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(71) Applicant: VALEO SCHALTER UND SENSOREN

GMBH [DE/DE]; Laiernstr. 12, 74321 Bietigheim-Bissingen (DE).

(72) Inventors: ABULADZE, Grigory; Laiernstr. 12, 74321

Bietigheim-Bissingen (DE). BERTSCHINGER, Bernd; Laiernstr. 12, 74321 Bietigheim-Bissingen (DE). STRICKER-SHAVER, Daniel; Laiernstr. 12, 74321 Bietigheim-Bissingen (DE).

(74) Agent: KLUTH, Philipp; Valeo Schalter und Sensoren

GmbH, Laiernstr. 12, 74321 Bietigheim-Bissingen (DE).

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(54) Title: LIDAR DEVICE FOR A VEHICLE AND METHOD FOR INCREASING THE DETECTION RANGE OF A CORRESPONDING LIDAR DEVICE

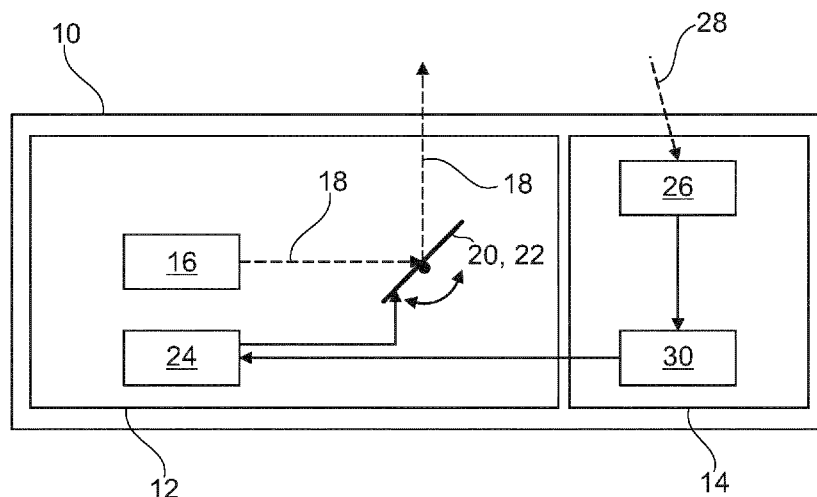


Fig. 1

(57) Abstract: The invention relates to a LIDAR device (10) for the imaging detection of an area in the vehicle environment of a vehicle, with a transmitting unit (12) for transmitting a laser beam (18) scanning the area, the transmitting unit (12) comprising a laser light source (16) having a predetermined laser power and a scanning unit (20), and a receiving unit (14) for receiving light (28) reflected in the vehicle environment, which receiving unit (14) comprises an optical sensor (26) generating individual pixels (34) and an evaluation unit (30) for pixel-based evaluation of the sensor signal of the optical sensor (26). The optical sensor (26) and/or the evaluation unit (30) is performing pixel binning to form at least one superpixel (36), wherein the evaluation unit (30) is further performing superpixel evaluation to obtain an increased detection range mode of the LIDAR device (10). The invention further relates to a method for increasing the detection range of a corresponding LIDAR device (10) and a corresponding computer program product.

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LIDAR device for a vehicle and method for increasing the detection range of a
corresponding LIDAR device

The invention relates to a LIDAR device for the imaging detection of an area in the vehicle environment of a vehicle, with (i) a transmitting unit for transmitting a laser beam scanning the area, the transmitting unit comprising a laser light source having a predetermined laser power and a scanning unit, and (ii) a receiving unit for receiving light reflected in the vehicle environment, which receiving unit comprises an optical sensor generating individual pixels and an evaluation unit for pixel-based evaluation of the sensor signal of the optical sensor.

The invention further relates to a corresponding method for increasing the detection range of a LIDAR device and a corresponding computer program product (LIDAR: light detection and ranging).

Document DE 10 2015 100 910 A1 describes a LIDAR device for the imaging detection of an area in the vehicle environment of a vehicle, with (i) a transmitting unit for transmitting a laser beam scanning the area, the transmitting unit comprising a laser light source having a predetermined laser power and a scanning unit, and (ii) a receiving unit for receiving light reflected in the vehicle environment, which receiving unit comprises an optical sensor generating individual pixels and an evaluation unit for pixel-based evaluation of the sensor signal of the optical sensor. The optical sensor is based on at least one diode. In this document the automotive LIDAR device is called in a more general way "a device for detecting objects for a motor vehicle".

Automotive LIDAR devices have to satisfy eye safety laser class 1 to be used in open environment. Thus the laser power they can emit is limited which it turns limit detection range. Current generation of automotive LIDAR devices have relatively low resolution which allows reasonable power budget of laser energy per pixel/ray. However practical applications urgently demand increasing resolution of LIDAR devices. In particular for proper segmentation and classification tasks. Higher resolution leaves each pixel/ray with much less energy available thus making problem of detection range even more profound.

It is an object of the invention to provide means to enhance the detection range of an automotive LIDAR device.

This object is achieved by a LIDAR device, a corresponding method, as well as a corresponding computer program product having the features according to the respective independent claims. Advantageous implementations of the invention are the subject matter of the dependent claims, of the description and of the figures.

According to several aspects of the inventive LIDAR device for the imaging detection of an area in the vehicle environment of a vehicle, with the LIDAR device comprising the following components: a transmitting unit for transmitting a laser beam scanning the area, which transmitting unit comprises a laser light source having a predetermined laser power and a scanning unit, and a receiving unit for receiving light reflected in the vehicle environment, which receiving unit comprises an optical sensor generating individual pixels and an evaluation unit for pixel-based evaluation of the sensor signal of the optical sensor, it is provided that the optical sensor and/or the evaluation unit is arranged to perform pixel binning to form at least one superpixel, wherein the evaluation unit is further arranged to perform superpixel evaluation to obtain an increased detection range mode of the LIDAR device. In other words, the optical sensor and/or the evaluation unit is arranged to perform superpixel segmentation.

First thing to mention - creating superpixel is the trade-off between spatial resolution and detection range. Superpixel allows detecting farther objects by cost of losing fine details of the imaged scene. There are two ways to combine pixels into a superpixel: (i) combining analogue signals. In this case generated electrons are combined directly before digitalization and (ii) statistical combination of individual pixels after digitalization. The first alternative provides natural, direct way to combine signal from multiple pixels in a form of sum which allow increase in signal value and corresponding adjustment of detection thresholds etc.

However usually in practice pixels and receiver HW design do not allow such approach. Therefore, according to a preferred embodiment of the invention, the evaluation unit is arranged to perform the pixel binning and superpixel evaluation in the digital domain.

This second alternative of combining pixels operates within digital information provided by individual pixels. This information is already “contaminated” by system noises: parasitic light (e.g. by the sun), shot noise, electronics noise.

According to another preferred embodiment of the invention, the pixel binning comprises a statistical combination of the corresponding pixels related to the respective superpixel. By this measure the evaluation unit counteracts the noise contamination. Statistical combination will allow to “averaging” noise component and “magnify” signal part of the mixture.

A simplified description of LIDAR operation can present as: send light out, receive reflected light, convert light to electrons. Then a detection algorithm based on provided threshold decides 1/0 based on sample (pixel) value bigger than a predefined threshold value.

According to yet another preferred embodiment of the invention, each of the superpixels includes at least 4 pixels. With a superpixel combining 4 or more pixels the detection range can be increased significantly. Preferably each of the superpixels includes at least 9 or 16 pixels.

According to another preferred embodiment of the invention, the evaluation unit is further arranged to perform a pixel-by-pixel evaluation of the pixels in a conventional detection mode. In this mode the spatial resolution has priority.

According to several aspects of the inventive method for increasing the detection range of a LIDAR device for the imaging detection of an area in the vehicle environment of a vehicle, with the LIDAR device comprising: a transmitting unit for transmitting a laser beam scanning the area, the transmitting unit comprising a laser light source having a predetermined laser power and a scanning unit, and a receiving unit for receiving light reflected in the vehicle environment, which receiving unit comprises an optical sensor generating individual pixels and an evaluation unit for pixel-based evaluation of the sensor signal of the optical sensor, it is provided that the optical sensor and/or the evaluation unit is performing pixel binning to form at least one superpixel, wherein the evaluation unit is further performing superpixel evaluation to obtain an increased detection range mode of the LIDAR device.

Preferably the aforementioned LIDAR device is arranged for executing this detection range increasing method.

According to a preferred embodiment of the method according to the invention, the evaluation unit performs the pixel binning and superpixel evaluation in the digital domain.

According to another preferred embodiment of method according to the invention, the pixel binning comprises a statistical combination of the corresponding pixels related to the respective superpixel. By this measure the evaluation unit counteracts the noise contamination.

Preferably each of the superpixels includes at least 4 pixels. With a superpixel combining 4 or more pixels the detection range can be increased significantly. More preferably each of the superpixels includes at least 9 or 16 pixels.

According to yet another preferred embodiment of the method according to the invention, the evaluation unit performs a pixel-by-pixel evaluation of the pixels in a conventional detection mode. In this mode the spatial resolution has priority.

The computer program product according to the invention comprises computer-executable program code portions having program code instructions configured to execute the aforementioned method when loaded into a processor of a computer based evaluation unit.

Further features of the invention are apparent from the claims, the figure and the description of the figure. All of the features and feature combinations mentioned above in the description as well as the features and feature combinations mentioned below in the description of the figure and/or shown in the figure alone are usable not only in the respectively specified combination, but also in other combinations or alone.

Now, the invention is explained in more detail based on a preferred embodiment as well as with reference to the attached drawings.

In the drawings:

- Fig. 1 shows a schematic representation of an automotive LIDAR device according to a preferred embodiment of the invention;
- Fig. 2 shows a schematic representation of a pixel matrix generated by use of the optical sensor of such a LIDAR device; and
- Fig. 3 shows two curves representing the probability density function of a single pixel 34 and the probability density function of a superpixel.

Fig. 1 shows an example of a LIDAR device 10. The LIDAR device 10 comprises a laser scanning device acting as a transmitting unit 12 (in short: a transmitter) and a receiving unit 14 (in short: a receiver).

The transmitting unit 12 has a laser light source 16 by which a laser light beam 18 is generated. The laser light source 16 is a laser device and transmits the generated laser light beam 18 to a scanning unit 20 formed as a micro-mirror 22 for generating a scanning motion of the laser beam. For this purpose, the laser light source 16 is arranged at a predefined angle to the scanning unit 20. According to the so-called MEMS technology (MEMS: Micro-Electro-Mechanical System), the micro-mirror 22 consists of small individual elements, each of which has a reflecting surface, and is therefore referred to in the following as the MEMS micro-mirror 22.

The MEMS micro-mirror 22 is arranged to the laser light source 16 in such a way that the laser light beam 18 impinges directly on the MEMS micro-mirror 22; one or more deflection mirrors being arranged between the laser light source 16 and the MEMS micro-mirror 22 in accordance with further design examples, so that the laser light beam 18 is deflected onto the MEMS micro-mirror 22 via the deflection mirrors.

The MEMS micro-mirror 22 can be moved about a first axis parallel to the drawing plane and, if necessary, about a second axis perpendicular to the drawing plane. The laser light beam 18 is deflected by the MEMS micro-mirror 22 in at least one direction of the environment. This direction can also be referred to as the scanning angle.

A control unit 24 is used to move the MEMS micro-mirror 22. The control unit 24 controls the MEMS micro-mirror 22 in such a way that it can be tilted in at least one direction (double arrow).

The laser light source 16 in the example comprises one or more laser diodes. The laser light source 16 is connected to the control unit 24 in such a way that the laser light source 16 is controlled by the control unit 24 and a pulsed laser light beam 18 is emitted as a transmitted light beam with a frequency, e.g. 100 kHz, by the control unit 24. The control unit 24 can also switch off the laser light source 16.

The receiving unit 14 has an optical sensor 26, which is a photodiode based sensor in the shown example. The optical sensor 26 receives light 28 which corresponds to the laser light beam 18 reflected or scattered back from the environment, especially objects in the environment. The received light 28 is converted into an electrical signal by the optical sensor 26 and its circuitry. The electrical signal is then fed to an evaluation unit 30 of the LIDAR device 10, which evaluation unit 30 is computer-based.

The LIDAR device 10 measures the distances to detected objects using a flight time measurement, i.e. a measurement according to the ToF principle (ToF: Time of Flight). If this scanning unit 20 is a MEMS micro-mirror 22, it oscillates almost cosinusoidally, usually with a natural frequency of several kHz. Such a "oscillating mirror" for beam deflection must be operated at its resonant frequency. Since this is in the kHz range, several oscillations of the MEMS micro-mirror 22 are required to hit each position in a scan range, which places higher demands on the quality of the mirror 22, among other things.

Fig. 2 shows a schematic representation of a pixel matrix 32 generated by use of the optical sensor 26. The shown pixel matrix 32 is a matrix of 8 x 8 pixels 34. In the digital domain the evaluation unit 30 performs pixel binning of a plurality of pixels 34 to form a superpixel 36. This superpixel 36 comprises the information of 4 x 4 pixels 34. In other words, the evaluation unit 30 is arranged to perform superpixel segmentation and to use the information from the superpixel 36 to obtain an increased detection range mode of the LIDAR device 10.

A simplified description of the LIDAR device operation can present as: sending light out by use of the transmitting unit 12, receiving reflected light by use of the receiving unit 14 and converting light to electrons by the optical sensor 26. Then a detection algorithm, which is running on the evaluation unit 30, based on provided threshold decides 1/0 based on a sample (pixel) value bigger than a corresponding threshold.

Fig. 3 shows two curves 38, 40 representing the probability density function (PDF) of a single pixel 34 (curve 38 with solid line) and the probability density function of a superpixel 36 as a combination of eighteen pixel 34 (curve 40 with dotted line) in a diagram wherein probability density pd is plotted as a function of the energy given as an electron equivalent by a number of electrons e . Further on an energy threshold of 10 electrons ($10e$) is marked.

In the following an estimation of the range increase versus the reduction of spatial resolution by use of a "superpixel mode" is given:

Let assume a system which has 1-sigma system noise of 7 electrons. The solid curve 38 in Fig. 3 shows the probability density function (PDF) for noise value for each individual pixel 34. The area 42 under the curve 38 bounded by the threshold value is equal probability to have output value bigger than the threshold. In the given example (threshold = $10e$) the system will report detection in 7.6% of cases while only noise is present - i.e. 7.6% of False Positive (FP) rate.

The same curve/graph could be used to solve reverse task: "what threshold needs to be selected to provide desired False Positive rate?" This formulation is usually one to have practical use. For example, desired $FP < 1\%$ in case of single pixel (curve 38 with solid line) will be achieved with threshold bigger than $16.3e$. In same time $16.3e$ pixel value define the maximum achievable range of the LIDAR device 10.

The other curve 40 (with dotted line) of Fig 3 is the probability density function (PDF) for noise value for eighteen (in numbers: 18) pixels 34 combined. The area 42 under the curve 38 bounded by the threshold value is equal probability to have output value bigger than the threshold for all 18 pixels 34 simultaneously. Solving reverse task - threshold value for $FP < 1\%$ will be threshold = $3.8e$. I.e. it is ~ 4 times smaller number of electrons

compare to single pixel decision, which means the detection range is almost doubled (~x2 detection range).

It is important to understand that all 18 pixels 34 should report detection with given threshold = 3.8e. I.e. the spatial resolution is about 18 times less in direct comparison to non-binned pixel-by-pixel evaluation case. However such sort of resolution reduction is still usable in practical cases.

For example:

- (a) it could be interested to just know there is an object at 200m in ego lane of the vehicle even without ability to see fine details of it i.e. not be able to classify it.
- (b) observation could be split in two stages. First with binned pixels 34 to detect the object and second with knowledge that there is an object (with selected FP rate) at given superpixel run classification task on pattern formed of individual pixels 34.

List of Reference signs

10	LIDAR device
12	transmitting unit
14	receiving unit
16	laser light source
18	laser beam
20	scanning unit
22	micro-mirror
24	control unit
26	optical sensor
28	reflected light
30	evaluation unit
32	pixel matrix
34	pixel
36	superpixel
38	curve
40	curve
42	area
e	electrons
pd	probability density

Claims

1. A LIDAR device (10) for the imaging detection of an area in the vehicle environment of a vehicle, with
a transmitting unit (12) for transmitting a laser beam (18) scanning the area, the transmitting unit (12) comprising a laser light source (16) having a predetermined laser power and a scanning unit (20), and
a receiving unit (14) for receiving light (28) reflected in the vehicle environment, which receiving unit (14) comprises an optical sensor (26) generating individual pixels (34) and an evaluation unit (30) for pixel-based evaluation of the sensor signal of the optical sensor (26),
characterized in that
the optical sensor (26) and/or the evaluation unit (30) is arranged to perform pixel binning to form at least one superpixel (36), wherein the evaluation unit (30) is further arranged to perform superpixel evaluation to obtain an increased detection range mode of the LIDAR device (10).
2. The LIDAR device according to claim 1,
characterized in that
the evaluation unit (30) is arranged to perform the pixel binning and superpixel evaluation in the digital domain.
3. The LIDAR device according to claim 2,
characterized in that
the pixel binning comprises a statistical combination of the corresponding pixels (34) related to the respective superpixel (36).
4. The LIDAR device according to any one of claims 1 to 3,
characterized in that
each of the superpixels (36) includes at least 4 pixels (34).
5. The LIDAR device according to any one of claims 1 to 4,
characterized in that

the evaluation unit (30) is further arranged to perform a pixel-by-pixel evaluation of the pixels (34) in a conventional detection mode.

6. A method for increasing the detection range of a LIDAR device (10) for the imaging detection of an area in the vehicle environment of a vehicle, the LIDAR device (10) comprising:
a transmitting unit (12) for transmitting a laser beam (18) scanning the area, the transmitting unit (12) comprising a laser light source (16) having a predetermined laser power and a scanning unit (20), and
a receiving unit (14) for receiving light (28) reflected in the vehicle environment, which receiving unit (14) comprises an optical sensor (26) generating individual pixels (34) and an evaluation unit (30) for pixel-based evaluation of the sensor signal of the optical sensor (26),
characterized in that
the optical sensor (26) and/or the evaluation unit (30) is performing pixel binning to form at least one superpixel (36), wherein the evaluation unit (30) is further performing superpixel evaluation to obtain an increased detection range mode of the LIDAR device (10).
7. The method according to claim 6,
characterized in that
the evaluation unit (30) performs the pixel binning and superpixel evaluation in the digital domain.
8. The method according to claim 7,
characterized in that
the pixel binning comprises a statistical combination of the corresponding pixels (34) related to the respective superpixel (36).
9. The method according to any one of claims 6 to 8,
characterized in that
each of the superpixels (36) includes at least 4 pixels (34).
10. The method according to any one of claims 6 to 8,

characterized in that
the evaluation unit (30) performs a pixel-by-pixel evaluation of the pixels (34) in a
conventional detection mode.

11. A computer program product comprising computer-executable program code portions having program code instructions configured to execute the method according to one of claims 6 to 10 when loaded into a processor of a computer based evaluation unit (30).

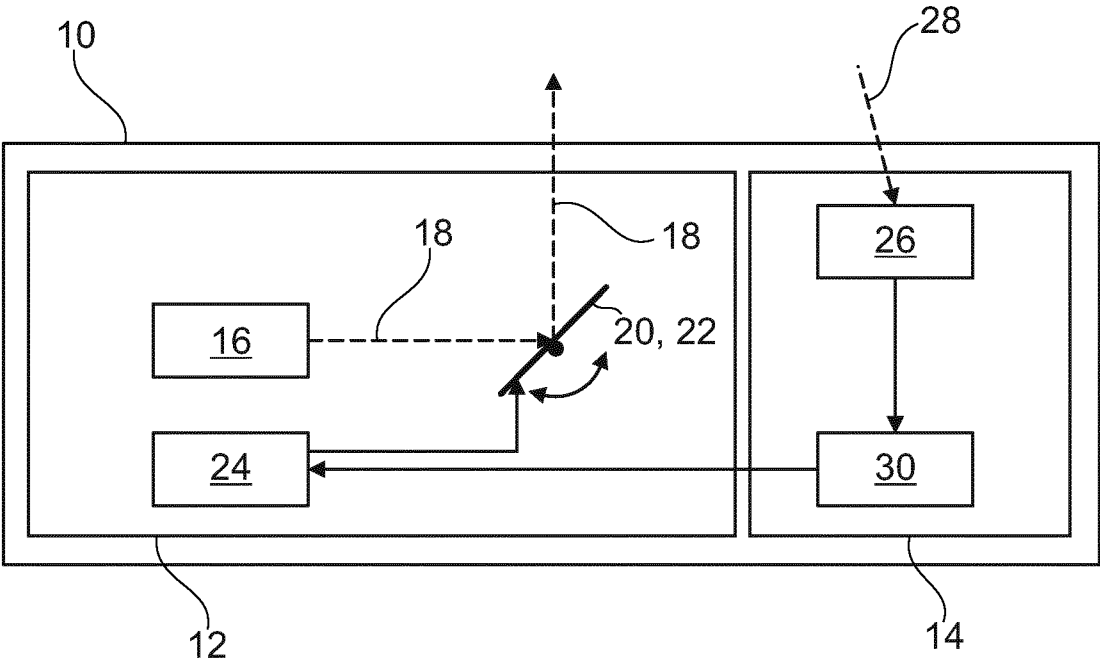


Fig. 1

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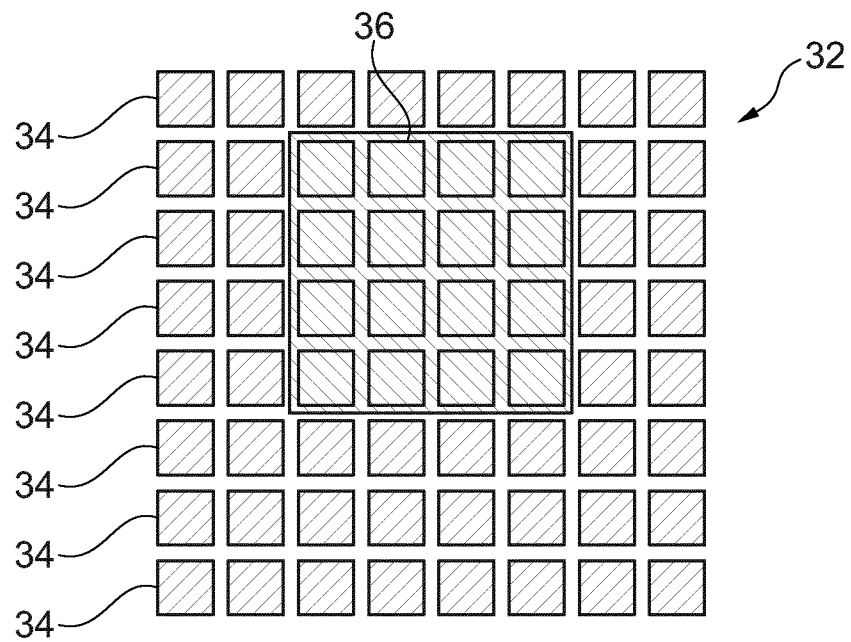


Fig. 2

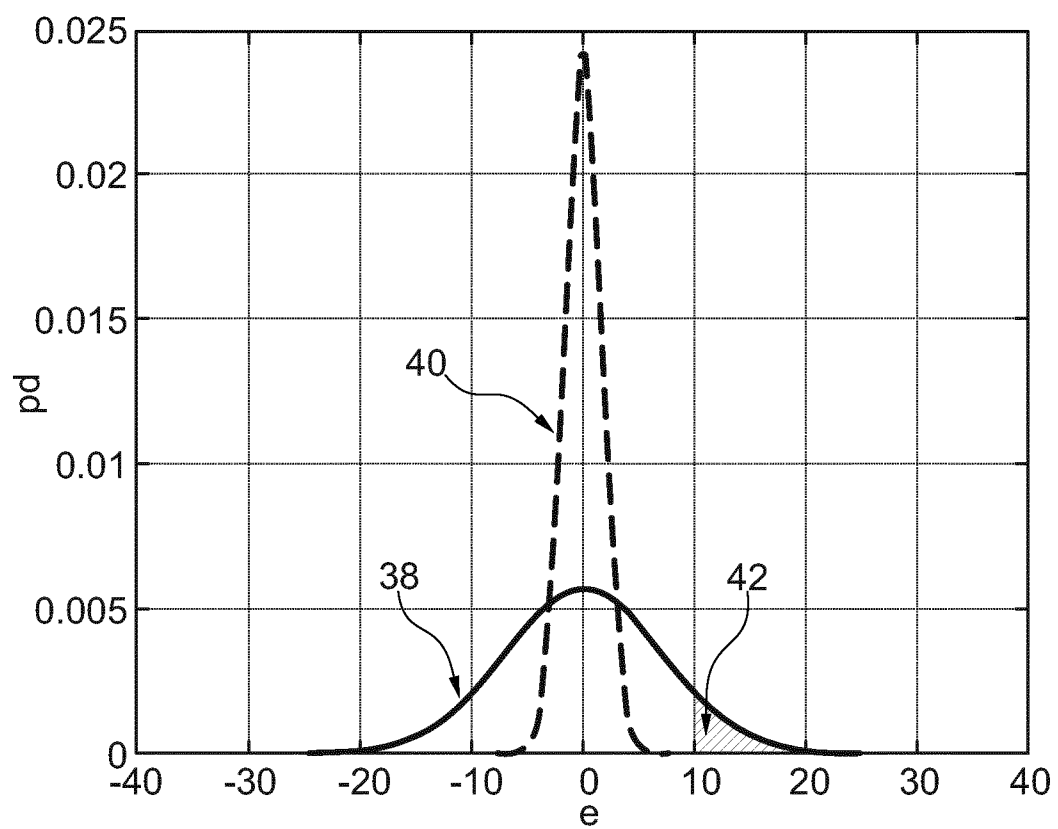


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/056589

A. CLASSIFICATION OF SUBJECT MATTER INV. G01S7/4863 G01S17/931 G01S7/481 G01S17/894 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G01S		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 187 237 A1 (HAMAMATSU PHOTONICS KK [JP]) 19 May 2010 (2010-05-19) abstract paragraphs [0001], [0008], [0011], [0021], [0034], [0069], [0092] -----	1-11
X	US 2015/293226 A1 (EISELE ANDREAS [DE] ET AL) 15 October 2015 (2015-10-15) abstract paragraphs [0017], [0018], [0022] -----	1-11
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 23 April 2020	Date of mailing of the international search report 06/05/2020	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Alberga, Vito	

INTERNATIONAL SEARCH REPORT

Information on patent family members

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