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2414
	Examiner Name	
	Attorney Docket Number	103033-1096583

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code 1	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	5659420	A	Aug 19, 1997	Wakai et al.	
	2	5953110	A	Sep 14, 1999	Burns	

U.S. PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code 1	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	3	20020003617	A1	Jan 10, 2002	Doemens et al.	
	4	20070057211	A1	Mar 15, 2007	Bahlman et al.	
	5	20150319349	A1	Nov 5, 2015	Mishra et al.	
	6	20150362585	A1	Dec 17, 2015	Ghosh et al.	

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number3	Country Code2	Kind Code4	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T5
	7	2014150856	WO		Sep 25, 2014	Pelican Imaging Corporation		
	8	2908166	EP		Aug 19, 2015	Yokogawa Electric Corporation		

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T5
	9	DKPA201970244 , "Office Action", April 24, 2020, 8 pages	

EXAMINER SIGNATURE

Examiner Signature		Date Considered	

PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16/046,643
	Filing Date	July 26, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2414
	Examiner Name	
	Attorney Docket Number	103033-1096583

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document.[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on June 18, 2020.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer-Johnson/

PATENT
Attorney Docket No.: 103033-1096583-P001USC2
Client Ref. No.: P001USC2

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 1720
Angus Pacala	Examiner: LEE, John R.
Application No.: 16/046,643	Technology Center/Art Unit: 2878
Filed: July 26, 2018	
For: OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patents and U.S. Patent Application Publications are not provided. Copies of the references are enclosed.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no

representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed *before* the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/ William L. Shaffer /

William L. Shaffer
Registration No. 37,234

KILPATRICK TOWNSEND & STOCKTON LLP

Attachment

(19)日本国特許庁(JP)　(12)公開特許公報(A)　(11)特許出願公開番号
特開2015-137987
(P2015-137987A)
(43)公開日　平成27年7月30日(2015.7.30)

(51)Int.Cl.		FI			テーマコード（参考）
G01C 3/06	(2006.01)	G01C	3/06	120P	2F065
G01B 11/00	(2006.01)	G01B	11/00	H	2F112

審査請求 未請求　請求項の数 8　ＯＬ　（全 8 頁）

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(22)出願日　平成26年1月24日(2014.1.24)

(71)出願人　000006666
アズビル株式会社
東京都千代田区丸の内２丁目７番３号
(74)代理人　100064621
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弁理士　山川　茂樹
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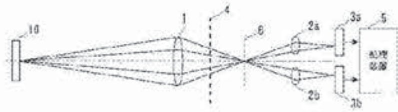
東京都千代田区丸の内２丁目７番３号　アズビル株式会社内

Ｆターム(参考)　2F065 AA06 DD04 DD06 FF01 FF04 FF05 HH00 JJ02 JJ03 JJ05 JJ25 JJ26 LL04 QQ21 QQ31
2F112 AC01 AC03 AC06 BA05 BA07 CA12 DA04 DA32 FA35

(54)【発明の名称】距離センサおよび距離計測方法

(57)【要約】
【課題】物体の表面状態の影響を受け難くし、演算量を少なくする。
【解決手段】距離センサは、物体１０からの光を集光する集光光学系１と、集光光学系１からの光を２つに分割して個別に結像させる２つのセパレータレンズ２ａ，２ｂと、セパレータレンズ２ａ，２ｂによって分割され集光された光を個別に受光する１次元または２次元の２つの撮像素子３ａ，３ｂと、集光光学系１とセパレータレンズ２ａ，２ｂとの間に配置され、光が通過する開口の形状の自己相関関数がデルタ関数に近似した符号化開口を有するマスク４と、撮像素子３ａ，３ｂで得られた２つの画像の重心の間隔を基に物体１０と撮像素子３ａ，３ｂとの距離を決定する処理装置５とを備える。
【選択図】　図１



【特許請求の範囲】
【請求項１】
物体からの光を集光する集光光学系と、
この集光光学系からの光を２つに分割して個別に結像させる２つのセパレータレンズと、
この２つのセパレータレンズによって分割され集光された光を個別に受光する１次元または２次元の２つの撮像素子と、
前記集光光学系と前記セパレータレンズとの間または前記セパレータレンズと前記撮像素子との間に配置され、光が通過する開口の形状の自己相関関数がデルタ関数に近似した符号化開口を有するマスクと、
前記２つの撮像素子で得られる２つの画像の重心の間隔を基に前記物体と前記撮像素子との距離を決定する処理手段とを備えることを特徴とする距離センサ。
【請求項２】
請求項１記載の距離センサにおいて、
前記処理手段は、
前記２つの画像の重心の間隔と、前記物体と前記集光光学系の焦点位置との距離を対応付けて予め記憶する記憶手段と、
前記２つの撮像素子で得られる２つの画像の重心の位置をそれぞれ検出する画像重心位置検出手段と、
この画像重心位置検出手段での検出結果を基に、前記２つの撮像素子で得られる２つの画像の重心の間隔を算出する重心間隔算出手段と、
この重心間隔算出手段が算出した重心の間隔に対応する、物体と集光光学系の焦点位置との距離の値を前記記憶手段から取得し、物体と撮像素子との距離を決定する距離決定手段とを備えることを特徴とする距離センサ。
【請求項３】
請求項１または２記載の距離センサにおいて、
さらに、対象とする物体が存在すると想定される監視空間に光を投光する投光器を備えることを特徴とする距離センサ。
【請求項４】
請求項１乃至３のいずれか１項に記載の距離センサにおいて、
さらに、前記集光光学系は、可変焦点機構を備え、
前記記憶手段は、前記２つの画像の重心の間隔と、前記物体と前記焦点位置の距離との関係を、前記集光光学系の焦点距離毎に予め記憶し、
前記距離決定手段は、前記集光光学系の焦点距離毎に前記記憶手段に記憶されている関係のうち、前記集光光学系の現在の焦点距離に対応する関係を用いて、前記重心間隔算出手段が算出した重心の間隔に対応する距離の値を決定することを特徴とする距離センサ。
【請求項５】
物体からの光を集光する集光光学系からの光を２つのセパレータレンズによって２つに分割する分割ステップと、
前記集光光学系と前記セパレータレンズとの間または前記セパレータレンズと撮像素子との間に配置され、形状の自己相関関数がデルタ関数に近似した符号化開口を有するマスクを介して、前記２つのセパレータレンズによって分割され集光された光を１次元または２次元の２つの前記撮像素子で個別に受光する受光ステップと、
前記２つの撮像素子で得られる２つの画像の重心の間隔を基に前記物体と前記撮像素子との距離を決定する処理ステップとを含むことを特徴とする距離計測方法。
【請求項６】
請求項５記載の距離計測方法において、
前記処理ステップは、
前記２つの撮像素子で得られる２つの画像の重心の位置をそれぞれ検出する画像重心位置検出ステップと、

この画像重心位置検出ステップでの検出結果を基に、前記２つの撮像素子で得られる２つの画像の重心の間隔を算出する重心間隔算出ステップと、

前記２つの画像の重心の間隔と、前記物体と前記集光光学系の焦点位置との距離を対応付けて予め記憶している記憶手段を参照し、前記重心間隔算出ステップで算出した重心の間隔に対応する、物体と集光光学系の焦点位置との距離の値を前記記憶手段から取得し、物体と撮像素子との距離を決定する距離決定ステップとを含むことを特徴とする距離計測方法。

【請求項７】

請求項５または６記載の距離計測方法において、

さらに、対象とする物体が存在すると想定される監視空間に光を投光する投光ステップを含むことを特徴とする距離計測方法。

【請求項８】

請求項５乃至７のいずれか１項に記載の距離計測方法において、

さらに、前記集光光学系は、可変焦点機構を備え、

前記記憶手段は、前記２つの画像の重心の間隔と、前記物体と前記焦点位置の距離との関係を、前記集光光学系の焦点距離毎に予め記憶し、

前記距離決定ステップは、前記集光光学系の焦点距離毎に前記記憶手段に記憶されている関係のうち、前記集光光学系の現在の焦点距離に対応する関係を用いて、前記重心間隔算出ステップで算出した重心の間隔に対応する距離の値を決定することを特徴とする距離計測方法。

【発明の詳細な説明】

【技術分野】

【０００１】

本発明は、物体からの光により物体との距離を計測する距離センサおよび距離計測方法に関するものである。

【背景技術】

【０００２】

従来より、三角測量法の原理で作動する距離センサが知られている（特許文献１参照）。このような距離センサでは、物体からの光がＣＣＤなどの位置検出素子に入射するが、センサから物体までの距離に応じて位置検出素子に入射する光の位置が変わる。したがって、この光の位置を測定することにより、センサから物体までの距離を求めることが可能である。

三角測量法の原理で作動する距離センサでは、物体の表面状態（例えば鏡面物体か否か、色むらの有無など）によって位置検出素子上で検出される光の位置が変わってしまうため、距離の計測誤差が発生するという問題点があった。

【０００３】

物体の表面状態の影響を受け難い距離センサとして、特許文献２に開示された距離センサが知られている。この距離センサでは、ぼけ量の解析が容易となるように構造化した光通過手段を通して物体からの光を取り込み、この光通過手段を通過した光を収束するレンズ系によって構成されたテレセントリック光学系を通過した光を、２つ以上の光に分離し、これら分離した光から、互いに相違する合焦位置の画像をそれぞれ取り込み、これら画像を用いて物体の距離を演算するようにしている。この距離センサでは、ぼけ量の解析が容易となるように構造化した光通過手段を用いることにより、物体の表面状態の影響を受け難くすることができる。

【先行技術文献】

【特許文献】

【０００４】

【特許文献１】特開２００２－２５０６２３号公報

【特許文献２】特許第２９６３９９０号公報

【発明の概要】

【発明が解決しようとする課題】

【０００５】

上記のように、三角測量法の原理で作動する距離センサでは、物体の表面状態によって距離の計測誤差が発生するという問題点があった。

一方、特許文献２に開示された距離センサでは、物体の表面状態の影響を受け難くすることができる。しかし、特許文献２に開示された距離センサでは、互いに相違する２つ以上の合焦位置の画像をそれぞれ取り込み、これら２つ以上の画像に対してフーリエ変換を含む演算処理を行って、物体との距離を求めるため、演算量が多くなるという問題点があった。

【０００６】

本発明は、上記課題を解決するためになされたもので、物体の表面状態の影響を受け難くすることができ、従来よりも演算量を少なくすることができる距離センサおよび距離計測方法を提供することを目的とする。

【課題を解決するための手段】

【０００７】

本発明の距離センサは、物体からの光を集光する集光光学系と、この集光光学系からの光を２つに分割して個別に結像させる２つのセパレータレンズと、この２つのセパレータレンズによって分割され集光された光を個別に受光する１次元または２次元の２つの撮像素子と、前記集光光学系と前記セパレータレンズとの間または前記セパレータレンズと前記撮像素子との間に配置され、光が通過する開口の形状の自己相関関数がデルタ関数に近似した符号化開口を有するマスクと、前記２つの撮像素子で得られる２つの画像の重心の間隔を基に前記物体と前記撮像素子との距離を決定する処理手段とを備えることを特徴とするものである。

また、本発明の距離センサの１構成例において、前記処理手段は、前記２つの画像の重心の間隔と、前記物体と前記集光光学系の焦点位置との距離を対応付けて予め記憶する記憶手段と、前記２つの撮像素子で得られる２つの画像の重心の位置をそれぞれ検出する画像重心位置検出手段と、この画像重心位置検出手段での検出結果を基に、前記２つの撮像素子で得られる２つの画像の重心の間隔を算出する重心間隔算出手段と、この重心間隔算出手段が算出した重心の間隔に対応する、物体と集光光学系の焦点位置との距離の値を前記記憶手段から取得し、物体と撮像素子との距離を決定する距離決定手段とを備えることを特徴とするものである。

【０００８】

また、本発明の距離センサの１構成例は、さらに、対象とする物体が存在すると想定される監視空間に光を投光する投光器を備えることを特徴とするものである。

また、本発明の距離センサの１構成例において、さらに、前記集光光学系は、可変焦点機構を備え、前記記憶手段は、前記２つの画像の重心の間隔と、前記物体と前記焦点位置の距離との関係を、前記集光光学系の焦点距離毎に予め記憶し、前記距離決定手段は、前記集光光学系の焦点距離毎に前記記憶手段に記憶されている関係のうち、前記集光光学系の現在の焦点距離に対応する関係を用いて、前記重心間隔算出手段が算出した重心の間隔に対応する距離の値を決定することを特徴とするものである。

【０００９】

また、本発明の距離計測方法は、物体からの光を集光する集光光学系からの光を２つのセパレータレンズによって２つに分割する分割ステップと、前記集光光学系と前記セパレータレンズとの間または前記セパレータレンズと撮像素子との間に配置され、形状の自己相関関数がデルタ関数に近似した符号化開口を有するマスクを介して、前記２つのセパレータレンズによって分割され集光された光を１次元または２次元の２つの前記撮像素子で個別に受光する受光ステップと、前記２つの撮像素子で得られる２つの画像の重心の間隔を基に前記物体と前記撮像素子との距離を決定する処理ステップとを含むことを特徴とするものである。

【発明の効果】

【００１０】
本発明によれば、符号化開口を備えたマスクを用いることにより、物体の表面状態の影響を受け難くすることができる。また、本発明では、２つの撮像素子で得られる２つの画像の重心の間隔を算出すれば、物体と撮像素子との距離を求めることができるので、従来の距離センサと比較して演算量を少なくすることができる。
【図面の簡単な説明】
【００１１】
【図１】本発明の実施の形態に係る距離センサの構成を示すブロック図である。
【図２】本発明の実施の形態に係る距離センサの処理装置の構成例を示すブロック図である。
【図３】物体の距離の変化による画像の重心間隔の変化を説明するための図である。
【図４】本発明の実施の形態に係るマスクの平面図である。
【図５】本発明の実施の形態において撮像素子で得られる画像の１例を示す図である。
【発明を実施するための形態】
【００１２】
以下、本発明の実施の形態について図面を参照して説明する。図１は本発明の実施の形態に係る距離センサの構成を示すブロック図である。距離センサは、物体１０からの光を集光する集光光学系１と、集光光学系１からの光を２つに分割して個別に結像させる２つのセパレータレンズ２ａ，２ｂと、セパレータレンズ２ａ，２ｂによって分割され集光された光を個別に受光する１次元または２次元の２つの撮像素子３ａ，３ｂと、集光光学系１とセパレータレンズ２ａ，２ｂとの間に配置され、光が通過する開口の形状の自己相関関数がデルタ関数に近似した符号化開口を有するマスク４と、撮像素子３ａ，３ｂで得られた２つの画像の重心の間隔を基に物体１０と撮像素子３ａ，３ｂとの距離を決定する処理装置５とを備えている。
【００１３】
物体１０からの光は、集光光学系１によって集光され、マスク４に入射する。入射した光のうち一部はマスク４によって遮られ、マスク４の符号化開口部に入射した光のみがマスク４を通過する。符号化開口は、マスク４を集光光学系１（またはセパレータレンズ２ａ，２ｂ）側から見たときの開口部の平面形状の自己相関関数がデルタ関数に近似した貫通孔（または貫通孔の集合）である。このような符号化開口については、例えば特許文献２に開示されている。
【００１４】
図１における６は集光光学系１の結像面である。２つのセパレータレンズ２ａ，２ｂは、この結像面６と撮像素子３ａ，３ｂとの間に配置される。セパレータレンズ２ａ，２ｂは、集光光学系１およびマスク４を通過した光を結像面６よりも後方の位置で２つに分割する。
【００１５】
撮像素子３ａ，３ｂは、例えば画素が線状に配置された１次元のＣＣＤ、または画素がマトリクス状に配置された２次元のＣＣＤからなる。セパレータレンズ２ａ，２ｂによって分割され集光された光を撮像素子３ａ，３ｂで個別に受光することにより、１次元または２次元の画像を２つ得ることができる。
【００１６】
処理装置５は、撮像素子３ａで得られた画像の重心と撮像素子３ｂで得られた画像の重心の間隔を基に物体１０と撮像素子３ａ，３ｂとの距離を決定する。図２は処理装置５の構成例を示すブロック図である。処理装置５は、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔と、物体１０と撮像素子３ａ，３ｂの距離とを対応付けて予め記憶する記憶部５０と、撮像素子３ａ，３ｂで得られる２つの画像の重心の位置をそれぞれ検出する画像重心位置検出部５１と、画像重心位置検出部５１での検出結果を基に、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔を算出する重心間隔算出部５２と、重心間隔算出部５２が算出した重心の間隔に対応する、物体１０と撮像素子３ａ，３ｂとの距離の値

を記憶部５０から取得する距離決定部５３とから構成される。

【００１７】

物体１０からの光が撮像素子３ａ，３ｂ上で結像したことによって得られる２つの画像の重心の間隔は、物体１０と集光光学系１の焦点位置（図３（Ａ）～図３（Ｃ）の７）との距離によって変わる。例えば図３（Ａ）のように物体１０が焦点位置７にある場合と比較して物体１０が近距離にある場合には、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔が狭くなる（図３（Ｂ））。反対に物体１０が焦点位置７より遠ざかると、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔が広くなる（図３（Ｃ））。このように、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔は、物体１０と集光光学系１の焦点位置７との距離に依存する。したがって、２つの画像の重心の間隔を計算することができれば、物体１０と撮像素子３ａ，３ｂとの距離を求めることができる。

【００１８】

記憶部５０は、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔と、物体１０と集光光学系１の焦点位置７との距離とを対応付けて予め記憶している。

図４に集光光学系１側から見たマスク４の平面形状の１例を示し、図５（Ａ）に撮像素子３ａで得られる画像の１例を示し、図５（Ｂ）に撮像素子３ｂで得られる画像の１例を示す。ここでは、記載を容易にするため、２次元の撮像素子３ａ，３ｂを用いるものとする。また、マスク４に形成される開口を２つの三日月型の開口とする。三日月型の開口は符号化開口ではないが、ここでは便宜的に２つの三日月型の開口で符号化開口を表現するものとする。

【００１９】

画像重心位置検出部５１は、撮像素子３ａ上での画像の重心（図５（Ａ）の３０ａ）の位置と撮像素子３ｂ上での画像の重心（図５（Ｂ）の３０ｂ）の位置とを検出する。なお、画像の重心位置を求める技術は画像処理において周知の技術であるので、詳細な説明は省略する。ここで、画像の重心としては、画像の形状重心と輝度重心とがあるが、本発明では、画像の形状重心の位置を求めてもよいし、画像の輝度重心の位置を求めてもよい。

【００２０】

重心間隔算出部５２は、画像重心位置検出部５１での検出結果を基に、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔を算出する。撮像素子３ａと３ｂの間隔は固定値であるから、撮像素子３ａ上での画像の重心の位置と撮像素子３ｂ上での画像の重心の位置とを検出することができれば、これら重心の間隔を算出することができる。

【００２１】

距離決定部５３は、重心間隔算出部５２が算出した重心の間隔に対応する、物体１０と集光光学系１の焦点位置７との距離の値を記憶部５０から取得し、物体１０と撮像素子３ａ，３ｂとの距離を決定する。集光光学系１の焦点位置７は既知であるので、物体１０と集光光学系１の焦点位置７との距離が分かれば、物体１０と撮像素子３ａ，３ｂとの距離を決定することができる。

本実施の形態では、符号化開口を備えたマスク４を用いることにより、物体１０の表面状態の影響を受け難くすることができる。また、本実施の形態では、撮像素子３ａ，３ｂで得られる２つの画像の重心の間隔を求めればよいので、特許文献２に開示された距離センサと比較して演算量を少なくすることができる。

【００２２】

なお、本実施の形態において、対象とする物体１０が存在すると想定される監視空間に光を投光する投光器を設けるようにしてもよい。これにより、投光器無しでは物体１０からの反射光量が弱過ぎて物体検知ができないような場合でも、物体１０と撮像素子３ａ，３ｂとの距離を計測することができる。

【００２３】

また、本実施の形態では、集光光学系１とセパレータレンズ２ａ，２ｂとの間、より正確には集光光学系１と集光光学系１の結像面６との間にマスク４を配置しているが、これに限るものではなく、結像面６とセパレータレンズ２ａ，２ｂとの間にマスク４を配置し

てもよいし、セパレータレンズ２ａ，２ｂと撮像素子３ａ，３ｂとの間にマスク４を配置してもよい。

【００２４】

また、本実施の形態では、固定焦点の集光光学系１を用いる場合について説明しているが、焦点距離を変化させることが可能な可変焦点機構を備えた集光光学系１を用いてもよい。ただし、この場合は、２つの画像の重心の間隔と、物体１０と集光光学系１の焦点位置７の距離との関係が、集光光学系１の焦点距離に応じて変化する。そこで、２つの画像の重心の間隔と、物体１０と集光光学系１の焦点位置７の距離との関係を、集光光学系１の焦点距離毎に記憶部５０に記憶させておく。距離決定部５３は、集光光学系１の焦点距離毎に記憶部５０に記憶されている関係のうち、集光光学系１の現在の焦点距離に対応する関係を用いて、重心間隔算出部５２が算出した重心の間隔に対応する距離の値を決定すればよい。

なお、セパレータレンズ２ａ，２ｂの近傍に絞りマスクを配置してもよい、これにより、不必要な光の混入を防止することができる。

【００２５】

本実施の形態で説明した処理装置５は、ＣＰＵ（Central Processing Unit）、記憶装置及びインタフェースを備えたコンピュータと、これらのハードウェア資源を制御するプログラムによって実現することができる。ＣＰＵは、記憶装置に格納されたプログラムに従って本実施の形態で説明した処理を実行する。

【産業上の利用可能性】

【００２６】

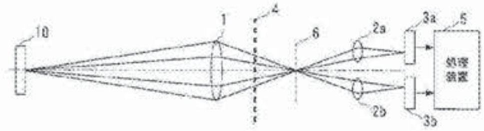
本発明は、物体からの光により物体との距離を計測する技術に適用することができる。

【符号の説明】

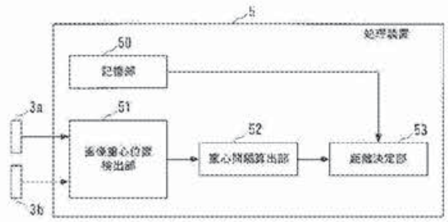
【００２７】

１…集光光学系、２ａ，２ｂ…セパレータレンズ、３ａ，３ｂ…撮像素子、４…マスク、５…処理装置、５０…記憶部、５１…画像重心位置検出部、５２…重心間隔算出部、５３…距離決定部。

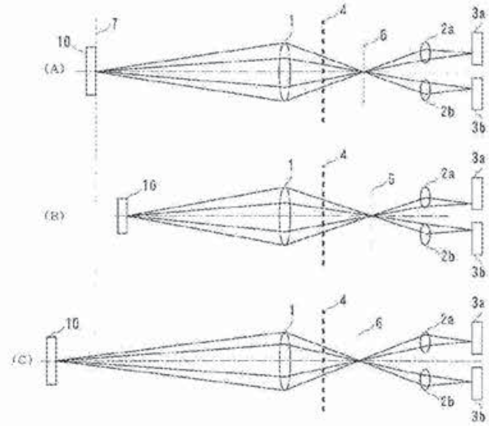
【図１】


10
1
4
6
2a
2b
3a
3b
5
処理装置

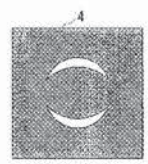
【図２】


5
処理装置
50
記憶部
3a
3b
51
画像重心位置検出部
52
重心間隔算出部
53
距離決定部

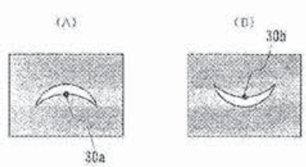
【図３】


(A)
(B)
(C)
10
7
1
4
6
2a
2b
3a
3b

【図４】


4

【図５】


(A)
(B)
30a
30b

[Document Name]Patent Claims

[Claim 1]
A condensing optical system for collecting light from an object, 2 separator lenses for separately forming the light from the condensing optical system by dividing the light into 2, and 2 or 2 dimensional image pickup elements which are divided by the 2 separator lenses and individually receive the light condensed by the 1 separator lenses ; A mask which is arranged between the condensing optical system and the separator lens or between the separator lens and the imaging element and has a self-interphase function in the form of an opening through which the light passes ; A distance sensor comprising a processing means for determining a distance between an object and an imaging element based on an interval between centroids of 2 images obtained by the 2 imaging elements.

[Claim 2]
The distance sensor according to claim 1, wherein the processing means has a storage means for storing a distance between the center of gravity of the 2 images and a focal position of the condensing optical system in advance, and an image center position detecting means for detecting the position of the center of gravity of the 2 images obtained by the 2 imaging elements. A center of gravity interval calculating means for calculating an interval of the center of gravity of the 2 images obtained by the 2 image pickup elements based on a result of detection by the image centroid position detecting means ; A distance sensor comprising : a distance determining unit which acquires a value of a distance between an object and a focal point of a condensing optical system corresponding to an interval of the center of gravity calculated by the center-of-gravity interval calculating unit from the storage unit, and determines a distance between the object and the imaging element.

[Claim 3]
A distance sensor according to claim 1 or 2, further comprising a projector for projecting light into a monitoring space in which an object of interest is assumed to be present.

[Claim 4]
In the distance sensor according to any one of claims 1 to 3, further, the condensing optical system includes a variable focus mechanism, and the storing means stores a relationship between a distance between the centers of gravity of the 2 images and a distance between the object and the focal point position for each focal length of the condensing optical system, and the distance determining means is used for the distance determination. The distance sensor according to claim 1, wherein the distance value corresponding to the distance of the center of gravity calculated by the center of gravity distance calculating means is determined by using a relationship corresponding to a current focal length of the condensing optical system among the relations stored in the storing means for each focal length of the condensing optical system.