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Lens drive module, imaging module, electronic device, and lens unit

Abstract

Provided are a lens drive module, an imaging module, an electronic device, and a lens unit that have a simple configuration and are advantageous in reducing power consumption. The lens drive module includes a lens unit that includes a plurality of lenses and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses, and a lens actuator that causes an electromagnetic force to act on the lens unit in response to energization.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS

(1) This application is a U.S. National Phase of International Patent Application No. PCT/JP2021/030166 filed on Aug. 18, 2021, which claims priority benefit of Japanese Patent Application No. JP 2020-152077 filed in the Japan Patent Office on Sep. 10, 2020. Each of the

above-referenced applications is hereby incorporated herein by reference in its entirety.

TECHNICAL FIELD

(2) The present disclosure relates to a lens drive module, an imaging module, an electronic device, and a lens unit.

BACKGROUND ART

(3) Recently, imaging devices have been developed to have a large number of pixels, a large aperture, a high performance, and a small size. With such imaging devices having a large number of pixels and a high performance, the power consumption of their solid-state imaging devices such as charge-coupled device (CCD) image sensors and complementary metal-oxide-semiconductor (CMOS) image sensors also tends to increase. In addition, such imaging devices having a large aperture include a large and heavy lens, so that the power consumption of an actuator that moves the lens for focus adjustment and the like tends to increase.

(4) Against the background of such an increase in power consumption, it is necessary to reduce the power consumption of the entire device. For example, in order to reduce the power consumption of an actuator that moves a lens, a device has been proposed that drives the lens to move while controlling the magnetic field.

(5) In an imaging module illustrated in FIG. 15 of PTL 1, a magnetic layer is provided on the outer circumference of a lens laminate. An electromagnetic driving force according to a magnetic field generated by an electromagnetic coil and the positional relationship between the magnetic layer and a fixed-side lens drive mechanism acts on the magnetic layer, and the lens laminate moves in the optical axis direction.

(6) In a lens drive device disclosed in PTL 2, an L-shaped yoke being disposed on the outside of a magnet prevents the magnetic force from leaking to the outside of the lens housing, so that the magnetic flux of the magnet is drawn into the yoke to suppress the reduction in the thrust force of the actuator.

(7) In a lens drive device disclosed in PTL 3, one of a moving body and a fixed body is provided with a first drive coil and a second drive coil, and the other is provided with a drive magnet. The moving body including a lens is moved in the optical axis direction by magnetic attraction and magnetic repulsion between the drive magnet and the first and second drive coils.

CITATION LIST

Patent Literature

(8) [PTL 1]

(9) JP 2016-106239 A

[PTL 2] JP 2010-85494 A

[PTL 3] JP 2005-37865 A

SUMMARY

Technical Problem

(10) In the imaging module of PTL 1, the magnetic layer, which is unnecessary in normal imaging modules, needs to be provided on the outer circumference of the lens laminate, which complicates the configuration of the device and increases the labor required for manufacturing. Further, in the imaging module of PTL 1, a ferromagnetic resin is used to bond the lenses together, and the application of such a resin requires precise control. This makes it difficult to increase productivity and also to manufacture the imaging module at low cost. Further, in imaging modules mounted on latest mobile terminals, lens holders are often used to align and fix lenses to each other. In the case of using the lens holders, it is not necessary to bond the lenses together using a resin. Further, the imaging module of PTL 1 does not have a spacer, so that stray light such as flare light cannot be removed. As a result, the imaging module is inferior in optical performance.

(11) The yoke, which has a unique shape, used in the lens drive device of PTL 2 is expensive, and such a yoke as installed results in a complicated structure. Further, in the case where a moving magnet type of camera shake correction mechanism, which has been widely used in recent years, is

applied to the lens drive device of PTL 2, the power consumption required for camera shake correction is large due to the weight of the yoke. Therefore, there is a concern that heat generated by the lens drive device is likely to be remarkable, and the driving time of the lens drive device is reduced when powered by a battery.

(12) In the lens drive device of PTL 3, in order to move the moving body including the lens, it is necessary to move the heavy drive magnet. Therefore, in the case where the moving magnet type of camera shake correction mechanism is applied to the lens drive device of PTL 3, there is a concern of an increased power consumption, heat generated in the lens drive device, and a reduced driving time of the lens drive device when powered by a battery.

(13) Accordingly, the present disclosure provides a lens drive module, an imaging module, an electronic device, and a lens unit that have a simple configuration and are advantageous in reducing power consumption.

Solution to Problem

(14) One aspect of the present disclosure relates to a lens drive module including: a lens unit that includes a plurality of lenses and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses; and a lens actuator that causes an electromagnetic force to act on the lens unit in response to energization.

(15) The lens unit may include a plurality of spacers each of which is provided between two adjacent lenses, and all the spacers included in the lens unit may include a ferromagnetic material.

(16) The lens unit may include a plurality of spacers each of which is provided between two adjacent lenses, and the plurality of spacers may include a spacer that includes a ferromagnetic material and a spacer that includes a non-ferromagnetic material.

(17) The lens actuator may include a coil that is provided integrally with the lens unit so as to be energized, and a magnet that applies a magnetic field to the coil.

(18) The coil may be located between the spacer that includes the ferromagnetic material and the magnet.

(19) The spacer that includes the ferromagnetic material, the coil, and the magnet may be located in a same straight line extending in a direction perpendicular to an optical axis of the plurality of lenses.

(20) Another aspect of the present disclosure relates to an imaging module including: a lens unit that includes a plurality of lenses and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses; an imaging element that performs photoelectric conversion of light entering through the plurality of lenses; and a lens actuator that causes an electromagnetic force to act on the lens unit in response to energization to adjust a distance between the lens unit and the imaging element.

(21) The imaging element may have a flip-chip structure.

(22) The imaging element may have a CSP structure.

(23) A lens may be provided that is located between the lens unit and the imaging element and is separate from the plurality of lenses included in the lens unit.

(24) An infrared cut filter may be provided.

(25) Another aspect of the present disclosure relates to an electronic device including: a lens unit that includes a plurality of lenses and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses; an imaging element that performs photoelectric conversion of light entering through the plurality of lenses; a lens actuator that causes an electromagnetic force to act on the lens unit in response to energization to adjust a distance between the lens unit and the imaging element; and a circuit board that receives an electrical signal from the imaging element.

(26) Another aspect of the present disclosure relates to a lens unit including: a plurality of lenses; and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses.

Description

BRIEF DESCRIPTION OF DRAWINGS

- (1) FIG. 1 is a cross-sectional view illustrating a schematic configuration of an example of a lens drive module.
- (2) FIG. 2 is a cross-sectional view illustrating a schematic configuration of another example of a lens drive module.
- (3) FIG. 3 is a graph of an example of a result of examining a relationship between the position of a lens unit and the thrust force ratio in the lens drive module illustrated in FIG. 2.
- (4) FIG. 4 is a diagram illustrating a schematic configuration of an example of an electronic device (imaging device).
- (5) FIG. 5 is a diagram illustrating a schematic configuration of another example of an electronic device (imaging device).
- (6) FIG. 6 is a diagram illustrating a schematic configuration of another example of an electronic device (imaging device).
- (7) FIG. 7 is a diagram illustrating a schematic configuration of another example of an electronic device (imaging device).

DESCRIPTION OF EMBODIMENTS

(8) [Lens Drive Module]

- (9) FIG. 1 is a cross-sectional view illustrating a schematic configuration of an example of a lens drive module **11**.
- (10) The lens drive module **11** includes a lens unit **10** including a plurality of lenses **20**; and a lens actuator **24** that causes an electromagnetic force to act on the lens unit **10** in response to energization.
- (11) The plurality of lenses **20** included in the lens unit **10** are arranged in a direction in which an optical axis Ax extends (hereinafter referred to as “optical axis direction”). The lens unit **10** illustrated in FIG. 1 includes four lenses **20**. However, the number of lenses **20** is not limited to a specific number.
- (12) Each lens **20** has a lens central portion positioned on the optical axis Ax through which a light beam is transmitted and a lens peripheral portion extending outward from the lens central portion. Light from a subject passes through the central portion of each lens **20**. A light-shielding film (not illustrated) that blocks stray light may be provided on the lens peripheral portion of each lens **20** (for example, a lens side surface and/or a surface in contact with a ferromagnetic spacer **21a**, which will be described later).
- (13) The spacer **21a** including a ferromagnetic material (hereinafter referred to as a “ferromagnetic spacer”) is provided between two lenses **20** adjacent to each other in the optical axis direction (especially, between lens peripheral portions). In the example illustrated in FIG. 1, all of the plurality of spacers included in the lens unit **10** are ferromagnetic spacers **21a**.
- (14) Each ferromagnetic spacer **21a** serves as a yoke into which a magnetic flux is drawn, as described below. Accordingly, each ferromagnetic spacer **21a** may exhibit ferromagnetism as a whole, such as being entirely formed from a ferromagnetic material or partially including a ferromagnetic material. The composition and form of the ferromagnetic material included in each ferromagnetic spacer **21a** are not limited. Examples of the ferromagnetic material included in each ferromagnetic spacer **21a** may include a soft magnetic material, a hard magnetic material, and other magnetic materials. Typically, a substance such as ferrite, iron, cobalt or nickel, which exhibits ferromagnetism at room temperature (for example, 1 to 30° C.) may be included as a part or a whole in each ferromagnetic spacer **21a**.
- (15) Each ferromagnetic spacer **21a** acts as a joint that defines a spacing between adjacent lenses. Each ferromagnetic spacer **21a** illustrated in FIG. 1 has a black color and has a light shielding

property of blocking and rejecting stray light such as flare light caused by diffuse reflection in the lens.

(16) The plurality of lenses **20** and the plurality of ferromagnetic spacers **21a** included in the lens unit **10** are integrally supported by a holder **22**. The holder **22** can be made from a plastic material such as polycarbonate, has a black color, and has a light shielding property.

(17) The holder **22** illustrated in FIG. **1** has a tubular shape with a through hole. The plurality of lenses **20** and the plurality of ferromagnetic spacers **21a** are arranged to be formed in layers in the through hole of the holder **22** and are fixedly supported. The manner in which the plurality of lenses **20** and the plurality of ferromagnetic spacers **21a** are supported by the holder **22** is not limited. In the example illustrated in FIG. **1**, one lens support portion **22a** and the other lens support portion (not illustrated) of the holder **22** sandwich and support the plurality of lenses **20** and the plurality of ferromagnetic spacers **21a** in the optical axis direction. In this way, the holder **22** cooperates with the spacers (the ferromagnetic spacers **21a** in this example) to align and fixably support the plurality of lenses **20** and the plurality of ferromagnetic spacers **21a**.

(18) The lens actuator **24** is a voice coil motor driven actuator, and includes a first coil **25** provided integrally with the lens drive module **11** and magnets (that is, permanent magnets) **26** that applies a magnetic field to the first coil **25**.

(19) In the example illustrated in FIG. **1**, the first coil **25** is fixedly wound around the outer circumference of the holder **22**, and the first coil **25** moves along with the lens unit **10** in the optical axis direction. At a position farther from the optical axis Ax than the first coil **25**, the plurality of magnets **26** are provided at equal angular intervals around the optical axis Ax. Each magnet **26** faces the first coil **25** at a distance from the first coil **25** to provide a magnetic field to the first coil **25**. Note that, in FIG. **1**, “N” indicates the north pole side of the corresponding magnet **26**, and “S” indicates the south pole side of the corresponding magnet **26**.

(20) Regardless of the position of the lens unit **10** in the optical axis direction, at least a portion of the first coil **25** is located between the ferromagnetic spacers **21a** and the magnets **26**. In other words, regardless of the position of the lens unit **10** in the optical axis direction, at least one or more ferromagnetic spacers **21a**, the first coil **25**, and the magnets **26** are located in a same straight line extending in a direction perpendicular to the optical axis Ax.

(21) In the lens drive module **11** having the configuration described above, the lens actuator **24** moves the lens unit **10** in the optical axis direction to adjust the focal position of the lens unit **10** (that is, the plurality of lenses **20**). By controlling the direction and magnitude of the current flowing through the first coil **25** under Fleming's left-hand rule, the magnitude and direction of the electromagnetic force to act on the first coil **25** can be adjusted, and the magnitude and direction of the thrust force to act on the lens unit **10** can in turn be adjusted. In this way, the electromagnetic force (Lorentz force) to act on the first coil **25** in response to the energization of the first coil **25** can be used to dispose the lens unit **10** at a desired position on the optical axis Ax, thereby adjusting the focal position.

(22) Note that the lens unit **10** is supported movably in the optical axis direction by a support unit (not illustrated). That support unit positions and supports the lens unit **10** at a reference position when the electromagnetic force in the optical axis direction does not act on the first coil **25**. On the other hand, when the electromagnetic force in the optical axis direction acts on the first coil **25**, the support unit supports the lens unit **10** while allowing the lens unit **10** to move in the optical axis direction. The lens unit **10** is disposed at a position where the electromagnetic force in the optical axis direction acting on the first coil **25** and the support force of the support unit are balanced. Such a support unit can be provided with any configuration. Typically, the support unit includes an elastic element such as a spring, and the elastic force of the elastic element can be used to support the lens unit **10**.

(23) In the lens drive module **11** according to the present embodiment, by the ferromagnetic spacers **21a**, the magnetic field of the magnets **26** can effectively act on to the first coil **25**. The

ferromagnetic spacers **21a** actively draws in the magnetic field of the magnets **26** to increase the strength (flux density) of the magnetic field from the magnets **26** towards the ferromagnetic spacers **21a**. Therefore, the strength of the magnetic field acting on the first coil **25** located between the ferromagnetic spacers **21a** and the magnets **26** also increases. As a result, even if the amount of current flowing through the first coil **25** is small, a large electromagnetic force acts on the first coil **25**.

(24) Note that there is a tendency that the larger each ferromagnetic spacer **21a** (that is, the larger the area occupied by the ferromagnetic spacers **21a**), the higher the strength of the magnetic field from the magnets **26** toward the ferromagnetic spacers **21a**. On the other hand, a telescopic lens unit generally tends to have large spacing between the lenses, and the spacers disposed between the lenses also tend to be large accordingly. Therefore, in the case where the lens unit **10** according to the present embodiment is telescopic, particularly large ferromagnetic spacers **21a** can be used to effectively increase the strength of the magnetic field acting on the first coil **25**.

(25) As described above, the lens unit **10** and the lens drive module **11** according to the present embodiment makes it possible to reduce the amount of power required to move the first coil **25** and the lens unit **10**. Such low power driving of the lens unit **10** makes it possible to suppress heat generated by the lens drive module **11** and thus to prolong the driving time of the lens drive module **11** when powered by a battery.

(26) Further, the lens unit **10** according to the present embodiment can be configured only with the non-ferromagnetic spacers of the existing lens unit replaced by the ferromagnetic spacers **21a**, thereby avoiding a complicated structure (in particular, a complicated structure outside the lenses **20**). Therefore, the lens unit **10** and the lens drive module **11** according to the present embodiment can reduce the power consumption compared to the conventional one while maintaining the same simple configuration as the conventional one.

(27) In addition, by reducing the power consumption required to move the lens unit **10**, restrictions on the size and weight of the lenses **20** to be used can be relaxed. The amount of current to be used to move the lens unit **10** is limited according to the battery capacity and the like, and thus it is necessary to appropriately select the size and weight of the lenses **20** within the allowable range of such a limited amount of current. According to the present embodiment, since the lens unit **10** can be driven with low power as described above, it is possible to use the high-performance lenses **20** that are larger and heavier than the conventional lenses.

(28) FIG. 2 is a cross-sectional view illustrating a schematic configuration of another example of a lens drive module **11**.

(29) A lens unit **10** illustrated in FIG. 2 includes a plurality of spacers as in the lens unit **10** illustrated in FIG. 1, and in particular, the plurality of spacers include not only a ferromagnetic spacer **21a** but also a spacer **21b** including a non-ferromagnetic material (referred to as “non-ferromagnetic spacer”).

(30) The non-ferromagnetic spacers **21b** is hardly magnetized as a whole, and can be formed from a paramagnetic material that is hardly magnetized in the direction of a magnetic field even when the magnetic field acts on them. The material(s) included in the non-ferromagnetic spacer **21b** are not limited. For example, the non-ferromagnetic spacer **21b** can be formed from a non-magnetic material such as aluminum or a plastic material including, for example, a synthetic resin.

(31) In the lens unit **10** illustrated in FIG. 2, two spacers located on both end sides in the optical axis direction are each the non-ferromagnetic spacer **21b**, and one spacer located in the center is the ferromagnetic spacer **21a**. However, the positions and number of ferromagnetic spacers **21a** and non-ferromagnetic spacers **21b** are not limited. For example, from the viewpoint of causing a large magnetic field to act on a first coil **25**, the largest spacer may correspond to the ferromagnetic spacer **21a**. In addition, regardless of the position of the lens unit **10** in the optical axis direction, the spacer that is always located together with the magnets **26** and the first coil **25** in a same straight line extending in a direction perpendicular to the optical axis Ax may correspond to the

ferromagnetic spacer **21a**.

(32) According to the lens unit **10** and the lens drive module **11** illustrated in FIG. 2, the lens unit **10** can be driven with low power while the increase in cost associated with the use of the ferromagnetic spacer **21a** is suppressed.

(33) The inventor(s) has performed a simulation based on the lens drive module **11** illustrated in FIG. 2 and examined a relationship between the position of the lens unit **10** and the thrust force ratio.

(34) FIG. 3 is a graph of an example of a result of examining the relationship between the position of the lens unit **10** and the thrust force ratio in the lens drive module **11** illustrated in FIG. 2.

(35) The “lens unit position” illustrated in FIG. 3 indicates the position of the lens unit **10** and the first coil **25** in the optical axis direction, and the reference position is represented by “0 μm ”. The “thrust force ratio” illustrated in FIG. 3 indicates the ratio of the magnitude of an electromagnetic force acting on the first coil **25** to the magnitude of an electromagnetic force acting on a first coil of a lens unit including spacers that are all non-ferromagnetic spacers (referred to as “reference lens unit”). In other words, the “thrust force ratio” in FIG. 3 can be represented by “thrust force ratio=

(electromagnetic force acting on the first coil **25** of the lens drive module **11** in FIG. 2)/(electromagnetic force acting on the first coil of the reference lens unit)”. In examination illustrated in FIG. 3, the lens unit **10** illustrated in FIG. 2 and the reference lens unit had the same properties except for the spacers. For example, in deriving the “electromagnetic force acting on the first coil” to obtain the thrust force ratio, the magnitude of the current flowing through the first coil of the lens unit **10** in FIG. 2 was set to be the same as that of the reference lens unit.

(36) In FIG. 3, as the ferromagnetic spacer **21a** of the lens drive module **11** of FIG. 2, a spacer was used that is formed from a general ferrite material having ferromagnetic properties (electric conductivity=1 S/m, relative permeability=640, and relative permittivity=1).

(37) In FIG. 3, the “thrust force ratio” of the lens drive module **11** in FIG. 2 indicates a value greater than “1.00” regardless of the position of the lens unit **10** in the optical axis direction. Therefore, it can be seen that the lens unit **10** including the ferromagnetic spacer **21a** can obtain a larger electromagnetic force than that of the reference lens unit not including the ferromagnetic spacer **21a**. Even if the relative position of the lens unit **10** and the first coil **25** with respect to the magnets **26** deviates from the reference position by 50 μm in the optical axis direction due to manufacturing errors or the like, the lens drive module **11** illustrated in FIG. 2 can obtain a thrust force 15% or more larger than that of the reference lens unit. Further, by optimizing the relative position of the lens unit **10** and the first coil **25** with respect to the magnets **26**, the lens drive module **11** illustrated in FIG. 2 can obtain a thrust force 20% or more larger than that of the reference lens unit (refer to “lens unit position=0 μm ” in FIG. 3).

(38) The result of examination of FIG. 3 demonstrates that such a lens unit **10** including the ferromagnetic spacer **21a** can obtain a large electromagnetic force (that is, a thrust force) with a smaller amount of power consumption. In other words, the result of examination of FIG. 3 demonstrates that the lens unit **10** including the ferromagnetic spacer **21a** can effectively reduce the power consumption required to obtain the desired thrust force.

(39) In FIG. 3, the ferromagnetic spacer **21a** is a spacer formed from a general ferrite material. However, the above-described functions and effects do not limit the ferromagnetic spacer **21a** to a specific material. The ferromagnetic spacer **21**, which is formed from any material exhibiting ferromagnetic properties, effectively draws in the magnetic field of the magnets **26** to increase the strength of the magnetic field to act on the first coil **25**, and thus can effectively reduce the power consumption required to obtain the desired thrust force.

(40) [Imaging Module and Electronic Device]

(41) The lens drive module **11** including the ferromagnetic spacer **21a** exemplified in FIGS. 1 and 2 can be applied to an imaging module including a solid-state imaging element, and the above-described lens actuator **24** can be used as an autofocus (AF) adjustment mechanism, for example.

Such an imaging module can be applied to various electronic devices. For example, the above-described lens drive module **11** can be advantageously used in an imaging module installed in an imaging device (for example, a digital camera) or a portable terminal (for example, a mobile phone, a smart phone, a tablet, a computer, etc.). Note that an electronic device such as an imaging device may itself be an independent device, or may be configured as a part of an independent device.

(42) Typical implementations of imaging modules and electronic devices to which the lens drive module **11** including the ferromagnetic spacer **21a** can be applied are exemplified below. Only a partial configuration of an imaging module and an electronic device will be described below, and the actual imaging module and electronic device may include components and configurations not described below as appropriate. Further, imaging modules and electronic devices to which the lens drive module **11** including the ferromagnetic spacer **21a** can be applied are not limited to the following examples.

(43) [First Example of Imaging Module and Electronic Device]

(44) FIG. **4** is a diagram illustrating a schematic configuration of an example of an electronic device **13**. In FIG. **4**, components that are the same as or similar to those illustrated in FIGS. **1** and **2** are designated by the same reference numerals, and detailed description thereof will be omitted.

(45) An imaging module **12** included in the electronic device **13** illustrated in FIG. **4** includes the lens drive module **11** illustrated in FIG. **1** and an imaging element **35** (for example, a CCD image sensor or a CMOS image sensor). Specifically, the imaging module **12** includes the lens unit **10** including the ferromagnetic spacers **21a**, the imaging element **35** that performs photoelectric conversion of light entering through the plurality of lenses **20**, and the lens actuator **24** that adjusts a distance between the lens unit **10** and the imaging element **35**.

(46) The imaging element **35** is fixed to the circuit board **38** via a support member **37** and positioned on the optical axis Ax so as to face the plurality of lenses **20** in the optical axis direction. Subject light is condensed at the light-receiving surface of the imaging element **35** by the plurality of lenses **20**, and the imaging element **35** acquires image data (that is, imaging data) of the subject under the control of a controller (not illustrated).

(47) The imaging element **35** is electrically connected to the circuitry (not illustrated) of the circuit board **38** via wiring **36** formed of metal wires. The circuitry of the circuit board **38** can receive electric signals (for example, imaging data) from the imaging element **35** and output them to the external devices. The circuit board **38** illustrated in FIG. **4** has a plate shape. However, the shape and configuration of the circuit board **38** are not limited, and the circuit board **38** may have a non-plate shape.

(48) An infrared cut filter **32** for removing infrared light is provided between the plurality of lenses **20** and the imaging element **35**. The light transmitted through the plurality of lenses **20** (in particular, the lens central portion) and entering the infrared cut filter **32** goes out from the infrared cut filter **32** with the infrared light component having been removed by the infrared cut filter **32**, and then heads toward the imaging element **35**.

(49) A plurality of connection support portions **34**, a lens controller **39**, a sensor **40**, a storage device **41**, and a connector **42** are fixedly attached to the circuit board **38**.

(50) A second coil **33** is fixed to an upper portion of each connection support portion **34**. Each connection support portion **34** electrically connects the circuitry of the circuit board **38** and the corresponding second coil **33**. Each second coil **33** is supplied with current from the lens controller **39** through the circuitry of the circuit board **38** and the corresponding connection support portion **34**.

(51) Each second coil **33** is positioned so as to face the corresponding magnet **26** held by an actuator holder **31** in the optical axis direction so that an electromagnetic force acts in a direction perpendicular to the optical axis Ax in response to energization. In this way, by the electromagnetic force acting on each second coil **33**, the relative position between the lens unit **10** (particularly the plurality of lenses **20**) and the imaging element **35** (particularly the light receiving surface) is

adjusted, so that the effects of camera shake are reduced. Thus, the second coils **33** and the magnets **26** work as an actuator for an optical image stabilizer (OIS) type of camera shake correction. Each magnet **26** provided in the actuator holder **31** also works as a lens actuator **24** for autofocus by cooperating with the first coil **25** as described above.

(52) The lens controller **39** includes an integrated circuit (IC), and functions as a camera shake correction driver as well as an autofocus driver. The lens controller **39** is electrically connected to the second coil **33** via the circuitry of the circuit board **38** and the connection support portion **34** as described above, and is electrically connected to the first coil **25** via the circuitry of the circuit board **38** and wiring (not illustrated). Further, the lens controller **39** is electrically connected to the sensor **40**, the storage device **41**, the connector **42**, and other devices through the circuitry of the circuit board **38**.

(53) For example, when a gyro sensor included in the sensor **40** detects camera shake, the lens controller **39** supplies to the second coil **33** a current corresponding to the camera shake detection signal from the gyro sensor to correct the camera shake. Further, the lens controller **39** supplies to the first coil **25** a current corresponding to an autofocus signal from a device (not illustrated) to move the lens unit **10** in the optical axis direction and thus perform focus adjustment.

(54) The storage device **41** stores and holds various types of data (including programs). For example, correction values for compensating for variations (individual differences) of the imaging module **12** are stored in the storage device **41**. Reading of data stored in the storage device **41** and writing (including updating) of data to the storage device **41** are performed as appropriate by various devices electrically connected to the storage device **41** via the circuitry of the circuit board **38**.

(55) The connector **42** constitutes an interface with other devices not illustrated. Accordingly, the connector **42** is connected to another device (for example, a controller not illustrated) to transmit and receive data (for example, imaging data transmitted from the lens drive module **11**) to and from the other device.

(56) In the imaging module **12** and the electronic device **13** illustrated in FIG. **4** as well, the lens unit **10** including the ferromagnetic spacers **21a** can reduce the power consumption required to move the lens unit **10** for autofocus driving.

(57) [Second Example of Imaging Module and Electronic Device]

(58) FIG. **5** is a diagram illustrating a schematic configuration of another example of an electronic device **13**. In FIG. **5**, components that are the same as or similar to those illustrated in FIG. **4** are designated by the same reference numerals, and detailed description thereof will be omitted.

(59) The imaging element **35** included in the imaging module **12** of this example has a flip-chip structure. Specifically, the imaging element **35** is electrically connected to the circuitry of the circuit board **38** via wiring **36** formed of bumps (that is, projecting terminals) instead of metal wires (see FIG. **4**). The imaging element **35** illustrated in FIG. **5** is electrically connected via the wiring **36** to circuitry exposed on a surface of the circuit board **38** (hereinafter referred to as the “backside circuit surface”) opposite to a surface of the circuit board **38** (hereinafter referred to as the “frontside circuit surface”) facing the lens unit **10**.

(60) The imaging element **35** and the wiring **36** are surrounded by a protective material **51** attached to the backside circuit surface of the circuit board **38**. The protective material **51** protects the imaging element **35** and the wiring **36** when the imaging element **35** is mounted on the circuit board **38** and when the imaging module **12** is mounted on the electronic device **13**.

(61) The circuit board **38** includes a translucent portion **52** that transmits light. The translucent portion **52** is formed from a through hole or a translucent member, and is located on the optical axis **Ax** so as to face the imaging element **35** (in particular, the entire light receiving surface of the imaging element **35**) in the optical axis direction. The infrared cut filter **32** is attached to the frontside circuit surface of the circuit board **38** to cover the entire translucent portion **52**.

(62) The light transmitted through the plurality of lenses **20** (in particular, the lens central portion)

sequentially passes through the infrared cut filter **32** and the translucent portion **52**, and enters the light receiving surface of the imaging element **35**. Accordingly, the imaging element **35** acquires imaging data.

(63) The lens controller **39**, the sensor **40**, the storage device **41**, and the connector **42**, which are illustrated in FIG. **5**, are attached to the backside circuit surface of the circuit board **38** and electrically connected to the circuitry exposed on the backside circuit surface. The circuitry exposed on the frontside circuit surface of the circuit board **38** and the circuitry exposed on the backside circuit surface are electrically connected to each other. Accordingly, similarly to the example illustrated in FIG. **4** described above, the lens controller **39** illustrated in FIG. **5** is connected to the second coil **33** via the circuitry of the circuit board **38** and the connection support portion **34**, and is connected to the first coil **25** via the circuitry of the circuit board **38** and wiring (not illustrated). Note that the lens controller **39**, the sensor **40**, the storage device **41**, and the connector **42** may be attached to the frontside circuit surface of the circuit board **38**, as in the example illustrated in FIG. **4**.

(64) Other configurations of the electronic device **13** illustrated in FIG. **5** are the same as those of the electronic device **13** illustrated in FIG. **4** described above.

(65) In the imaging module **12** and the electronic device **13** illustrated in FIG. **5** as well, the lens unit **10** including the ferromagnetic spacers **21a** can reduce the power consumption required to move the lens unit **10** for autofocus driving.

(66) [Third Example of Imaging Module and Electronic Device]

(67) FIG. **6** is a diagram illustrating a schematic configuration of another example of an electronic device **13**. In FIG. **6**, components that are the same as or similar to those illustrated in FIG. **4** are designated by the same reference numerals, and detailed description thereof will be omitted.

(68) The imaging element **35** included in the imaging module **12** of this example has a chip size package (CSP) structure. In other words, the imaging element **35** is provided as part of an ultra-compact package.

(69) The imaging element **35** illustrated in FIG. **6** is attached to the circuit board **38** via a wiring layer **58**. A fixing portion **59** having a light shielding property is provided between the imaging element **35** and the connection support portion **34** on the frontside circuit surface of the circuit board **38**. The imaging element **35** is adhered and fixed to the frontside circuit surface of the circuit board **38** by the fixing portion **59**. A glass layer **56** is adhered via a second transparent resin **57** to a surface (including the light receiving surface) of the imaging element **35** facing the lens unit **10**. The infrared cut filter **32** is adhered to the glass layer **56** further via a first transparent resin **55**.

(70) The light transmitted through the plurality of lenses **20** (in particular, the lens central portion) sequentially passes through the infrared cut filter **32**, the first transparent resin **55**, the glass layer **56**, and the second transparent resin **57**, and enters the light receiving surface of the imaging element **35**. Accordingly, the imaging element **35** acquires imaging data.

(71) Other configurations of the electronic device **13** illustrated in FIG. **6** are the same as those of the electronic device **13** illustrated in FIG. **4** described above.

(72) In the imaging module **12** and the electronic device **13** illustrated in FIG. **6** as well, the lens unit **10** including the ferromagnetic spacers **21a** can reduce the power consumption required to move the lens unit **10** for autofocus driving.

(73) [Fourth Example of Imaging Module and Electronic Device]

(74) FIG. **7** is a diagram illustrating a schematic configuration of another example of an electronic device **13**. In FIG. **7**, components that are the same as or similar to those illustrated in FIG. **6** are designated by the same reference numerals, and detailed description thereof will be omitted.

(75) The imaging module **12** of this example includes a lens (that is, a fixed lens) **63** located between the lens unit **10** and the imaging element **35**. The lens **63** is separate from the plurality of lenses **20** included in the lens unit **10**. The fixed lens **63** illustrated in FIG. **7** is located between the plurality of lenses **20** of the lens unit **10** and the infrared cut filter **32**, and is fixedly attached to the

infrared cut filter **32** in an imprint bonding manner.

(76) The fixed lens **63** constitutes an optical lens system of the imaging module **12** together with the plurality of lenses **20** included in the lens unit **10**. However, in autofocus driving, the plurality of lenses **20** included in the lens unit **10** are moved in the optical axis direction by the lens actuator **24** as described above, while the fixed lens **63**, which is integrated with the imaging element **35**, is not moved. In other words, the distance in the optical axis direction between the plurality of lenses **20** included in the lens unit **10** and the imaging element **35** is variable, while the distance in the optical axis direction between the fixed lens **63** and the imaging element **35** is invariable.

(77) Other configurations of the electronic device **13** illustrated in FIG. **7** are the same as those of the electronic device **13** illustrated in FIG. **6** described above.

(78) In the imaging module **12** and the electronic device **13** illustrated in FIG. **7** as well, the lens unit **10** including the ferromagnetic spacers **21a** can reduce the power consumption required to move the lens unit **10** for autofocus driving.

(79) As described above, the lens unit **10** including the ferromagnetic spacers **21a**, the lens drive module **11**, the imaging module **12**, and the electronic device **13** can effectively reduce the power consumption required to move the lens unit **10**.

(80) In particular, the above-described lens unit **10** can be configured with at least one or some of the spacers of the existing lens unit replaced by the ferromagnetic spacer **21a**. Therefore, the above-described lens unit **10** is widely and flexibly applied to various types of lens drive modules **11**, imaging modules **12**, and electronic devices **13**, without requiring to have a complicated structure. In addition, the above-described lens unit **10** can effectively contribute to suppressing an increase in manufacturing cost and miniaturizing the device (for example, reducing the size of the device in the optical axis direction).

(81) Further, even in the case where a magnet with a low magnetic flux density or a small magnet is used as the above-described magnet **26**, the ferromagnetic spacer **21a** effectively causes a magnetic field to act on the first coil **25**, so that the lens actuator **24** can properly drive the lens unit **10**. Therefore, according to the above-described lens unit **10** including the ferromagnetic spacers **21a**, the degree of freedom in selecting the magnets **26** is increased, and relatively inexpensive permanent magnets can be used as the magnets **26**.

(82) It should be noted that the embodiments and modifications disclosed herein are merely illustrative in all respects and should not be construed as limiting the present disclosure. The above-described embodiments and variations can be omitted, substituted, and modified in various ways without departing from the scope and spirit of the appended claims. For example, the above-described embodiments and modifications may be wholly or partially combined, and any combination of an embodiment other than above-described embodiments and the above-described embodiments or modifications may be made. In addition, the effects of the present disclosure described herein are merely exemplary and may have other effects.

(83) Further, the technical category in which the above-described technical ideas are embodied is not limited. For example, the above-described technical ideas may be embodied by a computer program for causing a computer to execute one or more procedures (steps) included in the device control method described above. The above-described technical ideas may be embodied by a non-transitory computer-readable recording medium in which such a computer program is recorded.

(84) The present disclosure can also be configured as follows:

(85) [Item 1]

(86) A lens drive module including: a lens unit that includes a plurality of lenses and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses; and a lens actuator that causes an electromagnetic force to act on the lens unit in response to energization.

[Item 2]

(87) The lens unit according to Item 1, wherein the lens unit includes a plurality of spacers each of

which is provided between two adjacent lenses, and all the spacers included in the lens unit include a ferromagnetic material.

[Item 3]

(88) The lens unit according to Item 1, wherein the lens unit includes a plurality of spacers each of which is provided between two adjacent lenses, and the plurality of spacers include a spacer that includes a ferromagnetic material and a spacer that includes a non-ferromagnetic material.

[Item 4]

(89) The lens unit according to any one of Items 1 to 3, wherein the lens actuator includes a coil that is provided integrally with the lens unit so as to be energized, and a magnet that applies a magnetic field to the coil.

[Item 5]

(90) The lens drive module according to Item 4, wherein the coil is located between the spacer that includes the ferromagnetic material and the magnet.

(91) [Item 6]

(92) The lens drive module according to Item 4 or 5, wherein the spacer that includes the ferromagnetic material, the coil, and the magnet are located in a same straight line extending in a direction perpendicular to an optical axis of the plurality of lenses.

(93) [Item 7]

(94) An imaging module including: a lens unit that includes a plurality of lenses and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses; an imaging element that performs photoelectric conversion of light entering through the plurality of lenses; and a lens actuator that causes an electromagnetic force to act on the lens unit in response to energization to adjust a distance between the lens unit and the imaging element.

[Item 8]

(95) The imaging module according to Item 7, wherein the imaging element has a flip-chip structure.

(96) [Item 9]

(97) The imaging module according to Item 7, wherein the imaging element has a CSP structure.

(98) [Item 10]

(99) The imaging module according to any one of Items 7 to 9, including a lens that is located between the lens unit and the imaging element and is separate from the plurality of lenses included in the lens unit.

(100) [Item 11]

(101) The imaging module according to any one of Items 7 to 10, including an infrared cut filter.

(102) [Item 12]

(103) An electronic device including: a lens unit that includes a plurality of lenses and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses; an imaging element that performs photoelectric conversion of light entering through the plurality of lenses; a lens actuator that causes an electromagnetic force to act on the lens unit in response to energization to adjust a distance between the lens unit and the imaging element; and a circuit board that receives an electrical signal from the imaging element.

[Item 13]

(104) A lens unit including: a plurality of lenses; and a spacer that includes a ferromagnetic material provided between two adjacent lenses among the plurality of lenses.

(105) [Item 14]

(106) The lens unit according to Item 13, including a plurality of spacers each of which is provided between two adjacent lenses, wherein all the spacers include a ferromagnetic material.

(107) [Item 15]

(108) The lens unit according to Item 13, including a plurality of spacers each of which is provided between two adjacent lenses, the plurality of spacers including a spacer that includes a

ferromagnetic material and a spacer that includes a non-ferromagnetic material.

REFERENCE SIGNS LIST

(109) **10** Lens unit **11** Lens drive module **12** Imaging module **13** Electronic device **20** Lens **21a** Ferromagnetic spacer **21b** Non-ferromagnetic spacer **24** Lens actuator **25** First coil **26** Magnet **32** Infrared cut filter **35** Imaging element **38** Circuit board **63** Fixed lens Ax Optical axis

Claims

1. A lens drive module, comprising: a lens unit that includes a plurality of lenses and a first spacer, wherein the first spacer includes a ferromagnetic material, and the first spacer is between two adjacent lenses of the plurality of lenses; and a lens actuator configured to cause an electromagnetic force to act on the lens unit, wherein the lens actuator includes: a coil that is integral with the lens unit; and a magnet configured to apply a magnetic field to the coil, the electromagnetic force that acts on the lens unit is based on energization of the coil and the magnetic field applied to the coil, and in a direction perpendicular to an optical axis of the plurality of lenses, the coil is between the magnet and the first spacer that includes the ferromagnetic material.
2. The lens drive module according to claim 1, wherein the lens unit further includes a plurality of spacers including the first spacer, each spacer of the plurality of spacers is between the two adjacent lenses of the plurality of lenses, and the each spacer of the plurality of spacers includes the ferromagnetic material.
3. The lens drive module according to claim 1, wherein the lens unit further includes a plurality of spacers including the first spacer, each spacer of the plurality of spacers is between the two adjacent lenses of the plurality of lenses, and the plurality of spacers further includes a second spacer that includes a non-ferromagnetic material.
4. An imaging module, comprising: a lens unit that includes a plurality of lenses and a spacer, wherein the spacer includes a ferromagnetic material, and the spacer is between two adjacent lenses of the plurality of lenses; an imaging element configured to perform photoelectric conversion of light that enters through the plurality of lenses; and a lens actuator configured to cause an electromagnetic force to act on the lens unit to adjust a distance between the lens unit and the imaging element, wherein the lens actuator includes: a coil that is integral with the lens unit; and a magnet configured to apply a magnetic field to the coil, the electromagnetic force that acts on the lens unit is based on energization of the coil and the magnetic field applied to the coil, and in a direction perpendicular to an optical axis of the plurality of lenses, the coil is between the magnet and the spacer that includes the ferromagnetic material.
5. The imaging module according to claim 4, wherein the imaging element has a flip-chip structure.
6. The imaging module according to claim 4, wherein the imaging element has a chip size package structure.
7. The imaging module according to claim 4, further comprising a lens between the lens unit and the imaging element, wherein the lens is separate from the plurality of lenses included in the lens unit.
8. The imaging module according to claim 4, further comprising an infrared cut filter on the imaging element.
9. An electronic device, comprising: a lens unit that includes a plurality of lenses and a spacer, wherein the spacer includes a ferromagnetic material, and the spacer is between two adjacent lenses of the plurality of lenses; an imaging element configured to perform photoelectric conversion of light that enters through the plurality of lenses; a lens actuator configured to cause an electromagnetic force to act on the lens unit to adjust a distance between the lens unit and the imaging element, wherein the lens actuator includes: a coil that is integral with the lens unit; and a magnet configured to apply a magnetic field to the coil, the electromagnetic force that acts on the lens unit is based on energization of the coil and the magnetic field applied to the coil, and in a

direction perpendicular to an optical axis of the plurality of lenses, the coil is between the magnet and the spacer that includes the ferromagnetic material; and a circuit board configured to receive an electrical signal from the imaging element.

10. A lens unit, comprising: a plurality of lenses; a first spacer that includes a ferromagnetic material, wherein the first spacer is between a first lens and a second lens of the plurality of lenses, and the first lens is adjacent to the second lens; and a second spacer that includes aluminum, wherein the second spacer is between the second lens and a third lens of the plurality of lenses, and the second lens is adjacent to the third lens.
