

# US Patent & Trademark Office

## Patent Public Search | Text View

---

United States Patent Application Publication

20250254424

Kind Code

A1

Publication Date

August 07, 2025

Inventor(s)

SAMBONGI; Sinsuke et al.

---

### FOCUS DETECTION DEVICE, IMAGING DEVICE, AND INTERCHANGEABLE LENS

---

#### Abstract

A focus detection device includes: an imaging unit having a first and second pixel each of which receives light transmitted through an optical system and outputs signal used for focus detection, and a third pixel which receives light transmitted through the optical system and outputs signal used for image generation; an input unit to which information regarding the optical system is input; a selection unit that selects one of the first and second pixel based on the information to the input unit; a readout unit that reads out the signal from one of the first and second pixel based on a selection result at a timing different from reading out the signal from the third pixel to be read out; and a focus detection unit that performs the focus detection based on at least one of the signals of the first and second pixel read out by the readout unit.

---

**Inventors:** SAMBONGI; Sinsuke (Wako-shi, JP), KINOSHITA; Akira (Yokohama-shi, JP), KITA; Yuki (Kawasaki-shi, JP)

**Applicant:** NIKON CORPORATION (Tokyo, JP)

**Family ID:** 69164874

**Assignee:** NIKON CORPORATION (Tokyo, JP)

**Appl. No.:** 19/177722

**Filed:** April 14, 2025

#### Foreign Application Priority Data

JP	2018-137274	Jul. 20, 2018
----	-------------	---------------

#### Related U.S. Application Data

parent US continuation 18414695 20240117 parent-grant-document US 12301987 child US 19177722

parent US continuation 18122310 20230316 parent-grant-document US 11917292 child US 18414695  
parent US continuation 17261979 20210121 parent-grant-document US 11641519 WO  
continuation PCT/JP2019/028478 20190719 child US 18122310

---

## Publication Classification

**Int. Cl.:** **H04N23/67** (20230101); **G03B13/36** (20210101); **G03B17/14** (20210101); **H04N23/55** (20230101); **H04N25/42** (20230101); **H04N25/704** (20230101)

**U.S. Cl.:**

**CPC** **H04N23/67** (20230101); **G03B13/36** (20130101); **G03B17/14** (20130101); **H04N23/55** (20230101); **H04N23/675** (20230101); **H04N25/42** (20230101); **H04N25/704** (20230101);

---

## Background/Summary

**RELATED APPLICATIONS** [0001] This application is a continuation application of U.S. patent application Ser. No. 18/414,695, filed Jan. 17, 2024, which is a continuation application of U.S. patent application Ser. No. 18/122,310, filed Mar. 16, 2023, which is a continuation application of U.S. patent application Ser. No. 17/261,979, filed Jan. 21, 2021, which is a National Stage Entry of PCT/JP2019/028478, filed Jul. 19, 2019, which claims priority to Japanese Patent Application No. 2018-137274, filed Jul. 20, 2018. The contents of those prior applications are incorporated herein by reference in their entireties.

### TECHNICAL FIELD

[0002] The present invention relates to a focus detection device, an imaging device, and an interchangeable lens.

### BACKGROUND ART

[0003] An image sensor that reads out a signal for focus detection and a signal for image generation is known (for example, Patent Literature 1: PTL1). In such an image sensor, it is desired to increase the speed of signal reading.

### CITATION LIST

Patent Literature

[0004] PTL 1: Japanese Laid-Open Patent Publication No. 2017-34606

### SUMMARY OF INVENTION

[0005] According to the 1st aspect of the present invention, a focus detection device comprises: an imaging unit having a first pixel and a second pixel each of which receives light transmitted through an optical system and outputs signal used for focus detection, and a third pixel which receives light transmitted through the optical system and outputs signal used for image generation; an input unit to which information regarding the optical system is input; a selection unit that selects at least one of the first pixel and the second pixel based on the information input to the input unit; a readout unit that reads out the signal from at least one of the first pixel and the second pixel based on a selection result of the selection unit at a timing different from a timing of reading out the signal from the third pixel to be read out; and a focus detection unit that performs the focus detection based on at least one of the signals of the first pixel and the second pixel read out by the readout unit.

[0006] According to the 2nd aspect of the present invention, an imaging device comprises: the

focus detection device according to the 1st aspect, and a generation unit that generates image data based on signals output from at least one of the first pixel, the second pixel, and the third pixel. [0007] According to the 3rd aspect of the present invention, an interchangeable lens comprises: a detachable portion that enables to attach and detach to the focus detection device according to the 1st aspect.

---

## Description

### BRIEF DESCRIPTION OF DRAWINGS

[0008] FIG. 1 is a diagram showing a configuration example of an imaging device according to the first embodiment.

[0009] FIG. 2 is a diagram showing a focus detection area of an imaging surface of the imaging device according to the first embodiment.

[0010] FIG. 3 is a diagram showing an arrangement example of pixels in the focus detection area of the imaging device according to the first embodiment.

[0011] FIG. 4 is a diagram showing a s configuration example of pixels in the imaging device according to the first embodiment.

[0012] FIG. 5 is a cross-sectional view showing three types of AF pixel pairs to be arranged at the central region of the imaging device according to the first embodiment.

[0013] FIG. 6 is a cross-sectional view showing three types of AF pixel pairs to be arranged at a region corresponding to a predetermined image height in the imaging device according to the first embodiment.

[0014] FIG. 7 is a cross-sectional view showing three types of AF pixel pairs to be arranged at a region corresponding to a predetermined image height in the imaging device according to the first embodiment.

[0015] FIG. 8 is a diagram showing the relationship between the reference exit pupil and the image height in the imaging device according to the first embodiment.

[0016] FIG. 9 shows various optical characteristics of an interchangeable lens whose exit pupil distance changes according to the image height, in the imaging device according to the first embodiment.

[0017] FIG. 10 is a diagram showing the relationship between the image height and the exit pupil in the imaging device according to the first embodiment.

[0018] FIG. 11 is a table showing a constant term and coefficients of a function that approximates representative optical characteristic curve in each focus position zone in the imaging device according to the first embodiment.

[0019] FIG. 12 is a table showing a constant term and coefficients of a function that approximates representative optical characteristic curve in each zone in the imaging device according to the first embodiment.

[0020] FIG. 13 is a diagram showing, in the imaging device according to the first embodiment, a threshold value of an exit pupil distance, first to third exit pupil distance ranges, and an optical characteristic curve.

[0021] FIG. 14 is a diagram showing a circuit configuration of the pixel of an image sensor according to the first embodiment.

[0022] FIG. 15 is a diagram showing a configuration of part of the image sensor according to the first embodiment.

[0023] FIG. 16 is a diagram showing a configuration sample of an AF pixel of an image sensor according to a variation.

[0024] FIG. 17 is a diagram showing a configuration sample of an AF pixel of an image sensor according to a variation.

## DESCRIPTION OF EMBODIMENTS

### First Embodiment

[0025] FIG. 1 is a diagram showing a configuration example of an electronic camera **1** (hereinafter, referred to as a camera **1**) which is an example of an imaging device according to the first embodiment. The camera **1** is configured with a camera body **2** and an interchangeable lens **3**. Since the camera **1** is configured with the camera body **2** and the interchangeable lens **3**, it is sometimes called a camera system.

[0026] The camera body **2** is provided with a body-side mount unit **201** to which the interchangeable lens **3** is to be attached. The interchangeable lens **3** is provided with a lens-side mount unit **301** that is to be attached to the camera body **2**. The lens-side mount unit **301** and the body-side mount unit **201** are provided with a lens-side connection portion **302** and a body-side connection portion **202**, respectively. The lens-side connection portion **302** and the body-side connection portion **202** are each provided with a plurality of terminals such as a terminal for a clock signal, a terminal for a data signal, and a terminal for supplying power. The interchangeable lens **3** is to be detachably attached to the camera body **2** by the lens-side mount unit **301** and the body-side mount unit **201**.

[0027] Upon being attached the interchangeable lens **3** to the camera body **2**, the terminal provided on the body-side connection portion **202** and the terminal provided on the lens-side connection portion **302** are electrically connected. Thereby, it becomes to be possible to supply power from the camera body **2** to the interchangeable lens **3** or to communicate between the camera body **2** and the interchangeable lens **3**.

[0028] The interchangeable lens **3** includes a photographing optical system (imaging optical system) **31**, a lens control unit **32**, and a lens memory **33**. The photographing optical system **31** includes, a plurality of lenses including a zoom lens (variable magnification lens) **31a** for changing the focal length and a focusing lens (focus adjustment lens) **31b**, and an aperture **31c**, and forms a subject image on the imaging surface **22a** of the image sensor **22**. Although the zoom lens **31a** and the focusing lens **31b** are schematically shown in FIG. 1, a common photographing optical system is generally configured with a lot of optical elements.

[0029] Further, as will be described later, the photographing optical system **31** of the interchangeable lens **3** has an optical characteristic that the position of the exit pupil thereof, that is, the exit pupil distance changes depending on the image height. In other words, the exit pupil distance of the photographing optical system **31** changes depending on the position on the imaging surface **22a**, that is, the distance from the optical axis OA1 of the photographing optical system **31** on the imaging surface **22a**. The optical axis OA1 of the photographing optical system **31** intersects the imaging surface **22a** at the center position of the imaging surface **22a**. Here, the exit pupil distance is the distance between the exit pupil of the photographing optical system **31** and the image plane of the image by the photographing optical system **31**. It is to be noted, the imaging surface **22a** of the image sensor **22** is, for example, a surface on which a photoelectric conversion unit described later is arranged or a surface on which a microlenses are arranged.

[0030] Moreover, the photographing optical system **31** differs depending on the type of the interchangeable lens **3** to be mounted on the body-side mount unit **201**. Therefore, the exit pupil distance of the photographing optical system **31** differs depending on the type of the interchangeable lens **3**. Further, the optical characteristics in which the exit pupil distance changes depending on the image height, also differ depending on the type of the interchangeable lens **3**.

[0031] The lens control unit **32** is configured with a processor such as a CPU, FPGA, and ASIC, and a memory such as ROM and RAM, and controls each part of the interchangeable lens **3** based on a control program. The lens control unit **32** controls the position of the zoom lens **31a**, the position of the focusing lens **31b**, and the drive of the aperture **31c** based on the signal output from a body control unit **210** of the camera body **2**.

[0032] Upon being input a signal indicating moving direction, movement amount or the like of the

focusing lens **31b** from the body control unit **210**, the lens control unit **32** moves the focusing lens **31b** forward or backward in the optical axis OA1 direction based on the signal, to adjust the focal position of the photographing optical system **31**. Further, the lens control unit **32** controls the position of the zoom lens **31a** and/or the aperture diameter of the aperture **31c** based on the signal output from the body control unit **210** of the camera body **2**.

[0033] The lens memory **33** is configured with, for example, a non-volatile storage medium or the like. Information related to the interchangeable lens **3** is stored (recorded) as lens information in the lens memory **33**. The lens information includes data on the optical characteristics (the exit pupil distance and/or an F number) of the photographing optical system **31**, data on the infinity position and the closest position of the focusing lens **31b**, and data on the shortest focal length and the longest focal length of the interchangeable lens **3**. It is to be noted that the lens information differs depending on the type of the interchangeable lens **3**. The lens information may be stored in the internal memory of the lens control unit **32**. Further, the lens information may be stored in the body memory **23** in the camera body **2** described later. In this case, the body memory **23** stores the lens information of the plurality of types of interchangeable lenses **3**.

[0034] In the present embodiment, the lens information includes information regarding the exit pupil distance of the photographing optical system **31**. Although regarding the information with respect to the exit pupil distance will be described later, it includes the information indicating the exit pupil distance (Co) at the position where the imaging surface **22a** and the optical axis OA1 intersect (the position where the image height is zero) and the information on coefficients (h4, h2) of the calculation formula showing the relationship between the exit pupil distance and the image height. The writing of data to the lens memory **33** and the reading of data from the lens memory **33** are controlled by the lens control unit **32**. Upon being attached the interchangeable lens **3** to the camera body **2**, the lens control unit **32** transmits the lens information to the body control unit **210** via the terminals of the lens-side connection portion **302** and the body-side connection portion **202**. Further, the lens control unit **32** transmits position information (focal length information) of the zoom lens **31a** being controlled, position information of the focusing lens **31b** being controlled, information of the F number of the aperture **31c** being controlled, and the like to the body control unit **210**.

[0035] In the present embodiment, the lens control unit **32** functions as an output unit that transmits information regarding the exit pupil distance of the photographing optical system **31** to the camera body **2**. The body control unit **210** functions as an input unit being input information, from the interchangeable lens **3**, regarding the exit pupil distance of the photographing optical system **31**.

[0036] The lens control unit **32** performs bidirectional communication between the camera body **2** and the interchangeable lens **3** via the terminals of the lens-side connection portion **302** and the body-side connection portion **202**. Upon being input a signal requesting transmission of information (h4, h2, Co) regarding the exit pupil distance from the camera body **2**, the lens control unit **32** transmits the information regarding the exit pupil distance to the camera body **2**. It is to be noted that the information regarding the exit pupil distance differs depending on the type of the interchangeable lens **3**. Further, the lens control unit **32** may transmit information regarding the exit pupil distance to the camera body **2** each time the image sensor **22** performs an image capturing. The lens control unit **32** may transmit information regarding the exit pupil distance to the camera body **2** in a case where the zoom lens **31a** moves and the focal length of the photographing optical system **31** changes. The lens control unit **32** may transmit the information on the focal length of the photographing optical system **31** and the information on the exit pupil distance to the camera body **2** by one time bidirectional communication.

[0037] Next, the configuration of the camera body **2** will be described. The camera body **2** is provided with the image sensor **22**, the body memory **23**, a display unit **24**, an operation unit **25**, and the body control unit **210**. The image sensor **22** is a CMOS image sensor, a CCD image sensor or the like. The image sensor **22** performs an image capturing of a subject image formed by the

photographing optical system **31**. In the image sensor **22**, a plurality of pixels each having a photoelectric conversion unit are arranged in two-dimensional manner (row direction and column direction). The photoelectric conversion unit is configured with a photodiode (PD). The image sensor **22** performs photoelectric conversion of the received light by the photoelectric conversion unit to generate a signal, and outputs the generated signal to the body control unit **210**.

[0038] As will be described later, the image sensor **22** has an imaging pixel that outputs a signal used for image generation and an AF pixel (a focus detection pixel) that outputs a signal used for focus detection. The imaging pixel includes a pixel (hereinafter, referred to as an R pixel) having a filter of a spectral characteristic that spectrally disperses the light having the first wavelength region (red (R) light) from the incident light, a pixel (hereinafter, referred to as a G pixel) having a filter of a spectral characteristic that spectrally disperses the light having the second wavelength region (green (G) light) from the incident light, and a pixel (hereinafter, referred to as a B pixel) having a filter of a spectral characteristic that spectrally disperses the light having the third wavelength region (blue (B) light) from the incident light. The R pixel, the G pixel, and the B pixel are arranged according to the Bayer arrangement. The AF pixels are arranged by replacing a part of the imaging pixels and are dispersedly arranged on substantially the entire surface of the imaging surface **22a** of the image sensor **22**. It is to be noted, in the following description, in a case the term “pixel” is simply used, it means either one or both of the imaging pixel and the AF pixel.

[0039] The body memory **23** is configured with, for example, a non-volatile storage medium or the like. In the body memory **23**, an image data, a control program, and the like are recorded. The writing of data to the body memory **23** and the reading of data from the body memory **23** are controlled by the body control unit **210**. The display unit **24** displays an image based on image data, an image showing a focus detection area (an AF area) such as an AF frame, information on photographing such as a shutter speed and the F number, a menu screen, and the like. The operation unit **25** includes various setting switches such as a release button, a power switch, and a switch for switching various modes, and outputs a signal corresponding to each operation to the body control unit **210**. Further, the operation unit **25** is a setting unit capable of setting an arbitrary focus detection area among a plurality of focus detection areas, and a user can select the arbitrary focus detection area by operating the operation unit **25**.

[0040] The body control unit **210** is configured with a processor such as a CPU, FPGA, and ASIC, and a memory such as ROM and RAM, and controls each part of the camera **1** based on a control program. The body control unit **210** includes an area setting unit **211**, a distance calculation unit **212**, a pixel selection unit **213**, a readout unit **214**, a focus detection unit **215**, and an image data generation unit **216**.

[0041] The area setting unit **211** sets (selects) at least one focus detection area **100** among the plurality of focus detection areas **100** provided on the imaging surface **22a** of the image sensor **22** shown in FIG. **2(a)**. The plurality of AF frames displayed on the display unit **24** correspond to the plurality of focus detection areas **100** provided on the image sensor **22**, respectively. The area setting unit **211** sets, among the plurality of AF frames displayed on the display unit **24**, the focus detection area **100** corresponding to the AF frame selected by the user by operating the operation unit **25**, or the focus detection area **100** which is selected by the camera **1** in automatically, as the area in which the focus detection is performed. As will be described later, the focus detection unit **215** detects the deviation amount (defocus amount) between the image by the photographing optical system **31** and the imaging surface **22a** using a signal output from the AF pixel in the focus detection area **100** set by the area setting unit **211**.

[0042] As shown schematically in FIG. **2(b)**, in the focus detection area **100**, in addition to the imaging pixels, a plurality types of pair of the AF pixels (the AF pixel pairs) are arranged. In the present embodiment, a first AF pixel pair, a second AF pixel pair, and a third AF pixel pair are arranged. The first AF pixel pair, the second AF pixel pair, and the third AF pixel pair are arranged for accurately detecting the defocus amount at the exit pupil distance that differs depending on the

image height or the type of interchangeable lens. One of the AF pixel among the AF pixel pair outputs a first signal Sig1, and the other of the AF pixel among the AF pixel pair outputs a second signal Sig2. The first AF pixel pair, the second AF pixel pair, and the third AF pixel pair will be described later. As shown in FIG. 2(a), the plurality of focus detection areas **100** are arranged in [0043] two-dimensional directions (row direction and column direction), and the image height differs depending on arranged position. The small region **110a** (see FIG. 2(b)) in the focus detection area **100a** at the center part of the imaging surface **22a** is located on the optical axis OA1 of the photographing optical system **31**, and the image height H here is substantially zero. As the focus detection area **100** being away from the center (optical axis OA1 of the photographing optical system **31**) of the imaging surface **22a**, the image height H thereat increases. In other words, as the distance from the center of the imaging surface **22a** to the focus detection area **100** increases, the image height H thereat increases. Therefore, in the row where the focus detection area **100a** exists, the focus detection areas **100** farthest from the optical axis OA1 of the photographing optical system **31** (the image height H is the highest) are a focus detection areas **100b** and **100c** located at the left end (the end in the -X direction) and the right end (the end in the +X direction). The focus detection areas **100** at which the image height H is highest in the image sensor **22** are four focus detection areas **100** at the corners of the imaging surface **22a**.

[0044] Since the focus detection area **100** has a predetermined area, the image height differs for each AF pixel depending on the position in the focus detection area **100**. That is, within the focus detection area **100**, the image height at the central small region **110a** (see FIG. 2(b)) is different from the image heights at the small regions **110b** and **110c** located at the left end (end in the -X direction) and the right end (end in the +X direction) respectively (see FIG. 2(b)). However, in the present embodiment, the value of the image height H at the center position of one focus detection area **100** is used as the value representing the image height of the entire focus detection area **100**. The image height of the focus detection area **100a** in the center part of the imaging surface **22a** is zero, and the image heights of the focus detection areas **100b** and **100c** are predetermined image heights H.

[0045] The distance calculation unit **212** calculates the exit pupil distance of the photographing optical system **31** at the image height H. The distance calculation unit **212** calculates the exit pupil distance Po (H) of the photographing optical system **31** at the image height H of the focus detection area **100** set by the area setting unit **211** by the following formula (1).

$$Po(H)=h4\times H.sup.4+h2\times H.sup.2+Co \quad (1)$$

[0046] Formula (1) is a calculation formula with the image height H as a variable, the parameter (h4) is the coefficient of the fourth-order term of the variable H, the parameter (h2) is the coefficient of the second-order term of the variable H, and the constant term Co is the exit pupil distance at the position where the image height is zero (the position of the optical axis OA1 on the imaging surface **22a**). The parameters (h4), (h2), and the constant term Co are information on the exit pupil distances corresponding to different image heights, and are values determined by the optical characteristics of the photographing optical system **31**. Information indicating the parameters (h4), (h2) and the constant term Co is transmitted from the interchangeable lens **3** to the camera body **2** as lens information. It is to be noted, the calculation formula (1) is stored in the internal memory of the body control unit **210**.

[0047] Based on the image height H of the focus detection area **100** set by the area setting unit **211**, the lens information (h4, h2, Co), and the calculation formula (1), the distance calculation unit **212** calculates the exit pupil distance Po (H) for the image height H of the focus detection area **100** having been set. It is to be noted that the calculation formula (1) may be stored in the internal memory of the lens control unit **32**. The lens control unit **32** may transmit the calculation formula (1) to the camera body **2** as lens information together with the parameters (h4), (h2) and the constant term Co.

[0048] The pixel selection unit **213** selects at least one type of the AF pixel pair among a plurality of types of the AF pixel pairs provided in the image sensor **22**. In the present embodiment, the pixel selection unit **213** selects any one type of three types of the AF pixel pairs (the first to third AF pixel pairs) arranged in the focus detection area **100** set by the area setting unit **211**. As will be described later, the pixel selection unit **213** selects the AF pixel pair suitable for the exit pupil distance  $P_o(H)$  calculated by the distance calculation unit **212** from among three types of the AF pixel pairs. In a case that a plurality of focus detection areas **100** are set by the area setting unit **211**, the pixel selection unit **213** selects the same type of the AF pixel pair in each selected focus detection area **100**.

[0049] The readout unit **214** reads out a signal from the image sensor **22**. In a case displaying a through image (live view image) of the subject on the display unit **24** and/or in a case shooting a moving image, the readout unit **214** reads out a signal used for image generation and/or a signal used for focus detection from the image sensor **22** at a predetermined cycle. The readout unit **214** sequentially selects the pixels of the image sensor **22** in row units and reads out the signal from the selected pixel row, that is, by a so-called rolling shutter method.

[0050] The readout unit **214** can perform to read out in a first readout mode and in a second readout mode. In the first readout mode, the readout unit **214** sequentially selects a row of pixels (hereinafter referred to as AF pixel row) in which the AF pixels constituting the AF pixel pair selected by the pixel selection unit **213** are arranged and a row of pixels (hereinafter referred to as an imaging pixel row) in which the AF pixel is not arranged, and reads out a signal from each pixel. In the second readout mode, the readout unit **214** separately reads out signals from the AF pixel row and from the imaging pixel row. For example, the readout unit **214** reads out in the first readout mode in a case

[0051] continuously shooting still images or in a case shooting a high-resolution moving image (for example, 4K moving image shooting). The readout unit **214** reads out in the second readout mode in a case displaying a through image on the display unit **24** or in a case performing low-resolution moving image shooting (for example, Full HD moving image shooting). The first readout mode and the second readout mode will be described later.

[0052] The focus detection unit **215** performs focus detection processing necessary for automatic focus adjustment (AF) of the photographing optical system **31**. The focus detection unit **215** detects the focus position (movement amount of the focusing lens **31b** to the focusing position) for focusing (forming) the image formed by the photographing optical system **31** on the imaging surface **22a**. The focus detection unit **215** calculates the defocus amount by the pupil division type phase difference detection method using the first and second signals Sig1 and Sig2 of the AF pixel pair read out by the readout unit **214**.

[0053] The focus detection unit **215** calculates an image shift amount by performing correlation calculation with a first signal Sig1 generated by capturing an image formed of a first light flux passed through a first pupil region of the exit pupil of the photographing optical system **31** and a second signal Sig2 generated by capturing an image formed of a second light flux passed through a second pupil region of the exit pupil of the photographing optical system **31**. The focus detection unit **215** converts the image shift amount into a defocus amount based on a predetermined conversion formula. The focus detection unit **215** calculates the movement amount of the focusing lens **31b** to the in-focus position based on the calculated defocus amount.

[0054] The focus detection unit **215** determines whether or not the defocus amount is within the permissible value. If the defocus amount is within the permissible value, the focus detection unit **215** determines that being an in-focus state. On the other hand, if the defocus amount exceeds the permissible value, the focus detection unit **215** determines that not being in-focus state and transmits signal for instructing the movement amount and moving operation of the focusing lens **31b** to the lens control unit **32** of the interchangeable lens **3**. Focus adjustment is performed automatically by the lens control unit **32** moving the focusing lens **31b** according to the movement



amount.

[0055] Further, the focus detection unit **215** can also perform the focus detection processing by the contrast detection method in addition to the focus detection processing by the phase difference detection method. The body control unit **210** calculates the contrast evaluation value of the subject image one after another based on the signal output from the imaging pixels while moving the focusing lens **31b** of the photographing optical system **31** along the optical axis OA1 direction. The body control unit **210** associates the position of the focusing lens **31b** and the contrast evaluation value by using the position information of the focusing lens **31b** transmitted from the interchangeable lens **3**. Then, the body control unit **210** detects the position of the focusing lens **31b** at which shows the peak value of the contrast evaluation value, that is, the maximum value, as the in-focus position. The body control unit **210** transmits information on the position of the focusing lens **31b** corresponding to the detected focusing position to the lens control unit **32**. The lens control unit **32** moves the focusing lens **31b** to the in-focus position to perform the focus adjustment.

[0056] The image data generation unit **216** generates image data by performing various image processing on the signals read out from the imaging pixels by the readout unit **214**. It is to be noted that the image data generation unit **216** may generate image data also using signals output from the AF pixels.

[0057] FIG. **3** is a diagram showing an arrangement example of pixels in the focus detection area **100**. The R pixel **13**, the G pixel **13**, and the B pixel **13** are arranged according to the Bayer arrangement. The first AF pixel **11** and the second AF pixel **12** are arranged by being replaced to a part of the imaging pixels **13** of the R, G, and B arranged in the Bayer arrangement. The first AF pixel **11** and the second AF pixel **12** each have a light-shielding portion **43**. The position of the light-shielding portion **43** in the first AF pixel **11** is different from the position of the light-shielding portion **43** in the second AF pixel **12**.

[0058] As shown in FIG. **3**, the image sensor **22** has a pixel group (a first imaging pixel row) **401** in which the R pixels **13** and the G pixels **13** are alternately arranged in left-right direction, that is, the row direction, and a pixel group (a second imaging pixel row) **402** in which the G pixels **13** and the B pixels **13** are alternately arranged in the row direction. Further, the image sensor **22** has a pixel group (a first AF pixel row) **403** in which the G pixels **13** and the first AF pixels **11** are alternately arranged in the row direction, and a pixel group (a second AF pixel row) **404** in which the G pixels **13** and the second AF pixels **12** are alternately arranged in the row direction.

[0059] In a first AF pixel row **403a**, the first AF pixels **11a** and the G pixels **13** are alternately arranged. In a second AF pixel row **404a**, which is separated from the first AF pixel row **403a** with a predetermined number of rows, the second AF pixels **12a** and the G pixels **13** are alternately arranged. It is to be noted, the arrangement position of the first AF pixel **11a** in the first AF pixel row **403a** and the arrangement position of the second AF pixel **12a** in the second AF pixel row **404a** are the same as each other. That is, the first AF pixel **11a** and the second AF pixel **12a** are arranged in the same column. The first AF pixel **11a** of the first AF pixel row **403a** and the second AF pixel **12a** of the second AF pixel row **404a** compose the first AF pixel pair.

[0060] In the first AF pixel row **403b**, which is separated from the second AF pixel row **404a** with a predetermined number of rows, the first AF pixels **11b** and the G pixels **13** are alternately arranged. In the second AF pixel row **404b**, which is separated from the first AF pixel row **403b** with a predetermined number of rows, the second AF pixels **12b** and the G pixels **13** are alternately arranged. It is to be noted, the arrangement position of the first AF pixel **11b** in the first AF pixel row **403b** and the arrangement position of the second AF pixel **12b** in the second AF pixel row **404b** are the same as each other. That is, the first AF pixel **11b** and the second AF pixel **12b** are arranged in the same column. The first AF pixel **11b** of the first AF pixel row **403b** and the second AF pixel **12b** of the second AF pixel row **404b** compose the second AF pixel pair.

[0061] In the first AF pixel row **403c**, which is separated from the second AF pixel row **404b** with a

predetermined number of rows, the first AF pixels **11c** and the G pixels **13** are alternately arranged. In the second AF pixel row **404c**, which is separated from the first AF pixel row **403c** with a predetermined number of rows, the second AF pixels **12c** and the G pixels **13** are alternately arranged. It is to be noted, the arrangement position of the first AF pixel **11c** in the first AF pixel row **403c** and the arrangement position of the second AF pixel **12c** in the second AF pixel row **404c** are the same as each other. That is, the first AF pixel **11c** and the second AF pixel **12c** are arranged in the same column. The first AF pixel **11c** of the first AF pixel row **403c** and the second AF pixel **12c** of the second AF pixel row **404c** compose the third AF pixel pair.

[0062] It is to be noted, the first AF pixel row **403a** and the second AF pixel row **404a** may be arranged in a plurality of rows, respectively, and a plurality of the first AF pixel pairs may be arranged. Further, the first AF pixel row **403b** and the second AF pixel row **404b** may be arranged in a plurality of rows, respectively, and a plurality of the second AF pixel pairs may be arranged. The first AF pixel row **403c** and the second AF pixel row **404c** may be arranged in a plurality of rows, respectively, and a plurality of the third AF pixel pairs may be arranged.

[0063] As described above, the first, second and third AF pixel pairs are arranged so as to accurately detect defocus amount even if the exit pupil distance changes depending on an image height or a type of the interchangeable lens. Accordingly, except for in the pixel pairs arranged around the optical axis OA1 (the center of the imaging surface **22a**) of the photographing optical system **31**, areas of the light-shielding portions of the first, second and third AF pixel pairs are different to each other. Except for the AF pixels around the optical axis OA1 of the photographing optical system **31**, the incident angles of the light incident on the AF pixels are different depending on the exit pupil distances being different. The incident angle increases as the exit pupil distance decreases, and the incident angle decreases as the exit pupil distance increases. The area of the light-shielding portion **43** differs depending on the AF pixel pair in order to block a part of the light incident at different incident angles depending on the exit pupil distance. Thereby, the focus detection unit **215** can accurately detect the defocus amount even if the exit pupil distance differs. It is to be noted, with respect to the pixel pair around the optical axis OA1 (center of the imaging surface **22a**) of the photographing optical system **31**, an incident angle is  $0^\circ$  in regardless of the exit pupil distance. Therefore, the areas of the light-shielding portions **43** of the first AF pixel pair, the second AF pixel pair, and the third AF pixel pair are the same. As will be described later, the area of the light-shielding portion **43** differs also depending on the position (image height) of the AF pixel.

[0064] Each of the first AF pixels **11a**, **11b**, **11c** and the second AF pixels **12a**, **12b**, **12c** is provided with a filter having spectral characteristics that spectrally disperses the second wavelength region (green (G)) of the incident light. It is to be noted, the filter being provided with each of the AF pixels of the first AF pixels **11a** to **11c** and the second AF pixels **12a** to **12c** may have spectral characteristics that spectrally disperses the first wavelength range (red (R) light) or the third wavelength range (blue (B) light). Alternatively, the first AF pixels **11a** to **11c** and the second AF pixels **12a** to **12c** may have filters having spectral characteristics that spectrally disperses the first, second, and third wavelength regions of the incident light.

[0065] FIG. 4 is a diagram for explaining a configuration example of an AF pixel and an imaging pixel provided in the image sensor **22** according to the first embodiment. FIG. 4(a) shows an example of a cross section of the first AF pixel **11** among the first and second AF pixels **11** and **12** constituting the AF pixel pair. FIG. 4(b) shows an example of a cross section of the second AF pixel **12** among the first and second AF pixels **11** and **12** constituting the AF pixel pair. FIG. 4(c) shows an example of a cross section of the imaging pixel **13** (R pixel, G pixel, B pixel).

[0066] In FIG. 4, each of the first and second AF pixels **11** and **12** and the imaging pixel **13** includes a microlens **44**, a color filter **51**, and a photoelectric conversion unit **42** (PD42) which photoelectrically converts the light transmitted (passed) through the microlens **44** and the color filter **51**. The first light flux **61** is a light flux that has passed through the first pupil region of the

exit pupil of the photographing optical system **31** among divided in substantially two equal regions. The second light flux **62** is a light flux that has passed through the second pupil region of the exit pupil of the photographing optical system **31** among divided in substantially two equal regions. [0067] In FIG. **4(a)**, the first AF pixel **11** is provided with a light-shielding portion **43L** that blocks the second light flux **62** among the first and second light fluxes **61** and **62**. The light-shielding portion **43L** is provided, between the color filter **51** and the photoelectric conversion unit **42** and so as to position above the photoelectric conversion unit **42**. In the example shown in FIG. **4(a)**, the light-shielding portion **43L** is arranged so as to block the left half ( $-X$  direction side) of the photoelectric conversion unit **42**. The right end (end in the  $+X$  direction) of the light-shielding portion **43L** substantially coincides with the center line that bisects the photoelectric conversion portion **42** to the left and right. The photoelectric conversion unit **42** of the first AF pixel **11** receives the first light flux **61**. The photoelectric conversion unit **42** of the first AF pixel **11** photoelectrically converts the first light flux **61** to generate an electric charge, and the first AF pixel **11** outputs signal Sig1 based on the electric charge generated by the photoelectric conversion unit **42**.

[0068] The area of the light-shielding portion **43L** differs depending on the position (image height) of the first AF pixel **11**, except for the first AF pixel **11** around the optical axis OA1 (center of the imaging surface **22a**) of the photographing optical system **31**. If the position of the first AF pixel **11** differs, that is, the image height differs, the incident angle of the light incident to the first AF pixel **11** differs. If the image height increases, the incident angle increases, if the image height decrease, the incident angle decreases, and if the image height is 0, the incident angle is  $0^\circ$ . The area of the light-shielding portion **43L** differs depending on the image height in order to block the second light flux **62** of the light incident at the incident angle that differs depending on the image height.

[0069] In FIG. **4(b)**, the second AF pixel **12** is provided with a light-shielding portion **43R** that blocks the first light flux **61** among the first and second light fluxes **61** and **62**. The light-shielding portion **43R** is provided, between the color filter **51** and the photoelectric conversion unit **42** and so as to position above the photoelectric conversion unit **42**. In the example shown in FIG. **4(b)**, the light-shielding portion **43R** is arranged so as to block the right half ( $+X$  direction side) of the photoelectric conversion unit **42**. The left end (end in the  $-X$  direction) of the light-shielding portion **43R** substantially coincides with the center line that bisects the photoelectric conversion portion **42** to the left and right. The photoelectric conversion unit **42** of the second AF pixel **12** receives the second light flux **62**. The photoelectric conversion unit **42** of the second AF pixel **12** photoelectrically converts the second light flux **62** to generate an electric charge, and the second AF pixel **12** outputs signal Sig2 based on the electric charge generated by the photoelectric conversion unit **42**.

[0070] Similarly to that of the first AF pixel **11**, the area of the light-shielding portion **43R** differs depending on the position (image height) of the second AF pixel **12**, except for the second AF pixel **12** around the optical axis OA1 (center of the imaging surface **22a**) of the photographing optical system **31**. The area of the light-shielding portion **43R** differs depending on the image height in order to block the first light flux **61** of the light incident at the incident angle that differs depending on the image height.

[0071] FIG. **4(c)** shows that the photoelectric conversion unit **42** of the imaging pixel **13** receives the first and second light fluxes **61** and **62** that have passed through the first and second pupil regions of the exit pupil of the photographing optical system **31**. The photoelectric conversion unit **42** of the imaging pixel **13** photoelectrically converts the first and second light fluxes **61** and **62** to generate an electric charge, and the imaging pixel **13** outputs signal based on the electric charge generated by the photoelectric conversion unit **42**.

[0072] FIG. **5** is a cross-sectional view of three types of AF pixel pairs arranged in a small region **110a** (see FIG. **2(b)**) within the focus detection area **100a**. FIG. **5(a)** shows the first and second AF pixels **11a** and **12a** constituting the first AF pixel pair arranged in the first AF pixel row **403a** and

the second AF pixel row **404a** of FIG. 3, respectively. FIG. 5(b) shows the first and second AF pixels **11b** and **12b** constituting the second AF pixel pair arranged in the first AF pixel row **403b** and the second AF pixel row **404b** of FIG. 3, respectively. FIG. 5(c) shows the first and second AF pixels **11c** and **12c** constituting the third AF pixel pair arranged in the first AF pixel row **403c** and the second AF pixel row **404c** of FIG. 3, respectively. As shown in FIG. 5, in each of the first AF pixels **11a** to **11c** and the second AF pixels **12a** to **12c**, the center line of the photoelectric conversion unit **42** and the optical axis OA2 of the microlens **44** substantially coincide. Light incident at an incident angle of  $0^\circ$  with respect to the optical axis OA2 of the microlens **44** is focused on the optical axis OA2 of the microlens. Since the line passing through the center of the photoelectric conversion unit **42** coincides with the optical axis OA2 of the microlens **44**, the light incident on the microlens **44** is focused on the line passing through the center of the photoelectric conversion unit **42**. That is, the light transmitted through the photographing optical system **31** is focused on a line passing through the center of the photoelectric conversion unit **42**.

[0073] In the first AF pixel **11a** shown in FIG. 5(a), the right end (end in the +X direction) of the light-shielding portion **43L** substantially coincides with the optical axis OA2 of the microlens **44**. The light-shielding portion **43L** of the first AF pixel **11a** shields the left half (−X direction side) of the photoelectric conversion unit **42**. The second light flux **62** transmitted through the microlens **44** is shielded by the light-shielding portion **43L** without being incident on the photoelectric conversion unit **42**. Thereby, the photoelectric conversion unit **42** of the first AF pixel **11a** receives the first light flux **61**. In the second AF pixel **12a**, the left end (end in the −X direction) of the light-shielding portion **43R** substantially coincides with the optical axis OA2 of the microlens **44**. The first light flux **61** transmitted through the microlens **44** is shielded by the light-shielding portion **43R** without being incident on the photoelectric conversion unit **42**. Thereby, the photoelectric conversion unit **42** of the second AF pixel **12a** receives the second light flux **62**.

[0074] In each of the first AF pixels **11b** and **11c** shown in FIG. 5(b) and FIG. 5(c), the right end (end in the +X direction) of the light-shielding portion **43L** substantially coincides with the optical axis OA2 of the microlens **44**. Therefore, each photoelectric conversion unit **42** of the first AF pixels **11b** and **11c**, similarly to that of the first AF pixel **11a**, receives the first light flux **61**. Further, in each of the second AF pixels **12b** and **12c**, the left end (end in the −X direction) of the light shielding portion **43R** substantially coincides with the optical axis OA2 of the microlens **44**. Therefore, similarly to the first AF pixel **12a**, each photoelectric conversion unit **42** of the second AF pixels **12b** and **12c** receives the second light flux **62**.

[0075] FIG. 6 is a cross-sectional view of three types of AF pixel pairs arranged in a small region **110c** (see FIG. 2(b)) separated from the small region **110a** in the focus detection area **100a** in the +X direction. FIG. 6(a) shows the first and second AF pixels **11a** and **12a** constituting the first AF pixel pair. FIG. 6(b) shows the first and second AF pixels **11b** and **12b** constituting the second AF pixel pair. FIG. 6(c) shows the first and second AF pixels **11c** and **12c** constituting the third AF pixel pair.

[0076] As shown in FIG. 6, in each of the first AF pixels **11a** to **11c** and the second AF pixels **12a** to **12c**, a line passing through the center of the photoelectric conversion unit **42** is being shifted in the +X direction with respect to the optical axis OA2 of the microlens **44**. In the present embodiment, in the first and second AF pixels arranged apart from the small region **110a** in the +X direction, the line passing through the center of the photoelectric conversion unit **42** is being shifted in the +X direction with respect to the optical axis OA2 of the microlens **44**. Further, in the first and second AF pixels arranged apart from the small region **110a** in the −X direction, the line passing through the center of the photoelectric conversion unit **42** is being shifted in the −X direction with respect to the optical axis OA2 of the microlens **44**.

[0077] As shown in FIG. 6, the areas of the light-shielding portions **43L** of the first AF pixels **11a** to **11c** are different to each other. The area of the light-shielding portion **43L** of the first AF pixel **11a** is smaller than the area of the light-shielding portion **43L** of the first AF pixel **11b**. The area of

the light-shielding portion **43L** of the first AF pixel **11b** is smaller than the area of the light-shielding portion **43L** of the first AF pixel **11c**. The areas of the light-shielding portions **43R** of the second AF pixels **12a** to **12c** are different to each other. The area of the light-shielding portion **43R** of the second AF pixel **12a** is larger than the area of the light-shielding portion **43R** of the second AF pixel **12b**. The area of the light-shielding portion **43R** of the second AF pixel **12b** is larger than the area of the light-shielding portion **43R** of the second AF pixel **12c**.

[0078] As shown in FIG. 6, the line passing through the center line of the photoelectric conversion unit **42** and the optical axis OA2 of the microlens **44** are deviated, and the area of the light-shielding portions **43** of the first AF pixel and the area of the light-shielding portions **43** of the second AF pixel are different. Thus, in each of the first and second AF pixels, the edge of the light-shielding portion and the optical axis OA2 of the microlens **44** are deviated from each other. In FIG. 6(a), for example, in the first AF pixel **11a**, the right end (end in the +X direction) of the light-shielding portion **43L** is located on the +X direction side by the deviation amount **d1** from the optical axis OA2 of the microlens **44**. Further, in the second AF pixel **12a**, the left end (end in the -X direction) of the light-shielding portion **43R** is located on the +X direction side by the deviation amount **d1** from the optical axis OA2 of the microlens **44**.

[0079] As shown in FIG. 6, each of the deviation amounts in the second and third AF pixel pairs is different from the deviation amount in the first AF pixel pair. The deviation amount **d2** in the first and second AF pixels **11b** and **12b** constituting the second AF pixel pair is larger than the deviation amount **d1** in the first and second AF pixels **11a** and **12a** constituting the first AF pixel pair. The deviation amount **d3** in the first and second AF pixels **11c** and **12c** constituting the third AF pixel pair is larger than the deviation amount **d2** in the first and second AF pixels **11b** and **12b** constituting the second AF pixel pair. That is,  $d1 < d2 < d3$ .

[0080] FIG. 7 is a cross-sectional view of three types of AF pixel pairs in a part of the focus detection area **100c** separated from the focus detection region **100a** shown in FIG. 2 in the +X direction. FIG. 7(a) shows the first and second AF pixels **11a** and **12a** constituting the first AF pixel pair. FIG. 7(b) shows the first and second AF pixels **11b** and **12b** constituting the second AF pixel pair. FIG. 7(c) shows the first and second AF pixels **11c** and **12c** constituting the third AF pixel pair.

[0081] Similarly to the three types of AF pixel pairs shown in FIG. 6, in each of the first AF pixels **11a** to **11c** and the second AF pixels **12a** to **12c** shown in FIG. 7, a line passing through the center of the photoelectric conversion unit **42** is being shifted in the +X direction with respect to the optical axis OA2 of the microlens **44**. Further, similarly to the three types of AF pixel pairs shown in FIG. 6, the areas of the light-shielding portions **43L** of the first AF pixels **11a** to **11c** are different to each other. Also, the areas of the light-shielding portions **43R** of the second AF pixels **12a** to **12c** are different to each other.

[0082] In the three types of AF pixel pairs shown in FIG. 6 and FIG. 7, each of the amounts of deviation of the line passing through the center of the photoelectric conversion unit **42** with respect to the optical axis OA2 of the microlens **44** differs to each other. Further, in the AF pixels other than the first AF pixel **11b** and the second AF pixel **12b**, the area of the light-shielding portion **43L** and the area of the light-shielding portion **43R** are different. Compared with the three types of AF pixel pairs shown in FIG. 6, the three types of AF pixel pairs shown in FIG. 7 have a larger deviation amount with respect to the optical axis OA2 of the microlens **44**. Further, as compared with the first AF pixel **11a** and the second AF pixel **12a** shown in FIG. 6, the first AF pixel **11a** and the second AF pixel **12a** shown in FIG. 7 respectively have a smaller area of the light-shielding portion **43L** and a larger area of the light-shielding portion **43R**. As compared with the first AF pixel **11c** and the second AF pixel **12c** shown in FIG. 6, the first AF pixel **11c** and the second AF pixel **12c** shown in FIG. 7 respectively have a larger area of the light-shielding portion **43L** and a smaller area of the light-shielding portion **43R**. The areas of the light-shielding portion **43L** and the light-shielding portion **43R** in each of the first AF pixel **11b** and the second AF pixel **12b** shown in

FIG. 7 are the same as the areas of those shown in FIG. 6.

[0083] In the first AF pixel **11a**, the right end (end in the +X direction) of the light-shielding portion **43L** is deviated by the amount **d4** in the +X direction with respect to the optical axis **OA2** of the microlens **44**. In the second AF pixel **12a**, the left end (end in the -X direction) of the light-shielding portion **43R** is deviated by the amount **d4** in the +X direction with respect to the optical axis **OA2** of the microlens **44**.

[0084] Each of the deviation amounts in the second and third AF pixel pairs is different from the deviation amount in the first AF pixel pair. The deviation amount **d5** in the first and second AF pixels **11b** and **12b** constituting the second AF pixel pair is larger than the deviation amount **d4** in the first and second AF pixels **11a** and **12a** constituting the first AF pixel pair. The deviation amount **d6** in the first and second AF pixels **11c** and **12c** constituting the third AF pixel pair is larger than the deviation amount **d5** in the first and second AF pixels **11b** and **12b** constituting the second AF pixel pair. That is,  $d4 < d5 < d6$ .

[0085] As shown in FIG. 5, FIG. 6 and FIG. 7, the deviation amount between the line passing through the center of the photoelectric conversion unit **42** and the optical axis **OA2** of the microlens **44** differs depending on the image height. The higher the image height, the larger the deviation amount, and the lower the image height, the smaller the deviation amount. At a position where the image height is high, light passes through the photographing optical system **31** and is obliquely incident to the microlens **44**. That is, the light is incident at an incident angle larger than  $0^\circ$  with respect to the optical axis **OA2** of the microlens **44**. Therefore, it can also be said that the larger the incident angle of light with respect to the microlens **44**, the larger the deviation amount. Incident light having an incident angle larger than  $0^\circ$  with respect to the optical axis **OA2** of the microlens **44** is focused as shifting in the +X direction or -X direction from the optical axis **OA2** of the microlens. Because the line passing through the center of the photoelectric conversion unit **42** and the optical axis **OA2** of the microlens **44** deviate from each other, the light incident on the microlens **44** is focused on the line passing through the center of the photoelectric conversion unit **42**. That is, the light transmitted through the photographing optical system **31** is focused on a line passing through the center of the photoelectric conversion unit **42**. Thereby, the amount of light transmitted through the photographing optical system **31** and incident on the photoelectric conversion unit **42** can be increased.

[0086] As shown in FIG. 5, FIG. 6 and FIG. 7, the area of the light-shielding portion **43** differs depending on the AF pixel pair. As described above, the exit pupil distance of the photographing optical system **31** differs depending on the type of the interchangeable lens **3**. Therefore, each of the first AF pixel pair, the second AF pixel pair, and the third AF pixel pair has a light-shielding portion **43** having a different area in order to accurately detect the defocus amount at different exit pupil distances. Further, the area of the light-shielding portion **43L** and the area of the light-shielding portion **43R** of the first AF pixel pair differ depending on the position (image height) where the first AF pixel pair is arranged. As described above, the exit pupil distance of the photographing optical system **31** differs depending on the image height. Therefore, the first AF pixel pair has a light-shielding portion **43L** and a light-shielding portion **43R** having an area that differs depending on the image height in order to accurately detect the defocus amount at different exit pupil distances. The same applies to the third AF pixel pair as in the first AF pixel pair. Thereby, the focus detection unit **215** can accurately detect the defocus amount even at different exit pupil distances. That is, the focus detection unit **215** can accurately detect the defocus amount even if the image height or the type of the interchangeable lens changes.

[0087] In the first to third AF pixel pairs, the deviation amount between the light-shielding portion **43** and the optical axis of the microlens **44** increases as the image height increases in the +X direction from the small region **110a** shown in FIG. 2(b). Comparing the deviation amounts of the first to third AF pixel pairs in the three regions where the image heights are  $H_a$ ,  $H_b$ , and  $H_c$  ( $H_a < H_b < H_c$ ) is as follows. The deviation amount in the first AF pixel pair at the region of image

height  $H_b$  is larger than the deviation amount in the first AF pixel pair at the region of image height  $H_a$ , and is smaller than the deviation amount in the first AF pixel pair at the region of image height  $H_c$ . Similarly, the deviation amount in each the second and third AF pixel pairs at the region of image height  $H_b$  is respectively larger than the deviation amount in each the second and third AF pixel pairs at the region of image height  $H_a$ , and is respectively smaller than the deviation amount in each the second and third AF pixel pairs at the region of image height  $H_c$ . The deviation amount  $d_4$  in the first AF pixel pair arranged in the focus detection area **100c** shown in FIG. 7 is larger than the deviation amount  $d_1$  in the first AF pixel pair arranged in the small region **110c** shown in FIG. 6. The deviation amounts  $d_5$  and  $d_6$  in the second and third AF pixel pairs arranged in the focus detection region **100c** shown in FIG. 7 are respectively larger than the deviation amounts  $d_2$  and  $d_3$  in the second and third AF pixel pairs arranged in the small region **110c** shown in FIG. 6.

[0088] To the first to third AF pixel pairs arranged in the small region **110b** separated from the small region **110a** shown in FIG. 2(b) in the  $-X$  direction, deviation amounts of the same amount as  $d_1$  to  $d_3$  are respectively given in the direction opposite to the deviation direction shown in FIG. 6. To the first to third AF pixel pairs arranged in the small region **110b** shown in FIG. 2(a), deviation amounts of the same amount as  $d_4$  to  $d_6$  are respectively given in the direction opposite to the deviation direction shown in FIG. 7. The deviation amount in the first to third AF pixel pairs arranged apart from the small region **110a** in the  $-X$  direction also increases as the image height increases.

[0089] As described above, the deviation amounts in the first to third AF pixel pairs are different from each other. Therefore, on the surfaces intersecting in the light incident direction, the areas of light receiving portions of the photoelectric conversion units **42** in each of the first AF pixels **11a** to **11c** are different from each other, and the areas of light receiving portions of the photoelectric conversion units **42** in each of the second AF pixels **12a** to **12c** are different from each other. As described above, in the present embodiment, since the light receiving areas of the photoelectric conversion units **42** are different from each other in the first to third AF pixel pairs, it is possible to perform pupil division corresponding to different incident angles. As a result, the focus detection unit **215** can accurately detect the defocus amount.

[0090] Next, an example of a method for determining the deviation amounts in the first to third AF pixel pairs in the focus detection area **100** will be described. In FIG. 8, **110a** represents the position of the small region **110** located at a distance corresponding to the image height  $H_d$  from the position **0** (the center position of the imaging surface **22a**) where the optical axis  $OA_1$  of the photographing optical system **31** intersects the imaging surface **22a** of the image sensor **22**. A first reference exit pupil  $EP_1$ , a second reference exit pupil  $EP_2$ , and a third reference exit pupil  $EP_3$  are set on the optical axis  $OA_1$  of the photographing optical system **31**. The second reference exit pupil  $EP_2$  exists closer to the imaging surface **22a** than the first reference exit pupil  $EP_1$  and exists to the  $+Z$  direction side than the first reference exit pupil  $EP_1$ . The third reference exit pupil  $EP_3$  exists closer to the imaging surface **22a** than the second reference exit pupil  $EP_2$  and exists to the  $+Z$  direction side than the second reference exit pupil  $EP_2$ .

[0091] The distance between the first reference exit pupil  $EP_1$  and the imaging surface **22a** is defined as the first reference exit pupil distance  $Po_1$ , the distance between the second reference exit pupil  $EP_2$  and the imaging surface **22a** is defined as the second reference exit pupil distance  $Po_2$ , and the distance between the third reference exit pupil  $EP_3$  and the imaging surface **22a** is defined as the third reference exit pupil distance  $Po_3$ . It is to be noted that  $Po_1 > Po_2 > Po_3$ .

[0092] In FIG. 8,  $L_1$  indicates the principal ray of the light flux that passes through the first reference exit pupil  $EP_1$  and is incident on the AF pixel in the small region **110** at the position **110a**.  $L_2$  indicates the principal ray of the light flux that passes through the second reference exit pupil  $EP_2$  and is incident on the AF pixel in the small region **110** at the position **110x**.  $L_3$  indicates the principal ray of the light flux that passes through the third reference exit pupil  $EP_3$  and is incident on the AF pixel in the small region **110** at the position **110a**.

[0093] In FIG. 8, assuming that  $\theta 1$  is the angle of incidence of the principal ray L1 to the AF pixel, the deviation amount in the first AF pixel pair in the small region 110 at the image height Hd is determined based on the angle of incidence  $\theta 1$ . Similarly, assuming that  $\theta 2$  and  $\theta 3$  respectively are the angles of incidence of the principal rays L2 and L3 to the AF pixels, the deviation amounts in the second and third AF pixel pairs in the small region 110 at the image height Hd are determined based on the angles of incidence  $\theta 2$  and  $\theta 3$ , respectively. As described above, the deviation amount increases as the incident angle increases. Further, except for the position where the image height is 0 (position 0), the longer the exit pupil distance, the smaller the incident angle, so that  $\theta 1 < \theta 2 < \theta 3$ . Therefore, in the first, second, and third AF pixel pairs shown in FIGS. 6(a) through 6(c), the deviation amounts d1, d2, and d3 are as  $d1 < d2 < d3$ . Further, in the first, second, and third AF pixel pairs shown in FIGS. 7(a) through 7(c), the deviation amounts d4, d5, and d6 are as  $d4 < d5 < d6$ .

[0094] In such a way, the deviation amount of the first AF pixel pair with respect to the first reference exit pupil EP1 (the first reference exit pupil distance Po1) is determined. Similarly, the deviation amount of the second AF pixel pair with respect to the second reference exit pupil EP2 (the second reference exit pupil distance Po2) and the deviation amount of the third AF pixel pair with respect to the third reference exit pupil EP3 (the third reference exit pupil distance Po3) are determined.

[0095] Next, the relationship between the exit pupil distance of the photographing optical system 31 and the first to third AF pixel pairs will be described. As shown in FIG. 8, a first threshold value Th1 regarding the exit pupil distance is set at an intermediate position between the first reference exit pupil EP1 and the second reference exit pupil EP2, and a second threshold value Th2 regarding the exit pupil distance is set at an intermediate position between the second reference exit pupil EP2 and the third reference exit pupil EP3. The region where the exit pupil distance is equal to or greater than the first threshold Th1 is defined as a first exit pupil distance range R1, the region where the exit pupil distance is between the first threshold Th1 and the second threshold Th2 is defined as a second exit pupil distance range R2, and the region where the exit pupil distance is equal to or less than the second threshold Th2 is defined as a third exit pupil distance range R3.

[0096] In a case that the exit pupil distance of the photographing optical system 31 is equal to or greater than the first threshold Th1, that is, in a case that the exit pupil distance of the photographing optical system 31 belongs to the first exit pupil distance range R1, the pixel selection unit 213 selects the first AF pixel pair. In a case that the exit pupil distance of the photographing optical system 31 is between the first threshold Th1 and the second threshold Th2, that is, in a case that the exit pupil distance of the photographing optical system 31 belongs to the second exit pupil distance range R2, the pixel selection unit 213 selects the second AF pixel pair. In a case that the exit pupil distance of the photographing optical system 31 is equal to or less than the second threshold Th2, that is, in a case that the exit pupil distance of the photographing optical system 31 belongs to the third exit pupil distance range R3, the pixel selection unit 213 selects the third AF pixel pair.

[0097] As described above, the pixel selection unit 213 selects an appropriate AF pixel pair from the first to third AF pixel pairs depending on, which the exit pupil distance of the photographing optical system belongs to among the first to third exit pupil distance ranges R1 to R3.

[0098] Next, the optical characteristics of the photographing optical system 31 of the interchangeable lens 3, specifically, the optical characteristics in which the exit pupil distance thereof changes depending on the image height will be described. FIG. 9 shows the optical characteristics of the interchangeable lens 3 to be mounted on the camera body 2 shown in FIG. 1 in which the exit pupil distance changes depending on the image height. In FIG. 9, the horizontal axis represents the exit pupil distance Po, and the vertical axis represents the image height H. FIG. 9(a), FIG. 9(b), FIG. 9(c), and FIG. 9(d) respectively show the optical characteristics of different types of interchangeable lenses. With respect to the optical characteristics of the photographing optical system 31 of the interchangeable lens 3, which is represented by the optical characteristic



curve **200a** in FIG. 9(a), the exit pupil distance  $P_o$  decreases as the image height  $H$  increases. The optical characteristic curve **200a** in FIG. 9(a) shows that, the exit pupil distance is  $P_{oa}$  at image height zero, the exit pupil distance gradually decreases as the image height  $H$  increases, and the exit pupil distance becomes  $(P_{oa}-\Delta p_1)$  at the maximum image height  $H_{max}$ .

[0099] With respect to the optical characteristics of the photographing optical system **31** of the interchangeable lens **3**, which is represented by the optical characteristic curve **200b** in FIG. 9(b), the exit pupil distance  $P_o$  increases as the image height  $H$  increases. The optical characteristic curve **200b** in FIG. 9(b) shows that, the exit pupil distance is  $P_{ob}$  at image height zero, the exit pupil distance gradually increases as the image height  $H$  increases, and the exit pupil distance becomes  $(P_{ob}+\Delta p_2)$  at the maximum image height  $H_{max}$ .

[0100] In the following description, an optical characteristic curve in which the exit pupil distance  $P_o$  decreases as the image height  $H$  increases, such as the optical characteristic curve **200a**, is referred to as a negative optical characteristic curve. On the other hand, an optical characteristic curve in which the exit pupil distance  $P_o$  increases as the image height  $H$  increases, such as the optical characteristic curve **200b**, is referred to as a positive optical characteristic curve.

[0101] The photographing optical system **31** of the interchangeable lens **3** shown in FIG. 9 (c) has an optical characteristic curve that differs, that is, changes depending on the position of the focusing lens **31b** shown in FIG. 1. This photographing optical system **31** exhibits an optical characteristic curve **200c** when the focusing lens **31b** is located at a first position and exhibits an optical characteristic curve **200d** when the focusing lens **31b** is located at a second position. The first and second positions of the focusing lens **31b** are arbitrary positions between the infinity position and the closest position, of the focusing lens **31b**, including the infinity position and the closest position. The infinity position of the focusing lens **31b** is a position where the subject at the infinity distance is in focus, and the closest position is a position where the subject at the closest distance is in focus.

[0102] In FIG. 9(c), the optical characteristic curve **200c** represents the optical characteristics of the photographing optical system **31** in a case where the focusing lens **31b** is at the first position. The optical characteristic curve **200c** shows that, the exit pupil distance is  $P_{oc}$  at image height zero, the exit pupil distance gradually decreases as the image height  $H$  increases, and the exit pupil distance becomes  $(P_{oc}-\Delta p_3)$  at the maximum image height  $H_{max}$ . The optical characteristic curve **200d** represents the optical characteristics of the photographing optical system **31** in a case where the focusing lens **31b** is at the second position. The optical characteristic curve **200d** shows that, the exit pupil distance is  $P_{od}$  at image height zero, the exit pupil distance gradually increases as the image height  $H$  increases, and the exit pupil distance becomes  $(P_{od}+\Delta p_4)$  at the maximum image height  $H_{max}$ .

[0103] In FIG. 9(c), the optical characteristic curve **200c** in the case where the focusing lens **31b** is at the first position is shown as the negative optical characteristic curve, and the optical characteristic curve **200d** in the case where the focusing lens **31b** is at the second position is shown as the positive optical characteristic curve. However, there can also be an interchangeable lens **3** having an optical characteristic in which both the optical characteristic curve **200c** and the optical characteristic curve **200d** are both positive or negative.

[0104] The photographing optical system **31** of the interchangeable lens **3** shown in FIG. 9(d) has an optical characteristic curve that differs, that is, changes depending on the focal length of the zoom lens (the position of the zoom lens **31a** in FIG. 1). This photographing optical system **31** exhibits an optical characteristic curve **200e** in a case where both the focal length is  $f_1$  and exhibits an optical characteristic curve **200f** in a case where the focal length is  $f_2$ .

[0105] In FIG. 9(d), the optical characteristic curve **200e** represents the optical characteristics of the photographing optical system **31** in a case where the focal length is  $f_1$ . The optical characteristic curve **200e** shows that, the exit pupil distance is  $P_{oe}$  at image height zero, the exit pupil distance gradually decreases as the image height  $H$  increases, and the exit pupil distance

becomes  $(P_{of}-\Delta p_5)$  at the maximum image height  $H_{max}$ . The optical characteristic curve **200f** represents the optical characteristics of the photographing optical system **31** in a case where the focal length is  $f_2$ . The optical characteristic curve **200f** shows that, the exit pupil distance is  $P_{of}$  at image height zero, the exit pupil distance gradually increases as the image height  $H$  increases, and the exit pupil distance becomes  $(P_{of}+\Delta p_6)$  at the maximum image height  $H_{max}$ .

[0106] In FIG. **9(d)**, the optical characteristic curve **200e** in the case where the focal length is  $f_1$  is shown as the negative optical characteristic curve, and the optical characteristic curve **200f** in the case where the focal length is  $f_2$  is shown as the positive optical characteristic curve. However, there can also be an interchangeable lens **3** having an optical characteristic in which both the optical characteristic curve **200e** and the optical characteristic curve **200f** are both positive or negative.

[0107] It is to be noted that the exit pupil distance  $P_o$  at the image height  $H$  in the above description is the distance of the exit pupil of the photographing optical system **31** from view of the image height  $H$  of the imaging surface **22a**. In other words, the exit pupil distance  $P_o$  at the image height  $H$  is the exit pupil distance (distance from the imaging surface **22a**) of the photographing optical system **31** through which the light flux that passes through the photographing optical system **31** and is incident on the position in correspondence with the image height  $H$  of the imaging surface **22a**.

[0108] FIG. **10** is a diagram showing the relationship between the image height  $H$  and the exit pupil distance  $P_o$ . In FIG. **10**, to the AF pixel (in FIG. **10**, the microlens **44** is shown on behalf of the AF pixel) located at the center position **0** (image height zero) of the imaging surface **22a**, the light flux that has passed through the exit pupil  $E_{Pa}$  (exit pupil distance  $P_{oa}$ ) of the imaging optical system **31** is incident. The exit pupil distance  $P_{oa}$  of this exit pupil  $E_{Pa}$  is the exit pupil distance of the exit pupil  $E_{Pa}$  for the image height zero.

[0109] Further, a light flux that has passed through the exit pupil  $E_{Pb}$  of the photographing optical system **31** is incident on the AF pixel (in FIG. **10**, the microlens **44** is shown as representative of the AF pixel) located at the image height  $H_e$ . The exit pupil distance  $(P_{oa}-\Delta p)$  of the exit pupil  $E_{Pb}$  is the exit pupil distance of the exit pupil  $E_{Pb}$  for the image height  $H$ .

[0110] Here, the relationship between the optical characteristics of each interchangeable lens **3** and the above formula (1) will be described.  $P_o(H)=h_4 \times H_{sup.4}+h_2 \times H_{sup.2}+C_o$  of the above formula (1) is a function to approximate the optical characteristic curves **200a**, **200b**, **200c**, **200d**, **200e**, **200f** and the like shown in FIG. **9(a)** through FIG. **9(d)**. The optical characteristic curve **200a** shown in FIG. **9(a)** is approximated by the calculation of the formula (1); by setting the constant term  $C_o$  to the exit pupil distance  $P_{oa}$  at the image height zero of FIG. **9(a)**, and by setting the coefficients  $h_4$  and  $h_2$  to the coefficients  $h_{4a}$  and  $h_{2a}$  corresponding to the curve of the optical characteristic curve **200a**. As described above, the interchangeable lens **3** having the optical characteristics of FIG. **9(a)** stores the constant term  $P_{oa}$  and the coefficients  $h_{4a}$  and  $h_{2a}$  in the lens memory **33** as lens information.

[0111] Similarly, with respect to the interchangeable lens **3** having the optical characteristics of FIG. **9(b)**, the constant terms  $P_{ob}$  and the coefficients  $h_{4b}$  and  $h_{2b}$ , that determines a calculation of the formula (1) that approximates the optical characteristics curve **200b** are stored in the lens memory **33** as the lens information.

[0112] Further, the interchangeable lens **3** shown in FIG. **9(c)** has optical characteristics in which the optical characteristic curve changes depending on the position of the focusing lens **31b**. The interchangeable lens **3** stores in the lens memory **33** the constant terms  $C_o$  and the coefficients  $h_4$  and  $h_2$  for the calculation of the formula (1) that approximate the optical characteristic curve for each position of the focusing lens **31b**. The range in which the focusing lens **31b** moves (between the infinity position and the closest position) is divided into a plurality of zones **Z1** to **Zn**, and one optical characteristic curve representing the zone (range) is determined for each section **Z1** to **Zn**. For example, the optical characteristic curve in a case where the focusing lens **31b** is located at the

intermediate position of one zone is defined as the optical characteristic curve representing that zone.

[0113] The optical characteristic curve representing the zone  $Z_k$  is defined as the optical characteristic curve  $Z_k$  ( $k=1, 2, \dots, n$ ). For the calculation of the formula (1) that approximates the optical characteristic curve  $Z_1$  representing the zone  $Z_1$ , the constant term  $C_0$  and the coefficients  $h_4$  and  $h_2$  are set to  $Poz_1$ ,  $h_{4z1}$  and  $h_{2z1}$ . For the calculation of the formula (1) that approximates the optical characteristic curve  $Z_2$  representing the zone  $Z_2$ , the constant term  $C_0$  and the coefficients  $h_4$  and  $h_2$  are set to  $Poz_2$ ,  $h_{4z2}$  and  $h_{2z2}$ . Similarly, for the calculation of the formula (1) that approximates the optical characteristic curve  $Z_n$  representing the zone  $Z_n$ , the constant term  $C_0$  and the coefficients  $h_4$  and  $h_2$  are set to  $Poz_n$ ,  $h_{4zn}$  and  $h_{2zn}$ . FIG. 11 shows these zones and the constant terms and coefficients for the calculation for approximating the optical characteristic curves representing these zones. The interchangeable lens 3 stores the zones  $Z_1$  to  $Z_n$ , the constant terms  $Poz_1$  to  $Poz_n$ , and the coefficients  $h_{4z1}$  to  $h_{4zn}$  and  $h_{2z1}$  to  $h_{2zn}$  shown in FIG. 11 in the lens memory 33, as lens information.

[0114] The interchangeable lens 3 shown in FIG. 9(d) is a zoom lens and has optical characteristics in which the optical characteristic curve changes depending on the focal length. The interchangeable lens 3 stores in the lens memory 33 the constant terms  $C_0$  and the coefficients  $h_4$  and  $h_2$  for the calculation of the formula (1) that approximate the optical characteristic curve for each focal length. The distance between the maximum focal length and the minimum focal length of the zoom lens set by the zoom lens 31a shown in FIG. 1 is divided into a plurality of zones  $W_1$  to  $W_n$ , and one optical characteristic curve representing the zone is determined for each zone  $W_1$  to  $W_n$ . For example, an optical characteristic curve at a focal length in the middle of one zone is defined as an optical characteristic curve representing that zone.

[0115] The optical characteristic curve representing the zone  $W_k$  is defined as the optical characteristic curve  $W_k$  ( $k=1, 2, \dots, n$ ). For the calculation of the formula (1) that approximates the optical characteristic curve  $W_1$  representing the zone  $W_1$ , the constant term  $C_0$  and the coefficients  $h_4$  and  $h_2$  are set to  $Pow_1$ ,  $h_{4w1}$  and  $h_{2w1}$ . For the calculation of the formula (1) that approximates the optical characteristic curve  $W_2$  representing the zone  $W_2$ , the constant term  $C_0$  and the coefficients  $h_4$  and  $h_2$  are set to  $Pow_2$ ,  $h_{4w2}$  and  $h_{2w2}$ . Similarly, for the calculation of the formula (1) that approximates the optical characteristic curve  $W_n$  representing the zone  $W_n$ , the constant term  $C_0$  and the coefficients  $h_4$  and  $h_2$  are set to  $Pow_n$ ,  $h_{4wn}$  and  $h_{2wn}$ . FIG. 12 shows these zones and the constant terms and coefficients for the calculation for approximating the optical characteristic curves representing these zones. The interchangeable lens 3 stores the zones  $W_1$  to  $W_n$ , the constant terms  $Pow_1$  to  $Pow_n$ , the coefficients  $h_{4w1}$  to  $h_{4wn}$ , and  $h_{2w1}$  to  $h_{2wn}$  in the lens memory 33 shown in FIG. 12, as lens information.

[0116] Although the interchangeable lens 3 of FIG. 9(d) is a zoom lens having optical characteristics in which the optical characteristic curve changes depending on the focal length, there is another zoom lens having optical characteristics in which the optical characteristic curve changes depending on the position of the focusing lens 31b in addition that the optical characteristic curve changes depending on the focal length. That is, the optical characteristic curve of the another zoom lens changes depending on both the position (focal length) of the zoom lens 31a and the position of the focusing lens 31b.

[0117] Next, the relationship between the optical characteristic curve showing the optical characteristics of the interchangeable lens 3 shown in FIG. 9 and the first to third exit pupil distance ranges  $R_1$  to  $R_3$  shown in FIG. 8 will be described. FIG. 13 shows; the first and second threshold values  $Th_1$  and  $Th_2$  regarding the exit pupil distance shown in FIG. 8, the first to third exit pupil distance ranges  $R_1$  to  $R_3$ , and the optical characteristic curve exemplified in FIG. 9. As shown in FIG. 13, in the entire optical characteristic curve 200g, that is, the exit pupil distance from the image height zero to the maximum image height  $H_{max}$  is located within the second exit pupil distance range  $R_2$ . In a case where the interchangeable lens 3 having such an optical

characteristic curve **200g** is attached to the camera body **2**, even if the region setting unit **211** set the focus detection area **100** for any image height H, the pixel selection unit **213** selects the second AF pixel pair.

[0118] With respect to the optical characteristic curve **200h**, the part corresponding to the exit pupil distance from the image height zero to the image height  $H_f$  belongs to the second exit pupil distance range **R2**, and the part corresponding to the exit pupil distance from the image height  $H_f$  to the maximum image height  $H_{max}$  belongs to the first exit pupil distance range **R1**. In a case where the area setting unit **211** sets the focus detection area **100** at which the image height is  $H_f$  or less, the pixel selection unit **213** selects the second AF pixel pair. Further, in a case where the area setting unit **211** sets the focus detection area **100** at which the image height is larger than  $H_f$ , the pixel selection unit **213** selects the first AF pixel pair.

[0119] With respect to the optical characteristic curve **200i**, the part corresponding to the exit pupil distance from the image height zero to the image height  $H_g$  belongs to the third exit pupil distance range **R3**, and the part corresponding to the exit pupil distance from the image height  $H_g$  to the maximum image height  $H_{max}$  belongs to the second exit pupil distance range **R2**. In a case where the area setting unit **211** sets the focus detection area **100** at which the image height is  $H_g$  or less, the pixel selection unit **213** selects the third AF pixel pair. Further, in a case where the area setting unit **211** sets the focus detection area **100** at which the image height is larger than  $H_g$ , the pixel selection unit **213** selects the second AF pixel pair.

[0120] It is to be noted, as described above, in a case where a plurality of focus detection areas **100** are set by the area setting unit **211**, the pixel selection unit **213** selects the same type of AF pixel pairs for all selected focus detection area **100**. In such case, the pixel selection unit **213** selects an AF pixel pair based on the position of the focus detection area **100** farthest from the optical axis **OA1** of the photographing optical system **31** (the image height H is the highest) among the plurality of selected focus detection areas **100**. In the present embodiment, the pixel selection unit **213** selects AF pixel pairs as described above based on the image height of the focus detection area **100** having the highest image height among the plurality of selected focus detection areas **100**. The pixel selection unit **213** selects AF pixel pairs of the same type as the selected AF pixel pair for the focus detection area **100** of the highest image height among the selected plurality of focus detection areas **100** with respect also to other focus detection areas **100**.

[0121] The circuit configuration and operation of the image sensor **22** according to the first embodiment will be described with reference to FIG. **14** and FIG. **15**. FIG. **14** is a diagram showing a configuration of a pixel of the image sensor **22** according to the first embodiment. The pixel **13** includes the photoelectric conversion unit **42**, a transfer unit **52**, a reset unit **53**, a floating diffusion (FD) **54**, an amplification unit **55**, and a selection unit **56**. The photoelectric conversion unit **42** is a photodiode PD, which converts incident light into electric charge and stores the photoelectrically converted electric charges.

[0122] The transfer unit **52** is configured with a transistor **M1** controlled by a signal TX, and transfers the charge photoelectrically converted by the photoelectric conversion unit **42** to the FD **54**. The transistor **M1** is a transfer transistor. A capacitor C of the FD **54** accumulates (retains) the charge transferred to the FD **54**.

[0123] The amplification unit **55** outputs a signal corresponding to the electric charge stored in the capacitor C of the FD **54**. The amplification unit **55** and the selection unit **56** configure an output unit that generates and outputs a signal based on the electric charge generated by the photoelectric conversion unit **42**.

[0124] The reset unit **53** is configured with a transistor **M2** controlled by a signal RST, discharges the electric charge accumulated in the FD **54**, and resets the voltage of the FD **54**. The transistor **M2** is a reset transistor.

[0125] The selection unit **56** is configured with a transistor **M4** controlled by a signal SEL, and electrically connects or disconnects the amplification unit **55** and a vertical signal line **60**. The

transistor **M4** is a selection transistor.

[0126] As described above, the charge photoelectrically converted by the photoelectric conversion unit **42** is transferred to the FD **54** by the transfer unit **52**. Then, a signal corresponding to the electric charge transferred to the FD **54** is output to the vertical signal line **60**. A pixel signal is an analog signal generated based on the electric charge photoelectrically converted by the photoelectric conversion unit **42**. The signal output from the imaging pixel **13** is converted into a digital signal and then output to the body control unit **210**.

[0127] It is to be noted, in the present embodiment, the circuit configurations of the first AF pixels **11** (**11a** to **11c**) and the second AF pixels **12** (**12a** to **12c**) are the same as the circuit configuration of the imaging pixel **13**. The signals output from the first AF pixel **11** and the second AF pixel **12** are converted into digital signals and then output to the body control unit **210** as the pair of signals (the first and second signals Sig1 and Sig2) used for focus detection.

[0128] FIG. **15** is a diagram showing a configuration example of the image sensor according to the first embodiment. The image sensor **22** includes a plurality of imaging pixels **13**, a first AF pixel **11** and a second AF pixel **12**, a vertical control unit **70**, and a plurality of column circuit units **80**. It is to be noted, in FIG. **15**, for simplification of the description, only 128 pixels of 8 pixels in the row direction ( $\pm X$  direction) $\times$ 16 pixels in the column direction ( $\pm Y$  direction) are shown. In FIG. **15**, the pixel in the upper left corner is defined as the imaging pixel **13** (1,1) in the 1st row and the 1st column, and the imaging pixel in the lower right corner is defined as the imaging pixel **13** (16, 8) in the 16th row and the 8th column. The image sensor **22** is provided with a plurality of vertical signal lines **60** (vertical signal lines **60a** to **60h**). The plurality of vertical signal lines **60** are connected to each of the pixel columns (1st column to 8th column), which is a column of a plurality of pixels arranged in the column direction, that is, in the vertical direction. To each of the vertical signal lines **60a**, **60c**, **60e**, **60g**, a plurality of imaging pixels **13** arranged in each of columns are connected, and the vertical signal lines **60a**, **60c**, **60e**, **60g** respectively output signals of the connected imaging pixels **13**. To each of the vertical signal lines **60b**, **60d**, **60f**, **60h**, a plurality of imaging pixels **13**, a plurality of the first AF pixels and a plurality of the second AF pixels arranged in each of columns are connected, and the vertical signal lines **60b**, **60d**, **60f**, **60h** respectively output signals of the connected imaging pixels **13**, the first AF pixels and the second AF pixels.

[0129] The vertical control unit **70** is provided so as to be common to a plurality of pixel columns. The vertical control unit **70** supplies the signal TX, the signal RST, and the signal SEL shown in FIG. **14** to each pixel to control the operation of each pixel. The vertical control unit **70** supplies a signal to the gate of each transistor of the pixel, and turns the transistor on (connected state, conducting state, short-circuited state) or off state (disconnected state, non-conducting state, open state, break-circuit state).

[0130] The column circuit unit **80** includes an analog/digital conversion unit (AD conversion unit), and converts an analog signal input from each pixel via the vertical signal line **60** into a digital signal and outputs the converted signal. The pixel signal converted into a digital signal is input to a signal processing unit (not shown), and after signal processing such as correlation double sampling and processing for correcting the signal amount, and output to the body control unit **210** of the camera **1**.

[0131] The readout unit **214** of the camera **1**, by controlling the vertical control unit **70**, performs the first readout mode in which all pixel rows are sequentially selected and signal of each pixel is readout, and the second readout mode in which signals from the AF pixel row and from the imaging pixel row are separately read out.

[0132] In a case the first readout mode has set by the readout unit **214**, the vertical control unit **70** sequentially selecting pixel row and makes each pixel output signal. In FIG. **15**, the vertical control unit **70** sequentially selects the imaging pixel rows **401**, **402**, the AF pixel rows **403a**, **404a**, **403b**, and **404b** from the 1st row toward the 16th row. Further, the vertical control unit **70** makes each pixel of the selected imaging pixel row or AF pixel row output signal to the vertical signal line **60**.

The readout unit **214** reads out the signal output to the vertical signal line **60**. An example of a signal readout method in the first readout mode will be described below.

[0133] First, the vertical control unit **70** turns to on state the selection units **56** of the R pixel **13** (1,1) through the G pixel **13** (1,8), which are the pixels in the first imaging pixel row **401** of the 1st row. Further, the vertical control unit **70** makes the selection units **56** of pixels in the rows other than the 1st row turn to off state. Thereby, each signal of the R pixel **13** (1,1) through the G pixel **13** (1,8) in the 1st row is output, via the selection unit **56**, to each of the signal lines **60a** to **60h** which are connected. The readout unit **214** reads out the signals of the R pixel **13** (1,1) through the G pixel **13** (1,8) having been output to the vertical signal lines **60**.

[0134] Next, the vertical control unit **70** turns to on state the selection units **56** of the G pixel **13** (2,1) through the first AF pixel **11a** (2,8), which are the pixels in the first AF pixel row **403a** of the 2nd row. Further, the vertical control unit **70** makes the selection units **56** of pixels in the rows other than the 2nd row turn to off state. Thereby, each signal of the G pixel **13** (2,1) through the first AF pixel **11a** (2,8) in the 2nd row is output to each of the signal lines **60a** to **60h**. The readout unit **214** reads out the signals of the G pixel **13** (2,1) through the first AF pixel **11a** (2,8), in the 2nd row, having been output to the vertical signal lines **60**.

[0135] Similarly, the vertical control unit **70** selects the 3rd and subsequent pixel rows (the first imaging pixel row **401**, the second imaging pixel row **402**, the first AF pixel row **403**, the second AF pixel row **404**) in the order of the 3rd row, the 4th row, the 5th row, and the 6th row. Further, the vertical control unit **70** makes each pixel of the selected imaging pixel row or AF pixel row output signal to the vertical signal line **60**. The readout unit **214** reads out the signal output to the vertical signal line **60**.

[0136] As described above, in the first readout mode, the readout unit **214** reads out a signal from each pixel of all the pixel rows. The signal having read out from each pixel is output to the body control unit **210** after being subjected to signal processing by the column circuit unit **80** or the like.

[0137] In a case the second readout mode is set by the readout unit **214**, the vertical control unit **70** separately performs of outputting of the signal of each pixel in the AF pixel row to the vertical signal lines **60** and outputting of the signal of each pixel in the imaging pixel row to the vertical signal lines **60**. In the present embodiment, the vertical control unit **70** first sequentially selects only the AF pixel row and let each pixel of the selected AF pixel row output a signal to the vertical signal lines **60**. Then, the vertical control unit **70** sequentially selects the imaging pixel row and let each pixel of the selected imaging pixel row output a signal to the vertical signal lines **60**. The readout unit **214** first reads out only the signal output to the vertical signal lines **60** from each pixel of the AF pixel row, and then reads out the signal output to the vertical signal lines **60** from each pixel of the imaging pixel row.

[0138] An example of a signal readout method in the second readout mode will be described below. It is to be noted, the vertical control unit **70** selects the AF pixel row in which the AF pixel pair selected by the pixel selection unit **213** is arranged, in one (or a plurality of) focus detection areas **100** set by the area setting unit **211**. In the example shown below, it is assumed that the first AF pixel pair is selected by the pixel selection unit **213** based on the exit pupil distance of the photographing optical system **31**.

[0139] First, the vertical control unit **70** turns to on state the selection units **56** of the G pixel **13** (2,1) through the first AF pixel **11a** (2,8) which constitute the first AF pixel row **403a** of the 2nd row shown in FIG. **15**. Further, the vertical control unit **70** makes the selection units **56** of pixels in the rows other than the 2nd row turn to off state. Thereby, each signal of the G pixel **13** (2,1) through the first AF pixel **11a** (2,8) is output, via the selection unit **56**, to each of the signal lines **60a** to **60h** which are connected. The readout unit **214** reads out the signals of the G pixel **13** (2,1) through the first AF pixel **11a** (2,8) having been output to the vertical signal lines **60**.

[0140] Next, the vertical control unit **70** turns to on state the selection units **56** of the G pixels **13** (6,1) through the second AF pixel **12a** (6,8) which constitute the second AF pixel row **404a** of the

6th row shown in FIG. 15. Further, the vertical control unit 70 makes the selection units 56 of pixels in the rows other than the 6th row turn to off state. Thereby, each signal of the G pixel 13 (6,1) through the second AF pixel 12a (6,8) is output to each of the signal lines 60a to 60h. The readout unit 214 reads out the signals of the G pixel 13 (6,1) through the second AF pixel 12a (6,8) in the 2nd row, having output to the vertical signal lines 60.

[0141] Although not shown, a plurality of the first AF pixel rows 403a and a plurality of the second AF pixel rows 404a are also arranged in after the 16th row. The vertical control unit 70 sequentially selects only the plurality of the first AF pixel rows 403a and the plurality of the second AF pixel row 404a toward the column direction (+Y direction). The vertical control unit 70 causes each pixel of the selected first AF pixel row 403a and the second AF pixel row 404a to output a signal to the vertical signal lines 60. The readout unit 214 reads out signals output to the vertical signal line 60 from the G pixels 13, the first AF pixels 11a, and the second AF pixels 12a. The signals sequentially read from each AF pixel row are output to the body control unit 210 after being subjected to signal processing by the column circuit unit 80 or the like.

[0142] After reading out the signal from each pixel of the AF pixel row, the vertical control unit 70 sequentially selects the imaging pixel row toward the column direction (+Y direction). The vertical control unit 70 causes each pixel of the selected imaging pixel row to output a signal to the vertical signal line 60. The readout unit 214 reads out signal output to the vertical signal line 60 from each pixel in the imaging pixel rows. The vertical control unit 70 turns to on state the selection units 56 of the R pixel 13 (1,1) through the G pixel 13 (1,8) which are in the first imaging pixel row 401 of the 1st row shown in FIG. 15. Further, the vertical control unit 70 makes the selection units 56 of pixels in the rows other than the 1st row turn to off state. Thereby, each signal of the R pixel 13 (1,1) through the G pixel 13 (1,8) is output to each of the signal lines 60a to 60h. The readout unit 214 reads out the signals of the R pixel 13 (1,1) through the G pixel 13 (1,8) having been output to the vertical signal lines 60.

[0143] Next, the vertical control unit 70 turns to on state the selection units 56 of the R pixel 13 (3,1) through the G pixel 13 (3,8) which constitute the first imaging pixel row 401 of the 3rd row shown in FIG. 15. Further, the vertical control unit 70 makes the selection units 56 of pixels in the rows other than the 3rd row turn to off state. Thereby, each signal of the R pixel 13 (3,1) through the G pixel 13 (3,8) is output to each of the signal lines 60a to 60h. The readout unit 214 reads out the signals of the R pixel 13 (3,1) through the G pixel 13 (3,8) having been output to the vertical signal lines 60.

[0144] Further, the vertical control unit 70 turns to on state the selection units 56 of the G pixel 13 (4,1) through the B pixel 13 (4,8) which constitute the first imaging pixel row 402 of the 4th row shown in FIG. 15. Further, the vertical control unit 70 makes the selection units 56 of pixels in the rows other than the 4th row turn to off state. Thereby, each signal of the G pixel 13 (4,1) through the B pixel 13 (4,8) is output to each of the signal lines 60a to 60h. The readout unit 214 reads out the signals of the G pixel 13 (4,1) through the B pixel 13 (4,8) having been output to the vertical signal lines 60.

[0145] Similarly, with respect to the 5th row and subsequent rows, the vertical control unit 70 sequentially selects the imaging pixel rows (first imaging pixel row 401, second imaging pixel row 402). The vertical control unit 70 makes each pixel of the selected the first imaging pixel row 401 and the second imaging pixel row 402 output signal to the vertical signal line 60. The readout unit 214 reads the signals output from the R pixel 13, the G pixel 13, and the B pixel 13 to the vertical signal line 60. The signals sequentially read from each imaging pixel row are output to the body control unit 210 after being subjected to signal processing by the column circuit unit 80 or the like.

[0146] As described above, in the second readout mode, the readout unit 214 controls the vertical control unit 70 to read out a signal from each pixel in the AF pixel row prior to read out a signal from each pixel in the imaging pixel row. Therefore, the first and second signals Sig1 and Sig2 of the AF pixel pair can be read out at high speed, and the time required for focus adjustment can be

shortened. Further, since the reading unit **214** reads out the signal of each pixel of the AF pixel row and the signal of each pixel of the imaging pixel row separately, the signal used for the focus detection can be efficiently obtained, and the load for processing signals for AF can be reduced. The camera **1** according to the present embodiment reads out the first and second signals Sig1 and Sig2 of the AF pixel pair selected based on the exit pupil distance of the photographing optical system **31** and performs the focus detection process. Thus, highly accurate focus detection can be performed.

[0147] It is to be noted, in a case the second readout mode is set, the readout unit **214** may read out a signal from each pixel of the imaging pixel row prior to read out a signal from each pixel in the AF pixel row. Even in such a case, since the signal of the AF pixel pair selected based on the exit pupil distance of the photographing optical system **31** is read out and the focus detection process is performed, the focus detection can be performed with high accuracy. Further, since the readout unit **214** reads out the signal of each pixel of the AF pixel row and the signal of each pixel of the imaging pixel row separately, the load for processing signals for AF can be reduced.

[0148] Moreover, the readout unit **214**, in a case reading out signals from each pixel in the imaging pixel row (the first imaging pixel row **401**, the second imaging pixel row **402**) in the second readout mode, may read out signals by performing thinning out readout in which pixels of specific row or column are thinned. In a case performing the thinning out reading, the reading unit **214** selects imaging pixels in a specific row or column among all the imaging pixels and reads out a signal from the selected imaging pixel. By controlling the vertical control unit **70**, since the readout unit **214** skips reading the signal of the pixel of a specific row or column, the signal can be read out at high speed. In this case, the signals from the AF pixel row can be read out before reading out the signals from the imaging pixel row in the second read mode, and the signals from the imaging pixel row can be read out at high speed. Therefore, in a case displaying a live view image or shooting a moving image, by performing in the second readout mode, it is possible to perform high-speed focus detection and high-speed shooting. It is to be noted, the readout unit **214** may read out signals from a plurality of imaging pixels through adding the signals.

[0149] According to the above-described embodiment, the following effects can be obtained.

[0150] (1) The focus detection device, comprises: the imaging unit (the image sensor **22**) having the first pixel and the second pixel (the AF pixels) each of which receives light transmitted through the optical system and outputs signal used for focus detection, and the third pixel (the imaging pixel) which receives light transmitted through the optical system and outputs signal used for image generation; the input unit (the body control unit **210**) to which the information regarding the optical system is input; the selection unit (the image selection unit **213**) that selects at least one of the first pixel and the second pixel based on the information input to the input unit; the readout unit (the readout unit **214**) that reads out the signal from at least one of the first pixel and the second pixel based on a selection result of the selection unit at a timing different from the timing of reading out the signal from the third pixel to be read out; and the focus detection unit **215** that performs the focus detection based on at least one of the signals of the first pixel and the second pixel which read out by the readout unit. In the present embodiment, the readout unit **214** reads a signal from each pixel in the AF pixel row prior to read out a signal from each pixel in the imaging pixel row. Therefore, the focus detection device can read out the signals of the AF pixel pair at high speed, and can perform focus adjustment at high speed. Moreover, since the readout unit **214** reads out the signal of each pixel of the AF pixel row and the signal of each pixel of the imaging pixel row separately, the load for processing signals for AF can be reduced. Further, the focus detection unit **215** performs the focus detection process using the signal output from the AF pixel pair selected based on the exit pupil distance of the photographing optical system **31**. Therefore, highly accurate focus detection can be performed.

[0151] The following variations are also within the scope of the present invention, and one or more of the variations can be combined with the above-described embodiment.



#### Variation 1

[0152] In the first embodiment, although three reference exit pupils (the first to third exit pupils EP1 to EP3) were used as the reference exit pupils, it may be two reference exit pupils or four or more reference exit pupils.

#### Variation 2

[0153] The method of obtaining the exit pupil distance depending on the image height is not limited to the method of obtaining using the above-mentioned formula (1). For example, instead of the formula (1), a calculation formula using the cube of the image height can be used. Further, information (table) showing the relationship between the image height and the exit pupil distance may also be used without using the calculation formula.

#### Variation 3

[0154] In the first embodiment, an example in which information regarding the exit pupil distance is stored in advance in the lens memory 33 or the like and the information regarding the exit pupil distance is input from the interchangeable lens 3 to the camera body 2 has been described. However, the information regarding the exit pupil distance may be input to the camera body 2 from other than the interchangeable lens 3. For example, the body memory 23 may store the information regarding the exit pupil distance in advance, and the body control unit 210 may acquire the information regarding the exit pupil distance from the body memory 23. Further, the camera body 2 may acquire the information regarding the exit pupil distance from a storage medium or may acquire the information regarding the exit pupil distance from an external device by wired communication or wireless communication. It is to be noted, the information regarding the exit pupil distance may be information regarding the exit pupil distance corresponding to one image height.

#### Variation 4

[0155] In the first embodiment, the parameters ( $h_4$ ) and ( $h_2$ ) and the constant term  $C_0$ , used for calculating the exit pupil distance  $P_0(H)$  have been described as examples of the information regarding the exit pupil distance. However, the camera body 2 may acquire the value  $P_0(H)$  itself of the exit pupil distance according to an image height, from the interchangeable lens 3, the storage medium, or the like as the information regarding the exit pupil distance.

#### Variation 5

[0156] In the above-described embodiment, an example in which first to third AF pixel pairs having different deviation amounts are arranged on the image sensor 22 as a plurality of types of AF pixel pairs has been described. However, a plurality of types of AF pixel pairs having different arrangement positions of the light-shielding portions between the color filter 51 and the photoelectric conversion unit 42 may be arranged on the image sensor 22. FIG. 16 is a diagram showing a configuration example of a AF pixel of the image sensor 22 according to the present variation. In the figure, the same reference signs are assigned to the same or corresponding parts as those in the above-described embodiment.

[0157] The light-shielding portion 43L of the first AF pixel 11a is provided, between the color filter 51 and the photoelectric conversion unit 42, with a predetermined distance  $h_1$  from the photoelectric conversion unit 42. The light-shielding portion 43L of the first AF pixel 11b is provided, between the color filter 51 and the photoelectric conversion unit 42, with a predetermined distance  $h_2$  from the photoelectric conversion unit 42. The light-shielding portion 43L of the first AF pixel 11c is provided, between the color filter 51 and the photoelectric conversion unit 42, with a predetermined distance  $h_3$  from the photoelectric conversion unit 42. The distance  $h_2$  is smaller than the distance  $h_1$  and larger than the distance  $h_3$ . That is,  $h_1 > h_2 > h_3$ . As described above, arranged positions of the light-shielding portions 43L are different in the first AF pixels 11a, 11b, and 11c to each other. Further, in the second AF pixels 12a, 12b, 12c constituting each AF pixel pair, the arrangement positions of the light-shielding portions 43R are different from each other. Thereby, the first to third AF pixel pairs can perform pupil division corresponding to different

incident angles, as in the case of the above-described embodiment.

#### Variation 6

[0158] In the first embodiment, an example in which one photoelectric conversion unit is arranged in one pixel has been described, however, a configuration in which two or more photoelectric conversion units are included per pixel may be adopted.

#### Variation 7

[0159] FIG. 17 is a diagram showing a configuration example of a AF pixel of the image sensor 22 according to the present variation. As an example, FIG. 17 shows a cross-sectional view of a part of three types of AF pixel pairs in the focus detection area 100c shown in FIG. 2. In the figure, the same reference signs are assigned to the same or corresponding parts as those in the above-described embodiment. Each of the three types of AF pixels shown in FIG. 17(a) to FIG. 17(c) includes a microlens 44, and a first and second photoelectric conversion units 42a and 42b each of which photoelectrically convert the light transmitted through the microlens 44. In the present variation, the light receiving areas, of a first photoelectric conversion units 42a and a second photoelectric conversion unit 42b are different from each other in the first to third AF pixel pair. In this case as well, the first to third AF pixel pairs can perform pupil division corresponding to different incident angles, as in the case of the above-described embodiment.

#### Variation 8

[0160] The pixel selection unit 213 may configure to select a plurality of types of AF pixel pairs. In this case, the focus detection unit 215 may calculate a plurality of defocus amounts from selected plurality of types of AF pixel pairs, and the movement amount of the focusing lens 31b may be calculated based on the average value of the defocus amounts. For example, the moving amount of the focusing lens 31b may be determined based on the average value of, the defocus amount calculated using the first and second signals Sig1 and Sig2 of the first AF pixel pair and the defocus amount calculated using the first and second signals Sig1 and Sig2 of the second AF pixel pair.

#### Variation 9

[0161] In the above-described embodiment, the case where the primary color system (RGB) color filter is used for the image sensor 22 has been described, but the complementary color system (CMY) color filter may be used.

#### Variation 10

[0162] The imaging device described in the above-described embodiment and variations may be applied to a camera, a smartphone, a tablet, a camera built in a PC, an in-vehicle camera, a camera mounted on an unmanned aerial vehicle (drone, radio-controlled model, etc.), etc.

[0163] Although various embodiments and variations have been described above, the present invention is not limited to these contents. Other aspects conceivable within the scope of the technical idea of the present invention are also included within the scope of the present invention.

[0164] The disclosure of the following priority application is herein incorporated by reference: Japanese Patent Application No. 2018-137274 filed Jul. 20, 2018.

#### REFERENCE SIGNS LIST

TABLE-US-00001      1 . . . Imaging Device,    2 . . . Camera Body,    3 . . . Interchangeable Lens,    11 . . . AF pixel,    12 . . . AF pixel,    13 . . . Imaging Pixel,    22 . . . Image Sensor,    31 . . . Photographing Optical System,    32 . . . Lens Control Unit,    42 . . . Photoelectric Conversion Unit,    210 . . . Body Control Unit,    211 . . . Area Setting Unit,    212 . . . Distance Calculation Unit,    213 . . . Pixel Selection Unit,    214 . . . Readout Unit,    215 . . . Focus Detection Unit,    216 . . . Image Data Generation Unit.

## Claims

1. An image sensor comprising: a first pixel and a second pixel each of which receives light transmitted through an optical system and outputs a signal used for focus detection; a third pixel

which receives light transmitted through the optical system and outputs a signal used for image generation; and a control unit that comprises a processor or a circuit and functions as a readout unit that reads out the signal of the first pixel or the signal of the second pixel, which is selected based on information regarding the optical system, at a timing different from a timing of reading out the signal from the third pixel.

---