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Objective optical system, imaging unit, endoscope and endoscope apparatus

Abstract

An objective optical system comprising a lens group that forms an object image, a polarizing beam splitter having an optical path dividing surface that divides an optical path into a first optical path that intersects the optical axis of the lens group and a second optical path that extends straight on the optical axis, a first reflection surface provided in the first optical path, a second reflection surface provided in the second optical path, and a quarter wave plate provided between the polarizing beam splitter and the first reflection surface. The objective optical system satisfies the following conditional expression (1):

$(Tp+Ts)/(100-Ts) \geq 1.25$ (1)

where Tp (%) is the transmittance of the optical path dividing surface for p-polarized light, and Ts (%) is the transmittance of the optical path dividing surface for s-polarized light.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATION (1) The present application is a continuation application of PCT/JP2021/034548 filed on Sep. 21, 2021, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION
Technical Field
(1) The present invention relates to an objective optical system, an imaging unit, an endoscope, and endoscope apparatus.

Description of the Related Art

(2) There is technology related to imaging units called "high dynamic range", which is used to capture images of objects with large brightness differences or large variations in the light levels. The high dynamic range is the technology that creates an image with an expanded dynamic range by combining a plurality of images having different exposures or different brightnesses. This allows to create high dynamic range images.

(3) Japanese Patent No. 6463573 discloses an endoscope imaging system that is configured to create a high dynamic range image from two images that are obtained from first frame data and differ in brightness and other two images that are obtained from second frame data and differ in brightness.

SUMMARY OF THE INVENTION

(4) An objective optical system according to at least some embodiments of the present invention, comprises a lens group that forms an object image, a polarizing beam splitter having an optical path dividing surface that divides an optical path into a first optical path that intersects the optical axis of the lens group and a second optical path that extends straight on the optical axis, a first reflection surface provided in the first optical path, a second reflection surface provided in the second optical path, and a quarter wave plate provided between the polarizing beam splitter and the first reflection surface. The objective optical system satisfies the following conditional expression (1):

$$(Tp+Ts)/(100-Ts)\geq1.25 \qquad (1)$$

where Tp (%) is the transmittance of the optical path dividing surface for p-polarized light, and Ts (%) is the transmittance of the optical path dividing surface for s-polarized light.

(5) An imaging unit according to at least some embodiments of the present invention comprises the objective optical system mentioned above and an imager that has an imaging surface located at the position of the object images formed by the objective optical system to capture two object images.

(6) An endoscope according to at least some embodiments of the present invention comprises the imaging unit mentioned above.

(7) An endoscope apparatus according to at least some embodiments of the present invention comprises the endoscope mentioned above and an image processor that combines the two object images.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a diagram showing an objective optical system, an imaging unit, and a processor according to a first embodiment;

(2) FIG. **2** is a diagram showing the structure of a polarizing beam splitter and an imager according to the first embodiment;

(3) FIG. **3** is a diagram showing imaging areas of the imager according to the first embodiment;

(4) FIGS. **4**A, **4**B, and **4**C show transmittance properties of polarizing beam splitters;

(5) FIGS. **5**A and **5**B show other transmittance properties of polarizing beam splitters;

(6) FIG. **6** is a diagram showing the structure of a polarizing beam splitter according to a second embodiment;

(7) FIG. **7** is a diagram showing imaging areas of the imager according to the second embodiment;

(8) FIG. **8** is a flow chart of a process of combining two images according to the second embodiment;

(9) FIG. **9** is a diagram showing an endoscope and an endoscope apparatus according to a third embodiment.

DETAILED DESCRIPTION OF THE INVENTION

(10) Prior to description of an example of the present invention, the operation and advantageous

effects of embodiments according to certain modes of the present invention will be described. To describe the operation and advantageous effects of the embodiments specifically, specific exemplary modes will be given. However, the exemplary modes and examples that will be described later constitute only a portion of the modes encompassed by the present invention, which can include many variations. Therefore, it should be understood that the present invention is not limited by the exemplary modes.

First Embodiment

(11) FIG. **1** is a diagram schematically showing the general configuration of an objective optical system **10**, an imaging unit **60**, and a processor **3** according to a first embodiment.

(12) The objective optical system **10** includes a lens group **1** for forming an image of an object, a polarizing beam splitter **20** having an optical path dividing surface **21***d* (shown in FIG. **2**) that divides the optical path into a first optical path A (shown in FIG. **2**) that intersects the optical axis AX of the lens group **1** and a second optical path B that extends straight on the optical axis AX, a first reflection surface REF**1** (shown in FIG. **2**) provided in the first optical path A, a second reflection surface REF**2** (shown in FIG. **2**) provided in the second optical path B, and a quarter wave plate **21***e* provided between the polarizing beam splitter **20** and the first reflection surface REF**1**.

(13) The polarizing beam splitter **20** satisfies the following conditional expression (1):

$$(Tp+Ts)/(100-Ts) \geq 1.25 \qquad (1)$$

where Tp (%) is the transmittance of the optical path dividing surface **21***d* for p-polarized light, and Ts (%) is the transmittance of the optical path dividing surface **21***d* for s-polarized light.

(14) The above transmittances are the values at the average wavelength of the visible light range for light travelling along the optical axis AX and incident on the optical path dividing surface **21***d* at an angle of 45 degrees.

(15) The imaging unit **60** includes the objective optical system **10** and an imager **22** having an imaging surface I located at the position of the object image formed by the objective optical system **10** to capture two images of the object.

(16) FIG. **2** is a diagram schematically showing the structure of the polarizing beam splitter **20** and the imager **22**. According to a preferred mode of the embodiment, the objective optical system **10** includes the lens group **1** for focusing light beams coming from an object, the imager **22** disposed near the focal position of the lens group **1**, and the polarizing beam splitter **20** disposed between the lens group **1** and the imager **22** and having the optical path dividing surface **21***d* that divides the light beams coming from the lens group **1** into reflected light beams and transmitted light beams.

(17) The polarizing beam splitter **20** has the first reflection surface REF**1** for reflecting back the light beams reflected by the optical path dividing surface **21***d* and the second reflection surface REF**2** for reflecting the light beams transmitted by the optical path dividing surface **21***d*.

(18) The light beams reflected by the first reflection surface REF**1** and passing through the optical path dividing surface **21***d* are focused on a first light receiving area **22***a* (shown in FIG. **3**) of the imager **22** to form a first object image (image A). The light beams reflected by the second reflection surface REF**2** are focused on a second light receiving area **22***b* (shown in FIG. **3**) of the imager **22** different from the first light receiving area **22***a* to form a second object image (image B).

(19) The processor **3** shown in FIG. **1** has a pre-processor **33** that photo-electrically converts the first object image and the second object image to output a first imaging signal and a second imaging signal respectively. The processor **3** will be described in further detail later.

(20) The structure of the polarizing beam splitter **20** will now be described with reference to FIG. **2**. The polarizing beam splitter **20** according to this embodiment is designed to split beams by polarization.

(21) The light emerging from the lens group **1** enters the polarizing beam splitter **20**. The polarizing beam splitter **20** splits the object image into two object images through the optical path dividing surface **21***d*. The imager **22** is disposed on the exit side (or image plane side) of the polarizing

beam splitter **20** to capture two object images formed in this way.

(22) As shown in FIG. **2**, the polarizing beam splitter **20** has an object side prism **21***a*, an image side prism **21***c*, a mirror **21***b*, and a quarter wave plate **21***e*. The object side prism **21***a* and the image side prism **21***c* have the optical path dividing surface **21***d*, which is slanted from the optical axis AX at an angle of 45 degrees.

(23) The optical path dividing surface **21***d* of the object side prism **21***a* is made of a polarization splitting film. The object side prism **21***a* and the image side prism **21***c* abut on each other through the polarization splitting film constitutes the optical path dividing surface **21***d* to constitute the polarizing beam splitter **20**.

(24) The mirror **21***b* is disposed in the vicinity of an end surface of the object side prism **21***a* with the quarter wave plate **21***e* between. The imager **22** is attached to an end of the image side prism **21***c* via a cover glass CG. The numeral reference "I" in FIG. **2** indicates the image plane (or imaging surface).

(25) The light coming from the lens group **1** is split by the optical path dividing surface **21***d* of the object side prism **21***a* into p-polarized transmitted light and s-polarized reflected light, so that the object image formed by the lens group **1** is separated into two, namely an object image with transmitted light and an object image with reflected light.

(26) The transmittance properties of the optical path dividing surface **21***d* will be described later.

(27) The object image with s-polarized light is reflected by the optical path dividing surface **21***d* in the direction away from the imager **22** to travel the optical path A, transmitted through the quarter wave plate **21***e*, and then reflected by the first reflection surface REF**1** of the mirror **21***b* back toward the imager **22**. The object image reflected back in this way is transmitted through the quarter wave plate **21***e* again to rotate its polarization direction by 90 degrees, transmitted through the optical path dividing surface **21***d*, and focused on the imager **22** as a low-exposure image A (shown in FIG. **3**).

(28) The object image with p-polarized light is transmitted through the optical path dividing surface **21***d* to travel the optical path B, reflected by the second reflection surface REF**2**, and focused on the imager **22** as a high-exposure image B (shown in FIG. **3**). The second reflection surface REF**2** is a surface of the image side prism **21***c* located on the transmission side of the optical path dividing surface **21***d* to bend the optical path B perpendicularly toward the imager **22**.

(29) It is basically preferred that the first reflection surface REF**1** and the second reflection surface REF**2** have high reflectance. The reflectance may be finely adjusted to achieve fine adjustment of the light quantities of images of different exposures.

(30) As above, the object side prism **21***a* and the image side prism **21***c* separate the object image into two object images of different exposures or different brightnesses.

(31) FIG. **3** is a diagram showing the first light receiving area (effective pixel area) **22***a* and the second light receiving area (effective pixel area) **22***b* of the imager **22**.

(32) As shown in FIG. **3**, the imager **22** has two light receiving areas in its entire pixel area, that is, the first light receiving area (effective pixel area) **22***a* and the second light receiving area (effective pixel area) **22***b*, so as to separately receive and capture two object images of different brightnesses.

(33) The first light receiving area **22***a* and the second light receiving area **22***b* are arranged to coincide with the image plane in which the two object images are focused so that it can capture these object images formed thereon.

(34) The imager **22** also has correction pixel areas **22***c* around the first light receiving area **22***a* and the second light receiving area **22***b*. The correction pixel area **22***c* is used to correct geometrical displacement between the two separate object images formed on the imager. Manufacturing errors are reduced in the correction pixel area **22***c*, and the geometrical displacement between the object images mentioned above is eliminated by correction through image processing performed by an image correction processor **32***a* (shown in FIG. **1**), which will be described later.

(35) As above, the system according to the embodiment has the quarter wave plate **21***e* that is

disposed between the object side prism **21***a* and the first reflection surface REF**1** to change the phase of the light beams reflected by the optical path dividing surface **21***d*. The light beams reflected by the first reflection surface REF**1** are transmitted through the quarter wave plate **21***e* and focused on the first light receiving area **22***a* of the imager **22** through the polarizing beam splitter **20**. In this way, the system can separate the light beams and capture the first object image with improved efficiency in utilization of the light quantity.

(36) In the system according to the embodiment, the light beams transmitted through the optical path dividing surface **21***d* are reflected by the second reflection surface REF**2**, which is a surface of the image side prism **21***c* that is located on the transmission side of the optical path dividing surface **21***d* to bend the optical path B perpendicularly toward the imager **22**, and focused on the second light receiving area **22***b* of the imager **22**. In this way, the system can separate the light beams and capture the second object image with improved efficiency in utilization of the light quantity.

(37) The system shown in FIG. **1** has an ID memory **40** used to store information on the difference in exposure between the first object image and the second object image on the imager **22**.

(38) The processor **3** shown in FIG. **1** will now be described. The processor **3** includes a controller **31**, an image processor **32**, a pre-processor **33**, and a CCD driver **34**.

(39) The controller **31** controls the pre-processor **33**, the CCD driver **34**, and other circuits such as a power supply circuit and a signal processing circuit.

(40) The pre-processor **33** receives imaging signals (namely, imaging signals for two object images of different exposures) from the imager **22** and applies pre-signal processing on the imaging signals. The pre-processor **33** includes known components or circuits such as a signal amplifier, a processing circuit, an A/D converter, and a white balance circuit.

(41) The image processor **32** includes an image correction processor **32***a* for image correction, an image combining processor **32***b* for performing image combining processing for combining two images after correction, and an image output unit **32***c* for outputting the combined image to a display **5**.

(42) The image correction processor **32***a* applies correction to image signals of the two object images formed respectively on the first light receiving area **22***a* and the second light receiving area **22***b* of the imager **22** to substantially align the positions, angles and the magnifications of the two object images relative to each other.

(43) The system shown in FIG. **1** includes a CCD driver, which drives the imager **22** in an endoscope **2** (shown in FIG. **9**).

(44) In the case where an object image is separated into two images that are focused separately on the imager **22**, there is a possibility that a geometrical difference between them may arise. More specifically, the object images formed respectively on the first light receiving area **22***a* and the second light receiving area **22***b* (shown in FIG. **3**) of the imager **22** may have a difference in the magnification, a positional displacement, and/or an angular displacement (i.e. rotational displacement) relative to each other.

(45) Such differences or displacements can hardly be eliminated completely in the manufacturing process. If the differences or displacements are large, the combined image can be a double image (i.e. an image containing two slightly displaced images) or an image having unnaturally uneven brightness. To avoid this from happening, the image correction processor is configured to correct geometrical differences and brightness differences mentioned above.

(46) The image combining processor **32***b* performs secondary image processing such as combining two images into one, color matrix, edge enhancement, and gamma correction. The image output unit **32***c* outputs an image that has undergone the secondary image processing. The image output unit **32***c* outputs the image to the display **5**.

(47) The system according to the embodiment is configured to combine two images of different exposures with the features that will be specifically described in the following. Satisfying the following conditional expression (1) allows an extended dynamic range without loss of light

quantity.

$(Tp+Ts)/(100-Ts)\geq1.25$ (1)

(48) Combining images of different exposures can extend the dynamic range. When conditional expression (1) is satisfied, it is possible to extend the dynamic range by 25% or more. In this way, it is possible to produce images of different exposures without loss of light quantity. Such images can resolve details more clearly than images that do not have an extended dynamic range. In particular, images with an extended dynamic range can resolve structures or features in the dark area that would be invisible in images without an extended dynamic range due to noises.

(49) Moreover, the system according to the embodiment does not need the use of an element for reducing the light quantity. This allows a reduction in the manufacturing cost and an increase in the space.

(50) It is more preferred that conditional expression (1) be further restricted by the following conditional expression (1'), (1''), or (1''').

$(Tp+Ts)/(100-Ts)\geq1.5$ (1')

(51) Satisfying conditional expression (1') allows a reduction of noises in the dark portion of images (dark noises).

$(Tp+Ts)/(100-Ts)\geq2$ (1'')

(52) Satisfying conditional expression (1'') allows a sufficient reduction of halation in the bright portion of images.

$(Tp+Ts)/(100-Ts)\geq3$ (1''')

Satisfying conditional expression (1''') allows a sufficient reduction of noses in the dark portion of images.

(53) FIGS. **4**A, **4**B, and **4**C show transmittance properties of the optical path dividing surface **21**d.

(54) FIG. **4**A shows the transmittance of the optical path dividing surface **21**d for p-polarized light and for s-polarized light in the case where the ratio of extend in the dynamic range (extended D range ratio) is 1.0.

(55) FIG. **4**B shows the transmittance of the optical path dividing surface **21**d for p-polarized light and for s-polarized light in the case where the ratio of extend in the dynamic range (extended D range ratio) is 1.25.

(56) FIG. **4**C shows the transmittance of the optical path dividing surface **21**d for p-polarized light and for s-polarized light in the case where the ratio of extend in the dynamic range (extended D range ratio) is 1.5.

(57) FIGS. **5**A and **5**B show other transmittance properties of the optical path dividing surface **21**d.

(58) FIG. **5**A shows the transmittance of the optical path dividing surface **21**d for p-polarized light and for s-polarized light in the case where the ratio of extend in the dynamic range (extended D range ratio) is 2.0.

(59) FIG. **5**B shows the transmittance of the optical path dividing surface **21**d for p-polarized light and for s-polarized light in the case where the ratio of extend in the dynamic range (extended D range ratio) is 3.0.

(60) Table 1 below shows exemplary values related to the system according to the embodiment for different extended D range ratios. The values of the transmittance and reflectance given in Table 1 are in percent. The values of the image intensity in surface A and the image intensity in surface B are in an arbitrary unit representing their relative value.

(61) TABLE-US-00001 TABLE 1

transmittance for p-polarized light	transmittance for s-polarized light	reflectance for s-polarized light	image intensity on surface A	image intensity on surface B	extended D range ratio
100	0	100	100	100	1.00
100	11	89	89	111	1.25
100	20	80	80	120	1.50
100	33	67	67	133	2.00
100	50	50	50	150	3.00

(62) According to a preferred mode of this embodiment, it is preferred that the following conditional expression (2) be satisfied:

$80\leq Tp$ (2).

(63) Conditional expression (2) defines an appropriate range of the transmittance for p-polarized light of the optical path dividing surface **21***d*. Satisfying conditional expression (2) allows a further reduction of loss of light quantity, leading to efficient use of light.

(64) According to a preferred mode of this embodiment, it is preferred that the object image through the first optical path A and the object image through the second optical path B be formed on the same plane I (i.e. the imaging surface) on the exit side of the polarizing beam splitter **20**.

(65) Then, images of different exposures can be captured by a single imager **22**.

Second Embodiment

(66) FIG. **6** is a diagram showing the structure of a polarizing beam splitter provided in an objective optical system according to a second embodiment. The components same as the corresponding components in the first embodiment are denoted by the same reference signs and will not be described in further detail.

(67) The system according to the second embodiment is configured to achieve a high dynamic range as described in the above description of the first embodiment and also an extended depth of field. The configuration of the system or apparatus according to the second embodiment is the same as that shown in FIG. **1**, but the procedure of processing applied to captured object images is different from that according to the first embodiment.

(68) In the system according to the second embodiment, the optical path length of a first optical path A**1** extending from the optical path dividing surface **21***d* to plane I (or the imaging surface) and the optical path length of a second optical path B**1** extending from the optical path dividing surface **21***d* to plane I are different from each other.

(69) FIG. **6** shows the structure of the polarizing beam splitter **120** used in the system according to the second embodiment. This system uses an object side prism **221***a* and an image side prism **221***c* to separate an object image into two optical images, namely object images with different focus positions. The polarizing beam splitter **120** is configured such that the optical path length (or glass path length) of the reflected light from the optical path dividing surface **21***d* to the imager **22** is shorter than the optical path length of the transmitted light from the optical path dividing surface **21***d* to the imager **22**.

(70) As shown in FIG. **7**, the imager **22** has a first light receiving area **222***a* and a second light receiving area **222***b*, which are arranged to coincide with the image plane of two object images to capture images of them. The focus position of the first light receiving area **222***a* of the imager **22** is relatively displaced from the focus position of the second light receiving area **222***b* toward near points, and the focus position of the second light receiving area **222***b* is relatively displaced from the focus position of the first light receiving area **222***a* toward far points. In this way, the system is configured such that two object images of different focus positions are formed on the light receiving surface of the imager **22**.

(71) The imager **22** separately receives and captures two object images AA and BB of different focus positions. For example, the object image AA of the near side focus position is the lower exposure image, and the object image BB of the far side focus position is the high exposure image.

(72) Different glass materials may be used for the object side prism **221***a* and the image side prism **221***c* to create a difference in the optical path length to the imager **22** and to displace the focus positions for the first light receiving area **222***a* and the second light receiving area **222***b* relative to each other.

(73) The image combining processor **32***b* (shown in FIG. **1**) in the system according to the second embodiment has the function of increasing the depth of field in addition to the function of increasing the dynamic range described above. The image combining processor **32***b* chooses an image having higher contrast in each of the corresponding areas of the two images to create a combined image. More specifically, the image combining processor **32***b* compares the contrast of the two images in each of the spatially identical (or corresponding) pixel areas and chooses the image having higher contrast in each pixel area to create a single combined image from the two

images.

(74) The image output unit **32***c* outputs an image that has undergone the secondary image processing. The image output unit **32***c* outputs the image to the display **5**.

(75) As above, two object images of different focus positions are captured, and then the image combining processor **32***d* combines the captured images to achieve a combined depth of field. When an endoscope is used to view a large area for the purpose of screening, far observation is suitable. When an endoscope is used for the purpose of detailed observation of lesions or diagnosis, close observation is suitable.

(76) It is preferred that the focus position of the darker object image be displaced toward near points, and the focus position of the brighter object image be displaced toward far points. This is because near points are brighter than far points, and far points are darker than near points. FIG. **8** is a flow chart of a process of combining two object images to extend the depth of field according to the second embodiment.

(77) In step S**101**, correction of the image signals of the two object images of different focus positions (namely, the far point image and the near point image) captured by the imager **22** is performed by the image correction processor **32***a*.

(78) Specifically, the image correction processor **32***a* corrects the two image signals according to predetermined correction parameters so as to substantially align the positions, angles, and magnifications of the optical images corresponding to the two image signals relative to each other and then outputs the corrected image signals to the image combining processor **32***b*. The image correction processor **32***a* may also correct the brightness and color difference of the two images, if necessary.

(79) In step S**102**, the corrected two image signals are combined by the image combining processor **32***b*. In this process, the image combining processor **32***b* calculates contrast values in corresponding pixel areas of the near point image and the far point image and compares them.

(80) In step S**103**, it is determined whether or not there is a difference larger than a predetermined value between the compared contrast values. If there is a large difference in the contrast value, the process proceeds to step S**105**, where the image of which the contrast value is higher is chosen in each pixel area and used in the combining process.

(81) There may be cases where the difference between the contrast values is small, namely where the contrast values are substantially equal. This may lead to instability in the process of choosing either one of the far point image and the near point image. For example, when the signals are unstable due to noise or other cause, undesirable results may occur. For example, discontinuous areas may be created in the combined image, and/or a blurred image will be produced from resolved original object images.

(82) To prevent the above troubles from occurring, in step S**104**, weighting is performed. When the contrast values of the two images are substantially equal in a pixel area in which the contrast values are compared, either one of the images is weighted, and the weighted images are added. In this way, instability in image choosing process is eliminated. In step S**105**, an image having a higher contrast value is chosen in each pixel area and used in the image combining process.

(83) As above, according to the second embodiment, it is possible to produce an image with extended depth of field without creating discontinuous areas in the combined image due to noise or other causes or blurring the optical image in both the close observation and the far observation.

(84) With the above features of the second embodiment, it is possible to extend the depth of field without deteriorating the resolving power even when an imager having an increased number of pixels is used, while achieving high dynamic range.

(85) In the following, a numerical example of the lens group **1** will be described as shown in FIG. **1**.

Numerical Example

(86) The lens group **1** includes, in order from the object side, a planoconcave negative lens L**1**

having a planar surface facing the object side, a plane parallel plate L2, a biconcave negative lens L3, a positive meniscus lens L4 having a convex surface facing the object side, a positive meniscus lens L5 having a convex surface facing the object side, a biconvex positive lens L6, a negative meniscus lens L7 having a convex surface facing the image side, an aperture stop S, a biconvex positive lens L8, a biconvex positive lens L9, and a negative meniscus lens L10 having a convex surface facing the image side.

(87) The negative meniscus lens L3 and the positive meniscus lens L4 are cemented together. The positive lens L6 and the negative meniscus lens L7 are cemented together. The positive lens L9 and the negative meniscus lens L10 are cemented together.

(88) The polarizing beam splitter 20 is disposed on the image side of the lens group 1. The optical path is bent by the optical path dividing surface of the prisms in the polarizing beam splitter 20. The plane parallel plate L2 is a filter having a coating for cutting off light of a specific wavelengths, for example 1060 nm of YAG laser, 810 nm of semiconductor laser, or an infrared range. The reference "I" in FIG. 1 indicates the image plane (or imaging surface).

(89) In the following numerical data of the above example is given, where r is the radius of curvature of each lens surface, d is the distance between adjacent surfaces, nd is the refractive index of each lens for d-line, vd is the abbe number of each lens, FNO is the F-number, ω is the half angle of view, and fb is the back focus. The back focus is the distance from the optical surface closest to the image side to the paraxial image surface, and it is represented by an equivalent distance in air. The total length is the distance from the lens surface closest to the object side to the optical surface closest to the image side (which is not an equivalent length in air) plus the back focus. The stop is an aperture stop.

Numeral Example

(90) TABLE-US-00002 Unit mm Surface data Surface number r d nd vd 1 8 0.49 1.88300 40.76 2 1.812 0.79 3 8 0.84 1.52100 65.12 4 8 0.34 5 −4.881 0.56 1.88300 40.76 6 1.866 2.13 1.84666 23.78 7 77.332 variable 8 2.010 0.81 1.48749 70.23 9 2.149 variable 10 3.354 1.13 1.64769 33.79 11 −1.665 0.32 2.00330 28.27 12 −9.987 0.04 13(stop) ∞ 0.56 14 512.363 0.95 1.69895 30.13 15 −3.552 0.36 16 9.128 0.94 1.48749 70.23 17 −2.180 0.39 1.92286 18.90 18 −4.093 4.59 19 (image pick up plane) ∞ Various data Focal length 1.00 F NO. 3.58 angle of view 2ω 144.9 fb (in air) 4.59 entire length (in air) 17.15 d7 0.47 d9 1.43

Third Embodiment

(91) FIG. 9 shows the configuration of an endoscope 2 and an endoscope apparatus 1 according to a third embodiment. The endoscope 2 and the endoscope apparatus 1 are designed to reduce loss of light quantity and to extend the dynamic range and the depth of field.

(92) The endoscope 2 has the imaging unit 60 described in the above description of the first embodiment.

(93) The endoscope apparatus 1 includes the endoscope 2 and an image processor 32 configured to combine two object images.

(94) As shown in FIG. 9, the endoscope apparatus 1 according to the third embodiment has the endoscope 2, a processor 3 that is detachable connected to the endoscope 2 to perform specific signal processing, a light source 4 that is detachably connected with the endoscope 2 to supply illumination light to the endoscope 2, and a display 5 that displays endoscope images based on image signals produced by the processor 3.

(95) The endoscope 2 has a thin, long insert part 6 to be inserted into a body cavity, an operation unit 7 provided at the rear end of the insert part 6, and a universal cord 8 extending from the operation unit 7. The universal cord 8 branches into a light guide cord 9 and a signal cord (or signal cable) 10a at a point near the base end or a midpoint.

(96) The light guide cord 9 has an optical source connector 11 at its end, which is detachably connected to the light source 4. The signal cord 10a has a signal connector 12 at its end, which is detachably connected to the processor 3.

(97) The signal connector **12** is provided with an ID memory **40**. The ID memory **40** is a storage unit that stores individual information for each endoscope **2**, for example individual information related to the polarizing beam splitter **20** and the imager **22**.

(98) A light guide **13** for transmitting illumination light is inserted through the operation unit **7** and the universal cord **8**. As the light source connector **11** is connected to the light source **4**, illumination light emitted from the light source **14** is transmitted through the light guide **13**, and the transmitted illumination light is emitted from the end face **13***a* of the light guide **13** attached to an illumination window provided in the distal end **14** of the insert part **6**.

(99) Alternatively, a combined connector including the light source connector **11** and the signal connector **12** may be used. The combined connector may be connected to the light source **4**, and signals may be transmitted between the signal connector **12** and the processor **3** through a cable that connects the light source **4** and the processor **3**.

(100) The distal end **14** is provided with an observation window (or imaging window) which is diposed adjacent to the illumination window. The imaging unit **60** including the objective optical system **1** is provided in the observation window (shown in FIG. **1**). The imaging unit **60** captures an optical image of an object such as an affected area illuminated with illumination light.

(101) An example of the imager **22** is a CCD image sensor. The imager **22** is connected to the processor **3** through the cable that is passed through the insert part **6** and the universal cord **8** and the signal connector **12**.

(102) As described above, the imager **22** used in the apparatus according to the third embodiment is configured such that the first and second object images, which are different optical images separated from each other, are formed (or focused) on specific areas of the same imaging surface of the CCD that are respectively corresponding to the two object images.

(103) The apparatus according to the third embodiment is configured to store information on the difference in exposure between the low-exposure first object image and the high-exposure second object image in the ID memory **40**. This information is related to the polarizing beam splitter **20**. This information will also be referred to as the exposure difference information.

(104) As described above, the controller **31** controls various circuits in the processor **3**. When the endoscope **2** is connected to the processor **3**, the processor **3** obtains focus position information and the exposure difference information stored in the ID memory **40** provided in the signal connector **12**. The focus position information and the exposure difference information are individual information on the endoscope **2**.

(105) As above, the endoscope and the endoscope apparatus according to the third embodiment can reduce loss of light quantity and extend the dynamic range.

(106) The polarizing beam splitter **120** described in the description of the second embodiment may be used in the endoscope apparatus **1** according to the third embodiment. The endoscope and the endoscope apparatus using the polarizing beam splitter **120** according to the second embodiment can reduce the loss of light quantity and extend the dynamic range and the depth of field.

(107) The objective optical system, the imaging unit, the endoscope, and the endoscope apparatus described above may adopt two or more of the above-described features.

(108) Adopting two or more features can improve the performance of the endoscope apparatus. Features to be adopted may be selected in any desired combination. The conditional expressions that further limit the upper and lower bounds of preceding conditional expressions may be modified to limit only one of the upper and lower bounds.

(109) While some embodiments of the present invention have been described, it should be understood that the present invention is not limited to or by the embodiments. It should also be understood that other embodiments that adopt any combination of the features of the above-described embodiment are also falls within the scope of the present invention.

(110) As above, the present invention can be suitably applied to objective optical systems, imaging units, endoscopes, and endoscope apparatuses that are desired to achieve a reduction of loss of light

quantity and/or an extend in the dynamic range.

(111) The present invention can provide an objective optical system, an imaging unit, an endoscope, and an endoscope apparatus that can reduce the loss of light quantity and produce images with an extended dynamic range.

Claims

1. An objective optical system comprising: a lens group that forms an object image; a polarizing beam splitter having an optical path dividing surface that divides an optical path into a first optical path that intersects the optical axis of the lens group and a second optical path that extends straight on the optical axis; a first reflection surface provided in the first optical path; a second reflection surface provided in the second optical path; and a quarter wave plate provided between the polarizing beam splitter and the first reflection surface, wherein the objective optical system satisfies the following conditional expression (1):

$(Tp+Ts)/(100-Ts) \geq 1.25$ (1) where Tp (%) is the transmittance of the optical path dividing surface for p-polarized light, and Ts (%) is the transmittance of the optical path dividing surface for s-polarized light.

2. An objective optical system according to claim 1, satisfying the following conditional expression (2):

$80 \leq Tp$ (2).

3. An objective optical system according to claim 1, wherein the object image formed through the first optical path and the object image formed through the second optical path are formed on the same plane.

4. An objective optical system according to claim 3, wherein the optical path length of the first optical path extending from the optical path dividing surface to the plane and the optical path length of the second optical path extending from the optical path dividing surface to the plane are different from each other.

5. An imaging unit comprising: an objective optical system according to claim 1; and an imager that has an imaging surface located at the position of the object images formed by the objective optical system to capture the two object images.

6. An endoscope comprising an imaging unit according to claim 5.

7. An endoscope apparatus comprising: an endoscope according to claim 6; and an image processor that combines the two object images.