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(54) SHAPE ESTIMATION DEVICE, ENDOSCOPE SYSTEM INCLUDING SHAPE ESTIMATION DEVICE, SHAPE ESTIMATION METHOD, AND PROGRAM FOR SHAPE ESTIMATION

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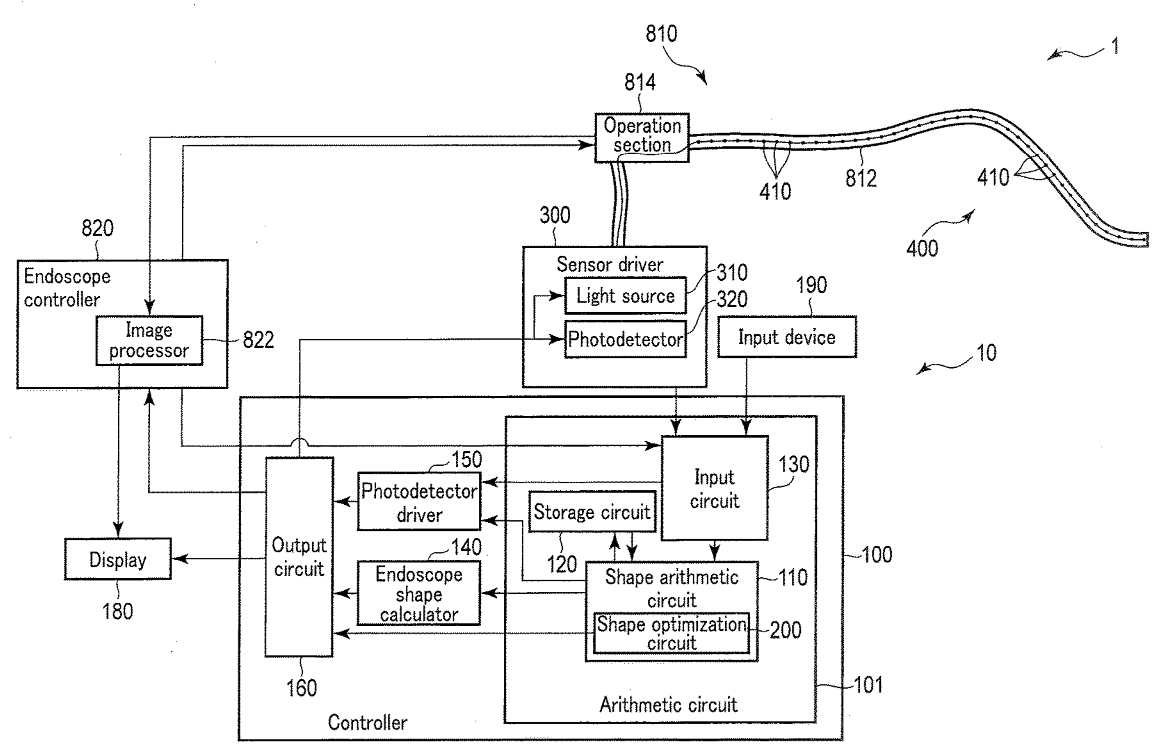
(57) **ABSTRACT**

A shape estimation device includes an input circuit, a storage circuit and an arithmetic circuit. The input circuit receives light amount information being a relationship between a wavelength and a light amount. The light amount information is acquired by using a sensor configured such that the light amount to be detected with respect to the wavelength corresponding to each of sensing parts varies in accordance with a shape of each sensing part. The storage circuit stores a light amount estimation relationship including a relationship among the shape, the wavelength and the light amount. The arithmetic circuit calculates a light amount estimation value by an optimization arithmetic operation such that the estimation value based on the light amount estimation relationship and the light amount information satisfy a predetermined condition.



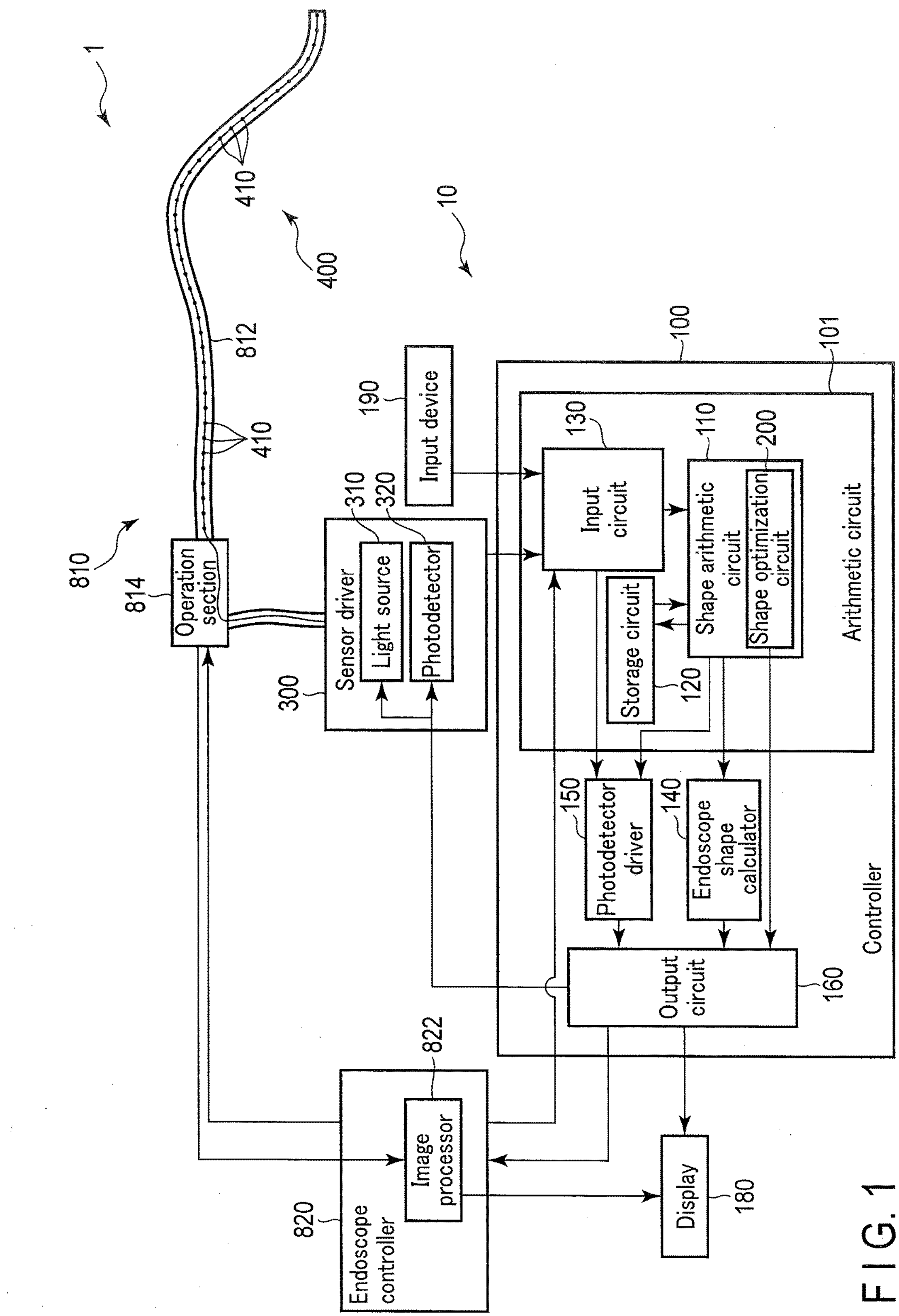
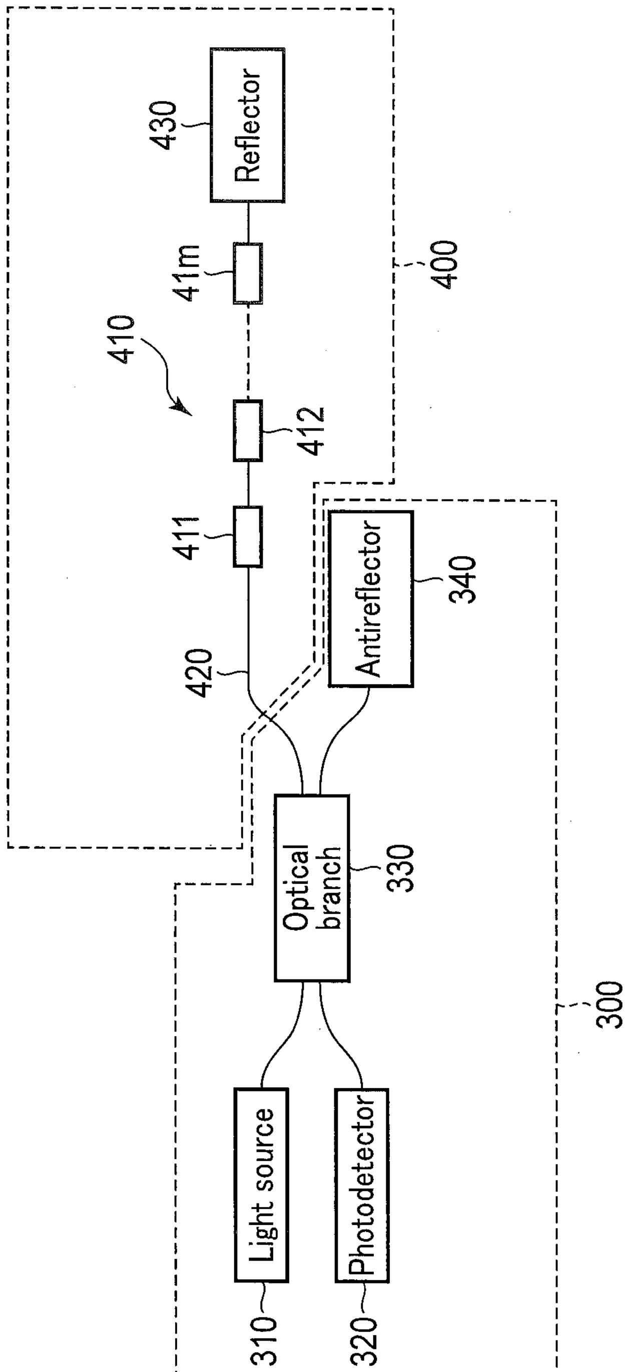
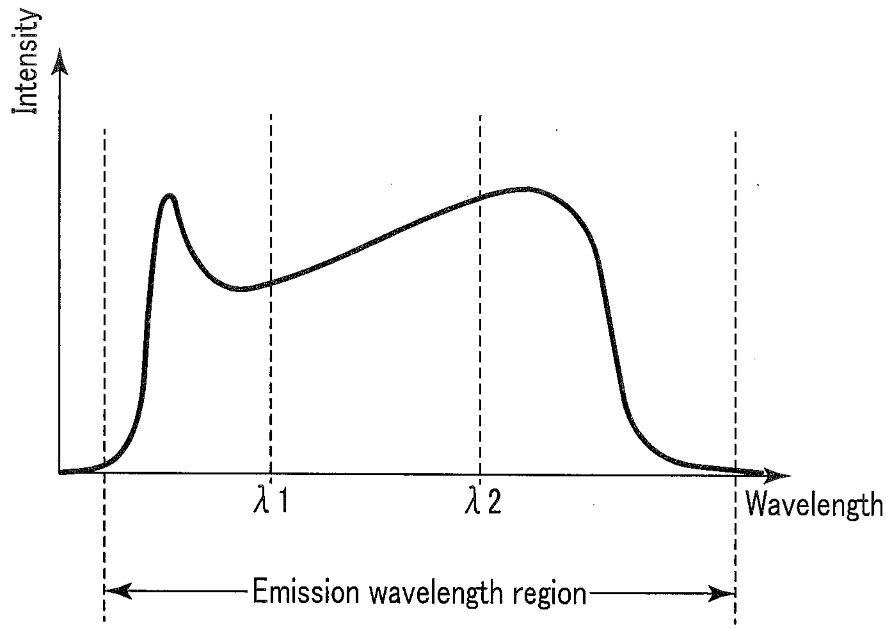

1
400
410
410
10
810
812
814
Operation section
300
Sensor driver
310
Light source
320
Photodetector
190
Input device
100
101
130
Input circuit
110
Shape arithmetic circuit
200
Shape optimization circuit
120
Storage circuit
Arithmetic circuit
150
Photodetector driver
140
Endoscope shape calculator
160
Output circuit
Controller
820
Endoscope controller
822
Image processor
180
Display

FIG. 1

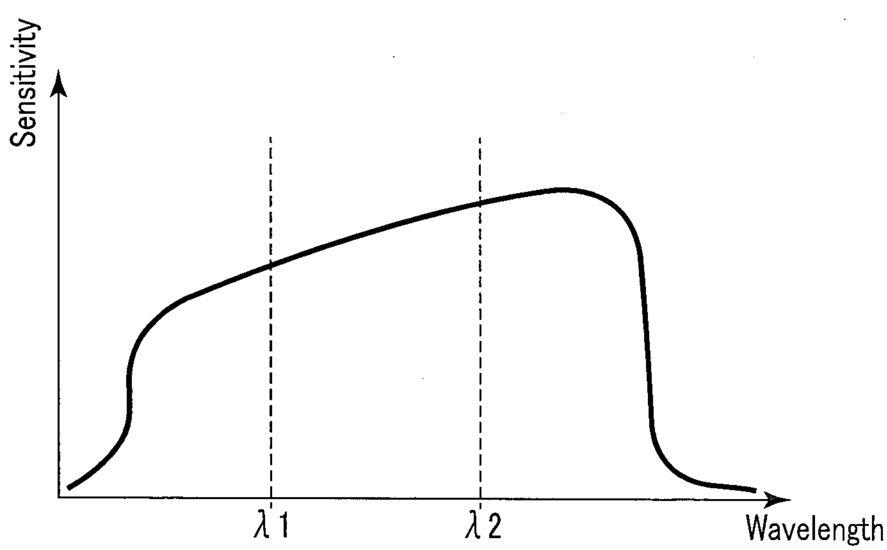


Reflector
430
41m
400
410
412
411
Antireflector
340
420
Optical branch
330
300
Light source
Photodetector
310
320

F I G. 2


Intensity
λ1
λ2
Wavelength
Emission wavelength region

F I G. 3


Sensitivity
λ1
λ2
Wavelength

F I G. 4

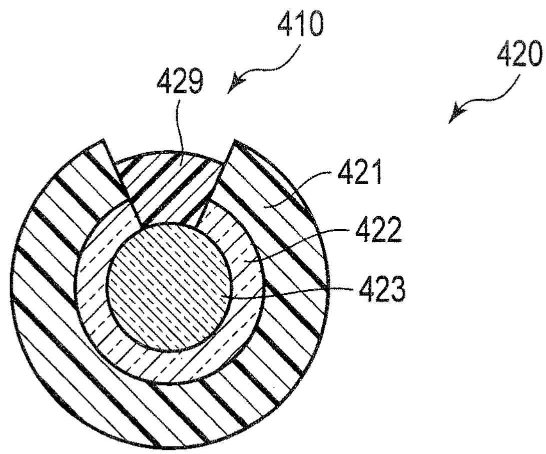

410
420
429
421
422
423

FIG. 5

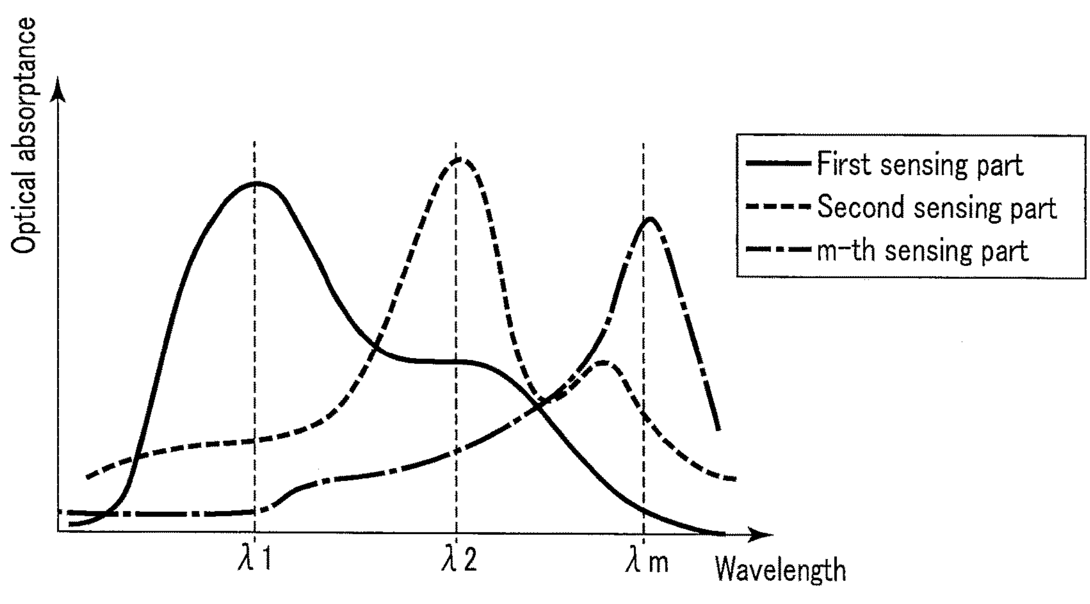

Optical absorptance
First sensing part
Second sensing part
m-th sensing part
λ1
λ2
λm
Wavelength

FIG. 6

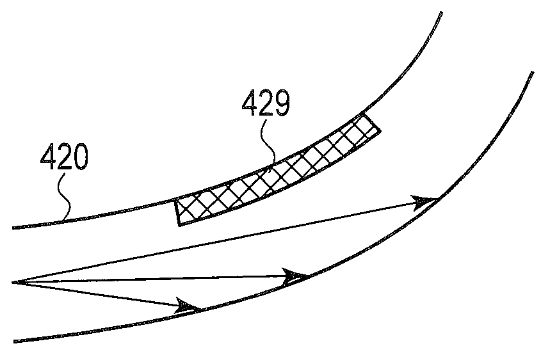


FIG. 7A

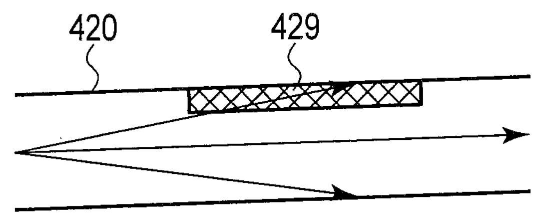


FIG. 7B

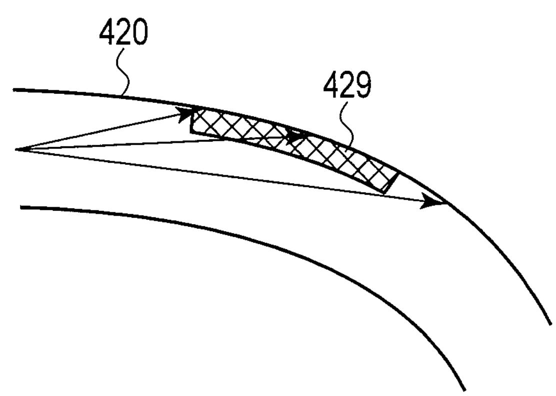
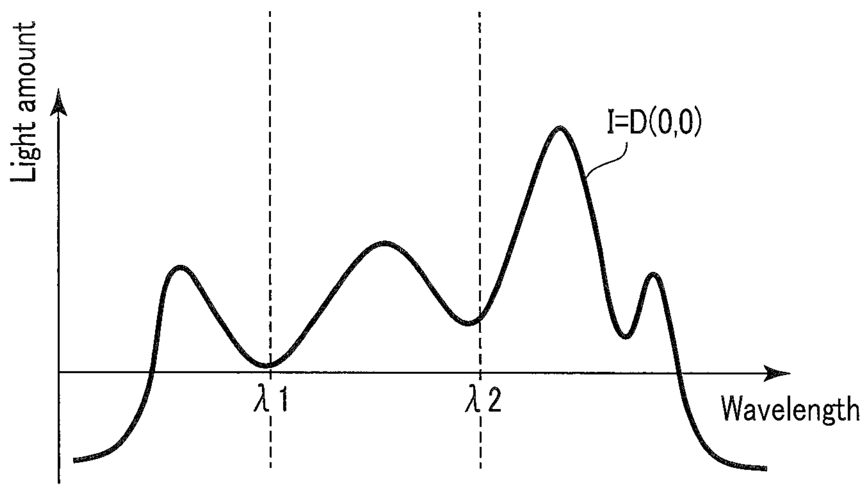
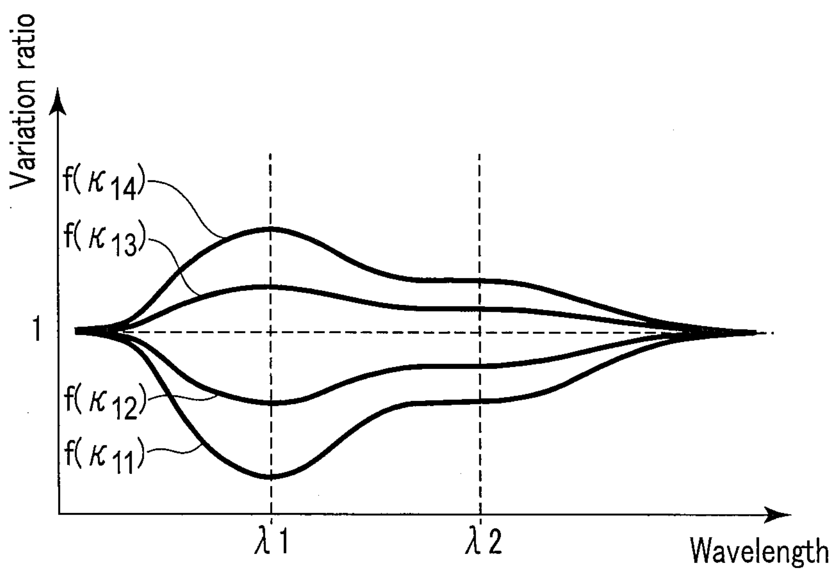


FIG. 7C



Light amount
I=D(0,0)
λ1
λ2
Wavelength

F I G. 8



Variation ratio
f(κ14)
f(κ13)
1
f(κ12)
f(κ11)
λ1
λ2
Wavelength

F I G. 9

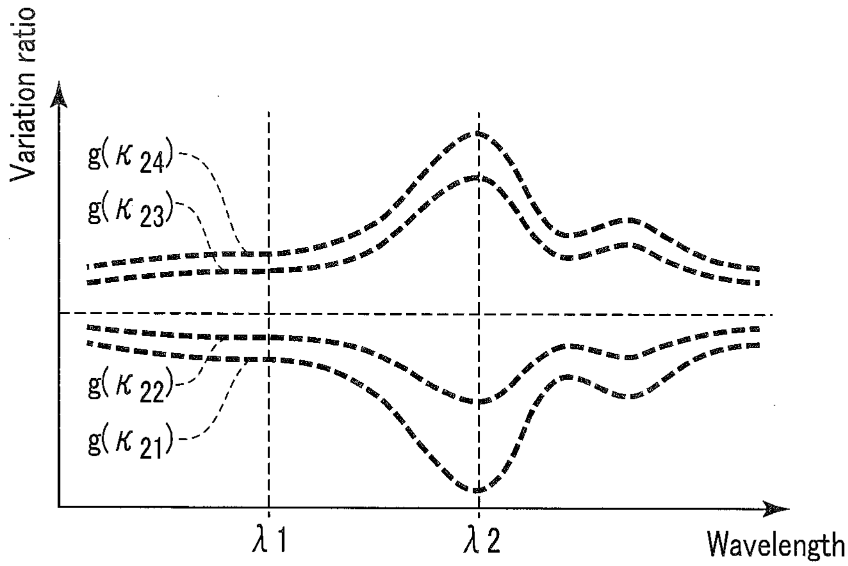

Variation ratio
g(κ 24)
g(κ 23)
g(κ 22)
g(κ 21)
λ1
λ2
Wavelength

FIG. 10

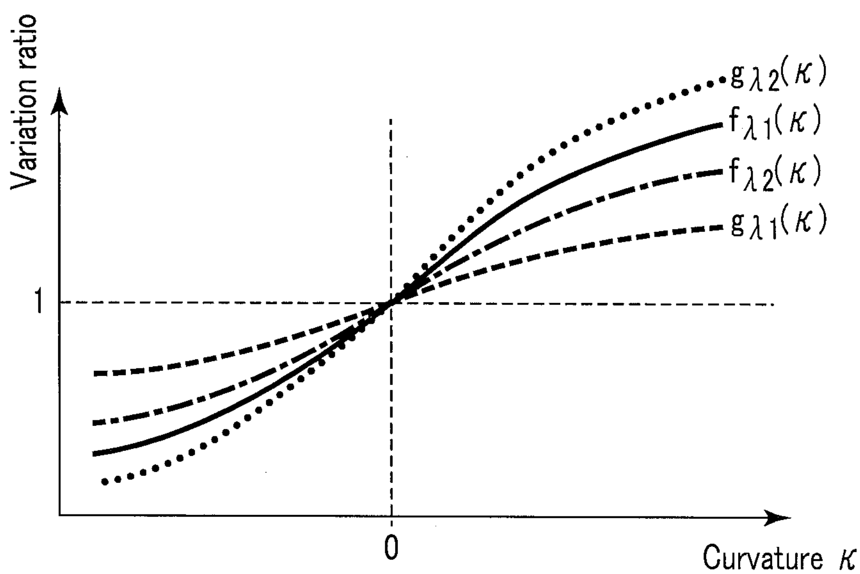
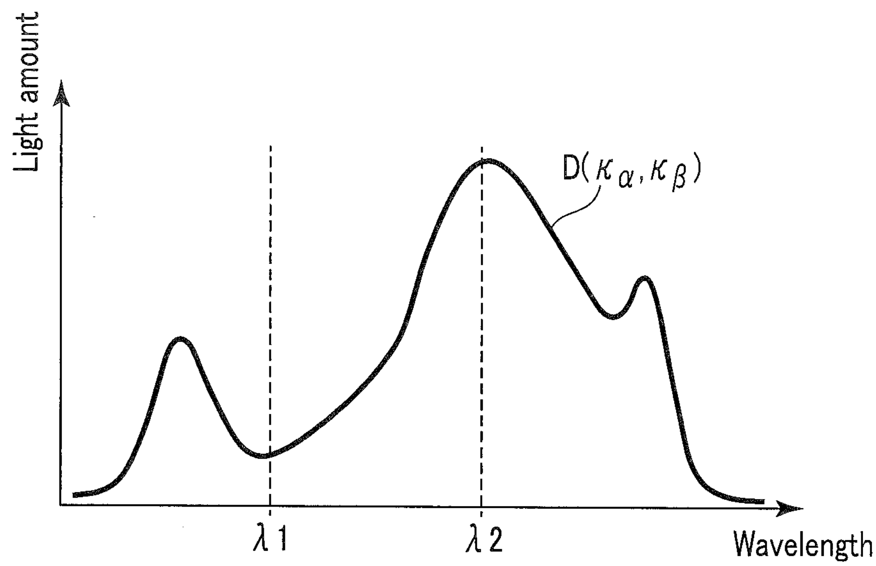
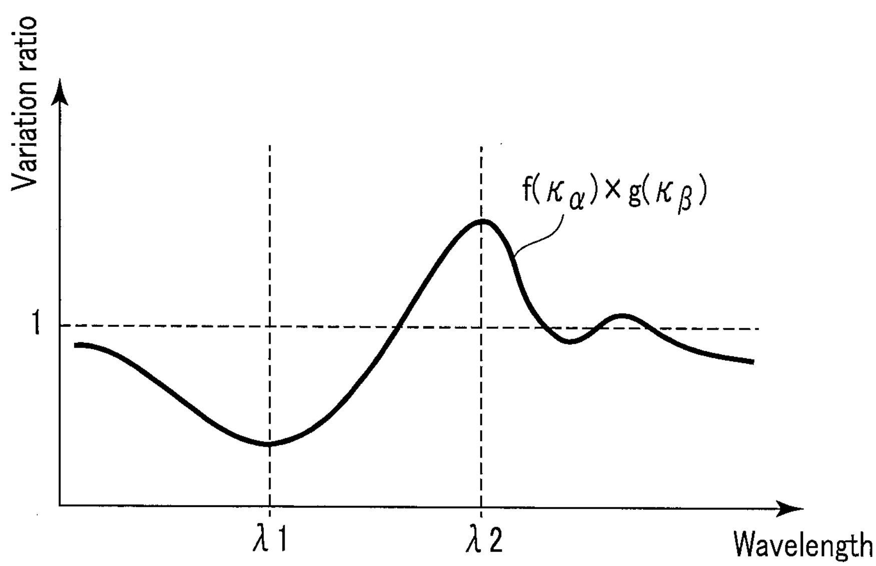

Variation ratio
gλ2(κ)
fλ1(κ)
fλ2(κ)
gλ1(κ)
1
0
Curvature κ

FIG. 11


Light amount
D(κ_α, κ_β)
λ1
λ2
Wavelength

F I G. 12


Variation ratio
f(κ_α)×g(κ_β)
1
λ1
λ2
Wavelength

F I G. 13

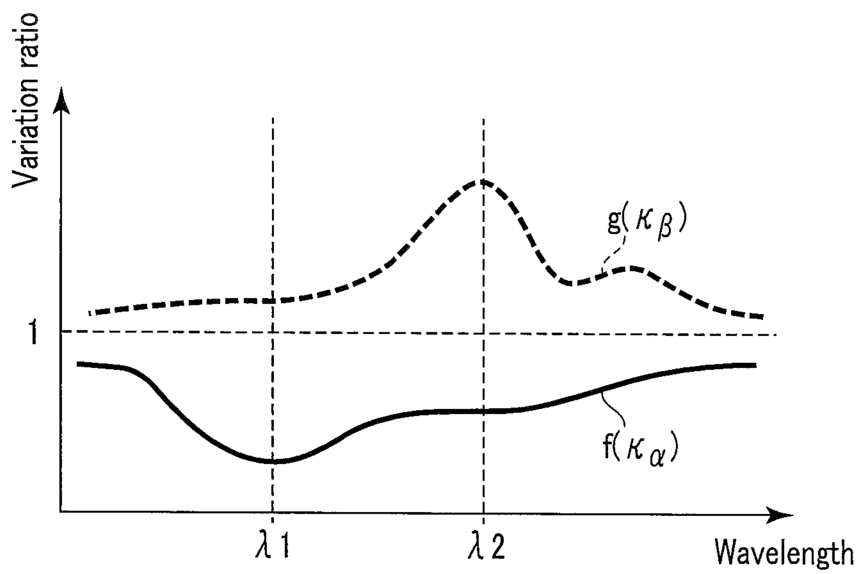
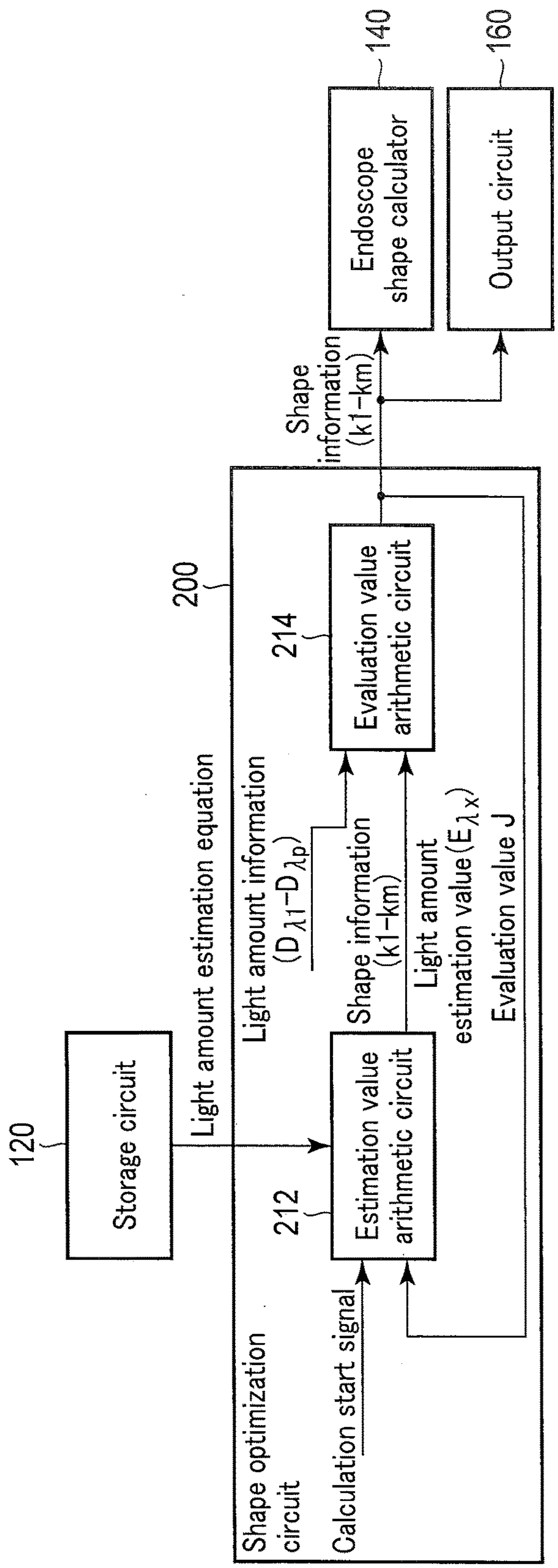
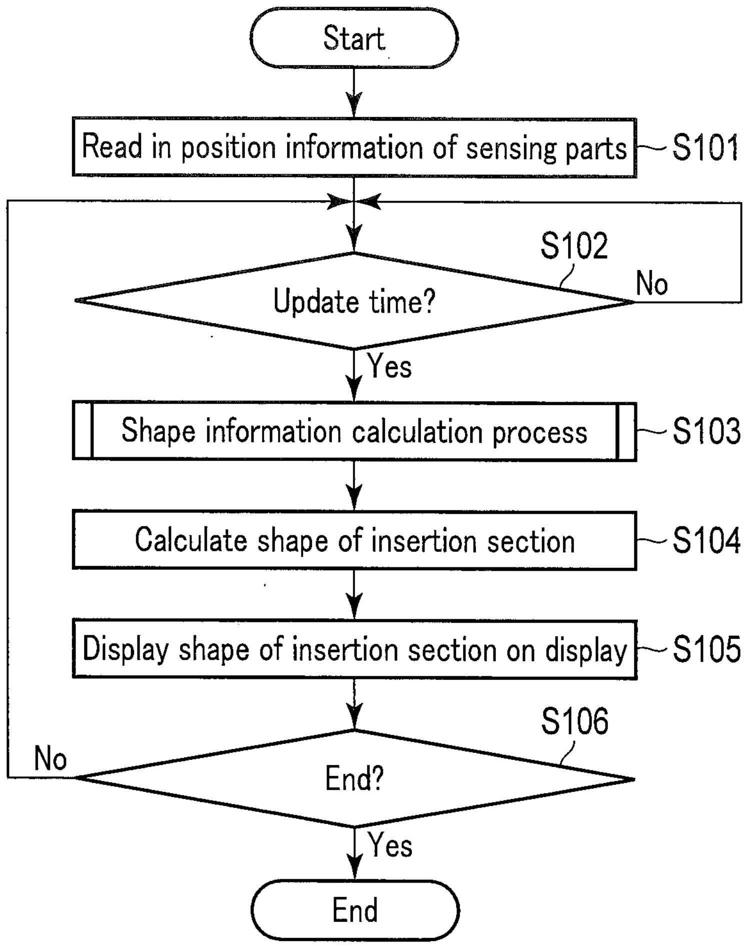

Variation ratio
g(κ_β)
1
f(κ_α)
λ1
λ2
Wavelength

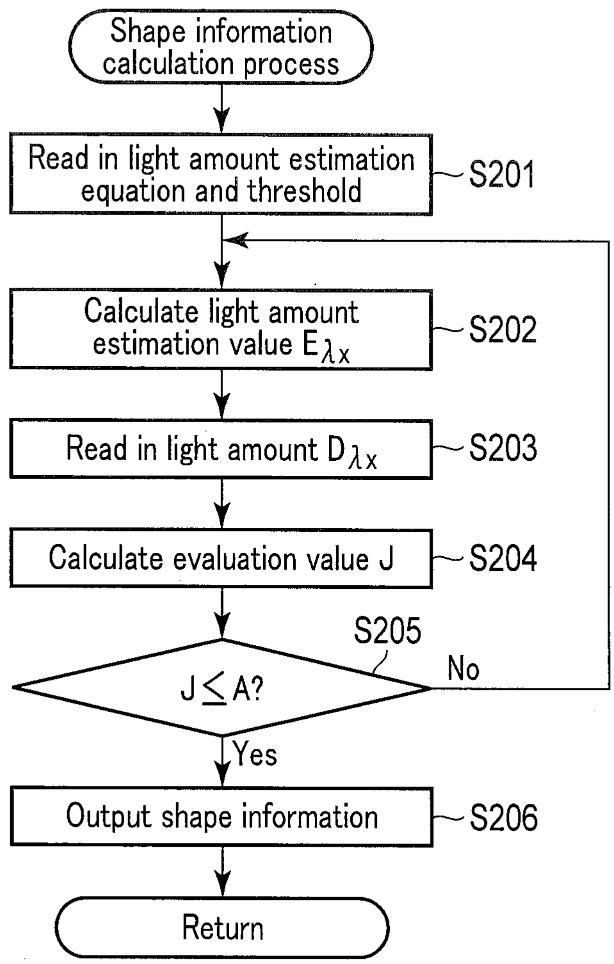
FIG. 14


140
Endoscope shape calculator
160
Output circuit
Shape information (k1-km)
200
Shape optimization circuit
120
Storage circuit
Light amount estimation equation
212
Estimation value arithmetic circuit
214
Evaluation value arithmetic circuit
Light amount information ($D_{\lambda 1}$-$D_{\lambda p}$)
Shape information (k1-km)
Light amount estimation value ($E_{\lambda x}$)
Evaluation value J
Calculation start signal

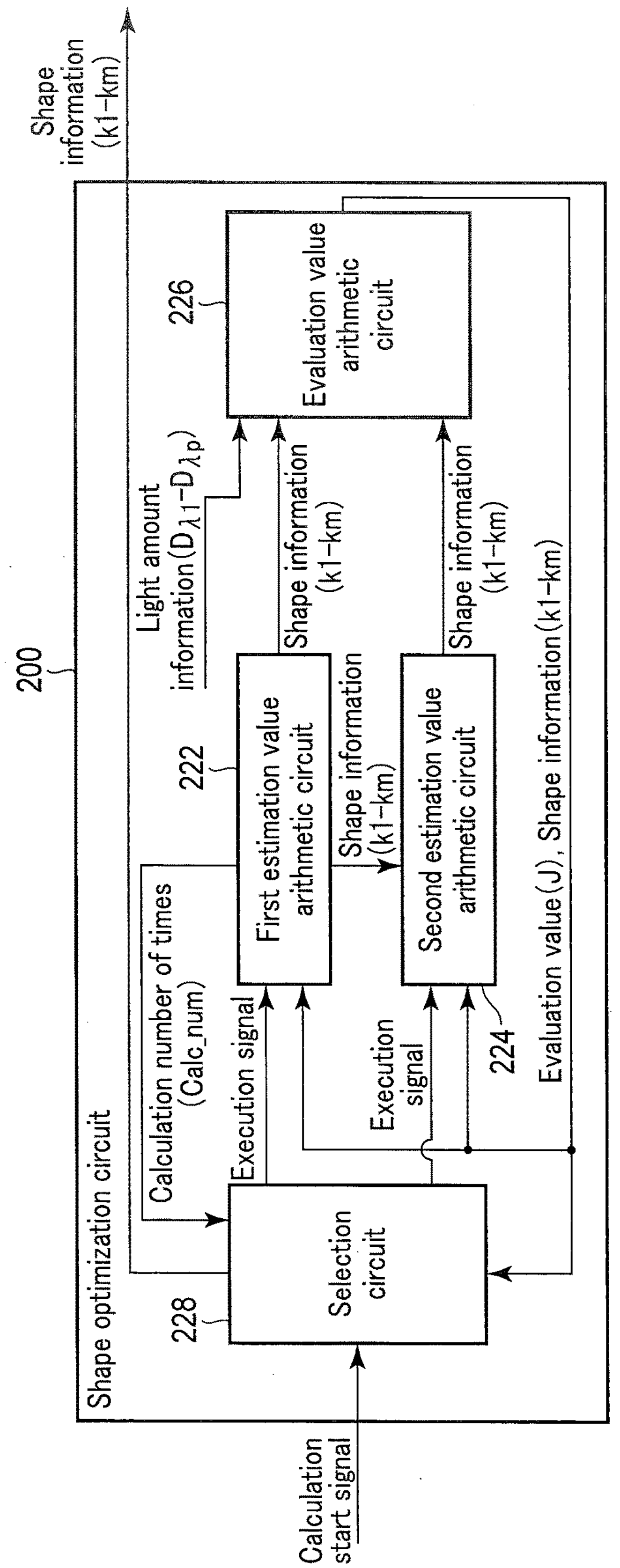
F I G. 15


Start
Read in position information of sensing parts
S101
S102
Update time?
No
Yes
Shape information calculation process
S103
Calculate shape of insertion section
S104
Display shape of insertion section on display
S105
S106
No
End?
Yes
End

F I G. 16


Shape information calculation process
Read in light amount estimation equation and threshold
S201
Calculate light amount estimation value $E_{\lambda x}$
S202
Read in light amount $D_{\lambda x}$
S203
Calculate evaluation value J
S204
S205
$J \leq A$?
No
Yes
Output shape information
S206
Return

F I G. 17


Shape information (k1-km)
200
Shape optimization circuit
226
Evaluation value arithmetic circuit
Light amount information ($D_{\lambda 1}$-$D_{\lambda p}$)
Shape information (k1-km)
Shape information (k1-km)
222
First estimation value arithmetic circuit
Shape information (k1-km)
Second estimation value arithmetic circuit
224
Calculation number of times (Calc_num)
Execution signal
Execution signal
Evaluation value (J), Shape information (k1-km)
228
Selection circuit
Calculation start signal

F I G. 18

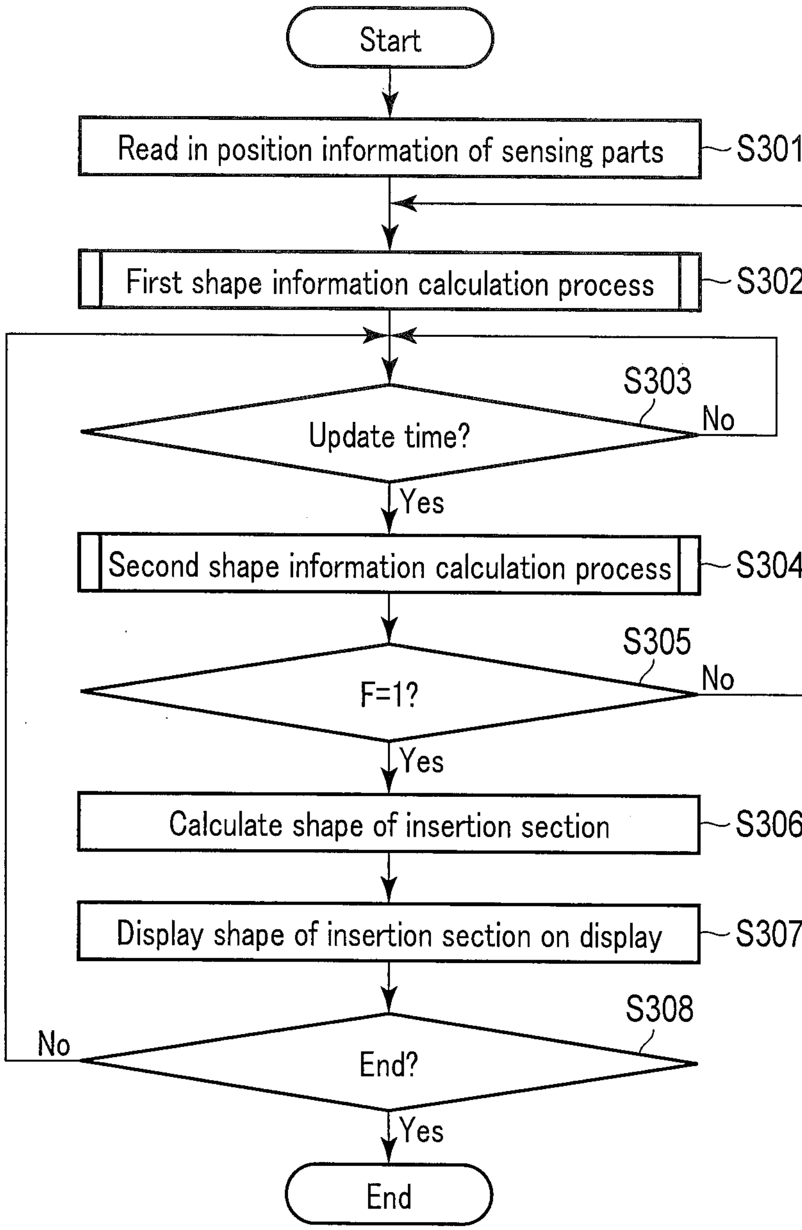

Start
Read in position information of sensing parts
S301
First shape information calculation process
S302
S303
Update time?
No
Yes
Second shape information calculation process
S304
S305
F=1?
No
Yes
Calculate shape of insertion section
S306
Display shape of insertion section on display
S307
S308
End?
No
Yes
End

FIG. 19

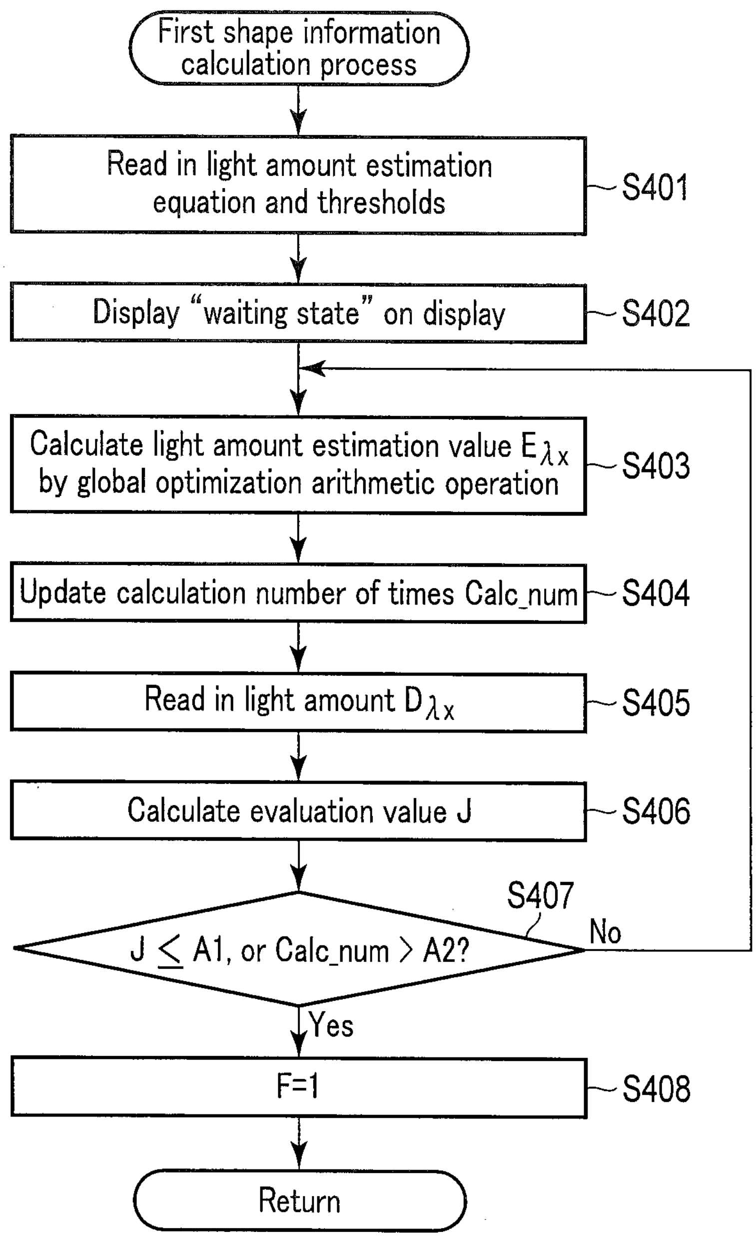
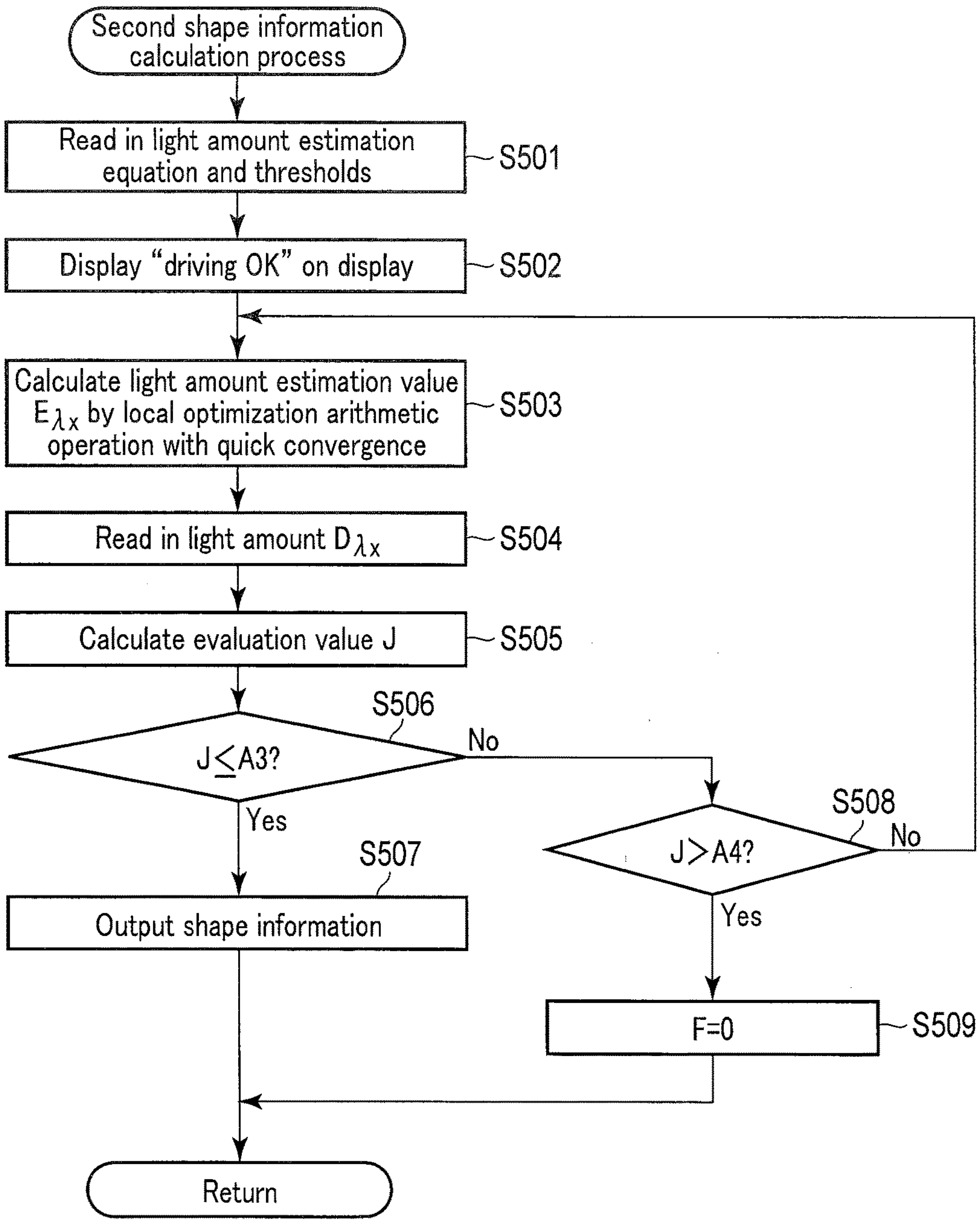

First shape information calculation process
Read in light amount estimation equation and thresholds
S401
Display "waiting state" on display
S402
Calculate light amount estimation value Eλx by global optimization arithmetic operation
S403
Update calculation number of times Calc_num
S404
Read in light amount Dλx
S405
Calculate evaluation value J
S406
S407
J ≤ A1, or Calc_num > A2?
No
Yes
F=1
S408
Return

FIG. 20



Second shape information calculation process
Read in light amount estimation equation and thresholds
S501
Display "driving OK" on display
S502
Calculate light amount estimation value $E_{\lambda x}$ by local optimization arithmetic operation with quick convergence
S503
Read in light amount $D_{\lambda x}$
S504
Calculate evaluation value J
S505
S506
J≤A3?
No
Yes
S507
Output shape information
S508
J>A4?
No
Yes
F=0
S509
Return

FIG. 21

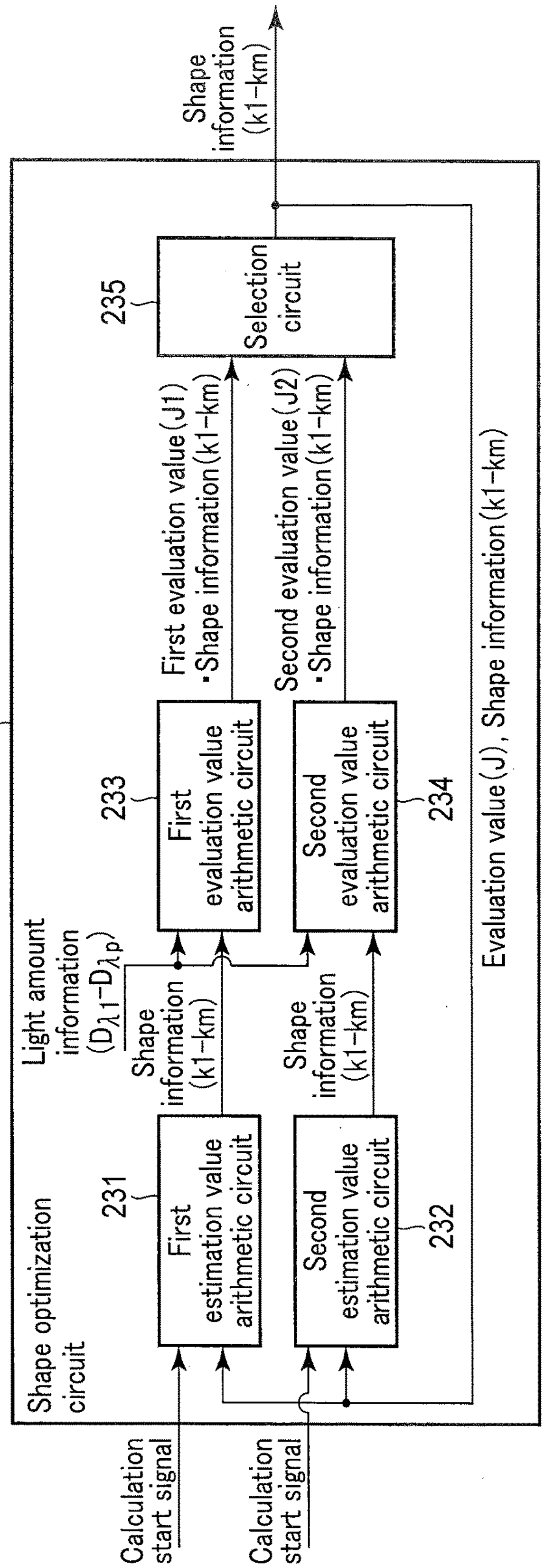
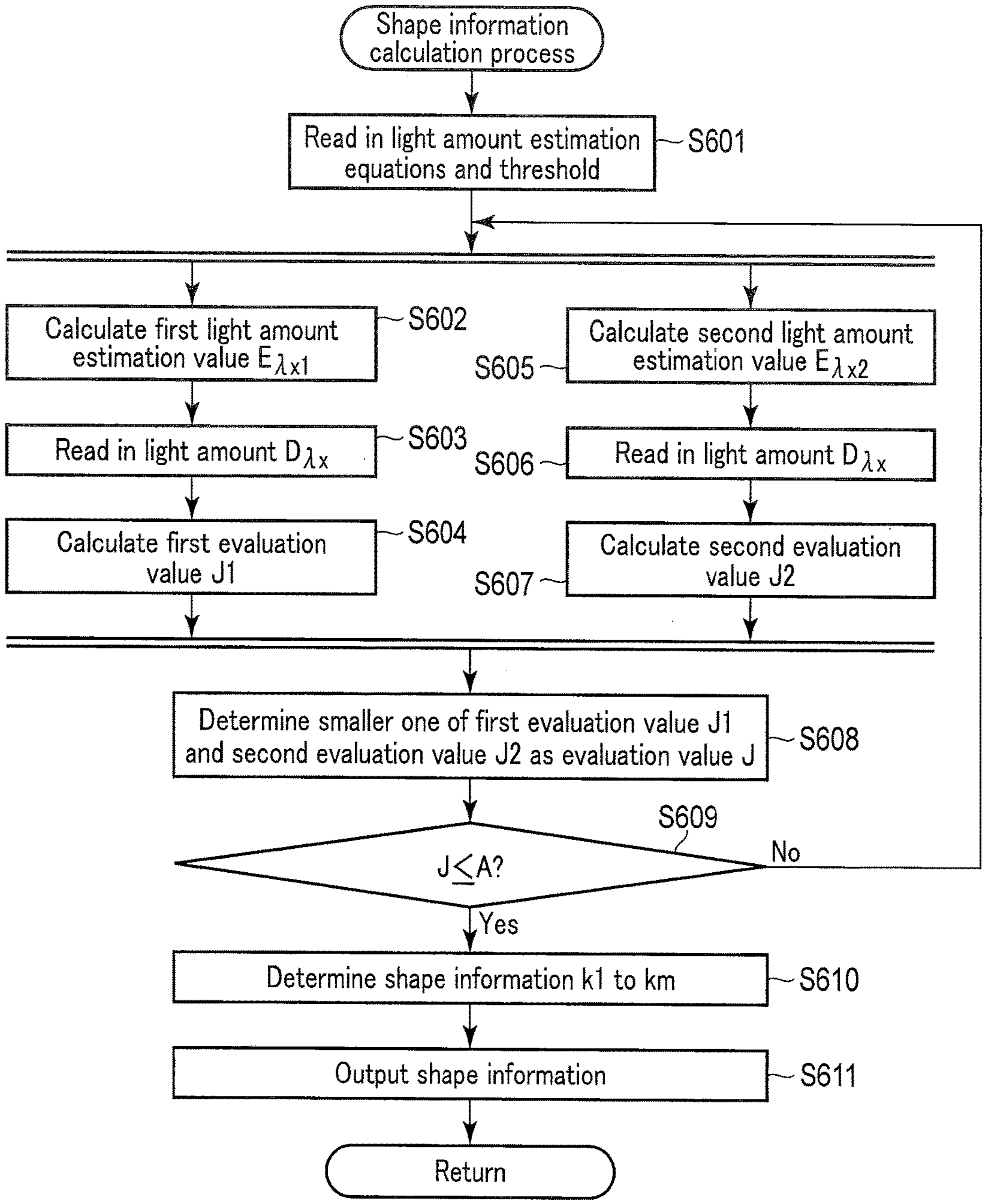

200
Shape optimization circuit
Calculation start signal
Calculation start signal
231
First estimation value arithmetic circuit
232
Second estimation value arithmetic circuit
Light amount information ($D_{\lambda 1}$–$D_{\lambda p}$)
Shape information (k1–km)
Shape information (k1–km)
233
First evaluation value arithmetic circuit
234
Second evaluation value arithmetic circuit
First evaluation value (J1) •Shape information (k1–km)
Second evaluation value (J2) •Shape information (k1–km)
235
Selection circuit
Shape information (k1–km)
Evaluation value (J), Shape information (k1–km)

FIG. 22



Shape information calculation process
Read in light amount estimation equations and threshold
S601
Calculate first light amount estimation value $E_{\lambda x1}$
S602
Read in light amount $D_{\lambda x}$
S603
Calculate first evaluation value J1
S604
Calculate second light amount estimation value $E_{\lambda x2}$
S605
Read in light amount $D_{\lambda x}$
S606
Calculate second evaluation value J2
S607
Determine smaller one of first evaluation value J1 and second evaluation value J2 as evaluation value J
S608
S609
J≤A?
No
Yes
Determine shape information k1 to km
S610
Output shape information
S611
Return

FIG. 23

SHAPE ESTIMATION DEVICE, ENDOSCOPE SYSTEM INCLUDING SHAPE ESTIMATION DEVICE, SHAPE ESTIMATION METHOD, AND PROGRAM FOR SHAPE ESTIMATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation Application of PCT Application No. PCT/JP2015/064959, filed May 25, 2015 and based upon and claiming the benefit of priority from prior the Japanese Patent Application No. 2014-131772, filed Jun. 26, 2014, the entire contents of all of which are incorporated herein by references.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a shape estimation device, an endoscope system including the shape estimation device, a shape estimation method, and a program for shape estimation.

[0004] 2. Description of the Related Art

[0005] There is known a device for detecting the shape of an endoscope. For example, Jpn. Pat. Appln. KOKAI Publication No. 2007-143600 discloses a technique relating to a shape detection probe using an optical fiber. The shape detection probe includes an optical fiber which bends as one piece with a scope of the endoscope. The optical fiber is provided with an optical modulator which modulates intensities, etc. of wavelength components being different from each other. KOKAI Publication No. 2007-143600 discloses that the shape detection probe can detect the shape of the endoscope, based on the intensities, etc. of wavelength components before and after modulation by the optical modulator. However, KOKAI Publication No. 2007-143600 fails to concretely disclose how to derive the shape of the endoscope, based on the intensities, etc. of the wavelength components.

BRIEF SUMMARY OF THE INVENTION

[0006] One embodiment of the present invention is a shape estimation device comprising an input circuit configured to receive light amount information which is a relationship between a wavelength and a light amount, the light amount information being acquired by using a sensor configured such that the light amount to be detected with respect to the wavelength corresponding to each of a plurality of sensing parts varies in accordance with a shape of each of the plurality of sensing parts, a storage circuit configured to store a light amount estimation relationship including shape characteristic information representing a relationship among the shape, the wavelength and the light amount with respect to each of the plurality of sensing parts, and a shape arithmetic circuit configured to calculate shape information being an estimation value of the shape by calculating a light amount estimation value by an optimization arithmetic operation such that the light amount estimation value calculated based on the light amount estimation relationship and the light amount information satisfy a predetermined condition, the light amount estimation value which is a relationship between the wavelength and the light amount.

[0007] Other embodiment of the present invention is an endoscope system comprising the above-described shape estimation device, an endoscope configured such that a light guide is provided in an insertion section, and an endoscope shape calculator configured to calculate a shape of the insertion section, based on the shape information.

[0008] Other embodiment of the present invention is a shape estimation method comprising acquiring light amount information which is a relationship between a wavelength and a light amount, the light amount information being acquired by using a sensor configured such that the light amount to be detected with respect to the wavelength corresponding to each of a plurality of sensing parts varies in accordance with a shape of each of the plurality of sensing parts, acquiring a light amount estimation relationship including shape characteristic information representing a relationship among the shape, the wavelength and the light amount with respect to each of the plurality of sensing parts, and calculating shape information being an estimation value of the shape, by calculating a light amount estimation value by an optimization arithmetic operation such that the light amount estimation value calculated based on the light amount estimation relationship and the light amount information satisfy a predetermined condition, the light amount estimation value which is a relationship between the wavelength and the light amount.

[0009] Other embodiment of the present invention is a program for shape estimation, which causes a computer to execute acquiring light amount information which is a relationship between a wavelength and a light amount, the light amount information being acquired by using a sensor configured such that the light amount to be detected with respect to the wavelength corresponding to each of a plurality of sensing parts varies in accordance with a shape of each of the plurality of sensing parts, acquiring a light amount estimation relationship including shape characteristic information representing a relationship among the shape, the wavelength and the light amount with respect to each of the plurality of sensing parts, and calculating shape information being an estimation value of the shape, by calculating a light amount estimation value by an optimization arithmetic operation such that the light amount estimation value calculated based on the light amount estimation relationship and the light amount information satisfy a predetermined condition, the light amount estimation value which is a relationship between the wavelength and the light amount.

[0010] Advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0011] The accompanying drawings, which are incorporated in and constitute apart of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

[0012] FIG. **1** is a block diagram which schematically shows a configurational example of an endoscope system according to an embodiment of the present invention.

[0013] FIG. **2** is a view which schematically shows a configurational example of a sensor driver and a sensor unit according to the embodiment.

[0014] FIG. **3** is a view showing an example of the relationship between the wavelength and intensity of light which is emitted by a light source.

[0015] FIG. **4** is a view showing an example of the relationship between the wavelength of light, which falls on a photodetector, and the detection sensitivity of the photodetector.

[0016] FIG. **5** is a cross-sectional view which schematically shows a configurational example of a sensing part.

[0017] FIG. **6** is a view showing an example of the relationship between the wavelengths of light and absorptivities in light absorbers.

[0018] FIG. **7**A is a view for explaining the sensing part.

[0019] FIG. **7**B is a view for explaining the sensing part.

[0020] FIG. **7**C is a view for explaining the sensing part.

[0021] FIG. **8** is a view showing an example of the relationship between wavelength and a reference light amount.

[0022] FIG. **9** is a view showing an example of curvature characteristic information being the relationship between wavelength and a variation ratio in light amount in a first sensing part.

[0023] FIG. **10** is a view showing an example of curvature characteristic information being the relationship between wavelength and a variation ratio in light amount in a second sensing part.

[0024] FIG. **11** is a view showing an example of curvature characteristic information being the relationship between the curvatures and variation ratios in light amount of the first sensing part and second sensing part.

[0025] FIG. **12** is a view showing an example of the relationship between wavelength and a light amount, which is obtained by the photodetector.

[0026] FIG. **13** is a view showing an example of the relationship between wavelength, and a product between a variation ratio in light amount in the first sensing part and a variation ratio in light amount in the second sensing part.

[0027] FIG. **14** is a view showing an example of the relationship between wavelength, a variation ratio in light amount in the first sensing part and a variation ratio in light amount in the second sensing part.

[0028] FIG. **15** is a block diagram which schematically shows a configurational example of a shape optimization circuit according to a first calculation method.

[0029] FIG. **16** is a flowchart showing an example of an operation according to the first calculation method.

[0030] FIG. **17** is a flowchart showing an example of a shape information calculation process according to the first calculation method.

[0031] FIG. **18** is a block diagram which schematically shows a configurational example of a shape optimization circuit according to a second calculation method.

[0032] FIG. **19** is a flowchart showing an example of an operation according to the second calculation method.

[0033] FIG. **20** is a flowchart showing an example of a first shape information calculation process according to the second calculation method.

[0034] FIG. **21** is a flowchart showing an example of a second shape information calculation process according to the second calculation method.

[0035] FIG. **22** is a block diagram which schematically shows a configurational example of a shape optimization circuit according to a third calculation method.

[0036] FIG. **23** is a flowchart showing an example of a shape information calculation process according to the third calculation method.

DETAILED DESCRIPTION OF THE INVENTION

[0037] An embodiment of the present invention will be described with reference to the drawings. FIG. **1** schematically shows a configurational example of an endoscope system **1** in which a shape estimation device **10** according to the invention is used. As shown in FIG. **1**, the endoscope system **1** includes an endoscope **810**. The endoscope **810** includes an insertion section **812** which has an elongated shape and is free to bend, and an operation section **814** for performing various operations of the endoscope **810**. The endoscope system **1** further includes an endoscope controller **820** for controlling various operations of the endoscope **810**. The endoscope controller **820** is provided with an image processor **822** for processing an image acquired by the endoscope **810**.

[0038] The endoscope system **1** includes the shape estimation device **10** according to the present invention. The shape estimation device **10** is a device which estimates a shape of the insertion section **812** in the endoscope **810**. The endoscope system **1** further includes a display **180** and an input device **190**. The display **180** is a general display device, and is, for instance, a liquid crystal display, a CRT display, or an organic EL display. The display **180** is connected to the endoscope controller **820**, and displays an image acquired by the endoscope **810**. In addition, the display **180** is connected to a controller **100** (to be described later) of the shape estimation device **10**, and displays information of the shape of the insertion section **812** of the endoscope **810** acquired by the shape estimation device **10**.

[0039] The input device **190** is a general device for input, and is, for instance, a keyboard, a mouse, a pointing device, a tag reader, a button switch, a slider, or a dial. The input device **190** is connected to the controller **100** (to be described later) of the shape estimation device **10**. The input device **190** is used in order for a user to input various instructions for operating the shape estimation device **10**. In addition, the input device **190** may be a storage medium. In this case, the information stored in the storage medium is input to the controller **100**.

[0040] The shape estimation device **10** will be described. The shape estimation device **10** includes the controller **100**, a sensor driver **300** and a sensor unit **400**. The sensor driver **300** in the shape estimation device **10** includes a light source **310** and a photodetector **320**. The sensor unit **400** includes a plurality of sensing parts **410** provided within the insertion section **812** in the endoscope **810**. The outline of a configurational example of the sensor driver **300** and sensor unit **400** will be described with reference to FIG. **2**.

[0041] As shown in FIG. **2**, the sensor driver **300** includes the light source **310**, the photodetector **320**, an optical branch **330**, and an antireflector **340**.

[0042] The light source **310** is, for example, a generally known light emission unit, such as a lamp, an LED, or a laser diode. The light source **310** may further include a fluorescent element for converting wavelength. The light source **310** emits light in a predetermined emission wavelength region.

FIG. **3** is a view showing an example of the relationship between the wavelength and intensity of light which is emitted by a light source **310**. The first wavelength **λ1** as shown in FIG. **3** is a characteristic wavelength of a spectrum which a first sensing part **411** (to be described later) of the sensor unit **400** absorbs. Here, the characteristic wavelength is, for example, a wavelength at which absorption becomes maximum. Similarly, the second wavelength **λ2** as shown in FIG. **3** is a characteristic wavelength of a spectrum which a second sensing part **412** of the sensor unit **400** absorbs. As shown in FIG. **3**, the emission wavelength region includes wavelength to be used by the sensor unit **400**, for example, the first wavelength **λ1** or the second wavelength **λ2**.

[0043] The photodetector **320** includes an element for separation of light into its spectral components, such as a spectroscope or a color filter; and a light reception element such as a photodiode. The photodetector **320** detects the intensity of light in a predetermined wavelength region, and outputs light amount information. Here, the light amount information is information indicative of the relationship between a specific wavelength in the predetermined wavelength region and the intensity of light at this wavelength. FIG. **4** is a view showing an example of the relationship between the wavelength of light, which falls on the photodetector **320**, and the detection sensitivity of the photodetector **320**. As shown in FIG. **4**, the photodetector **320** has detection sensitivity within a wavelength region including the above-described first wavelength **λ1** and second wavelength **λ2**.

[0044] The photodetector **320** may be configured to acquire light amounts of various wavelengths at the same time, or may be configured to acquire these light amounts in a time-division manner. In addition, the light source **310** may be configured to successively emit lights of different wavelengths in a time-division manner, and the photodetector **320** may not include the element for separation of light into its spectral components and may be configured to detect light amounts of different wavelengths in a time-division manner.

[0045] The optical branch **330** includes an optical coupler or a semitransparent mirror. The optical branch **330** guides light emitted from the light source **310** to a light guide **420** (to be described later) of the sensor unit **400**, and guides light guided by the light guide **420** to the photodetector **320**.

[0046] The antireflector **340** is a member which absorbs that part of the light emitted from the light source **310**, which did not enter the light guide **420**. The antireflector **340** functions to prevent a part of the light emitted from the light source **310**, which did not enter the light guide **420**, from returning to the photodetector **320**.

[0047] The sensor unit **400** includes the plurality of sensing parts **410**, the light guide **420** and a reflector **430**. The light guide **420** is, for example, an optical fiber, and has flexibility. The light guide **420** is provided within the insertion section **812** of the endoscope **810** along the longitudinal direction of the insertion section **812**. The light guide **420** is arranged on a region where the shape is to be calculated in the insertion section **812**. As described above, the light emitted from the light source **310** enters the light guide **420** via the optical branch **330**. The light guide **420** guides the fell light along the light guide **420**.

[0048] The light guide **420** is provided with the plurality of sensing parts **410**. The sensing parts **410** include a first sensing part **411** and a second sensing part **412**. Similarly, the sensing parts **410** include an m-th sensing part **41*m***. Here, "m" is an arbitrary number. The first sensing part **411**, the second sensing part **412**, etc. are arranged at different positions in the longitudinal direction of the light guide **420**.

[0049] The outline of a configurational example of the sensing part **410** will be described with reference to FIG. **5**. FIG. **5** is a view which schematically shows a cross section perpendicular to the longitudinal axis of the light guide **420**. The sensing part **410** has such a configuration that a light absorber **429** is coated on an exposed part of a core **423** exposed by removing parts of a coating **421** and a cladding **422** of the light guide **420** that is, for example, an optical fiber. Light absorbers **429** having different light absorptivities for respective wavelengths are used for the respective sensing parts **410**.

[0050] FIG. **6** shows an example of the relationship between the wavelengths of light and absorptivities in the light absorbers **429**. In FIG. **6**, a solid line indicates absorption characteristics of the light absorber **429** provided in the first sensing part **411**, a broken line indicates absorption characteristics of the light absorber **429** provided in the second sensing part **412**, and a dot-and-dash line indicates absorption characteristics of the light absorber **429** provided in the m-th sensing part **41*m***. As shown in FIG. **6**, the light absorbers **429** provided in the different sensing parts **410** have absorption characteristics being different from each other. The wavelength with the highest light absorptivity in the light absorber **429** provided in the first sensing part **411** is referred to as the above-described first wavelength **λ1**, the wavelength with the highest light absorptivity in the light absorber **429** provided in the second sensing part **412** is referred to as the above-described second wavelength **λ2**, and the wavelength with the highest light absorptivity in the light absorber **429** provided in the m-th sensing part **41*m*** is referred to as an m-th wavelength λm.

[0051] The sensing part **410** will be further described with reference to FIG. **7**A, FIG. **7**B and FIG. **70**. FIG. **7**A, FIG. **7**B and FIG. **7**C are views which schematically show the shapes of the light guide **420** and the optical path in the light guide **420** at the time of each shape. For example, as shown in FIG. **7**A, when the light guide **420** bends such that the light absorber **429** is located inside, the light fell on the light absorber **429** is relatively small, and the optical transmissibility by the light guide **420** increases. On the other hand, as shown in FIG. **7**C, when the light guide **420** bends such that the light absorber **429** is located outside, the light fell on the light absorber **429** is relatively large, and the optical transmissibility by the light guide **420** decreases. As shown in FIG. **7**B, when the light guide **420** is not bent, the optical transmissibility by the light guide **420** is lower than in the case shown in FIG. **7**A, and is higher than in the case shown in FIG. **7**C. For the purpose of the description below, it is assumed that the bend of the light guide **420** in such a direction that the optical transmissibility by the light guide **420** increases, as shown in FIG. **7**A, is referred to as the bend in a positive direction, and that the bend of the light guide **420** in such a direction that the optical transmissibility by the light guide **420** decreases, as shown in FIG. **7**C, is the bend in a negative direction. In this manner, for example, the respective light absorbers **429** function as optical members which exert different effects on the spectrum of light guided by the light guide.

[0052] Referring back to FIG. **2**, the sensor driver **300** and the sensor unit **400** will be described. The reflector **430** is provided at an end portion of the light guide **420**, that is, a distal end thereof, on the side on which the light guide **420** is not connected to the optical branch **330**. The reflector **430** reflects the light guided from the optical branch **330** by the light guide **420** in a direction of the optical branch **330**.

[0053] By the above configuration, the light emitted from the light source **310** is guided to the light guide **420** via the optical branch **330**. This light is transmitted in the light guide **420** from the proximal-end side to the distal-end side. At this time, in the sensing part **410** provided on the light guide **420**, the light is absorbed in accordance with the bend state of this sensing part **410**, and the amount of transmitted light decreases at each wavelength. This light is reflected by the reflector **430**, and the reflected light is transmitted in the light guide **420** from the distal-end side to the proximal-end side. This reflected light is guided to the photodetector **320** via the optical branch **330**. The photodetector **320** detects the intensity of the guided light at each wavelength. Based on the detected intensity at each wavelength detected by the photodetector **320**, the bend state of each sensing part **410**, that is, the shape of the insertion section **812** of the endoscope **810** can be derived.

[0054] The sensor driver **300** including the optical branch **330**, and the sensor unit **400** may be fixed or may be configured to be detachably attached.

[0055] The controller **100** will be described. The controller **100** is composed of an electronic calculator which is, for instance, a personal computer. The controller **100** includes an arithmetic circuit **101**, an endoscope shape calculator **140**, a photodetector driver **150**, and an output circuit **160**.

[0056] The arithmetic circuit **101** is composed of, for example, a device including a CPU or an ASIC. The arithmetic circuit **101** includes a shape arithmetic circuit **110**, a storage circuit **120** and an input circuit **130**.

[0057] Light amount information relating to the wavelength and detected light intensity is input to the input circuit **130** from the photodetector **320**. The input circuit **130** transmits the input light amount information to the shape arithmetic circuit **110**. In addition, a signal or the like representing a user's instruction that was input by the input device **190** is input to the input circuit **130**. Besides, for example, identification information for identifying the type or the individual of the sensor unit **400** is input to the input circuit **130**. In addition, shape characteristic information of the sensing parts **410** may be input to the input circuit **130**. Further, information output from the endoscope controller **820** may be input to the input circuit **130**. The input circuit **130** transmits the input signals to the photodetector driver **150** or shape arithmetic circuit **110**.

[0058] The storage circuit **120** stores various kinds of information being necessary for arithmetic operations that are executed by the shape arithmetic circuit **110**. The storage circuit **120** stores, for example, programs including a calculation algorithm, and a light amount estimation relationship including shape characteristic information (to be described later) of the sensing parts **410**.

[0059] The shape arithmetic circuit **110** calculates the shape of each sensing part **410**, based on the light amount information acquired via the input circuit **130**, and the information stored in the storage circuit **120**. The shape arithmetic circuit **110** includes a shape optimization circuit **200** to be used for shape calculation. The details of the shape optimization circuit **200** will be described later. The shape arithmetic circuit **110** transmits the calculated shape of the sensing part **410** to the endoscope shape calculator **140** and output circuit **160**. In addition, the shape arithmetic circuit **110** outputs to the photodetector driver **150** the information relating to the operation of the photodetector **320** being necessary for the shape calculation, such as a gain of the photodetector **320**.

[0060] The endoscope shape calculator **140** including the controller includes, for example, a CPU or an ASIC. Based on the shape of each sensing part **410** calculated by the shape arithmetic circuit **110**, the endoscope shape calculator **140** calculates the shape of the insertion section **812** of the endoscope **810**, in which the sensing parts **410** are arranged. The calculated shape of the insertion section **812** is transmitted to the output circuit **160**. The endoscope shape calculator **140** may be assembled in the shape arithmetic circuit **110**.

[0061] The photodetector driver **150** generates a driving signal of the photodetector **320**, based on the information acquired from the input circuit **130**. By this driving signal, the photodetector driver **150** switches on/off the operation of the photodetector **320**, for example, based on the user's instruction input to the input device **190** and is acquired via the input circuit **130**, or adjusts the gain of the photodetector **320**, based on the information acquired from the shape arithmetic circuit **110**. In addition, the photodetector driver **150** may be configured to also control the operation of the light source **310**. The photodetector driver **150** transmits the generated driving signal to the output circuit **160**.

[0062] The output circuit **160** outputs to the display **180** the shape of the insertion section **812** acquired from the endoscope shape calculator **140** to the display **180**, and causes the display **180** to display the shape of the insertion section **812**. In addition, the output circuit **160** outputs to the endoscope controller **820** the shape of the sensing part **410** acquired from the shape arithmetic circuit **110**. The endoscope controller **820** controls the operation of the endoscope **810**, based on the acquired shape of the insertion section **812** and the acquired shape of the sensing part **410**. Besides, the output circuit **160** outputs the driving signal acquired from the photodetector driver **150** to the photodetector **320**, and drives the photodetector **320**.

[0063] Next, the operation of the endoscope system **1** according to the present embodiment will be described. The insertion section **812** of the endoscope **810** is inserted in an insertion target by the user. During insertion, the insertion section **812** bends in accordance with the shape of the insertion target. The endoscope **810** performs image by an image device provided in the distal end of the insertion section **812**. The image signal acquired by the image is transmitted to the image processor **822** of the endoscope controller **820**. The image processor **822** creates an endoscopic image, based on the acquired image signal. The image processor **822** causes the display **180** to display the created endoscopic image.

[0064] When the user wishes to cause the display **180** to display the shape of the insertion section **812**, or when the user wishes to cause the endoscope controller **820** to perform various operations using the shape of the insertion section **812**, the user inputs the corresponding instruction to the controller **100** through the input device **190**. Then, the shape estimation device **10** operates.

[0065] If the shape estimation device **10** operates, the light source **310** of the sensor driver **300** emits light of a predetermined emission wavelength region. The light emitted from the light source **310** is guided to the light guide **420** of the sensor unit **400** via the optical branch **330**. The guided light is reflected on the reflector **430** provided on the distal end of the light guide **420**, and propagated in the light guide **420** from the proximal-end side to the distal-end side. When the light travels in the light guide **420**, light amount of each wavelength varies in accordance with the shape of the sensing parts **410**. The light reaches the photodetector **320** via the optical branch **330**.

[0066] The photodetector **320** detects the intensity of the light, which has reached at the photodetector **320**, at each wavelength. The photodetector **320** outputs the detected light intensity to the input circuit **130** of the controller **100**. The shape arithmetic circuit **110** calculates the shape of each sensing part **410**, based on the light intensity detected by the photodetector **320** and acquired via the input circuit **130**.

[0067] The endoscope controller **820** acquires information of the shape of each sensing part **410** from the shape arithmetic circuit **110** via the output circuit **160**. The endoscope controller **820** controls the operation of the endoscope **810** by using the information of the shape of each sensing part **410**.

[0068] In addition, the endoscope shape calculator **140** acquires information of the shape of each sensing part **410** from the shape arithmetic circuit **110**. Based on the shape of each sensing part **41**, the endoscope shape calculator **140** calculates the shape of the insertion section **812** of the endoscope **810**. The endoscope shape calculator **140** causes, via the output circuit **160**, the display **180** to display the calculated shape of the insertion section **812**. Furthermore, the endoscope controller **820** acquires information of the shape of the insertion section **812** from the endoscope shape calculator **140** via the output circuit **160**, and uses the information for the control of the endoscope **810**.

[0069] In this manner, according to the shape estimation device **10**, the shape of each sensing part **410** is acquired. Based on the acquired shape of the sensing part **410**, the endoscope shape calculator **140** calculates the shape of the insertion section **812** of the endoscope **810**. Thereby, the user can understand the shape of the insertion section **812** while operating the endoscope **810**. In addition, the endoscope controller **820** performs various arithmetic calculation based on the shape of the sensing parts **410**. Thereby, the endoscope controller **820** can properly control the operation of the endoscope **810** in accordance with the shape of the insertion section **812**.

[0070] Next, a detailed description will be given of arithmetic operations which are executed by the arithmetic circuit **101** in the shape estimation device **10** of the present embodiment. For easier understanding, a case in which only the first sensing part **411** and second sensing part **412** are included in the sensing parts **410** is described by way of example.

[0071] To begin with, information to be prepared in advance before the use of the endoscope system **1**, will be described. A light amount $D_{\lambda n}$ of light of wavelength λn, which is detected by the photodetector **320**, is given by the following equation (1).

$$D_{\lambda n}=E_{\lambda n}\times A_{\lambda n}\times B_{\lambda n}\times L_{\lambda n} \quad \text{equation (1)}$$

Here, $E_{\lambda n}$ is a light amount of light of wavelength λn, which is emitted from the light source **310**; $A_{\lambda n}$ is an absorptivity of light of wavelength An in the first sensing part **411**; $B_{\lambda n}$ is an absorptivity of light of wavelength λn in the second sensing part **412**; and $L_{\lambda n}$ is an absorptivity of light of wavelength λn by members other than the sensing parts **410**, such as the optical branch **330**, light guide **420** and reflector **430**.

[0072] The emission light amount $E_{\lambda n}$ and absorptivity $L_{\lambda m}$ do not depend on the shape of the sensing part **4'10**. Accordingly, the light amount $D_{\lambda n}$ can be rewritten as hereinafter. Specifically, the light amount of light of wavelength λn, which is detected by the photodetector **320** when each sensing part **410** is in a predetermined referenced shape (hereinafter referred to as "reference shape"), is calculated in advance as a reference light amount $I_{\lambda n}$. In addition, the ratio between the light amount of light of wavelength λn, which is detected by the photodetector **320** when all sensing parts **410** (in this example, the second sensing part **412**), other than the first sensing part **411**, are in the referenced shape, and the reference light amount $I_{\lambda n}$, is set as a variation ratio $\alpha_{\lambda n}$ in the first sensing part **411**. Besides, the ratio between the light amount of light of wavelength λ_n, which is detected by the photodetector **320** when all sensing parts **410** (in this example, the first sensing part **411**), other than the second sensing part **412**, are in the referenced shape, and the reference light amount $I_{\lambda n}$, is set as a variation ratio $\beta_{\lambda n}$ in the second sensing part **412**. At this time, the light amount $D_{\lambda n}$ is given by the following equation (2).

$$D_{\lambda n}=I_{\lambda n}\times\alpha_{\lambda n}\times\beta_{\lambda n} \quad \text{equation (2)}$$

[0073] The light absorptivity in each sensing part **410** varies in accordance with the shape of each sensing part **410**, for example, curvature κ. Accordingly, the above-described ratio $\alpha_{\lambda n}$ in the first sensing part **411** is given by the following equation (3).

$$\alpha_{\lambda n}=f_{\lambda n}(\kappa_\alpha) \quad \text{equation (3)}$$

Here, κ_α is the curvature of the first sensing part **411**, and a function $f_{\lambda n}$ is a variation ratio which is stored in the storage circuit **120** as a curvature characteristic information.

[0074] Similarly, the above-described ratio $\beta_{\lambda n}$ is given by the following equation (4).

$$\beta_{\lambda n}=g_{\lambda n}(\kappa_\beta) \quad \text{equation (4)}$$

Here, κ_β is the curvature of the second sensing part **412**, and a function $g_{\lambda n}$ is a variation ratio which is stored in the storage circuit **120** as a curvature characteristic information.

[0075] From equation (2), equation (3) and equation (4), the following equation (5) is obtained.

$$D_{\lambda n}(\kappa_\alpha,\kappa_\beta)=I_{\lambda n}\times f_{\lambda n}(\kappa_\alpha)\times g_{\lambda n}(\kappa_\beta) \quad \text{equation (5)}$$

[0076] For the reference shape for determining the reference light amount $I_{\lambda n}$, for example, the case is adopted in which all of the sensing parts **410** are in the straight shape, that is, the case in which the curvature is 0 and the radius of curvature thereof is ∞. However, the reference shape is not limited to this case, and the reference shape may be a shape other than the straight shape. In addition, the reference shape may not be the same shape with respect to all sensing parts, and arbitrary shapes may be set for the respective sensing parts.

[0077] Hereinafter, a description will be given of the case in which the reference shape that is the straight shape is adopted for all sensing parts **410**. The relationship between wavelength and a reference light amount I shows a spectrum such as FIG. **8**. A light amount $D_{\lambda n}(0, 0)$ at a time when all sensing parts **410** are in the reference shape is, by definition, given by the following equation (6).

$$D_{\lambda n}(0,0)=I_{\lambda n} \quad \text{equation (6)}$$

Specifically, by definition, the reference light amount is $I_{\lambda n}$, $f_{\lambda n}(0)=1$, and $g_{\lambda n}(0)=1$.

[0078] The function $f_{\lambda n}$ and function $g_{\lambda n}$ being curvature characteristic information can be obtained by varying, in a state in which the shapes of the sensing parts, other than a target sensing part, are set to be the reference shape, the curvature of the target sensing part within a possible range.

[0079] The curvature characteristic information of the first sensing part **411**, that is, the relationship between the wavelength and variation ratio, is indicated by spectra as shown in, for example, FIG. **9**. Here, the curvature κα is $\kappa_{11}<\kappa_{12}<\kappa_{13}<\kappa_{14}$. In addition, the curvature characteristic information of the second sensing part **412**, that is, the relationship between the wavelength and variation ratio, is indicated by spectra as shown in, for example, FIG. **10**. Here, the curvature κ_β is $\kappa_{21}<\kappa_{22}<\kappa_{23}<\kappa_{24}$.

[0080] Each of FIG. **9** and FIG. **10** shows curvature characteristic information relating to four curvatures. However, as the curvature characteristic information, the relationship between the wavelength and variation ratio in the emission wavelength range are obtained with respect to various curvatures as shown in FIG. **9** and FIG. **10**. In this manner, the curvature characteristic information of the first sensing part **411**, which represents the relationship between the curvature κ_α and variation ratio $\alpha_{\lambda n}$, and the curvature characteristic information of the second sensing part **412**, which represents the relationship between the curvature κ_β and variation ratio $\beta_{\lambda n}$, are obtained as shown in FIG. **11**.

[0081] In the meantime, from equation (5), the function $f_{\lambda n}(\kappa_\alpha)$ is given by the following equation (7).

$$f_{\lambda n}(\kappa_\alpha)=\frac{D_{\lambda n}(\kappa_\alpha,0)}{I_{\lambda n}} \quad \text{equation (7)}$$

[0082] Similarly, the function $g_{\lambda n}(\kappa_\beta)$ is given by the following equation (8).

$$g_{\lambda n}(\kappa_\beta)=\frac{D_{\lambda n}(0,\kappa_\beta)}{I_{\lambda n}} \quad \text{equation (8)}$$

[0083] The curvature characteristic information and reference light amount information $I_{\lambda n}$, as shown in FIG. **8**, are acquired in advance, for example, when the endoscope system **1** is manufactured, or when the endoscope system **1** is installed, and are prestored in the storage circuit **120**. The curvature characteristic information and reference light amount $I_{\lambda n}$ may be acquired at each time of use. For example, at a time of starting the endoscope system **1**, the reference light amount $I_{\lambda n}$ may be actually measured by setting the insertion section **812** in the straight shape, and then the shape of the insertion section **812** may be successively changed to predetermined bent shapes, and the curvature characteristic information may be acquired from the light amount detected at this time.

[0084] The curvature characteristic information and reference light amount $I_{\lambda n}$ may be stored not in the storage circuit **120** provided in the controller **100**, but in a storage provided in the sensor driver **300** or sensor unit **400**. By doing so, such characteristic information can be used even when the sensor driver **300** or sensor unit **400** is connected to other devices.

[0085] Additionally, for example, such a configuration may be adopted that the sensor driver **300** or sensor unit **400** is provided with identification information including a value inherent to the device, and the storage circuit **120** may store the curvature characteristic information and reference light amount $I_{\lambda n}$ associated with this identification information. By doing so, the controller **100** can manage and use the curvature characteristic information and reference light amounts $I_{\lambda n}$ of a plurality of sensor drivers **300** and sensor units **400**. The identification information may be input from a keyboard that is the input device **190**, may be read out from an RF-ID tag, or may be read out from the storage provided in the sensor driver **300** or sensor unit **400**.

[0086] Next, arithmetic operations to be executed at the time of using the endoscope system **1** will be described. The case is now considered in which the curvatures of the first sensing part **411** and the second sensing part **412** are arbitrary curvatures κ_α and κ_β, respectively. Here, a light amount D (κ_α, κ_β) indicates a spectrum shown in, for example, FIG. **12**. This light amount D (κ_α, κ_β) is acquired by the photodetector **320**.

[0087] Based on equation (5) and the pre-acquired reference light amount $I_{\lambda n}$ as shown in FIG. **8**, $f(\kappa_\alpha)\times g(\kappa_\beta)$ can be calculated, which is a product of variation ratio of the first sensing part **411** and the variation ratio of the second sensing part **412**. The relationship between the wavelength and $f(\kappa_\alpha)\times g(\kappa_\beta)$ is, for example, as shown in FIG. **13**.

[0088] For example, if the relationship between the wavelength and $f(\kappa_\alpha)\times g(\kappa_\beta)$, which is shown in FIG. **13**, can be separated into the relationship between the wavelength and $f(K_\alpha)$ and the relationship between the wavelength and $g(\kappa_\beta)$, as shown in FIG. **14**, the curvature κ_a of the first sensing part **411** and the curvature κ_β of the second sensing part **412** can be calculated from the light amount D (κ_α, κ_β).

[0089] As an example, in order to calculate the curvature κ_α of the first sensing part **411** and the curvature κ_β of the second sensing part **412**, attention is now paid to the first wavelength **λ1** and second wavelength **λ2**, and consideration is given to the following equation (9) with respect to the light amount $D_{\lambda 1}$ and light amount $D_{\lambda 2}$ at respective wavelengths detected by the photodetector **320**.

$$\begin{cases} D_{\lambda 1}(\kappa_\alpha,\kappa_\beta)=I_{\lambda 1}\times f_{\lambda 1}(\kappa_\alpha)\times g_{\lambda 1}(\kappa_\beta) \\ D_{\lambda 2}(\kappa_\alpha,\kappa_\beta)=I_{\lambda 2}\times f_{\lambda 2}(\kappa_\alpha)\times g_{\lambda 2}(\kappa_\beta) \end{cases} \quad \text{equation (9)}$$

[0090] The storage circuit **120** prestores $I_{\lambda 1}$ and $I_{\lambda 2}$ being reference light amounts, and $f_{\lambda 1}$, $f_{\lambda 2}$, $g_{\lambda 1}$ and $g_{\lambda 2}$ being curvature characteristic information. Thus, based on the light amount $D_{\lambda 1}$ and light amount $D_{\lambda 2}$, the curvature κ_α of the first sensing part **411** and the curvature κ_β of the second sensing part **412** can be calculated.

[0091] Although the case in which the sensing parts **410** includes two sensing parts, namely the first sensing part **411** and second sensing part **412**, was described by way of example, the same calculations can be executed even when the number of sensing parts is three or more.

[0092] In the above example, in order to calculate the curvature κ_α of the first sensing part **411** and the curvature κ_β of the second sensing part **412**, the first wavelength **λ1** and second wavelength **λ2** are used, but the restriction to this is unnecessary. Wavelengths other than the first wavelength **λ1** and second wavelength **Λ2** may be used. However, the precision in calculation of curvature is enhanced if use is made of the wavelength at which the light absorptivity of the light absorber **429** of each sensing part **410** becomes maximum.

[0093] Additionally, the wavelength used here may have a certain degree of band width. However, it is preferable that the band including the wavelength, at which the light absorptivity of the light absorber **429** becomes maximum, is used. By using the light amount for the wavelength having a bandwidth for arithmetic operations, it becomes unnecessary to greatly increase the resolution of the photodetector **320**, and the reduction in cost of the shape estimation device **10** can be realized. Besides, since local wavelengths are not used, the robustness to the influence of noise is advantageously increased. A plurality of wavelength bands to be used for arithmetic operations may partly overlap. As regards the wavelengths to be used in arithmetic operations, the same applies to the following description.

[0094] Additionally, as regards the above equation (9), logarithms may be taken. By using logarithms, the calculation can be facilitated.

[0095] [First Calculation Method]

[0096] In the above description, the example was shown in which the number of sensing parts **410** is two, and the curvature κ_α of the first sensing part **411** and the curvature κ_β of the second sensing part **412** are calculated. However, in general, the number of sensing parts is arbitrary, and the case of two or more is considered here. In addition, the parameter representing the shape of the sensing part **410** is not limited to the curvature, and may include rotation, etc. In the description below, consideration will be given to shape information k1 to km being information representing the shapes of the sensing parts of the first sensing part **411** to the m-th sensing part **41***m*. The shape information may include various values representing shapes, such as curvature, a radius of curvature, an angle of bend, an angle of rotation, etc. The information referred to as "curvature characteristic information" in the above example, will be referred to as "shape characteristic information".

[0097] Hereinafter, in order to calculate the shape information k1 to km, an example of executing a convergence calculation is described. Specifically, it is now considered that, when a light amount estimation value repeatedly calculated in the convergence calculation is set as $E_{\lambda x}$, the shape information k1 to km is obtained by converging the light amount estimation value $E_{\lambda x}$ to a light amount $D_{\lambda x}$ detected by the photodetector **320**.

[0098] For example, in the case of the sensing parts **410** including only the first sensing part **411** and second sensing part **412** described with reference to the above equation (5), the light amount estimation value $E_{\lambda x}$ corresponds to the following equation (10).

$$E_{\lambda x}(\kappa_1,\kappa_2)=I_{\lambda x}\times f_{\lambda x}(\kappa_1)\times g_{\lambda x}(\kappa_2) \quad \text{equation (10)}$$

Here, κ_1 is an estimation value of the curvature of the first sensing part **411**, and κ_2 is an estimation value of the curvature of the second sensing part **412**. In this manner, the light amount estimation value $E_{\lambda x}$ is given as a function of the shape information k1 to km of the first to m-th sensing parts. For example, a light amount estimation equation for calculating the light amount estimation value corresponding to equation (10) is stored in the storage circuit **120**.

[0099] Using the light amount $D_{\lambda x}$ detected by the photodetector **320** and the light amount estimation value $E_{\lambda x}$, an evaluation value J is defined as in the following equation (11).

$$J=\sum_{x=1}^{pl}(D_{\lambda x}-E_{\lambda x}(k1,\ \dots\ ,km))^2 \quad \text{equation (11)}$$

Here, p is the number of wavelengths used for arithmetic operations, and p is m or more. Specifically, the evaluation value J is a value obtained by adding the square of an error of the light amount estimation value $E_{\lambda x}$ calculated by using the light amount estimation value, relative to the detected light amount $D_{\lambda x}$.

[0100] The convergence calculation is executed by the shape optimization circuit **200** in the shape arithmetic circuit **110**. FIG. **15** shows the outline of a configurational example of the shape optimization circuit **200** according to the present calculation method. As shown in FIG. **15**, the shape optimization circuit **200** includes an estimation value arithmetic circuit **212** and an evaluation value arithmetic circuit **214**.

[0101] The estimation value arithmetic circuit **212** acquires the light amount estimation equation from the storage circuit **120**. A calculation start signal is input to the estimation value arithmetic circuit **212**. When the calculation start signal has been input, the estimation value arithmetic circuit **212** starts calculation of the light amount estimation value $E_{\lambda x}$. The estimation value arithmetic circuit **212** outputs the calculated light amount estimation value $E_{\lambda x}$ and shape information k1 to km to the evaluation value arithmetic circuit **214**.

[0102] The evaluation value arithmetic circuit **214** calculates the evaluation value J by using the equation (11), based on the light amount estimation value $E_{\lambda x}$ acquired from the estimation value arithmetic circuit **212** and the light amount $D_{\lambda x}$ acquired by the photodetector **320**. If the evaluation value J is greater than a predetermined threshold A, the evaluation value arithmetic circuit **214** returns the evaluation value J to the estimation value arithmetic circuit **212**, and causes the estimation value arithmetic circuit **212** to repeat the calculation of the light amount estimation value $E_{\lambda x}$. On the other hand, if the evaluation value J is not greater than the predetermined threshold A, the evaluation value arithmetic circuit **214** outputs the shape information acquired from the estimation value arithmetic circuit **212** to the endoscope shape calculator **140** and output circuit **160**.

[0103] The algorithm used in the present calculation method is a single optimization algorithm, or a composite optimization method in which some optimization algorithms are combined. The algorithm that is used may be any kind of algorithm. Examples of the algorithm that is used include population-based descent methods including Particle Swarm Optimization (PSO) and Differential Evolution (DE), Genetic Algorithm (GA), Simulated Annealing (SA), Newton's method, steepest descent method, least squares method, and simplex method.

[0104] The operation of the controller **100** using the first calculation method will now be described with reference to a flowchart of FIG. **16**. The operation to be described here is an operation of displaying on the display **180** the shape of the insertion section **812** of the endoscope **810**. The operation is started, for example, when the user has requested, with use of the input device **190**, that the shape of the insertion section **812** be displayed on the display **180**.

[0105] In step S**101**, the controller **100** reads in position information of the sensing parts **410** stored in the storage circuit **120**. Here, the position information is information relating to the position of each sensing part **410** relative to the insertion section **812** of the endoscope **810**. The position information is used when the shape of the insertion section **812** is calculated based on the shapes of the sensing parts **410**.

[0106] In step S**102**, the controller **100** determines whether a predetermined update time has come. Here, the update time means a time of updating the display of the shape of the insertion section **812** on the display **18**. Specifically, in the present operation, the calculation and display of the shape of the insertion section **812** are repeated at every update time. In the determination of step S**102**, if it is determined that the update time has not come, the process repeats step S**102**, and stands by until the update time has come. On the other hand, if it is determined that the update time has come, the process advances to step S**103**.

[0107] In step S**103**, the controller **100** executes a shape information calculation process according to the first calculation method. Specifically, the calculation start signal is input to the estimation value arithmetic circuit **212**, and the shape information calculation process by the shape optimization circuit **200** is started. Referring to a flowchart of FIG. **17**, the shape information calculation process will be described.

[0108] In step S**201**, the estimation value arithmetic circuit **212** of the shape optimization circuit **200** reads in the light amount estimation equation and predetermined threshold A from the storage circuit **120**, the light amount estimation equation and predetermined threshold A being used in subsequent arithmetic operations.

[0109] In step S**202**, based on the light amount estimation equation, the estimation value arithmetic circuit **212** calculates the light amount estimation value $E_{\lambda x}$ and the shape information k1 to km. The estimation value arithmetic circuit **212** sends the calculated light amount estimation value $E_{\lambda x}$ and shape information k1 to km to the evaluation value arithmetic circuit **214**.

[0110] In step S**203**, the evaluation value arithmetic circuit **214** of the shape optimization circuit **200** acquires the light amount $D_{\lambda x}$ detected by the photodetector **320** from the photodetector **320** via the input circuit **130**. In step S**204**, the evaluation value arithmetic circuit **214** of the controller **100** calculates the evaluation value J by using the equation (11), based on the light amount estimation value $E_{\lambda x}$ acquired from the estimation value arithmetic circuit **212** and the light amount $D_{\lambda x}$ acquired from the photodetector **320**.

[0111] In step S**205**, the evaluation value arithmetic circuit **214** determines whether the evaluation value J is equal to or less than the predetermined threshold A. If it is determined that the evaluation value J is not equal to or less than the predetermined threshold A, the process returns to step S**202**. Specifically, the evaluation value arithmetic circuit **214** causes the estimation value arithmetic circuit **212** to calculate once again the light amount estimation value $E_{\lambda x}$. On the other hand, in step S**205**, if it is determined that the evaluation value J is equal to or less than the predetermined threshold A, the process advances to step S**206**. In step S**206**, the evaluation value arithmetic circuit **214** of the controller **100** outputs the shape information k1 to km calculated by the estimation value arithmetic circuit **212**. Thereafter, the process returns to the process described with reference to FIG. **16**.

[0112] Referring back to FIG. **16**, a further description will be given. In step S**104**, the endoscope shape calculator **140** of the controller **100** calculates the shape of the insertion section **812** of the endoscope **810**, based on the shape information k1 to km calculated by the shape optimization circuit **200** and the position information of the sensing parts **410**. Since the distance between the respective sensing parts **410** is included in the position information, the shape of the insertion section **812** is calculated if the positions of the respective sensing parts **410** are connected based on the shape information k1 to km. In step S**105**, the controller **100** causes the display **180** to display the calculated shape of the insertion section **812**.

[0113] In step S**106**, the controller **100** determines whether an instruction to end the operation has been input. If the instruction to end the operation has not been input, the process returns to step S**102** and repeats the above-described operation. On the other hand, if the instruction to end the operation has been input, the process relating to this operation is terminated. Such a configuration may be adopted that the present operation is terminated also when the instruction to end the operation has been input in the repeating operation of step S**102**, or that the present operation is terminated also when the instruction to end the operation has been input in the repeating operation of step S**202** to step S**205**.

[0114] Although the example in which the optimal light amount estimation value $E_{\lambda x}$ is calculated by the repetitive arithmetic operations was shown, a method may be used in which the optimal light amount estimation value $E_{\lambda x}$ is calculated for the light amount $D_{\lambda x}$ acquired by a one-time arithmetic operation, such as least squares method. In the optimization arithmetic operation, use may be made of a light amount estimation table expressed by the form of a table, not limited to the light amount estimation equation expressed by the form of a function. The light amount estimation relationships, which can be expressed in such various forms, are stored in the storage circuit **120**. In this manner, use may be made of various optimization arithmetic operations by which the optimal light amount estimation value $E_{\lambda x}$ can be calculated for the light amount $D_{\lambda x}$ acquired by the photodetector **320**.

[0115] Additionally, the evaluation value J is not limited to equation (11), and may be any value which properly expresses the difference between the light amount $D_{\lambda x}$ detected by the photodetector **320** and the calculated optimal light amount estimation value $E_{\lambda x}$.

[0116] According to the above operation, the shape estimation device **10** can calculate the shape of the insertion section **812** of the endoscope **810**. According to the present embodiment, the sensor unit **400** is generally composed of only the light guide **420** which is, for example, an optical fiber. Furthermore, the information of each of the plural sensing parts **410** is separated by the difference in wavelength. These are advantageous in reducing the size of the insertion section **812**.

[0117] According to the first calculation method, the shape of each sensing part **410** can be easily calculated with high precision by the execution of the optimization arithmetic operation. In addition, in the first calculation method, the number of wavelengths which are used, that is, p in equation

(11), can be arbitrarily set if this number is set to be the number of sensing parts, i.e., m, or more. By making p greater, the shapes of sensing parts **410** can be calculated more precisely.

[0118] The shape estimation device **10** according to the embodiment can be used for estimating shapes of various kinds of articles. Specifically, the shape estimation device **10** can be used for estimating shapes of endoscopes for medical use and industrial use, can be used for estimating the shapes of, for example, a catheter and a surgery-assisting robot, and can be used for estimating the shapes of various robots and deformable instruments, not limited to medical uses.

[0119] [Second Calculation Method]

[0120] A second calculation method will be described. Different points from the first calculation method will be described, and a description of common parts is omitted. FIG. **18** shows the outline of a configurational example of a shape optimization circuit **200** according to the second calculation method. As shown in FIG. **18**, the shape optimization circuit **200** includes a first estimation value arithmetic circuit **222**, a second estimation value arithmetic circuit **224**, an evaluation value arithmetic circuit **226**, and a selection circuit **228**. In this manner, the second calculation method differs from the first calculation method in that the two estimation value arithmetic circuits are included in the shape optimization circuit **200**.

[0121] The first estimation value arithmetic circuit **222** executes a first optimization arithmetic operation. The first optimization arithmetic operation is a global optimization arithmetic operation. Here, the global optimization arithmetic operation is a method which can derive an optimal solution without falling into a local solution, such as Particle Swarm Optimization (PSO), Differential Evolution (DE), Genetic Algorithm (GA) and Simulated Annealing (SA). The first estimation value arithmetic circuit **222** outputs the light amount estimation value $E_{\lambda x}$ and shape information k1 to km, which were calculated by the global optimization arithmetic operation, to the evaluation value arithmetic circuit **226**. In addition, the first estimation value arithmetic circuit **222** may output, where necessary, the shape information k1 to km to the second estimation value arithmetic circuit **224**. Further, the first estimation value arithmetic circuit **222** counts the calculation number of times, and retains the counted result as a calculation number of times Calc_num. Moreover, the first estimation value arithmetic circuit **222** outputs the calculation number of times Calc_num to the selection circuit **228**.

[0122] On the other hand, the second estimation value arithmetic circuit **224** executes a second optimization arithmetic operation. The second optimization arithmetic operation is a local optimization arithmetic operation with quick convergence. Here, the optimization arithmetic operation with quick convergence is a neighborhood search method for finding a local solution, such as Newton's method, a steepest descent method, and a simplex method. The second estimation value arithmetic circuit **224** outputs the light amount estimation value $E_{\lambda x}$ and shape information k1 to km, which were calculated by the local optimization arithmetic operation, to the evaluation value arithmetic circuit **226**.

[0123] The above-described first arithmetic operation and second arithmetic operation are merely examples. The first arithmetic operation requires a longer calculation time than the second arithmetic operation, but can derive a proper solution with high precision. On the other hand, there is concern that the second arithmetic operation, compared to the first arithmetic operation, may derive, for example, an improper local solution, but the calculation time in the second arithmetic operation is shorter. If the first arithmetic operation has higher precision than the second arithmetic operation, and if the second arithmetic operation has quicker convergence than the first arithmetic operation, the first arithmetic operation and second arithmetic operation may be any combination of methods.

[0124] The evaluation value arithmetic circuit **226** calculates the evaluation value J by using the equation (11), based on the light amount estimation value $E_{\lambda x}$ acquired from the first estimation value arithmetic circuit **222** or second estimation value arithmetic circuit **224**, and the light amount $D_{\lambda x}$ acquired by the photodetector **320**. The evaluation value arithmetic circuit **226** outputs the evaluation value J and shape information k1 to km to the selection circuit **228**.

[0125] A calculation start signal is input to the selection circuit **228**. When the calculation start signal has been input, the selection circuit **228** causes the first estimation value arithmetic circuit **222** to start the optimization arithmetic operation. In addition, based on the evaluation value J and shape information k1 to km acquired from the evaluation value arithmetic circuit **226** and the calculation number of times Calc_num acquired from the first estimation value arithmetic circuit **222**, the selection circuit **228** selects and executes one of an operation of causing the first estimation value arithmetic circuit **222** to execute the optimization arithmetic operation, an operation of causing the second estimation value arithmetic circuit **224** to execute the optimization arithmetic operation, and an operation of outputting the shape information k1 to km which is the result of the arithmetic operation. When the selection circuit **228** causes the first estimation value arithmetic circuit **222** to execute the optimization arithmetic operation, the selection circuit **228** outputs the currently retained shape information k1 to km to the first estimation value arithmetic circuit **222**. In addition, when the selection circuit **228** causes the second estimation value arithmetic circuit **224** to execute the optimization arithmetic operation, the selection circuit **228** outputs the currently retained shape information k1 to km to the second estimation value arithmetic circuit **224**.

[0126] The operation of the controller **100** using the second calculation method will now be described with reference to a flowchart of FIG. **19**. In step S**301**, the controller **100** reads in position information of the sensing parts **410** stored in the storage circuit **120**.

[0127] The process of step S**302** to step S**305** is executed by the shape optimization circuit **200**. In step S**302**, the shape optimization circuit **200** of the controller **100** executes a first shape information calculation process. Referring to a flowchart of FIG. **20**, the first shape information calculation process will be described.

[0128] In step S**401**, the selection circuit **228** of the shape optimization circuit **200** reads in various thresholds which are stored the storage circuit **120**. In addition, the first estimation value arithmetic circuit **222** of the shape optimization circuit **200** reads in the light amount estimation equation stored in the storage circuit **120**. In step S**402**, the shape optimization circuit **200** causes the display **180** to display, for example, "waiting state".

[0129] In step S**403**, the first estimation value arithmetic circuit **222** of the shape optimization circuit **200** calculates the light amount estimation value $E_{\lambda x}$ by the global optimization arithmetic operation. In step S404, the first estimation value arithmetic circuit **222** of the shape optimization circuit **200** updates the calculation number of times Calc_num. Specifically, the calculation number of times Calc_num is updated as follows:

Calc_num=Calc_num+1

The first estimation value arithmetic circuit **222** outputs the light amount estimation value $E_{\lambda x}$ and shape information k1 to km, which are the calculation result, to the evaluation value arithmetic circuit **226**. In addition, the first estimation value arithmetic circuit **222** outputs the calculation number of times Calc_num to the selection circuit **228**. Besides, since the second estimation value arithmetic circuit **224** utilizes the light amount estimation value $E_{\lambda x}$ and shape information k1 to km, the first estimation value arithmetic circuit **222** may output the light amount estimation value $E_{\lambda x}$ and shape information k1 to km to the second estimation value arithmetic circuit **224**. Specifically, the second estimation value arithmetic circuit **224** may acquire the light amount estimation value $E_{\lambda x}$ to be used in the arithmetic operation, from the evaluation value arithmetic circuit **226**, or from the first estimation value arithmetic circuit **222**.

[0130] In step S**405**, the evaluation value arithmetic circuit **226** of the shape optimization circuit **200** reads in the light amount $D_{\lambda x}$ from the photodetector **320**. In step S**406**, the evaluation value arithmetic circuit **226** of the shape optimization circuit **200** calculates the evaluation value J by using the equation (11), based on the light amount estimation value $E_{\lambda x}$ and calculation number of times Calc_num, which were acquired from the first estimation value arithmetic circuit **222**, and the light amount $D_{\lambda x}$ acquired from the photodetector **320**. The evaluation value arithmetic circuit **226** outputs to the selection circuit **228** the evaluation value J, and the light amount estimation value $E_{\lambda x}$ and shape information k1 to km, which were acquired from the first estimation value arithmetic circuit **222**.

[0131] In step S**407**, the selection circuit **228** of the shape optimization circuit **200** determines whether the evaluation value J is equal to or less than the predetermined threshold A, or whether Calc_num is greater than a predetermined threshold A2. If the evaluation value J is greater than the predetermined threshold A, and Calc_num is not greater than the predetermined threshold A2, the process returns to step S**403**. At this time, the calculation of the light amount estimation value $E_{\lambda x}$ is repeatedly executed. On the other hand, if the evaluation value J is equal to or less than the predetermined threshold A, or if Calc_num is greater than the predetermined threshold A2, the process advances to step S**408**.

[0132] In step S**408**, the selection circuit **228** of the shape optimization circuit **200** sets "1" as the value of a flag F which indicates that the global optimization arithmetic operation has properly been finished. Thereafter, the process returns to the process described with reference to FIG. **19**.

[0133] Referring back to FIG. **19**, a further description will be given. After the first shape information calculation process, in step S**303**, the selection circuit **228** included in the shape optimization circuit **200** of the controller **100** determines whether a predetermined update time has passed. If it is determined that the predetermined update time has not passed, the process repeats step S**303**, and stands by. On the other hand, if it is determined that the predetermined update time has passed, the process advances to step S**304**.

[0134] In step S**304**, the shape optimization circuit **200** of the controller **100** executes a second shape information calculation process. Referring to a flowchart of FIG. **21**, the second shape information calculation process will be described.

[0135] In step S**501**, the selection circuit **228** of the shape optimization circuit **200** reads in various thresholds which are stored the storage circuit **120**. In addition, the second estimation value arithmetic circuit **224** of the shape optimization circuit **200** reads in the light amount estimation equation stored in the storage circuit **120**. In step S**502**, the selection circuit **228** of the shape optimization circuit **200** causes the display **180** to display, for example, "driving OK".

[0136] In step S**503**, the second estimation value arithmetic circuit **224** of the shape optimization circuit **200** calculates the light amount estimation value $E_{\lambda x}$ by the local optimization arithmetic operation with quick convergence. The second estimation value arithmetic circuit **224** outputs the light amount estimation value $E_{\lambda x}$ and shape information k1 to km, which are the calculation result, to the evaluation value arithmetic circuit **226**.

[0137] In step S**504**, the evaluation value arithmetic circuit **226** of the shape optimization circuit **200** reads in the light amount $D_{\lambda x}$ from the photodetector **320**. In step S**505**, the evaluation value arithmetic circuit **226** of the shape optimization circuit **200** calculates the evaluation value J by using the equation (11), based on the light amount estimation value $E_{\lambda x}$ acquired from the second estimation value arithmetic circuit **224**, and the light amount $D_{\lambda x}$ acquired from the photodetector **320**. The evaluation value arithmetic circuit **226** outputs to the selection circuit **228** the evaluation value J, and the light amount estimation value $E_{\lambda x}$ and shape information k1 to km, which were acquired from the second estimation value arithmetic circuit **224**.

[0138] In step S**506**, the selection circuit **228** of the shape optimization circuit **200** determines whether the evaluation value J is equal to or less than a predetermined threshold A3. Here, the threshold A3 is less than the threshold A1. If the evaluation value J is equal to or less than the predetermined threshold A3, the process advances to step S**507**. In step S**507**, the selection circuit **228** of the shape optimization circuit **200** outputs the shape information k1 to km of the sensing parts calculated by the light amount estimation equation, and the calculation number of times Calc_num, to, for example, the endoscope shape calculator **140** or output circuit **160**. Thereafter, the process returns to the process described with reference to FIG. **19**.

[0139] In the determination of step S**506**, if it is determined that the evaluation value J is not equal to or less than the predetermined threshold A3, the process goes to step S**508**. In step S**508**, the selection circuit **228** of the shape optimization circuit **200** determines whether the evaluation value J is greater than a predetermined threshold A4. Here, the predetermined threshold A4 is greater than the predetermined threshold A1. If it is determined that the evaluation value J is not greater than the predetermined threshold A4, the process returns to step S**503**. At this time, the calculation of the light amount estimation value $E_{\lambda x}$ is repeatedly executed. On the other hand, if it is determined that the evaluation value J is greater than the predetermined threshold A4, the process advances to step S**509**. In step S**509**, the selection circuit **228** of the shape optimization circuit **200** sets "0" as the value of the flag F. Thereafter, the process returns to the process described with reference to FIG. **19**.

[0140] Referring back to FIG. **19**, a further description will be given. After the second shape information calculation process, in step S**305**, the selection circuit **228** included in the shape optimization circuit **200** of the controller **100** determines whether the flag F is "1" or not. If the flag F is not "1", the process returns to step S**302**. Specifically, while the second shape information calculation process is being executed, if convergence to an improper solution is about to occur, the flag F becomes "0" in step S**509**, and the first shape information calculation process is executed once again. On the other hand, if it is determined that the flag F is "1", the process advances to step S**306**. In this manner, the convergence to an improper solution by the second shape information calculation process with relatively low precision can be prevented.

[0141] In step S**306**, the endoscope shape calculator **140** of the controller **100** calculates the shape of the insertion section **812** of the endoscope **810**, based on the shape information k1 to km calculated by the shape optimization circuit **200** and the position information of the sensing parts **410**. In step S**307**, the controller **100** causes the display **180** to display the calculated shape of the insertion section **812**. In step S**308**, the controller **100** determines whether an instruction to end the operation has been input. If the instruction to end the operation has not been input, the process returns to step S**303**. On the other hand, if the instruction to end the operation has been input, the process relating to this operation is terminated.

[0142] According to the process using the second calculation method, while the calculation of an improper local solution is prevented by the global optimization arithmetic operation by the first estimation value arithmetic circuit **222**, proper shape information can be quickly calculated by the optimization arithmetic operation with high convergence by the second estimation value arithmetic circuit **224**. According to the second calculation method, the calculation of shape information, which is quick and exact as a whole, can be realized.

[0143] While the global optimization arithmetic operation by the first estimation value arithmetic circuit **222** is being executed, it is preferable that the shape of the insertion section **812** does not vary, in order to converge the arithmetic operation. Thus, "waiting state" is displayed on the display **180**, and the user is prompted not to move the insertion section **812**. In addition, while the optimization arithmetic operation with high convergence by the second estimation value arithmetic circuit **224** is being executed, it is possible to adapt to a change in shape of the insertion section **812**, and thus "driving OK" is displayed on the display **180**. By such display, the arithmetic operation is prevented from failing to converge. The display of "waiting state" or "driving OK" is merely an example, and any kind of display may be adopted. In addition, not limited to display, such a configuration as to notify the user by sound may be adopted.

[0144] In the second calculation method, the selection circuit **228** selects the execution of the first optimization arithmetic operation or the execution of the second optimization arithmetic operation. However, the shape estimation device **10** may be configured to enable the user to make such selection. In this case, the shape estimation device **10** is provided with a selection input circuit for the user to input his/her own selection. By the configuration which enables the user to select the kind of arithmetic operation, the user can select by himself/herself either the exactness or the quickness of display, which is necessary for the user.

[0145] [Third Calculation Method]

[0146] A third calculation method will be described. Different points from the second calculation method will be described, and a description of common parts is omitted. FIG. **22** shows the outline of a configurational example of a shape optimization circuit **200** according to the third calculation method. As shown in FIG. **22**, the shape optimization circuit **200** includes a first estimation value arithmetic circuit **231**, a second estimation value arithmetic circuit **232**, a first evaluation value arithmetic circuit **233**, a second evaluation value arithmetic circuit **234**, and a selection circuit **235**.

[0147] Like the first estimation value arithmetic circuit **222** in the second calculation method, the first estimation value arithmetic circuit **231** is an estimation value arithmetic circuit which executes the global optimization arithmetic operation. The first estimation value arithmetic circuit **231** calculates a first light amount estimation value $E_{\lambda x1}$ based on first shape information k1' to km'. The first estimation value arithmetic circuit **231** outputs the first light amount estimation value $E_{\lambda x1}$ and first shape information k1' to km' to the first evaluation value arithmetic circuit **233**.

[0148] The first evaluation value arithmetic circuit **233** calculates, based on the following equation (12), a first evaluation value J1 for the first light amount estimation value $E_{\lambda x1}$ calculated by the first estimation value arithmetic circuit **231**.

$$J1 = \sum_{x=1}^{p} (D_{\lambda x} - E_{\lambda x1}(k1', \ldots , km'))^2 \qquad \text{equation (12)}$$

The first evaluation value arithmetic circuit **233** outputs the first evaluation value J1 and first shape information k1' to km' to the selection circuit **235**.

[0149] Like the second estimation value arithmetic circuit **224** in the second calculation method, the second estimation value arithmetic circuit **232** is an estimation value arithmetic circuit which executes the local optimization arithmetic operation. The second estimation value arithmetic circuit **232** calculates a second light amount estimation value $E_{\lambda x2}$ based on second shape information k1" to km". The second estimation value arithmetic circuit **232** outputs the second light amount estimation value $E_{\lambda x2}$ and second shape information k1" to km" to the second evaluation value arithmetic circuit **234**.

[0150] The second evaluation value arithmetic circuit **234** calculates, based on the following equation (13), a second evaluation value J2 for the second light amount estimation value $E_{\lambda x2}$ calculated by the second estimation value arithmetic circuit **232**.

$$J2 = \sum_{x=1}^{p} (D_{\lambda x} - E_{\lambda x1}(k1'', \ldots , km''))^2 \qquad \text{equation (13)}$$

The second evaluation value arithmetic circuit **234** outputs the second evaluation value J2 and second shape information k1" to km" to the selection circuit **235**.

[0151] In the third calculation method, the global optimization arithmetic operation by the first estimation value arithmetic circuit **231** and first evaluation value arithmetic circuit **233** and the local optimization arithmetic operation by the second estimation value arithmetic circuit **232** and second evaluation value arithmetic circuit **234** are executed in parallel.

[0152] The selection circuit **235** determines the evaluation value J, based on the first evaluation value J1 and second evaluation value J2. Based on the evaluation vale J, the selection circuit **235** determines whether the optimization arithmetic operation is repeatedly executed, or the arithmetic operation is finished and the calculation result is output. The selection circuit **235** outputs, as shape information k1 to km, either the first shape information k1' to km' or the second shape information k1" to km", which is more appropriate.

[0153] The operation of the controller **100** using the third calculation method will be described. This operation is similar to the operation of the controller **100** using the first calculation method described with reference to FIG. **16**. However, the operation of the shape information calculation process is different. Referring to a flowchart of FIG. **23**, a description will be given of the operation of the shape information calculation process using the third calculation method.

[0154] In step S**601**, the shape optimization circuit **200** reads in the light amount estimation equation and threshold. Specifically, the first estimation value arithmetic circuit **231** reads in the light amount estimation equation to be used in the calculation of the first light amount estimation value $E_{\lambda x1}$. The second estimation value arithmetic circuit **232** reads in the light amount estimation equation to be used in the calculation of the second light amount estimation value $E_{\lambda x2}$. The selection circuit **235** reads in the threshold A.

[0155] The process of step S**602** to step S**604** by the first estimation value arithmetic circuit **231** and first evaluation value arithmetic circuit **233** and the process of step S**605** to step S**607** by the second estimation value arithmetic circuit **232** and second evaluation value arithmetic circuit **234** to be executed after step S**601**, are parallel processes.

[0156] In step S**602**, the first estimation value arithmetic circuit **231** of the shape optimization circuit **200** calculates the first light amount estimation value $E_{\lambda x1}$. The first estimation value arithmetic circuit **231** outputs the calculated first light amount estimation value $E_{\lambda x1}$ to the first evaluation value arithmetic circuit **233**.

[0157] In step S**603**, the first evaluation value arithmetic circuit **233** of the shape optimization circuit **200** reads in the light amount $D_{\lambda x}$ from the photodetector **320**. In step S**604**, the first evaluation value arithmetic circuit **233** of the shape optimization circuit **200** calculates the first evaluation value J1 by using the equation (12), based on the first light amount estimation value $E_{\lambda x1}$ acquired from the first estimation value arithmetic circuit **231** and the light amount $D_{\lambda x}$ acquired from the photodetector **320**. The first evaluation value arithmetic circuit **233** outputs to the selection circuit **235** the calculated first evaluation value J1 and first shape information k1' to km' relating to the first light amount estimation value $E_{\lambda x1}$.

[0158] In step S**605**, the second estimation value arithmetic circuit **232** of the shape optimization circuit **200** calculates the second light amount estimation value $E_{\lambda x2}$. The second estimation value arithmetic circuit **232** outputs the calculated second light amount estimation value $E_{\lambda x2}$ to the second evaluation value arithmetic circuit **234**.

[0159] In step S**606**, the second evaluation value arithmetic circuit **234** of the shape optimization circuit **200** reads in the light amount $D_{\lambda x}$ from the photodetector **320**. In step S**607**, the second evaluation value arithmetic circuit **234** of the shape optimization circuit **200** calculates the second evaluation value J2 by using the equation (13), based on the second light amount estimation value $E_{\lambda x2}$ acquired from the second estimation value arithmetic circuit **232** and the light amount $D_{\lambda x}$ acquired from the photodetector **320**. The second evaluation value arithmetic circuit **234** outputs to the selection circuit **235** the calculated second evaluation value J2 and second shape information k1" to km" relating to the second light amount estimation value $E_{\lambda x2}$.

[0160] After the process of step S**602** to step S**604** and the process of step S**605** to step S**607**, the selection circuit **235** of the shape optimization circuit **200** compares, in step S**608**, the first evaluation value J1 acquired from the first evaluation value arithmetic circuit **233** and the second evaluation value J2 acquired from the second evaluation value arithmetic circuit **234**, and determines the smaller one as the evaluation value J.

[0161] In step S**609**, the selection circuit **235** of the shape optimization circuit **200** determines whether the evaluation value J is equal to or less than the predetermined threshold A. If it is determined that the evaluation value J is not equal to or less than the predetermined threshold A, the process returns to the parallel arithmetic operations of step S**602** and step S**605**. At this time, the first estimation value arithmetic circuit **231** and second estimation value arithmetic circuit **232** may use the shape information calculated by themselves in the previous arithmetic operations, or the first estimation value arithmetic circuit **231** and second estimation value arithmetic circuit **232** may both use the shape information of the smaller evaluation value. On the other hand, if it is determined that the evaluation value J is equal to or less than the predetermined threshold A, the process advances to step S**610**.

[0162] In step S**610**, the selection circuit **235** of the shape optimization circuit **200** compares the first evaluation value J1 and second evaluation value J2. When the first evaluation value J1 is smaller, the selection circuit **235** determines the first shape information k1" to km" as the shape information k1 to km. In addition, when the second evaluation value J2 is smaller, the selection circuit **235** determines the second shape information k1" to km" as the shape information k1 to km.

[0163] In step S**611**, the selection circuit **235** of the shape optimization circuit **200** outputs the shape information k1 to km determined in step S**610**, to, for example, the endoscope shape calculator **140**. Thereafter, the process returns to the process described with reference to FIG. **16**.

[0164] If the third calculation method is used, a proper optimal solution can be quickly calculated by the parallel arithmetic operations of the global optimization arithmetic operation by the first estimation value arithmetic circuit **231** and the optimization arithmetic operation with high convergence by the second estimation value arithmetic circuit **232**. Furthermore, while the global optimization arithmetic operation does not properly converge, the result of the optimization arithmetic operation with high convergence is output. When the global optimization arithmetic operation properly converges, the result of the global optimization arithmetic operation with high precision is output. Therefore, unlike the case of the second calculation method, the shape information can constantly be output.

[0165] Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. A shape estimation device comprising:

an input circuit configured to receive light amount information which is a relationship between a wavelength and a light amount, the light amount information being acquired by using a sensor configured such that the light amount to be detected with respect to the wavelength corresponding to each of a plurality of sensing parts varies in accordance with a shape of each of the plurality of sensing parts;

a storage circuit configured to store a light amount estimation relationship including shape characteristic information representing a relationship between the shape, the wavelength and the light amount with respect to each of the plurality of sensing parts; and

a shape arithmetic circuit configured to calculate shape information being an estimation value of the shape by calculating a light amount estimation value by an optimization arithmetic operation such that the light amount estimation value calculated based on the light amount estimation relationship and the light amount information satisfy a predetermined condition, the light amount estimation value which is a relationship between the wavelength and the light amount.

2. The shape estimation device according to claim **1**, wherein the optimization arithmetic operation to be executed by the shape arithmetic circuit includes at least two kinds of arithmetic methods,

at least one of the at least two kinds of arithmetic methods includes a convergence calculation, and

the at least two kinds of arithmetic methods have different convergences.

3. The shape estimation device according to claim **2**, wherein the at least two kinds of arithmetic methods include a first optimization arithmetic operation and a second optimization arithmetic operation,

the first optimization arithmetic operation has a higher precision than the second optimization arithmetic operation, and

the second optimization arithmetic operation has a higher convergence than the first optimization arithmetic operation.

4. The shape estimation device according to claim **3**, wherein the shape arithmetic circuit is configured to successively execute the at least two kinds of arithmetic methods.

5. The shape estimation device according to claim **4**, wherein the shape arithmetic circuit is configured to execute the second optimization arithmetic operation after executing the first optimization arithmetic operation.

6. The shape estimation device according to claim **5**, wherein the shape arithmetic circuit is configured to use, in the second optimization arithmetic operation, the shape information calculated by the first optimization arithmetic operation.

7. The shape estimation device according to claim **3**, wherein the shape arithmetic circuit is configured:

to execute the second optimization arithmetic operation after executing the first optimization arithmetic operation,

to use, in the second optimization arithmetic operation, the shape information calculated by the first optimization arithmetic operation, and

to suspend the second optimization arithmetic operation and execute the first optimization arithmetic operation, when an error between the light amount information and the light amount estimation value has become greater than a predetermined threshold while the shape arithmetic circuit is executing the second optimization arithmetic operation.

8. The shape estimation device according to claim **2**, wherein the shape arithmetic circuit is configured:

to execute, in parallel, operations using the at least two kinds of arithmetic methods, respectively, and

to select optimal said shape information from between at least two pieces of the shape information obtained as results of the arithmetic operations.

9. The shape estimation device according to claim **8**, wherein the shape arithmetic circuit is configured to select the shape information, based on a magnitude of an error between the light amount information and the light amount estimation value.

10. The shape estimation device according to claim **1**, wherein the optimization arithmetic operation includes a convergence calculation, and

the shape arithmetic circuit is configured to terminate the convergence calculation and determine the shape information, when an error between the light amount information and the light amount estimation value has become less than a predetermined threshold.

11. The shape estimation device according to claim **3**, further comprising a selection input circuit configured to receive an input of selection between the first optimization arithmetic operation and the second optimization arithmetic operation,

wherein the shape arithmetic circuit is configured to execute either the first optimization arithmetic operation or the second optimization arithmetic operation, in accordance with the input to the selection input circuit.

12. The shape estimation device according to claim **3**, wherein the shape arithmetic circuit is configured to output a signal indicative of a waiting state, while the shape arithmetic circuit is executing the first optimization arithmetic operation.

13. The shape estimation device according to claim **12**, wherein the signal indicative of the waiting state is a signal for causing a display to display the wait state.

14. The shape estimation device according to claim **1**, wherein the shape arithmetic circuit is configured to store a result of the optimization arithmetic operation previously executed.

15. The shape estimation device according to claim **1**, further comprising:

a light source configured to emit light; and

the sensor,

the sensor including:

a light guide configured to guide the light emitted from the light source;

a plurality of the sensing parts including a plurality of optical members provided on the light guide and configured to exert mutually different effects on a spectrum of light guided by the light guide; and

a photodetector configured to detect light guided by the light guide and affected by the plurality of optical members, and to output the light amount information.

16. An endoscope system comprising:

the shape estimation device according to claim **15**;

an endoscope configured such that the light guide is provided in an insertion section; and

an endoscope shape calculator configured to calculate a shape of the insertion section, based on the shape information.

17. A shape estimation method comprising:

acquiring light amount information which is a relationship between a wavelength and a light amount, the light amount information being acquired by using a sensor configured such that the light amount to be detected with respect to the wavelength corresponding to each of a plurality of sensing parts varies in accordance with a shape of each of the plurality of sensing parts;

acquiring a light amount estimation relationship including shape characteristic information representing a relationship between the shape, the wavelength and the light amount with respect to each of the plurality of sensing parts; and

calculating shape information being an estimation value of the shape, by calculating a light amount estimation value by an optimization arithmetic operation such that the light amount estimation value calculated based on the light amount estimation relationship and the light amount satisfy a predetermined condition, the light amount estimation value which is a relationship between the wavelength and the light amount.

18. A program for shape estimation, which causes a computer to execute:

acquiring light amount information which is a relationship between a wavelength and a light amount, the light amount information being acquired by using a sensor configured such that the light amount to be detected with respect to the wavelength corresponding to each of a plurality of sensing parts varies in accordance with a shape of each of the plurality of sensing parts;

acquiring a light amount estimation relationship including shape characteristic information representing a relationship between the shape, the wavelength and the light amount with respect to each of the plurality of sensing parts; and

calculating shape information being an estimation value of the shape, by calculating a light amount estimation value by an optimization arithmetic operation such that the light amount estimation value calculated based on the light amount estimation relationship and the light amount information satisfy a predetermined condition, the light amount estimation value which is a relationship between the wavelength and the light amount.

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