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- b) I am a translator that handles translations for TransPerfect Translations;
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|                                                                                                                       | Continued on last page                                                                     |

(54) [Title of invention] Radar device

(57) [Scope of Claims]  
[Claim 1]

A radar device (1) comprising of a light irradiation means (2) for irradiating light;  
a scanning means (3) for scanning the irradiation light, which is the light irradiated from the light irradiation means, along a preset irradiation light scanning direction;  
a reflected light detection means (5) configured by arranging a plurality of light receiving units in a two-dimensional matrix, for detecting the reflected light of the light irradiated from the light irradiation means for each of the plurality of light receiving units (26);  
and a time measuring means (6) for measuring the flight time, which is the time from when the light irradiation means irradiates light until the light receiving units of the reflected light detection means detects the reflected light;  
the light irradiation means  
irradiates light shaped so that a length along a direction perpendicular to the irradiation light scanning direction is longer than a length along the irradiation light scanning direction;  
scans the reflected light on a light receiving surface in which the plurality of light receiving units are arranged in a two-dimensional matrix, corresponding to the scanning of the irradiation light along the irradiation light scanning direction, where the direction is the scanning direction of the reflected light;  
the reflected light is applied to one light receiving unit along the reflected light scanning direction, and the irradiation light is applied so that the reflected light is irradiated onto the plurality of light receiving units along a direction perpendicular to the reflected light scanning direction;  
the light receiving unit comprises

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a plurality of light receiving elements (51) and a control unit for controlling the operation of each of the plurality of light receiving elements;

the plurality of light receiving elements are arranged in a two-dimensional matrix with respect to the irradiation light scanning direction;

the light receiving unit comprises a readout circuit (52) for reading a detection signal from the light receiving element and converting the detection signal into a digital pulse signal, adjacent to the light receiving element;

the light receiving element is an avalanche photodiode, which operates in the Geiger mode.

[Claim 2]

A radar device according to Claim 1, wherein

the reflected light detection means permits the operation of the light receiving unit irradiated with the reflected light among the plurality of light receiving units according to the position of the reflected light obtained by scanning the irradiation light, and the operation of the light receiving unit to which the reflected light is not irradiated is prohibited.

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[Claim 3]

A radar device according to any one of Claims 1 and 2, wherein the light irradiation means

scans the reflected light on a light receiving surface in which the plurality of light receiving units are arranged in a two-dimensional matrix, corresponding to the scanning of the irradiation light along the irradiation light scanning direction, where the direction is the scanning direction of the reflected light;

the irradiation light is applied a plurality of times within a time period during which the reflected light scans one light receiving unit along the reflected light scanning direction.

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[Claim 4]

A radar device according to any one of Claims 1 and 2, wherein the light irradiation means

scans the reflected light on a light receiving surface in which the plurality of light receiving units are arranged in a two-dimensional matrix, corresponding to the scanning of the irradiation light along the irradiation light scanning direction, where the direction is the scanning direction of the reflected light;

the irradiation light is scanned in an interlaced manner so that the light receiving units irradiated with the reflected light on the light receiving surface are thinned out along the reflected light scanning direction.

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[Claim 5]

A radar device according to any one of Claims 1 to 4, wherein the light receiving unit comprises of a measurement start determination unit that outputs a measurement start detection signal when the number of output signals from the pulse shaping unit corresponding to each of the plurality of the light receiving elements is greater than or equal to a predetermined measurement start determination value.

[Claim 6]

A radar device according to any one of Claims 1 to 5, wherein the scanning means

does not arrange the light receiving elements when the reflected light is applied to the area where the light receiving elements are arranged on the light receiving surface in which the plurality of light receiving units are arranged in a two-dimensional matrix; the scanning speed along the irradiation light scanning direction is slower than when the reflected light is irradiated to an area in which the light receiving element is not disposed.

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[Claim 7]

A radar device according to any one of Claims 1 to 6, comprising of an information acquisition means (99) that obtains the flight time information indicative of the flight time measured by the time measurement means each time the light irradiation means irradiates light;

a histogram preparation means (84) for creating a histogram of the flight time using a plurality of the flight time information obtained by the information acquisition means through multiple irradiations by the light irradiation means;

and a distance determining means (85) for determining the distance to an object reflecting the light irradiated by the light irradiation means based on the histogram generated by the histogram preparation means

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## [Claim 8]

A radar device according to Claim 7, wherein the distance determining means extracts a maximum peak from the histogram, which is the peak with the greatest frequency, and determine the distance based on the flight time corresponding to the maximum peak if the difference between the maximum peak frequency and the other portion of the histogram is greater than or equal to a predetermined determination value.

## [Claim 9]

A radar device according to Claim 8, wherein the distance determining means prohibits the determination of the distance when the frequency of the maximum peak is less than the predetermined determination value,  
and the predetermined determination value is set to have a positive correlation with the irradiation of the background light.

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## [Claim 10]

A radar device according to Claim 8 or 9, wherein the predetermined determination value is set to have a negative correlation with the time-of-flight corresponding to the maximum peak

## [Claim 11]

A radar device according to any one of Claims 8 to 10, wherein the distance determining means determines that the difference between the frequency of the maximum peak and the frequency of the other portions of the histogram, and if the difference between the maximum peak frequency and the other portions of the histogram is less than the predetermined determination value, the past distance determination results by the distance determination means shall be considered to determine whether to determine the distance based on the flight time corresponding to the maximum peak.

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## [Claim 12]

A radar device according to any one of Claims 1 to 11, wherein the radar device is mounted on a vehicle, and the light irradiation means changes the intensity of the irradiation light according to the running speed of the vehicle so that there is a positive correlation between the running speed and the intensity.

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## [Claim 13]

A radar device according to any one of Claims 1 to 12, wherein the radar device is mounted on a vehicle, and the scanning means changes a scanning range scanned along the irradiation light scanning direction in accordance with the running speed of the vehicle so that there is a negative correlation between the running speed and the scanning range.

## [Detailed description of the invention]

## [Technical field]

## [0001]

The present invention relates to a radar device that acquires information about an object that reflects light by irradiating light and receiving the reflected light.

## (Background Technology)

## [0002]

Conventionally, in a radar device that acquires information about an object that reflects light (for example, the distance to the object) by irradiating light and detecting the light reflected by the object, it is known that a coaxial optical system is used in which the optical axis when the irradiated light passes through the radar device (hereinafter referred to as the irradiation optical axis) is aligned with the optical axis when the reflected light passes through the radar device (hereinafter referred to as the reflected optical axis)(see, for example, Non-Patent Literature 1).

## [0003]

However, in a radar device that employs a coaxial optical system, it is difficult to measure the distance from the radar device to a nearby object due to the influence of internally scattered light that is generated when the irradiation light passing through the radar device is reflected inside the radar device.

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[0004]

In order to avoid the effects of internal scattered light as described above, a radar device is known that employs a different axis optical system in which the irradiation optical axis and the reflected optical axis are different (see, for example, Non-Patent Literature 2).

(Prior Art Literature)

[Non-patent literature]

[0005]

[Non-Patent Literature 1] 19th Image Sensing Symposium OS2-03

[Non-Patent Literature 2] OPTICS EXPRESS, Vol. 20, No. 11, pp. 11863-11881

[Summary of Invention]

[Problems to be Solved by the Invention]

[0006]

However, even if a different-axis optical system is employed, it is not possible to avoid the influence of background light such as sunlight entering the radar device. In order to accurately detect an object under conditions where background light is incident in the radar device, it is necessary to irradiate the light multiple times in one location and integrate the results of the detected reflected light.

[0007]

However, depending on the scanning period and irradiation period of the irradiation light, it may not be possible to perform multiple irradiations at one location, and in such cases, the detection results of the reflected light cannot be sufficiently accumulated, and there is a risk that the detection accuracy of the detection results for the light reflecting object may be reduced.

[0008]

The present invention is made in consideration of such problems and is intended to suppress the detection accuracy of the detection results of the radar device from being reduced.

[Means for Solving the Problems]

[0009]

The radar device of the present invention for achieving the above objectives comprises of the light irradiation means, scanning means, reflected light detection means, and time measurement means.

In the radar device of the present invention, the light irradiation means first irradiates the light and the scanning means scans the irradiated light, which is the light irradiated from the light irradiation means, along a predetermined irradiation light scanning direction. The reflected light detection means configured by arranging a plurality of light receiving units in a two-dimensional matrix detects the reflected light of the light irradiated from the light irradiation means for each of the plurality of light receiving units. Further, the time measurement means measures the time of flight, which is the time from the irradiation of light by the light irradiation means to the detection of the reflected light by the light receiving unit of the reflected light detection means. Further, the light irradiation means irradiates light shaped so that the length along the direction perpendicular to the irradiation light scanning direction is longer than the length along the irradiation light scanning direction.

[0010]

In the radar device configured in this manner, the reflected light is irradiated onto the light receiving surface on which the plurality of light receiving units are arranged in a two-dimensional matrix. The reflected light travels in a direction perpendicular to the reflected light scanning direction, with the direction in which the reflected light is scanned on the light receiving surface corresponding to the scanning of the irradiation light along the irradiation light scanning direction, and with a length that is longer than the length along the reflected light scanning direction.

[0011]

Therefore, with one light irradiation by the light irradiation means, it is possible to irradiate a single light receiving unit with the reflected light along the reflected light scanning direction and simultaneously irradiate a plurality of light receiving portions along a direction perpendicular to the reflected light scanning direction with the reflected light (that is, to irradiate the reflected light to more light receiving units than in the case of irradiating the reflected light toward only one light receiving unit).

[0012]

For example, if N (N is an integer equal to or greater than 2) light receiving units are arranged on the light receiving surface along the direction perpendicular to the reflected light scanning direction, in the radar device of the present

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invention, it is possible to irradiate the reflected light onto N light receiving units along the direction perpendicular to the reflected light scanning direction by one light irradiation from the light irradiation means. On the other hand, in the case of irradiating the reflected light toward only one light receiving unit, in order to irradiate the reflected light to N light receiving units along a direction perpendicular to the reflected light scanning direction, N light irradiation must be performed. In the radar device of the present invention, by causing the light irradiation means to perform light irradiation N times, it is possible to irradiate reflected light N times to each of the N light receiving units along the direction perpendicular to the reflected light scanning direction.

[0013]

Therefore, according to the radar device of the present invention, it is possible to increase the number of times that one light receiving unit is irradiated with the reflected light within a certain period of time, and to increase the number of detection results that can be accumulated for one light receiving unit within a certain period of time. As a result, the radar device of the present invention can suppress deterioration in the detection accuracy of the detection result of the radar device obtained by detecting the reflected light.

[Brief Description of Drawings]

[0014]

[FIG. 1] A block diagram showing the configuration of the radar device 1.

[FIG. 2] A perspective view of the radar device 1 and a diagram showing the predetermined scanning angle range and the scanning period.

[FIG. 3] A diagram showing the path of the laser light irradiated from light source 2.

[FIG. 4] A plan view showing a schematic configuration of pixels 26.

[FIG. 5] A circuit diagram showing the configuration of the light receiving element 51 and the readout circuit 52.

[FIG. 6] A block diagram showing the configuration of the pixel data processing unit 31.

[FIG. 7] An image diagram showing an example histogram.

[FIG. 8] A diagram comparing the radar device 1 and the optical cutting method.

[Detailed Description of the Embodiments]

[0015]

Embodiments of the present invention will be described below with reference to the drawings.

The radar device 1 is mounted in a vehicle and comprises of a light source 2, a one-dimensional scanner 3, a scanning control unit 4, a light detection unit 5 and a processing unit 6, as shown in FIG. 1.

[0016]

The light source 2 is composed of, for example, a semiconductor laser diode, and emits pulsed laser light as a radar wave.

The one-dimensional scanner 3 receives a supply of the driving force from the drive source, not shown, and vibrates the mirror 11 (see FIG. 3) about the axis of rotation 12 (see FIG. 3), thereby performing a one-dimensional scan of laser light irradiated from the light source 2 in a predetermined scanning angle range R1 (see FIG. 3). The scanning mechanism of the one-dimensional scanner 3 is composed of a MEMS (Micro Electro Mechanical System) or a micromotor.

[0017]

The scanning controller 4 detects the scanning angle of the one-dimensional scanner 3 and controls the laser light irradiation by the light source 2 and the laser light scanning by the one-dimensional scanner 3 based on this detection result. The scanning control unit 4 also inputs a vehicle speed signal from the vehicle speed sensor indicating the vehicle speed (hereinafter referred to as vehicle speed) of the vehicle equipped with the radar device 1, and controls the light source 2 and the one-dimensional scanner 3 according to the vehicle speed. Further details of the control of the light source 2 and the one-dimensional scanner 3 by the scanning control unit 4 are described below.

[0018]

The light detection unit 5 comprises a two-dimensional pixel array 21 and a decoder 22. The two-dimensional pixel array 21 is composed of a plurality of pixels 26 arranged in a two-dimensional matrix. Pixel 26 outputs a detection signal when the laser light enters its receiving surface. The circuit configuration of pixel 26 is described below.

[0019]

The decoder 22 is a circuit for selecting the pixels 26 used for detecting the laser light. The decoder 22 includes a selection control line CL provided for each column of the matrix comprised of a plurality of pixels 26. The selection

control line CL is connected to all of the pixels 26 arranged in the corresponding column. The decoder 22 selects the pixels 26 in columns by applying a selective control voltage  $V_{SEL}$  to the selective control line CL.

[0020]

The processing unit 6 measures the distance to the object that reflected the laser beam based on the difference between the time when the light source 2 irradiated the pulsed laser beam and the time when the reflected laser beam was detected by the light detection unit 5.

[0021]

The processing unit 6 includes a plurality of pixel data processing unit 31. A pixel data processing unit 31 is provided for each row of matrix consisting of a plurality of pixels 26. The pixel data processing unit 31 inputs a detection signal from each of the plurality of pixels 26 arranged in the corresponding row. Further details of the configuration and data processing of the pixel data processing section 31 are described below.

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[0022]

As shown in FIG. 2 (a), the radar device 1 irradiates a rectangularly shaped laser light with a direction perpendicular to the scanning direction SD1 (see the scanning light SL). The radar device 1 also irradiates pulsed laser light, for example, with a pulse width of 4 ns and an emission period of 4  $\mu$ s in the present embodiment.

[0023]

The predetermined scanning angle range R1 of this embodiment is  $-27^\circ$  to  $+27^\circ$ , as shown in FIG. 2 (b). Also, the scanning period of the present embodiment is 50 ms, and after scanning from  $-27^\circ$  to  $+27^\circ$  in 40 ms, it returns from  $+27^\circ$  to  $-27^\circ$  in 10 ms.

[0024]

As also shown in FIG. 3, the light source 2 irradiates the laser light towards the one-dimensional scanner 3 via the collimating lens 41 (see light L1). The laser light that has reached the one-dimensional scanner 3 is reflected by the mirror 11, and is irradiated as a radar wave in a direction corresponding to the scanning angle of the mirror 11 (see light L2). Thereafter, when the laser light emitted forward of the vehicle reaches an object located in front of the vehicle (hereinafter also referred to as a front object) (see scanning light SL), the laser light is reflected by this front object. Then, the reflected laser light (hereinafter also referred to as the reflected light) reaches the two-dimensional pixel array 21 after passing through the light receiving lens 42 (see light L3).

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[0025]

As described above, the laser light is shaped into a rectangular shape. Thus, on the light receiving surface RP of the two-dimensional pixel array 21, the reflected light shaped in a rectangular shape with a direction perpendicular to the scanning direction SD2 of the reflected light is reached (see reflected light RL).

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[0026]

The longitudinal length of the irradiated light irradiated by the radar device 1 is then set such that the longitudinal length of the reflected light shaped into a rectangular shape is longer than the short direction length of the light receiving surface RP formed into the rectangular shape.

[0027]

As also shown in FIG. 4, the pixel 26 comprises four light receiving elements 51 and a readout circuit (Read Out Circuit) 52 provided corresponding to each of the four light receiving elements 51. The light receiving element 51 of this embodiment is a single photon avalanche diode (SPAD). The SPAD is an avalanche photodiode operating in Geiger mode, capable of detecting single photon incidence. A pre-set reverse voltage  $V_{SPAD}$  is applied between the anode and the cathode of the SPAD to be greater than or equal to the yield voltage (see FIG. 5). When photons enter the SPAD receiving elements 56 in this state, the SPAD generates an avalanche current. As such, the SPAD can output a signal indicating that the photon has detected the incident.

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[0028]

The readout circuit 52 is also a circuit that converts the signal output by the light receiving element 51 into a digital pulse signal when the laser light enters the light receiving element 51. The circuit configuration of readout circuit 52 is described below.

[0029]

The four light receiving elements 51 are also arranged in a two-dimensional matrix such that two light receiving elements 56 are arranged in the column direction and two light receiving elements 56 are arranged in the row direction. In addition, four readout circuits 52 are arranged adjacent along the row direction D1 relative to the corresponding

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light receiving element 51. However, the readout circuit 52 is arranged such that two light receiving elements 51 are arranged along the row direction D1 between the two readout circuits 52 arranged in the same row. That is, four light receiving elements 51 are arranged in the central portion of the pixel 26 and four readout circuits 52 are arranged in the peripheral portion of the pixel 26.

[0030]

In the present embodiment, the radar device 1 emits, for example, 16 pulsed laser light within a period of time during which the reflected light scans the region E1 in which the four light receiving elements 51 are disposed at one pixel 26 along the scanning direction SD2.

[0031]

As also shown in FIG. 5, the readout circuit 52 comprises a quench resistor 61, a digital transducer 62, an inverter 63, a buffer 64, and a selector 65. 10

The quench resistor 61 is an N-channel type MOSFET (hereinafter referred to as a N-type transistor). The drain of the N-type transistor constituting the quench resistance 61 is connected to the anode of the SPAD constituting the light receiving element 51 and the source is grounded via the selector 65. A quench voltage  $V_{QCH}$  set in advance is applied to the gate of the N-type transistor so that the N-type transistor acts as a quench resistor.

[0032]

The digital transducer 62 comprises a resistor 71 and an N-type transistor 72. The power supply voltage  $V_{DD}$  is applied to the drain of the N-type transistor 72 via the resistor 71, and the source is grounded. The gate of the N-type transistor 72 is also connected to the connection point CP1 of the anode of the SPAD and the quench resistor 61.

[0033]

The inverter 63 includes a P-channel type MOSFET (hereinafter referred to as a P-type transistor) 73 and an N-type transistor 74. The drain of the P-type transistor 73 is subjected to a supply voltage  $V_{DD}$ , and the source is connected to the drain of the N-type transistor 74. The gate of the P-type transistor 73 and the gate of the N-type transistor 74 are connected to the connection point CP2 between the drain and the resistor 71 of the N-type transistor 72. The source of the N-type transistor 74 is grounded. 20

[0034]

The buffer 64 is a circuit for impedance conversion. The input terminal of the buffer 64 is then connected to the connection point CP3 between the source of the P-type transistor 73 and the drain of the N-type transistor 74.

[0035]

The selector 65 is an N-type transistor. The drain of the N-type transistor that constitutes the selector 65 is connected to the source of the N-type transistor that constitutes the quench resistor 61 and the source is grounded. Also, the gate of the N-type transistor is connected to the decoder 22. The selector 65 is turned on when the selection control voltage  $V_{SEL}$  is applied from the decoder 22. 30

[0036]

Next, the operation of the readout circuit 52 constructed in this manner will be described.

First, when the selector 65 is in the ON state, a reverse voltage  $V_{SPAD}$  is applied to the SPAD, causing the light receiving element 51 to be in an operational state. On the other hand, if the selector 65 is in the OFF state, the reverse voltage  $V_{SPAD}$  is not applied to the SPAD and operation of the light receiving element 51 is inhibited.

[0037]

Then, when the selector 65 is in the ON state, the reflected light enters the light receiving element 51 and an avalanche current is generated; the avalanche current flows to the quench resistor 61 and the voltage at the connection point CP1 increases. Then, when the voltage at the connection point CP1 is higher than the ON voltage of the N-type transistor 72, the N-type transistor 72 is turned ON, and the voltage at the connection point CP2 changes from the supply voltage  $V_{DD}$  to 0 V. 40

[0038]

This changes the voltage of the connection point CP3 from 0 V to the supply voltage  $V_{DD}$  as the P-type transistor 73 changes from the OFF state to the ON state and the N-type transistor 74 changes from the ON state to the OFF state.

[0039]

This causes the voltage  $V_{OUT}$  at the output terminal of buffer 64 to be at a high level. 50

Then, as the voltage rise at connection point CP1 continues, the voltage applied between the anode and cathode of

the SPAD becomes less than the yield voltage and the avalanche current stops. This causes the voltage at the connection point CP1 to drop and the N-type transistor 72 to be turned OFF, and the voltage  $V_{OUT}$  at the output terminal of the buffer 64 to be at a low level.

[0040]

In this way, the readout circuit 52 outputs a digital pulse signal at a high level after the N-type transistor 72 is turned ON due to the occurrence of reflected light and the avalanche current until the avalanche current stops and the N-type transistor 72 is turned OFF.

[0041]

Also shown in FIG. 6, the pixel data processing unit 31 comprises of a pulse shaping unit 81, a measurement start determination unit 82, a time measurement unit 83, a histogram preparation unit 84, a distance determination unit 85, and a data storage unit 86.

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[0042]

The pulse shaping unit 81 comprises a plurality of D-type flip-flop circuits 91 provided corresponding to each of the plurality of light receiving elements 51 constituting the pixel 26 and a plurality of delay circuits 92 provided corresponding to each of the plurality of D-type flip-flop circuits 91.

[0043]

The D-type flip-flop circuits 91 includes the input terminal D, the clock terminal CLK, the output terminal Q, and the reset terminal CLR. Then, the input terminal D is applied at a high level. The digital pulse signal of the corresponding light receiving element 51 is the input to the clock terminal CLK through the readout circuit 52. Therefore, the D-type flip-flop circuits 91 initiate the output of the high level signal from output terminal Q at the timing when the above digital pulse signal is the input to the clock terminal CLK.

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[0044]

The signal output from output terminal Q is the input to the reset terminal CLR via the delay circuit 92. The delay circuit 92 delays the input signal by a preset delay time and outputs the delayed signal. Therefore, the high level signal is the input to the reset terminal CLR after the delay time above has elapsed because the output terminal Q outputs a high level signal. Then, when the high level signal enters the reset terminal CLR, the D-type flip-flop circuit 91 stops outputting the high level signal. That is, when the digital pulse signal of the corresponding light receiving element 51 is the input, the D-type flip-flop circuit 91 outputs a pulse signal that remains at a high level for the above-described delay time. This pulse signal is hereinafter referred to as a light reception detection signal.

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[0045]

The measurement start determination unit 82 comprises of an input count determination circuit 93, a plurality of D-type flip-flop circuits 94, and an addition circuit 95.

The input count determination circuit 93 receives the light receiving detection signal from each of the D-type flip-flop circuits 91 that make up the pulse shaping unit 81. The input count determination circuit 93 outputs a pulse signal that continues to be high for a predetermined period of time when the number of input of the light reception detection signal is equal to or greater than a predetermined measurement start determination value (2 in the present embodiment). This pulse signal is hereinafter referred to as a measurement start detection signal.

[0046]

A D-type flip-flop circuit 94 is provided corresponding to each of a plurality of D-type flip-flop circuits 91 that forms the pulse shaping unit 81. It should be noted that FIG. 6 shows one D-type flip-flop circuit 94 for simplification of illustration.

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[0047]

The D-type flip-flop circuit 94 includes an input terminal D, a clock terminal CLK, and an output terminal Q. The above light reception detection signal of the corresponding D-type flip-flop circuit 91 is the input to the input terminal D. The measurement start detection signal of the input count determination circuit 93 is the input to the clock terminal CLK. For this reason, the D-type flip-flop circuit 94 outputs a high level signal when the above light reception detection signal enters the input terminal D at the timing when the above measurement start detection signal is the input to the clock terminal CLK.

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[0048]

The addition circuit 95 inputs the signal output from the output terminal Q for each of the plurality of D-type flip-flop circuits 94 that make up the measurement start determination unit 82. The addition circuit 95 then measures the number of high-level signals among the input signals, and outputs a digital signal indicating the measurement value. Hereinafter, the signal indicating the above measurement value is referred to as the light reception number signal.

In FIG. 6, because the number of light receiving elements 51 is four, the count value is any one of 0, 1, 2, 3, and 4. Because three bits are required to digitally represent integer values from 0 to 4, the addition circuit 95 has three signal output lines for outputting the digital signal representing the count value.

The time measurement unit 83 includes a Time to Digital Converter (TDC) 96, a plurality of D-shaped flip-flop circuits 97, a delay circuit 98, and a data generation unit 99.

The TDC 96 enters the above measurement start detection signal from the input count determination circuit 93. The TDC 96 then measures the time from when the light source 2 irradiates the pulsed laser beam to when the measurement start detection signal is inputted, and outputs a digital signal indicating the measured time. It should be noted that the TDC 96 of the present embodiment comprises 11 signal output lines for outputting 11 bits of digital signal. The digital signal output by the TDC 96 is hereinafter referred to as a time measurement signal.

A D-type flip-flop circuit 97 is provided corresponding to each of the plurality of signal output lines provided by the addition circuit 95. It should be noted that FIG. 4 shows one D-type flip-flop circuit 97 for simplification of illustration.

The D-type flip-flop circuit 97 includes an input terminal D, a clock terminal CLK, and an output terminal Q. A signal is inputted to the input terminal D from the corresponding signal output line. In addition, the above measurement start detection signal output from the input count determination circuit 93 is inputted to the clock terminal CLK via the delay circuit 98. The delay circuit 98 delays the input signal by a preset delay time and outputs the delayed signal. The delay time of the delay circuit 98 is set so that the above measurement start detection signal enters the D-type flip-flop circuit 97 immediately after the signal from the addition circuit 95 enters to the D-type flip-flop circuit 97.

Accordingly, the D-type flip-flop circuit 97 outputs a digital signal (light reception number signal) indicating the count result by the addition circuit 95 when the above measurement start detection signal is inputted.

The data generation unit 99 enters the time measurement signal from the TDC 96 and the light reception number signal from the D-type flip-flop circuit 97. The data generation unit 99 then generates and outputs data corresponding to the time measurement signal and the light reception number signal.

The histogram preparation unit 84 creates a histogram by collecting the data input from the data generation unit 99 every time the reflected light scans the light receiving surface of one pixel 26 along the scanning direction SD2 (hereinafter referred to as the unit scanning time).

As shown in FIG. 7, the time measured by the TDC 96 is on the horizontal axis, and the vertical axis represents the number of light receptions detected by the light receiving element 51 of the pixel 26 integrated within a unit scanning time (hereinafter referred to as the photometric integration value).

The distance determination unit 85 uses a histogram created by the histogram preparation unit 84 to determine the distance to an object (forward object) located in front of the vehicle. Specifically, peaks are first extracted from the histogram (in FIG. 7, the peak PK1, PK2, and PK3 are extracted). Thereafter, if the difference between the photometric integration value of the highest peak (peak PK1 in FIG. 7) and the photometric integration value of the other peaks (peak PK2 and PK3 in FIG. 7) is greater than or equal to the predetermined determination value, the distance is calculated based on the time corresponding to the highest peak. The calculated distance is then determined to be the distance to the forward object, and outputs the distance data indicative of the distance to the forward object.

The distance determination unit 85 also calculates the irradiation of the background light based on the photometric integration value of this portion using the portion other than the peak in the histogram (see background light BG in

FIG. 7) as the background light. The distance determination unit 85 then determines the predetermined determination value by referring to the predetermined determination value table in which the correspondence between the irradiation of the background light and the predetermined determination value is set in advance. In the predetermined determination value table, the higher the illuminance of the background light, the higher the predetermined determination value.

[0058]

Furthermore, the distance determination unit 85 determines whether the photometric integration value of the highest peak (peak PK1 in FIG. 7) is equal to or greater than the predetermined determination value. Here, if the photometric integration value of the highest peak is less than the predetermined determination value, an output is made assuming that the object does not exist.

[0059]

The data storage unit 86 temporarily stores the data output by the data generation unit 99 (data corresponding to the time indicated by the time measurement signal and the numerical value indicated by the light reception number signal) until the distance determination unit 85 determines the distance.

[0060]

Further, the scanning control unit 4 also scans along the scanning direction SD2 slower when the reflected light is scanning along the scanning direction SD2 in the region E1 (see FIG. 4) where the four receiving elements 51 are disposed at the receiving surface RP of the two-dimensional pixel array 21 (see FIG. 3) than when the reflected light is scanning along the region other than the aforementioned region E1.

[0061]

The scanning control unit 4 also changes the light emission intensity of the light source 2 according to the vehicle speed. Specifically, the scanning control unit 4 decreases the emission intensity when the vehicle speed is low, and increases the emission intensity when the vehicle speed is high.

[0062]

The scanning control unit 4 also changes the predetermined scanning angle range R1 of the one-dimensional scanner 3 according to the vehicle speed. Specifically, the scanning control unit 4 increases the predetermined scanning angle range R1 when the vehicle speed is low, and decreases the predetermined scanning angle range R1 when the vehicle speed is high.

[0063]

The light detection unit 5 also obtains scan angle information indicative of the scan angle of the one-dimensional scanner 3 from the scanning control unit 4, and based on this scan angle information, the unit determines the row in which reflected light is irradiated on the light receiving surface RP of the two-dimensional pixel array 21. The light detection unit 5 then applies a selective control voltage  $V_{SEL}$  to the selective control line CL corresponding to the determined row.

[0064]

The radar device 1 configured as described above includes a light source 2, a one-dimensional scanner 3, a light detection unit 5 and a processing unit 6.

In the radar device 1, the light source 2 first irradiates the laser light, and the one-dimensional scanner 3 scans the irradiation light, which is the laser light emitted from the light source 2, along the scanning direction SD1. The light detection unit 5, which is configured to arrange the plurality of pixels 26 in a two-dimensional matrix, detects the reflected light of the laser beam emitted from the light source 2 for each of the plurality of the pixels 26. Further, the processing unit 6 measures the time of flight from when the light source 2 irradiates the laser light until when the pixels 26 of the light detection unit 5 detect the reflected light. The light source 2 also irradiates a rectangularly shaped laser light such that the length along the direction perpendicular to the scanning direction SD1 is longer than the length along the scanning direction SD1.

[0065]

In the radar device 1 configured as described above, the reflected light is irradiated onto the light receiving surface RP on which a plurality of pixels 26 are arranged in a two-dimensional matrix. This reflected light then extends along the direction perpendicular to the scanning direction SD2 in which the reflected light is scanned on the light receiving surface RP corresponding to the scanning of the irradiation light along the scanning direction SD1 is longer than the length along the scanning direction SD2.

[0066]

Therefore, a single laser light irradiation by the light source 2 can irradiate the reflected light to one pixel 26 along

the scanning direction SD2 and simultaneously irradiate the reflected light to multiple pixels 26 along a direction perpendicular to the scanning direction SD2 (that is, to irradiate more pixels 26 with the reflected light than in the case of irradiating only one pixel 26 with the reflected light).

[0067]

For example, if N (N is an integer of 2 or more) pixels 26 are disposed in the light receiving surface RP along a direction perpendicular to the scanning direction SD2, the radar device 1 may irradiate N pixels 26 with the reflected light along a direction perpendicular to the scanning direction SD2 in a single laser light irradiation by the light source 2. On the other hand, when irradiating the reflected light toward only one pixel 26, N laser light irradiation is required to irradiate N pixels 26 along a direction perpendicular to scanning direction SD2. The radar device 1 can then irradiate the reflected light N times for each of the N pixels 26 along a direction perpendicular to the scanning direction SD2 by causing the light source 2 to irradiate N times.

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[0068]

Thus, according to the radar device 1, it is possible to increase the number of times one pixel 26 is irradiated with the reflected light within a certain period of time, and to increase the number of detection results that can be accumulated for one pixel 26 within a certain period of time. As a result, the radar device 1 can suppress deterioration in the detection accuracy of the detection result of the radar device 1 obtained by detecting the reflected light.

[0069]

The light detection unit 5 also permits the operation of the pixel 26 to which reflected light is irradiated by applying a selective control voltage  $V_{SEL}$  to the corresponding selection control line CL, while prohibiting operation of the pixel 26 to which the reflected light is not irradiated by not applying a selective control voltage  $V_{SEL}$  to the corresponding selection control line CL. As a result, it is possible to reduce the influence of the detection signal output due to erroneous detection in the pixel 26 not irradiated with the reflected light on the detection result of the light detection unit 5.

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[0070]

The light source 2 also irradiates the laser light a plurality of times (16 times in this embodiment) within a unit scanning time during which the reflected light scans one pixel 26 along the scanning direction SD2. For this reason, in the processing unit 6, the histogram preparation unit 84 can create a histogram within the unit scanning time. Therefore, the data output from the time measurement unit 83 to the histogram preparation unit 84 can be discarded after the unit scanning time has elapsed. That is, the storage capacity of the data storage unit 86 may be such that one column of data of the two-dimensional pixel array 21 configured in the two-dimensional matrix can be stored by the number of pulsed laser emission times (accumulated number) within a unit scanning time.

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[0071]

The pixel 26 also includes a plurality of (four in the present embodiment) light receiving elements 51. This makes it possible to employ a detection method in which the reflected light is detected by the pixels 26 when light is detected simultaneously by a plurality of (for example, two) light receiving elements 51. As a result, erroneous detection of pixels 26 can be reduced. This is because the possibility of erroneous detection by the plurality of light receiving elements 51 at the same time is low.

[0072]

The pixels 26 also includes a readout circuit 52 that reads the signals from the light receiving element 51, and each of the four light receiving elements 51 is arranged such that the readout circuit 52 is not located between adjacent light receiving elements 51. This can increase the likelihood that the reflected light will enter into at least two light receiving elements 51 simultaneously.

[0073]

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In the one-dimensional scanner 3, when the area E1 where the light receiving element 51 is arranged on the light receiving surface RP is irradiated with the reflected light, the scanning speed is made slower than when the area where the light receiving element 51 is not arranged is irradiated with the reflected light. This can increase the number of times the reflected light is irradiated to the light receiving element 51 within a unit scanning time.

[0074]

The data generator 99 also acquires data in which the time measurement signal measured by the TDC 96 is associated with the light reception number signal output from the D-type flip-flop circuit 97 each time the light source 2 irradiates the laser beam. The histogram preparation unit 84 then integrates the number of received light signals for each TDC resolution time acquired by the data generation unit 99 by the number of times the laser light is emitted,

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and creates a histogram. Further, the distance determination unit 85 determines the distance to the object that reflected the laser light emitted by the light source 2 based on the histogram created by the histogram preparation unit 84. When a histogram is created by aggregating the results of the laser light multiple times in this manner, the frequency of the light reception number signal detected based on the reflected light is higher than that of the other light reception number signal in the prepared histogram. This is because the time measurement signal detected based on the reflected light is approximately constant over multiple irradiations, while the time measurement signal detected based on the background light varies randomly. Thus, the influence of background light can be reduced in distance determination.

[0075]

Moreover, due to the characteristics of the SPAD, there is a possibility that it will respond even if no light is incident, and there is a possibility that it will not respond even if light is incident. In order to reduce the effect of such characteristics on the detection results, it is necessary to create a histogram using the light reception number signal for each TDC resolution time obtained from multiple irradiations.

[0076]

The distance determination unit 85 also extracts the maximum peak, which is the peak with the highest frequency, from the histogram, and determines the distance based on the flight time corresponding to the maximum peak if the difference between the frequency of the maximum peak (photometric integration value) and the frequency of other portions of the histogram is equal to or greater than the predetermined determination value. Accordingly, it is possible to determine whether or not the flight time is detected based on the reflected light by a simple method of determining whether or not it is equal to or greater than the predetermined determination value.

[0077]

In addition, the distance determination unit 85 prohibits the determination of the distance when the maximum peak frequency is less than the predetermined determination value, and the predetermined determination value is set to have a positive correlation with the illuminance of the background light. In addition, "a positive correlation between the illuminance of the background light and the predetermined determination value" not only includes the continuous increase of the predetermined determination value as the illuminance of the background light increases, but also includes the stepwise decrease of the predetermined determination value as the illuminance of the background light increases. As a result, the greater the illuminance of the background light, the greater the frequency of the maximum peak for determining the time-of-flight detected based on the reflected light. Thus, due to the increased illumination of the background light, it is possible to suppress the occurrence of a situation where the flight time detected based on the background light is determined to be the flight time detected based on the reflected light.

[0078]

The light source 2 also changes the intensity of the laser light according to the vehicle speed so that there is a positive correlation between the vehicle speed and the intensity of the laser light. In addition, "a positive correlation between the vehicle speed and the intensity of the laser beam" not only includes a continuous increase in the intensity of the laser light as the vehicle speed increases, but also a stepwise decrease in the intensity of the laser light as the vehicle speed increases. As a result, when the vehicle speed is low and it is necessary to consider the presence of pedestrians in the vicinity of the vehicle, the intensity of the laser light can be reduced, thus avoiding situations in which pedestrians are irradiated with a high-intensity laser light. In addition, in situations when the vehicle speed is high and it is generally necessary to detect the presence of a vehicle in front as soon as possible, the intensity of the laser light is increased, making it possible to detect the distant vehicle.

[0079]

The one-dimensional scanner 3 also changes the predetermined scanning angle range R1 to have a negative correlation between the vehicle speed and the predetermined scanning angle range R1 depending on the vehicle speed. It should be noted that "having a negative correlation between the vehicle speed and the predetermined scanning angle range R1" means not only that the predetermined scanning angle range R1 continuously decreases as the vehicle speed increases, but also that the predetermined scanning angle range R1 decreases gradually as the vehicle speed increases. It also includes the reduction of the predetermined scanning angle range R1. As a result, when the vehicle speed is reduced and it is necessary to consider the presence of pedestrians around the vehicle, the predetermined scanning angle range R1 becomes large, and pedestrians around the vehicle can be detected as early as possible. In addition, when the vehicle speed is high and it is generally necessary to detect a vehicle ahead, the predetermined scanning angle range R1 is reduced, and areas where there is a high possibility that no vehicle exists ahead can be excluded

from the scanning range, so distant vehicles can be detected as early as possible.

[0080]

In the embodiment described above, the light source 2 is a light illumination means in the present invention, the one-dimensional scanner 3 is a scanning means in the present invention, the light detection unit 5 is a reflected light detection means in the present invention, the processing unit 6 is a time measurement means in the present invention, the pixel 26 is a light receiving unit in the present invention, the readout circuit 52 is a reading circuit in the present invention, the data generation unit 99 is an information acquisition means in the present invention, the histogram preparation unit 84 is a histogram preparation means in the present invention, and the distance determination unit 85 is a distance determination means in the present invention.

[0081]

Although one embodiment of the invention has been described above, the invention is not limited to the above embodiments, and various forms can be taken as long as they fall within the technical scope of the invention.

For example, in the above embodiment, a determination value was shown to be a constant value. However, the determination value may be set to have a negative correlation with the flight time corresponding to the highest peak (peak PK1 in FIG. 7). It should be noted that "having a negative correlation between the flight time and the determination value" means not only that the determination value continuously decreases as the flight time increases, it also includes the stepwise reduction of the determination value as the flight time increases. For example, the determination value may be inversely proportional to the flight time (i.e. distance) or inversely proportional to the square of the flight time (i.e. distance). As a result, erroneous detection of forward objects positioned near the radar device can be reduced, and the detection probability of forward objects positioned far from the radar device can be improved.

[0082]

Also, in the above embodiment, if the difference between the photometric integration value of the highest peak (peak PK1 in FIG. 7) and the photometric integration value of the other peaks (peak PK2 and PK3 in FIG. 7) is equal to or greater than the determination value, the distance is calculated based on the time corresponding to the highest peak. However, even if the above difference is less than the determination value, the past distance determination result (for example, the result from one scanning cycle before to the current time) may be referred to so that if an object was present at the same distance, the distance may be calculated based on the time corresponding to the highest peak.

[0083]

In the above embodiment, it is also shown that one pixel 26 in a two-dimensional pixel array 21 composed of a plurality of pixels 26 arranged in a two-dimensional matrix is emitted multiple times (16 times in the present embodiment) in a time (unit scanning time) when reflected light is scanned along the scanning direction SD2. In this case, as mentioned above, a storage capacity is required to store data for one column of the two-dimensional pixel array 21 configured in a two-dimensional matrix for the number of pulse laser emission times (accumulated number) within a unit scanning time.

[0084]

On the other hand, when the scanning speed of the one-dimensional scanner 3 is high and, for example, one pulsed laser beam is emitted within the unit scanning time, the histogram preparation unit 84 requires the cumulative number of times  $x$  the time of the scanning period in order to create the histogram. Therefore, it is not possible to discard the data output from the time measurement unit 83 to the histogram preparation unit 84 until the time of this cumulative number of times  $x$  the scanning period has elapsed. That is, a storage capacity is required that can store data for all columns of the two-dimensional pixel array 21 configured in a two-dimensional matrix.

[0085]

Therefore, in the radar device 1, when the scanning speed of the one-dimensional scanner 3 is high and the number of pulsed laser light emissions within a unit scanning time is small, the light receiving surface RP of the two-dimensional pixel array 21 is irradiated with reflected light. It is preferable to scan the irradiation light in an interlaced manner so as to thin out the columns to be scanned. As a result, there is no need to store the data for the thinned-out columns, and an increase in the storage capacity of the data storage unit 86 can be suppressed.

[0086]

Also in the above embodiments, a bandpass filter corresponding to the wavelength of the pulsed laser light may be provided to eliminate the effect of background light.

Further, in the above embodiments, some of the elements (for example, the inverter 63 and the buffer 64) that make up the readout circuit 52 may be extended by wiring so as to be located outside the light receiving surface RP of the two-dimensional pixel array 21. In addition, extending with wiring increases the signal delay, and even between the pixels 26 of the same row connected to the pixel data processing unit 31, there is a possibility that the difference in the transmission time of the signal transmitted between the pixels 26 and the pixel data processing section 31 becomes large. Therefore, a mechanism for correcting the difference in transmission time between the pixels 26 in the same row may be provided.

[0087]

Further, in the above embodiment, some of the elements that make up the readout circuit 52 may be arranged on the back side of the light receiving surface RP of the two-dimensional pixel array 21 by Through Silicon Via, Back Side Illumination, etc.

[0088]

In addition, in the above-described embodiment, although a rectangular shaped laser beam is shown, an oval shaped laser beam may be used.

Also, the configuration of the radar device 1 in the above embodiments is similar to the optical cutting method as shown in FIG. 8. However, the radar device 1 and the light-section method have different circuit configurations due to different ranging methods. The light cutting method also requires a memory of the entire area.

[Reference Signs List]

[0089]

1 ...Radar device, 2 ...Light irradiation means, 3 ... one-dimensional scanner, 4 ...Scanning control unit, 5 ...Light detection unit, 6 ...Processing unit, 26 ...Pixels

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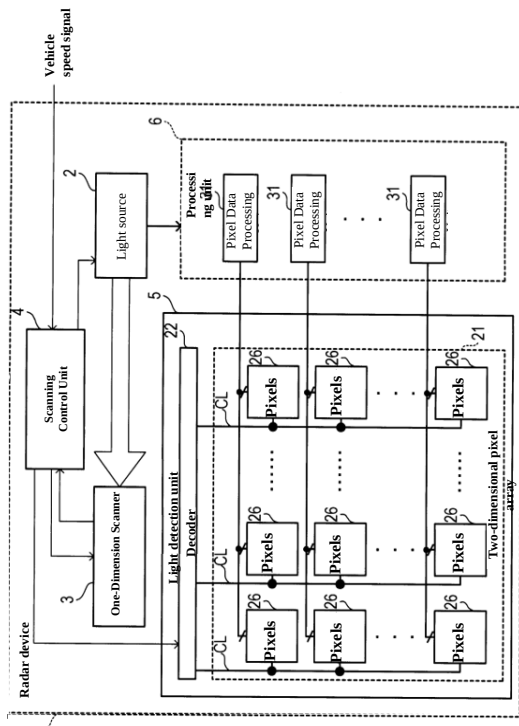
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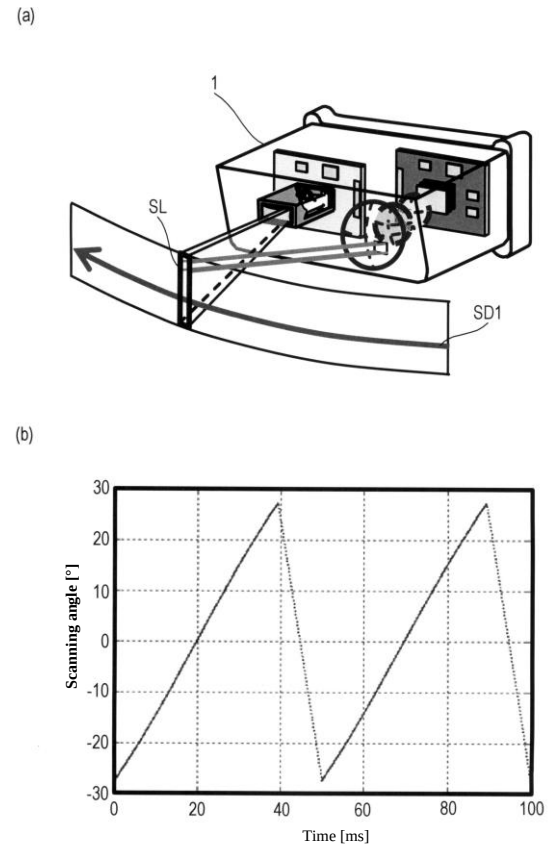
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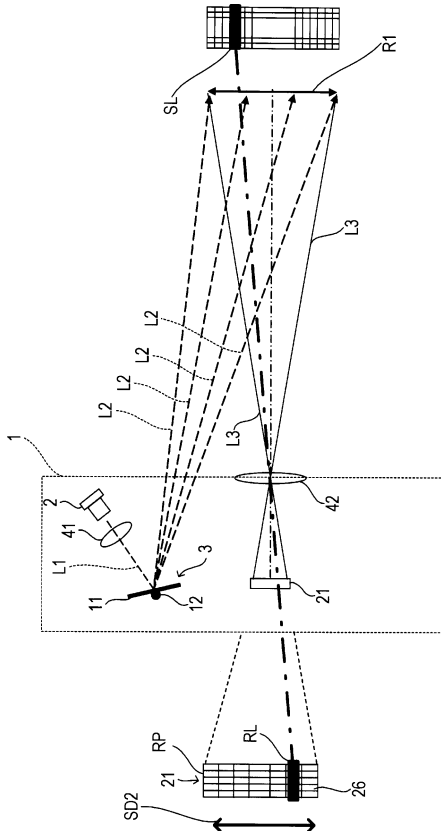
0 [FIG. 1]



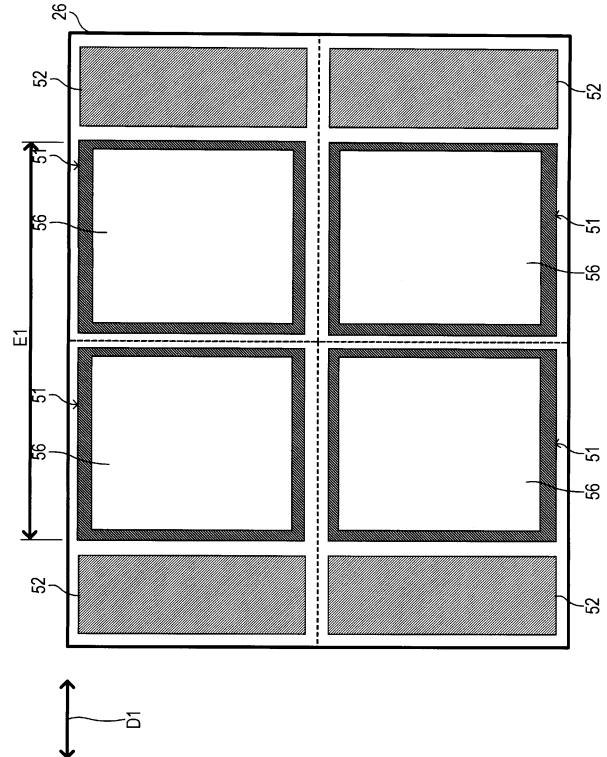
[FIG. 2]



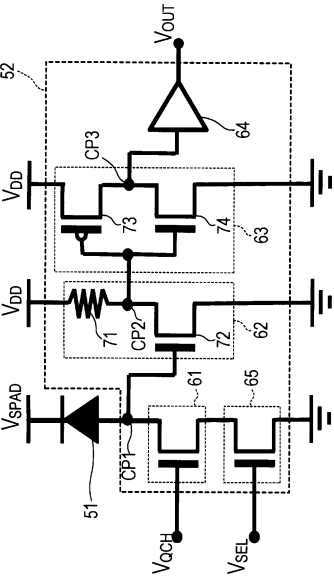
[FIG. 3]



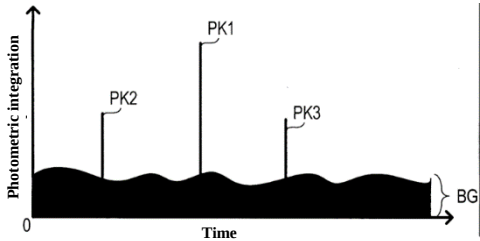
[FIG. 4]



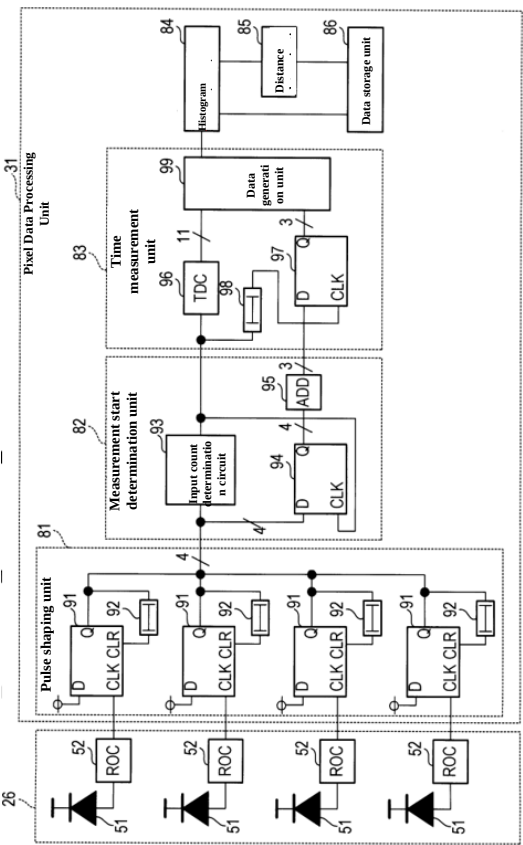
[FIG. 5]



[FIG. 7]



[FIG. 6]



[FIG. 8]

| Ranging | Light cutting          |                     | Radar device 1                         |            |                |           |
|---------|------------------------|---------------------|----------------------------------------|------------|----------------|-----------|
|         | Triangulation by image |                     | TOF ranging method (ranging from light |            |                |           |
| Block   | One-<br>..             | Two-<br>..          | One-<br>..                             | Two-<br>.. | Pulse emission | Memory (1 |
| ..      | Continuous             | ADC                 | Peak detector                          | TDC        |                |           |
|         | Image                  | Memory (all pixels) |                                        |            |                |           |

Continued from front page

Examiner Nobuhiro Ukezono

- (56) References Japanese Patent Application Laid-Open No. 2002-323561 (JP, A)  
Japanese Patent Application Laid-Open No. 2012-060012 (JP, A)  
Japanese Unexamined Patent Application No. 10-170221 (JP, A)  
Japanese Patent Application Laid-Open No. 2013-206903 (JP, A)  
Japanese Patent Application Laid-Open No. 2010-091377 (JP, A)  
Japanese Patent Application Laid-Open No. 2005-077379 (JP, A)  
Japanese Patent Application Laid-Open No. 2008-096112 (JP, A)  
International Publication No. 2012/085151 (WO, A1)  
US Patent Application Publication No. 2012/0153120 (US, A1)  
Japanese Patent Application Laid-Open No. 2002-328166 (JP, A)  
Japanese Patent Application Laid-Open No. 2001-050723 (JP, A)

- (58) Investigated fields (Int. Cl., DB name)

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