United States Patent	12386046
Kind Code	B2
Date of Patent	August 12, 2025
Inventor(s)	Tachino; Yoshihide

Optical ranging device and method for detecting occurrence of abnormality in the same

Abstract

In an optical ranging device, a light source unit is configured to emit irradiation light to irradiate a measurement region, and a light receiving unit has a light-receiving surface provided with an array of single photon avalanche diodes (SPADs) and is configured to use the SPADs to detect photons of reflected light of the irradiation light. A controller is configured to control the light source unit and the light receiving unit and perform a distance measurement process to measure a distance to an object in the measurement region using signals output from the SPADs upon receipt of measurement reflected light that is reflected light of the irradiation light from the object in the measurement region. A determiner is configured to determine presence or absence of an abnormality in the light receiving unit using signals output during a dead time following incidence of photons of clutter reflected light on the SPADs.

Inventors:	**Tachino; Yoshihide (Kariya, JP)**
Applicant:	**DENSO CORPORATION** (Kariya, JP)
Family ID:	**1000008750423**
Assignee:	**DENSO CORPORATION (Kariya, JP)**
Appl. No.:	**17/375795**
Filed:	**July 14, 2021**

Prior Publication Data

Document Identifier	Publication Date
US 20210341592 A1	Nov. 04, 2021

Foreign Application Priority Data

JP	2019-004953	Jan. 16, 2019

Related U.S. Application Data

continuation parent-doc WO PCT/JP2019/049602 20191218 PENDING child-doc US 17375795

Publication Classification

Int. Cl.: **G01S7/497** (20060101); **G01S7/484** (20060101); **G01S7/4863** (20200101); **G01S17/931** (20200101); **H10F30/225** (20250101)

U.S. Cl.:

CPC **G01S7/497** (20130101); **G01S7/484** (20130101); **G01S7/4863** (20130101); **G01S17/931** (20200101); **H10F30/225** (20250101);

Field of Classification Search

CPC: G01S (7/4811); G01S (7/4813); G01S (7/4814); G01S (7/4816); G01S (7/484); G01S (7/486); G01S (7/4861); G01S (7/4863); G01S (7/497); G01S (17/08); G01S (17/10); G01S (17/931); H01L (31/107)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
2009/0315135	12/2008	Finkelstein	257/E31.113	H01L 31/107
2012/0236290	12/2011	Eisele	356/6	G01S 7/497
2014/0218715	12/2013	Li	356/4.01	G01S 7/497
2015/0261065	12/2014	Sartor	341/137	G02F 7/00
2016/0306032	12/2015	Schwarz	N/A	G01S 7/4812
2019/0011541	12/2018	O'Keeffe	N/A	N/A
2019/0170866	12/2018	Iguchi	N/A	G01S 17/10

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
10-319121	12/1997	JP	N/A
2016-176750	12/2015	JP	N/A

Primary Examiner: Xiao; Yuqing

Assistant Examiner: Qi; Zhengqing

Attorney, Agent or Firm: Maschoff Brennan

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) This application is based on and claims the benefit of priority from Japanese Patent Application No. 2019-004953 filed Jan. 16, 2019, the entire disclosure of which is incorporated herein by

reference.

BACKGROUND

Technical Field

(2) This disclosure relates to an optical ranging device.

Related Art

(3) An optical ranging device is known that measures a distance to an object based on a time of flight (TOF) of light from emission of the light into a measurement region to receipt of its reflected light from the object in the measurement region. For example, an optical ranging device is known that uses, as an optical element that receives the reflected light from the measurement region, a single photon avalanche diode (SPAD) for detecting incidence of a single photon.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) In the accompanying drawings:

(2) FIG. **1** is a schematic diagram of an optical ranging device;

(3) FIG. **2** is a flowchart of an abnormality detection process according to a first embodiment;

(4) FIG. **3**A is an illustration of an example time variation of a signal value during a clutter reflected light period;

(5) FIG. **3**B is an illustration of an example case where the signal value fails to increase to a target rise value;

(6) FIG. **4** is a flowchart of an abnormality detection process according to a second embodiment;

(7) FIG. **5** is an illustration of signal values acquired during a dead time; and

(8) FIG. **6** is a flowchart of an abnormality detection process according to a third embodiment.

DESCRIPTION OF SPECIFIC EMBODIMENTS

(9) In the above known optical ranging device, as disclosed in JP-A-2016-176750, abnormalities may occur in the light receiving unit due to, for example, time degradation caused by defects within a semiconductor of each SPAD, and the like. Such time degradation of the SPAD may cause an increase in dark current that flows regardless of light reception, leading to degradation in the measurement performance of the ranging device and a source of failures. The abnormalities in the light receiving unit, not limited to the time degradation of the SPAD, can be readily detected in environments where the ambient light is constant, as in environments where tests are performed in the initial shipping phase. However, the optical ranging device is commonly used in environments where the ambient light is not always constant, such as for vehicle use. Thus, it has not been easy to detect abnormalities in the light receiving unit under such ordinary usage environments.

(10) In view of the above, in the optical ranging device, there is still room for improvement in accurately detecting abnormalities in the light receiving unit without being affected by the ambient light.

(11) One aspect of the present disclosure provides an optical ranging device. In this optical ranging device, a light source unit is configured to emit irradiation light to irradiate a measurement region, and a light receiving unit has a light-receiving surface provided with an array of single photon avalanche diodes (SPADs) and is configured to use the SPADs to detect photons of reflected light of the irradiation light. A housing accommodates the light source unit and the light receiving unit. A controller is configured to control the light source unit and the light receiving unit and perform a distance measurement process to measure a distance to an object in the measurement region using signals output from the SPADs upon receipt of measurement reflected light that is reflected light of the irradiation light from the object in the measurement region. A determiner is configured to determine presence or absence of an abnormality in the light receiving unit using signals output from the SPADs upon receipt of clutter reflected light that is reflected light of the irradiation light

reflected within the housing. The determiner is further configured to determine presence or absence of an abnormality in the light receiving unit using signals output during a dead time following incidence of photons of the clutter reflected light on the SPADs.

(12) With the ranging device configured as above, the clutter reflected light reflected within the housing is used to detect an abnormality in the light receiving unit. Therefore, even in an environment where ambient light is not constant, occurrence of an abnormality in the light receiving unit **30** can be accurately detected.

1. First Embodiment

(13) Referring to FIG. **1**, an optical ranging device **10** in a first embodiment uses a time of flight (TOF) of light from emission of irradiation light IL into a measurement region MR to receipt of its reflected light from an object OB in the measurement region MR to measure a distance to the object OB. Hereinafter, the optical ranging device **10** is also simply referred to as the ranging device **10**. The process in which the ranging device **10** emits the irradiation light IL into the measurement region MR and thereby measures the distance to the object OB in the measurement region MR is called a “distance measurement process”. In the first embodiment, the ranging device **10** is mounted to a vehicle and measures a distance between the vehicle and an object OB around the vehicle via the distance measurement process.

(14) The ranging device **10** includes a light source unit **20** that emits irradiation light IL, a light receiving unit **30** that receives reflected light RL of the irradiation light IL, and a measurement unit **40** that processes a signal output from the light receiving unit **30** and outputs a result of measurement of distances, and a controller **50** that controls the entire ranging device **10**. The ranging device **10** further includes a housing **60**. The light source unit **20** and the light receiving unit **30** are fixed in an internal space surrounded by inner walls of the housing **60**. In FIG. **1**, the right end of the housing **60** is omitted for convenience of illustration.

(15) The light source unit **20** includes a laser source **21** and a scanning unit **22**. The laser source **21** is formed of a semiconductor laser diode and configured to emit pulsed laser light as irradiation light IL. The scanning unit **22** includes a mirror **24** that rotates around a rotary shaft **23** under control of the controller **50**. The mirror **24** is, for example, a micro-electromechanical system (MEMS) mirror. The irradiation light IL emitted from the laser source **21** is reflected by the mirror **24** of the scanning unit **22**. The irradiation light IL is scanned according to the rotation angle of the mirror **24**. When the mirror **24** is at a given angle of rotation, the irradiation light IL reflected by the mirror **24** is emitted into the measurement region MR through a launch opening **61** provided in the housing **60**, as illustrated by the solid arrow in FIG. **1**. The irradiation light IL that is not emitted from the launch opening **61** is reflected and scattered within the housing **60** as indicated by the dashed arrow in FIG. **1**.

(16) The light receiving unit **30** has a light-receiving surface **32** provided with an array of single photon avalanche diodes (SPADs) **31** that operate in a Geiger mode. The SPADs **31** form a two-dimensional array on the light-receiving surface **32**. Each of the SPADs **31** is configured to, in response to incidence of a single photon, output a pulse signal indicating incidence of the single photon, with a certain probability. In response to light incident on the light-receiving surface **32**, signals will be output from the number of SPADs **31** corresponding to the intensity of the incident light. That is, the higher the intensity of light incident on the light-receiving surface **32**, the greater the number of SPADs **31** that respond to the incident light.

(17) As described above, the light receiving unit **30** receives reflected light RL of the irradiation light IL emitted from the light source unit **20**. Hereinafter, the reflected light RL of the irradiation light IL, reflected from the object OB in the measurement region MR, is referred to as “measurement reflected light RLm”, and internal scattering light that is the reflected light RL of the irradiation light IL, reflected within the housing **60**, is referred to as “clutter reflected light RLc”. As indicated by the solid arrow in FIG. **1**, the measurement reflected light RLm enters the housing **60** from the measurement region MR through an incident opening **62** and reaches the light-

receiving surface **32** of the light receiving unit **30**. As indicated by the dashed arrow in FIG. **1**, the clutter reflected light RLc is reflected from an inner wall surface of the housing **60** and reaches the light-receiving surface **32** of the light receiving unit **30**.

(18) In the ranging device **10**, signals output from the SPADs **31** during a predetermined period of time from emission of one pulse of irradiation light IL by the light source unit **20** are considered to be signals output in response to incidence of the clutter reflected light RLc and are not used in the distance measurement process. Hereinafter, the predetermined period of time from emission of one pulse of irradiation light IL by the light source unit **20** is referred to as a “clutter reflected light period”. The clutter reflected light period is determined based on the speed of light and an optical distance between the light source unit **20** and the light receiving unit **30** within the housing **60**. The clutter reflected light period may be defined as a period of time greater than a period of time from emission of the irradiation light IL by the light source unit **20** to arrival of the clutter reflected light RLc at the light-receiving surface **32** of the light receiving unit **30**. The clutter reflected light period may further be defined as a period of time less than at least a minimum expected period of time from emission of the irradiation light IL by the light source unit **20** to arrival of the measurement reflected light RLm at the light-receiving surface **32**.

(19) The ranging device **10** according to the present embodiment uses signals output from the SPADs **31** in response to incidence of the clutter reflected light RLc during the clutter reflected light period, in an abnormality detection process for detecting occurrence of an abnormality in the light receiving unit **30**. The abnormality detection process will be described later. In the distance measurement process, the ranging device **10** uses signals output from the light receiving unit **30** after the clutter reflected light period elapses from emission of the irradiation light IL by the light source unit **20** to determine a distance to the object OB in the measurement region MR.

(20) The measurement unit **40** includes an integrator **41**, a histogram generator **42**, a peak detector **43**, and a distance calculator **44**. Each of these elements of the measurement unit **40** is formed of one or two or more integrated circuits. In an alternative embodiment, at least some of these elements of the measurement unit **40** may be implemented in a software-based manner by a CPU executing a program.

(21) The signals output from the respective SPADs **31** of the light receiving unit **30** are input to the integrator **41**. The integrator **41** acquires an integrated value that results from counting the number of pulse signals output from the respective SPADs **31** at approximately the same time, and outputs, to the histogram generator **42**, the integrated value as a signal value of an output signal from the light receiving unit **30**. Each signal value output from the integrator **41** represents the number of responses of the SPADs **31** to receipt of the reflected light RL by the light receiving unit **30**. During the abnormality detection process described later, the integrator **41** outputs, to the determiner **51** of the controller **50**, the signal values of the output signals from the light receiving unit **30** during the clutter reflected light period.

(22) The histogram generator **42** generates a histogram based on the signal values received from the integrator **41**. Each bin of this histogram indicates a TOF from emission of the irradiation light IL by the light source unit **20** to arrival of the reflected light RL at the light-receiving surface **32**. Frequencies of this histogram are the signal values output from the integrator **41** and represent intensities of the reflected light RL. The histogram generator **42** generates a histogram by recording the signal value output from the integrator **41** for each TOF according to a predetermined record timing signal, and outputs the histogram to the peak detector **43**.

(23) The peak detector **43** detects a peak from the histogram output from the histogram generator **42**. The peak detector **43** determines that a portion of the histogram having the highest frequency is a peak. The peak in the histogram indicates that there is an object OB at a distance corresponding to the TOF corresponding to the peak.

(24) The distance calculator **44** calculates a distance value D from the TOF corresponding to the peak detected by the peak detector **43**. The distance calculator **44** calculates the distance value D

according to the following equation (1):

$D=(c\times\Delta t)/2$ (1)

where Δt is the TOF corresponding to the peak, c is the speed of light, and D is the distance value.

(25) The distance value D measured by the measurement unit **40** is output from the ranging device **10** to an electronic control unit (ECU) of the vehicle. The ECU of the vehicle uses the distance value D acquired from the ranging device **10** to detect an object OB that is an obstacle in the measurement region MR. The ECU of the vehicle provides vehicle driving assistance to avoid a collision with the detected obstacle.

(26) The controller **50** is configured as a microcomputer including a processor and a memory. The controller **50** is connected to the light source unit **20**, the light receiving unit **30**, and the measurement unit **40** through signal lines. The controller **50** controls the light source unit **20**, the light receiving unit **30**, and the measurement unit **40** to perform the distance measurement process described above. The controller **50** includes, as a functional block, a determiner **51** that performs an abnormality detection process described later to determine the presence or absence of an abnormality in the light receiving unit **30**. In an alternative embodiment, the determiner **51** may be separate from the controller **50**.

(27) Referring to FIG. **2**, in the abnormality detection process, the determiner **51** detects occurrence of an abnormality in the light receiving unit **30** using the signals output from the light receiving unit **30** in response to the clutter reflected light RLc. The determiner **51** performs the abnormality detection process at predetermined timings while the controller **50** is not performing the distance measurement process. The abnormality detection process is performed with a predefined periodicity, for example, at predetermined timings while the vehicle is stopped or parked. The abnormality detection process may be performed at timings commanded by the user. The user may preset the frequency at which the abnormality detection process is performed by the determiner **51**.

(28) At step S**10**, the determiner **51** causes the light source unit **20** to emit irradiation light IL. The intensity of the irradiation light IL may be similar to the intensity as in the distance measurement process. At step S**20**, the determiner **51** acquires, from the integrator **41**, signal values of signals output from the light receiving unit **30** during the clutter reflected light period described above. At step S**30**, the determiner **51** acquires signal values during a period of time in which signals indicating incidence of photons of the clutter reflected light RLc on the SPADs **31** are output, among the signal values acquired at step S**20**. In the first embodiment, at steps S**40** to S**50**, the determiner **51** determines whether an abnormality is occurring in the light receiving unit **30**, using the signal values of the signals indicating incidence of photons of the clutter reflected light RLc on the SPADs **31**.

(29) In FIG. **3**A, time t**0** is a time at which the light source unit **20** emitted the irradiation light IL, and a period of time from t**0** to t**1** is the clutter reflected light period. Before and after the clutter reflected light period, the signal value output from the integrator **41** takes a value near a reference value S corresponding to ambient light. Within the clutter reflected light period, immediately after time t**0** at which the light source unit **20** emitted the irradiation light IL, the light receiving unit **30** receives the clutter reflected light RLc, and almost all of the SPADs **31** are each ready to output a High signal indicating incidence of a photon. Since the clutter reflected light RLc is light reflected at a close distance from the light source unit **20**, the intensity of the clutter reflected light RLc is significantly higher than intensities of the ambient light and the measurement reflected light RLm. Therefore, when the light receiving unit **30** receives the clutter reflected light RLc, the signal value output from the integrator **41** increases sharply and clips at a signal value S.sub.CL. The signal value S.sub.CL indicates the number of SPADs **31** that outputted the High signal upon arrival of the clutter reflected light RLc at the light-receiving surface **32**. When all of the SPADs **31** forming the light-receiving surface **32** output the High signal, the signal value S.sub.CL clips at a maximum value sat as illustrated in FIG. **3**A.

(30) At step S**40**, the determiner **51** determines whether the signal value of the signal indicating

incidence of photons of the clutter reflected light RLc has increased to a target rise value TR. In the first embodiment, the determiner **51** determines whether the signal value S.sub.CL at which the signal value clips in response to incidence of the clutter reflected light RLc is equal to or greater than the target rise value TR. If the signal value of the signal indicating incidence of photons of the clutter reflected light RLc has increased to the target rise value TR, that is, if the signal value S.sub.CL at which the signal value clips is equal to or greater than the target rise value TR, the determiner **51** ends the abnormality detection process without setting a flag indicating that an abnormality has been detected.

(31) As illustrated in FIG. **3**B, if the signal value of the signal indicating incidence of photons of the clutter reflected light RLc fails to increase to the target rise value TR, that is, the signal value S.sub.CL at which the signal value S.sub.CL clips is less than the target rise value TR, then at step S**50** the determiner **51** detects that an abnormality is occurring in the light receiving unit **30**. The fact that the signal value S.sub.CL fails to increase to the target rise value TR means that the number of SPADs **31** in a Low-abnormality state exceeds an allowable number, where each SPAD in the Low-abnormality state does not output the High signal even in response to incidence of a photon and continues to output a Low signal. In the first embodiment, the determiner **51** determines that the abnormality in the light receiving unit **30** is arising from an increase in the number of SPADs **31** in the Low-abnormality state. The determiner **51** then sets a flag indicating that an abnormality has been detected and ends the abnormality detection process.

(32) In the abnormality detection process, if the flag indicating that an abnormality has been detected in the light receiving unit **30** is set by the determiner **51**, the controller **50** notifies the user of occurrence of the abnormality in the light receiving unit **30** via a notification device (not shown). As the number of SPADs **31** in the Low-abnormality state increases, an amount of decrease in the signal value S.sub.CL from a maximum signal value sat increases. The controller **50** may calculate the amount of decrease in the signal value S.sub.CL from the maximum signal value sat and acquire the number of SPADs **31** in the Low-abnormality state from the calculated amount of decrease in the signal value S.sub.CL and output it.

(33) As described above, the ranging device **10** of the first embodiment uses, to detect an abnormality in the light receiving unit **30**, the signals output in response to incidence of the clutter reflected light RLc that is irradiation light IL reflected within the housing **60**. The intensity of the clutter reflected light RLc is significantly higher than the intensity of ambient light. Therefore, even in an environment where the ambient light is not constant, occurrence of an abnormality in the light receiving unit **30** can be accurately detected. In addition, the ranging device **10** of the first embodiment uses the signals indicating incidence of photons of the clutter reflected light RLc on the SPADs **31**, which enables detection of an abnormality in the light receiving unit **30** caused by the presence of the SPADs **31** in the Low-abnormality state. The ranging device **10** of the first embodiment is configured to, in response to the signal value of the signal indicating incidence of photons of the clutter reflected light RLc on the SPADs **31** failing to reach the target rise value TR, determine that an abnormality is occurring in the light receiving unit **30**. This can inhibit an abnormality in the light receiving unit **30** from being detected hypersensitively, for example, in cases where the number of SPADs **31** in the Low-abnormality state does not adversely affect the distance measurement.

2. Second Embodiment

(34) Referring to FIG. **4**, the abnormality detection process of a second embodiment is performed by the ranging device **10** having the same configuration as described in the first embodiment. The abnormality detection process of the second embodiment is substantially the same as the abnormality detection process of the first embodiment illustrated in FIG. **2** except in that steps S**60** to S**80** are performed instead of steps S**30** to S**50** after steps S**10** to S**20**.

(35) At step S**60**, the determiner **51** acquires, from the integrator **41**, signal values of signals output during a dead time in response to incidence of photons of the clutter reflected light RLc on the

SPADs **31**. The “dead time” means a period of time in which the SPADs **31** fail to detect photons because output signals from the SPADs **31** temporarily decrease to a Low level due to saturation of the SPADs **31** after incidence of photons.

(36) Referring to FIG. **5**, the dead time within the clutter reflected light period is a period of time from when the signal value decreases to below the reference value S after having increased and being clipped in response to incidence of photons of the clutter reflected light RLc on the SPADs **31** to when the signal value increases again to the reference value S. Since, during this dead time, the SPADs **31** are saturated and thus fail to respond to incidence of photons of the clutter reflected light RLc, the signal value decreases sharply and clips regardless of the presence or absence of ambient light. As the number of SPADs **31** in a High-abnormality state increases, a signal value S.sub.DT at which the signal value clips increases, as indicated by the broken line graph in FIG. **5**. The High-abnormality state is a state such that the SPAD **31** in the High-abnormality state does not normally output the Low signal even though in the dead time, but continues to output the High signal.

(37) At step S**70**, the determiner **51** determines whether the signal value of the signal indicating incidence of photons of the clutter reflected light RLc has decreased to a predetermined target drop value TD within the dead time. In the second embodiment, the determiner **51** determines whether the signal value S.sub.DT at which the signal value clips within the dead time is less than the target drop value TD. If the signal value S.sub.DT decreases to below the target drop value TD, that is, if the signal value S.sub.DT at which the signal value clips within the dead time is less than the target drop value TD, the determiner **51** ends the abnormality detection process without setting a flag indicating that an abnormality has been detected.

(38) If the signal value fails to decrease to below the target drop value TD within the dead time, that is, the signal value S.sub.DT at which the signal value clips within the dead time is equal to or greater than the target drop value TD, then at step S**80** the determiner **51** detects that an abnormality is occurring in the light receiving unit **30**. The fact that the signal value S.sub.DT fails to decrease to the target drop value TD means that the number of SPADs **31** in the High-abnormality state exceeds an allowable number. In the second embodiment, the determiner **51** determines that the abnormality in the light receiving unit **30** is arising from an increase in the number of SPADs **31** in the High-abnormality state. The determiner **51** sets a flag indicating that an abnormality has been detected and ends the abnormality detection process.

(39) In the abnormality detection process, if the flag indicating that an abnormality has been detected in the light receiving unit **30** is set by the determiner **51**, the controller **50** notifies the user of occurrence of the abnormality in the light receiving unit **30** via a notification device (not shown). The controller **50** may calculate an amount of increase in the signal value S.sub.DT at which the signal value clips within the dead time from the signal value when assumed that all of the SPADs **31** output the Low signal during the dead time and calculate the number of SPADs **31** in the High-abnormality state based on the calculated amount of increase in the signal value S.sub.DT.

(40) As described above, the ranging device **10** of the second embodiment uses, to detect an abnormality in the light receiving unit **30**, the signals output in response to incidence of the clutter reflected light RLc that is irradiation light IL reflected within the housing **60**. Therefore, as in the first embodiment, even in an environment where the ambient light is not constant, occurrence of an abnormality in the light receiving unit **30** can be accurately detected. In addition, the ranging device **10** of the second embodiment uses the signals output during the dead time after incidence of photons of the clutter reflected light RLc on the SPADs **31**, which enables detection of an abnormality in the light receiving unit **30** caused by the presence of the SPADs **31** in the High-abnormality state. The ranging device **10** of the second embodiment is configured to, in response to the signal value failing to decrease to the target drop TD within the dead time, determine that an abnormality is occurring in the light receiving unit **30**. This can inhibit an abnormality in the light receiving unit **30** from being detected hypersensitively, for example, in cases where the number of

SPADs **31** in the High-abnormality state does not adversely affect the distance measurement.

3. Third Embodiment

(41) Referring to FIG. **6**, the abnormality detection process of a third embodiment is performed by the ranging device **10** of the same configuration as described in the first embodiment. The abnormality detection process of the third embodiment is substantially the same as the abnormality detection process of the first embodiment illustrated in FIG. **2** except in that steps S**60** to S**80** are performed after steps S**10** to S**50**.

(42) The abnormality detection process of the third embodiment allows detection of the abnormality in the light receiving unit **30** caused by the presence of the SPADs **31** in the Low-abnormality state at steps S**30** to S**50**. The abnormality detection process of the third embodiment allows detection of the abnormality in the light receiving unit **30** caused by the presence of the SPADs **31** in the High-abnormality state at steps S**60** to S**80**. In addition, the abnormality detection process of the third embodiment further allows determining whether occurrence of the abnormality in the light receiving unit **30** is arising from the presence of the SPADs **31** in the Low-abnormality state, the presence of the SPADs **31** in the High-abnormality state, or both. The controller **50** may output the detected number of SPADs **31** in the Low-abnormality state and the detected number of SPADs **31** in the High-abnormality state. In addition, the method of detecting an abnormality in both the optical ranging device **10** and the light receiving unit **30** according to the third embodiment can provide various advantages similar to those described in the first embodiment and the second embodiment.

4. Modifications

(43) The various configurations described in the above respective embodiments may be modified, for example, as described below. The modifications described below are all examples of the aspects of the present disclosure.

(44) (M1) In an alternative embodiment to each of the above first and third embodiments, the determiner **51** may not make the determination at step S**40** using the signal value S.sub.CL at which the signal value clips in response to incidence of photons of the clutter reflected light RLc on the SPADs **31** and the target rise value TR. The determiner **51** may detect an abnormality other than the Low abnormality in the SPADs **31** of the light receiving unit **30**, using the signals indicating incidence of photons of the clutter reflected light RLc on the SPADs **31**. In another alternative embodiment, the determiner **51** may detect that an abnormality is occurring in the light receiving unit **30** in cases where the signals indicating incidence of photons of the clutter reflected light RLc on the SPADs **31** are significantly different in waveform from a prepared reference signal.

(45) (M2) In an alternative embodiment to each of the above second and third embodiments, the determiner **51** may not make the determination at step S**70** using the signal value S.sub.DT at which the signal value clips within the dead time and the target drop value TD. The determiner **51** may detect an abnormality other than the High abnormality in the SPADs **31** of the light receiving unit **30**, using the signals output from the light receiving unit **30** during the dead time. In another alternative embodiment, the determiner **51** may detect that an abnormality is occurring in the light receiving unit **30** in cases where the signals output from the light receiving unit **30** during the dead time are significantly different in waveform from a prepared reference signal.

(46) (M3) In an alternative embodiment to each embodiment described above, the ranging device **10** may not be mounted to the vehicle. For example, the ranging device **10** may be configured as a ranging device to be carried by the user.

5. Others

(47) It should be appreciated that the present disclosure is not to be limited to the optical ranging device disclosed above and the method of detecting occurrence of an abnormality in the light receiving unit of the optical ranging device. The present disclosure may be implemented in numerous ways, such as a vehicle having the optical ranging device disclosed above mounted thereto, a control method of controlling the optical ranging device, a computer program for

enabling a computer to implement the control method, and a non-transitory computer readable storage medium storing such a computer program.

(48) The present disclosure is not limited to any of the embodiments, the examples and the modifications described above but may be implemented by a diversity of other configurations without departing from the scope of the disclosure. For example, the technical features of the embodiments, examples or modifications corresponding to the technical features of the respective aspects may be replaced or combined appropriately, in order to solve part or all of the issues described above or in order to achieve part or all of the advantages described above. Any of the technical features may be omitted appropriately unless the technical feature is described as essential herein.

Claims

1. An optical ranging device comprising: a light source unit configured to emit irradiation light to irradiate a measurement region; a light receiving unit having a light-receiving surface provided with an array of single photon avalanche diodes (SPADs) and configured to use the SPADs to detect photons of reflected light of the irradiation light; a housing accommodating the light source unit and the light receiving unit; a controller configured to control the light source unit and the light receiving unit and perform a distance measurement process to measure a distance to an object in the measurement region using signals output from the SPADs upon receipt of measurement reflected light that is reflected light of the irradiation light from the object in the measurement region; and a determiner configured to determine presence or absence of an abnormality in the light receiving unit using signals output from the SPADs upon receipt of clutter reflected light during a clutter reflected light period, the clutter reflected light comprising reflected light of the irradiation light reflected within the housing, the clutter reflected light period comprising a time period beginning immediately after the light source unit emits the irradiation light to irradiate the measurement region and ending before receipt of the measurement reflected light, the determiner configured to determine the presence or absence of the abnormality in the light receiving unit using signals output from the SPADs by acquiring a signal value output from the light receiving unit during a clutter reflected light period, comparing the signal value to a target rise value, and determining the presence of the abnormality in the light receiving unit based on the signal value not exceeding the target rise value, wherein the determiner is further configured to determine presence or absence of an abnormality in the light receiving unit using signals output during a dead time following incidence of photons of the clutter reflected light on the SPADs, the dead time comprising a period of time within the clutter reflected light period from a time when the signal value decreases to below a reference value to a time when the signal value increases to the reference value.
2. The optical ranging device according to claim 1, wherein the determiner is configured to determine presence or absence of an abnormality in the light receiving unit using signals indicating incidence of photons of the clutter reflected light on the SPADs.
3. The optical ranging device according to claim 2, wherein the determiner is configured to, in response to a signal value that results from counting a number of signals indicating incidence of photons of the clutter reflected light on the SPADs failing to increase to a predetermined target rise value, determine that an abnormality is occurring in the light receiving unit.
4. The optical ranging device according to claim 1, wherein the determiner is configured to, in response to a signal value that results from counting a number of signals output during the dead time failing to decrease to a predetermined target drop value, determine that an abnormality is occurring in the light receiving unit.
5. The optical ranging device according to claim 1, wherein the determiner is configured to, in response to determining that an abnormality is occurring in the light receiving unit, output a

number of the SPADs in which the abnormality is occurring using the signals output from the SPADS.

6. A method for determining presence or absence of an abnormality in a light receiving unit having a light-receiving surface provided with an array of single photon avalanche diodes (SPADs), the light receiving unit being incorporated in an optical ranging device configured to perform a distance measurement process to measure a distance to an object in a measurement region using signals output from the SPADs upon receipt of measurement reflected light of irradiation light reflected from the object, the irradiation light being emitted from a light source unit incorporated in the optical ranging device, the method comprising: causing the light receiving unit to receive clutter reflected light that is reflected light of the irradiation light reflected within a housing accommodating the light source unit and the light receiving unit; determining presence or absence of an abnormality in the light receiving unit using signals output from the SPADs upon receipt of the clutter reflected light during a clutter reflected light period, the clutter reflected light comprising reflected light of the irradiation light reflected within the housing, the clutter reflected light period comprising a time period beginning immediately after the light source unit emits the irradiation light to irradiate the measurement region and ending before receipt of the measurement reflected light, the presence or absence of the abnormality in the light receiving unit being determined using signals output from the SPADs by acquiring a signal value output from the light receiving unit during a clutter reflected light period, comparing the signal value to a target rise value, and determining the presence of the abnormality in the light receiving unit based on the signal value not exceeding the target rise value, wherein the determining including determining presence or absence of an abnormality in the light receiving unit using signals output during a dead time following incidence of photons of the clutter reflected light on the SPADs, the dead time comprising a period of time within the clutter reflected light period from a time when the signal value decreases to below a reference value to a time when the signal value increases to the reference value.

7. An optical ranging device comprising: a light source unit configured to emit irradiation light to irradiate a measurement region; a light receiving unit having a light-receiving surface provided with an array of single photon avalanche diodes (SPADs) and configured to use the SPADs to detect photons of reflected light of the irradiation light; a housing accommodating the light source unit and the light receiving unit; a controller configured to control the light source unit and the light receiving unit and perform a distance measurement process to measure a distance to an object in the measurement region using signals output from the SPADs upon receipt of measurement reflected light that is reflected light of the irradiation light from the object in the measurement region; and a determiner configured to determine presence or absence of an abnormality in the light receiving unit using signals output from the SPADs upon receipt of clutter reflected light that is reflected light of the irradiation light reflected within the housing, the determiner being further configured to determine presence or absence of an abnormality in the light receiving unit using signals output during a dead time following incidence of photons of the clutter reflected light on the SPADs, wherein the determiner is configured to, in response to a signal value that results from counting a number of signals output during the dead time failing to decrease to a predetermined target drop value, determine that an abnormality is occurring in the light receiving unit.

8. A method for determining presence or absence of an abnormality in a light receiving unit having a light-receiving surface provided with an array of single photon avalanche diodes (SPADs), the light receiving unit being incorporated in an optical ranging device configured to perform a distance measurement process to measure a distance to an object in a measurement region using signals output from the SPADs upon receipt of reflected light of irradiation light reflected from the object, the irradiation light being emitted from a light source unit incorporated in the optical ranging device, the method comprising: causing the light receiving unit to receive clutter reflected light that is reflected light of the irradiation light reflected within a housing accommodating the

light source unit and the light receiving unit; determining presence or absence of an abnormality in the light receiving unit using signals output from the SPADs upon receipt of the clutter reflected light, the determining including determining presence or absence of an abnormality in the light receiving unit using signals output during a dead time following incidence of photons of the clutter reflected light on the SPADs, wherein in response to a signal value that results from counting a number of signals output during the dead time failing to decrease to a predetermined target drop value, an abnormality is determined to be occurring in the light receiving unit.