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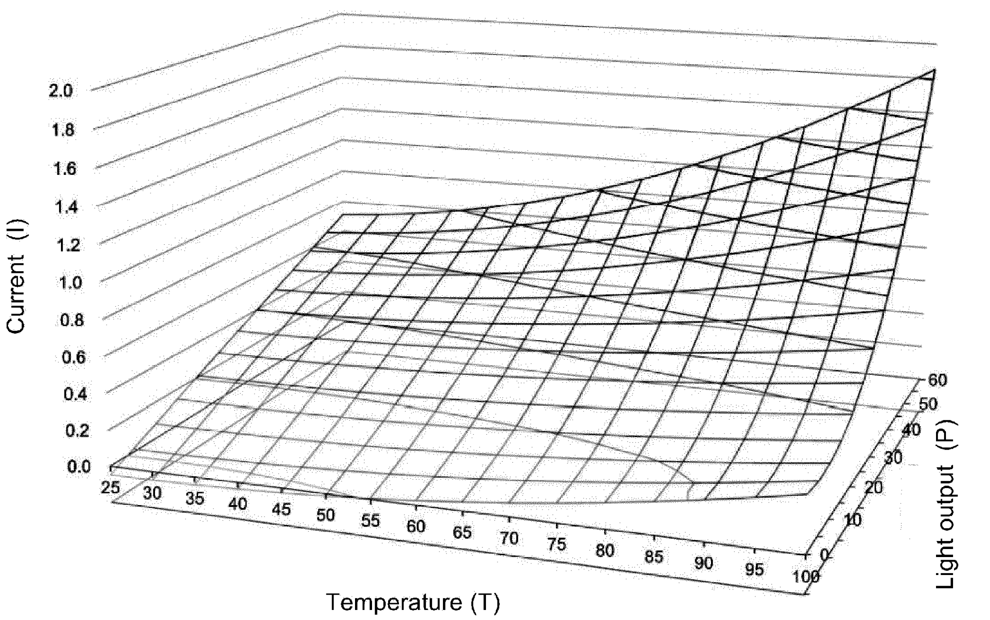
(54) LIGHT SOURCE APPARATUS AND CALIBRATION DEVICE

(57) Provided is a light source apparatus capable of performing light output control with high responsiveness. The light source apparatus (1) includes a light-emitting element (12), a temperature detector (19), a drive circuit (21), a control unit (22), and a target light output receiving unit (31). The control unit (22) includes: a first storage unit (26) in which a control function for obtaining a third variable correlated with a current supplied to the light-emitting element from a first variable correlated with the temperature and a second variable correlated with the light output is recorded, and an arithmetic processing unit (25) substitutes the temperature T and the target value Φ into the first variable and the second variable in the control function to determine the amount of current supplied to the light-emitting element (12) which is the third variable.

Fig. 4



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a light source apparatus, and more particularly to a light source apparatus that exhibits high controllability for light output. The present invention also relates to a calibration device for maintaining high controllability for the light source apparatus.

Description of the Related Art

[0002] It is known that a light-emitting element such as a light-emitting diode (LED) varies in an actual amount of light emission depending on the temperature of the light-emitting element even when the same amount of current is applied. Under such a background, as a technique for stabilizing the light output of the LED, there is conventionally feedback control in which a part of the emitted light from the LED is received by a photosensor, and an amount of current supplied from a power supply circuit to the LED is adjusted based on the amount of received light.

[0003] However, in the feedback control using a photosensor, the photosensor itself is affected by temperature, resulting in that it is difficult to control the light output with high accuracy. In addition, the photosensor is easily affected by other disturbances, so the photosensor has poor followability to a variation in output in a short time.

[0004] As a countermeasure to such a problem, feedforward control has been proposed in which a temperature of an LED is measured and a value of a current supplied to the LED is controlled according to a value of the measured temperature (see, for example, Patent Document 1 below).

Prior Art Document

Patent Document

[0005] Patent Document 1: JP-A-3-36777

SUMMARY OF THE INVENTION

[0006] Accordingto the method described in Patent Document 1, a data table in which a relationship among a light output, a temperature, and a current is recorded in advance is prepared, and in order to obtain a desired light output, control is performed to supply a current corresponding to a current value read from the data table to the LED. However, in order to accurately control the light output by this method, it is necessary to record a huge amount of data in the data table.

[0007] In addition, it is necessary to perform processing of reading data close to the desired light output and to the measured temperature from the data table and complement processing in order to determine a necessary current amount, and therefore, there is a limit in achieving quick responsiveness. In particular, for a light source used in an application, such as an endoscope, in which a light output is expected to be finely adjusted during illumination, quick responsiveness to the adjustment of the light output is required, and thus, it is difficult to adopt the above-described control method.

[0008] Given the above problems, an object of the present invention is to provide a light source apparatus capable of performing light output control with high responsiveness even with a smaller amount of data than that of a control method using a conventional feedforward method. In addition, an object of the present invention is to provide a calibration device for maintaining high controllability for such a light source apparatus.

[0009] A light source apparatus according to the present invention includes:

a light-emitting element;
a temperature detector that detects a temperature of an installation location of the light-emitting element;
a drive circuit that supplies a current to the light-emitting element;
a control unit that controls the current supplied from the drive circuit to the light-emitting element; and
a target light output receiving unit that receives an input of information corresponding to a target value Φ of a light output of the light-emitting element, wherein
the control unit includes:

a first storage unit in which a control function is recorded for obtaining a third variable correlated with the current supplied to the light-emitting element from a first variable correlated with the temperature of the installation location of the light-emitting element and a second variable correlated with the light output of the light-emitting element; and

an arithmetic processing unit that determines a supply current amount to the light-emitting element, which is the third variable, by reading the control function from the first storage unit, substituting a temperature T detected by the temperature detector for the first variable, and substituting the target value Φ for which the target light output receiving unit has received input for the second variable,

the control function is a curved surface function specified in mathematical formula (1) below that includes an independent variable x, an independent variable y, and a dependent variable z, the control function being a function converted into a formula for obtaining the third variable by assigning the first variable, the second variable, and the third variable to one of the independent variable x, the independent variable y, and the dependent variable z, and the curved surface function has a shape determined by a coefficient α_{ts} in mathematical formula (1) below

$$z = \sum_{t=0}^{k} \left(\sum_{s=0}^{j} \alpha_{ts} \cdot y^{s} \right) \cdot x^{t} \qquad (1)$$

where α_{ts} ($0 \leq t \leq k$, $0 \leq s \leq j$) is the coefficient, one of k or j is an integer of 2 or more, and another one is an integer of 1 or more.

[0010] The "temperature of the installation location of the light-emitting element" may be a temperature of a region (substrate) in which the light-emitting element is mounted, or may be a temperature of the light-emitting element itself. When the light-emitting element is placed in a closed space, the "temperature of the installation location of the light-emitting element" may be a temperature of the atmosphere in the closed space.

[0011] According to the above configuration, when the information corresponding to a desired light output (target value Φ) is input, an amount of current necessary for obtaining a light output corresponding to the target value Φ at the current temperature is determined only by performing an arithmetic operation by applying the information regarding the target value Φ and the information regarding the temperature of the installation location of the light-emitting element at present to the control function recorded in the first storage unit. Then, the control unit outputs information regarding the determined current amount to the drive circuit, so that a specified amount of current is supplied from the drive circuit to the light-emitting element, and a light output close to the target value Φ is obtained.

[0012] That is, according to the above configuration, the necessary current amount is determined only by performing a simple arithmetic operation by the arithmetic processing unit in the control unit, whereby it is possible to control the light output with a small number of processes. As a result, high responsiveness is achieved.

[0013] In addition, since one of k or j in mathematical formula (1) is an integer of two or more as described above, the control function is a multidimensional polynomial in which at least one of the independent variables x and y is represented by a multidimensional polynomial of degree two or more. The use of the control function described above is particularly effective because highly accurate control can be performed on a light source apparatus used for applications such as an endoscope, an exposure device, and a printing machine. The endoscope is used in a situation where the distance between an observation site and a light source changes by the minute. Therefore, when the control function described above is used, the irradiance of the observation site can be constantly maintained with high accuracy. Further, when using the control function described above, the exposure device and the printing machine can repeatedly irradiate an object with a constant dose with high accuracy. Note that the control function represented by a linear expression fails to accurately fit the relationship between the current, the temperature, and the light output. As a result, when feedforward control using the control function represented by a linear expression is performed, a non-negligible deviation occurs between the target value Φ and the actually obtained light output, and the responsiveness also decreases.

[0014] The information regarding the control function may be derived in advance, for example, before the light source apparatus is shipped, and the derived information may be recorded in the first storage unit. The control function is derived as follows. For example, a plurality of relationships between the temperature and the light output is measured with an amount of current being changed to prepare a plurality of coordinates including these three elements, and fitting processing is performed on these coordinates by arithmetic processing.

[0015] The first variable may correspond to the independent variable x, the second variable corresponds to the independent variable y, the third variable corresponds to the dependent variable z, and

the arithmetic processing unit may determine the supply current amount to the light-emitting element by a value of the dependent variable z in the control function which is obtained by an arithmetic operation based on mathematical formula (1) with applying the temperature T to the independent variable x in the control function and applying the target value Φ to the independent variable y in the control function.

[0016] In this case, both k and j in mathematical formula (1) may be 2, and the arithmetic processing unit may determine the supply current amount by a current amount I obtained by an arithmetic operation based on mathematical formula (2) below:

$$I = \alpha_0(T) + \alpha_1(T) \cdot \Phi + \alpha_2(T) \cdot \Phi^2 \qquad (2)$$

where $\alpha_0(T)$, $\alpha_1(T)$, and $\alpha_2(T)$ correspond to formulas below, respectively:

$$\alpha_0(T) = \alpha_{00} + \alpha_{01} \cdot T + \alpha_{02} \cdot T^2$$

$$\alpha_1(T) = \alpha_{10} + \alpha_{11} \cdot T + \alpha_{12} \cdot T^2$$

$$\alpha_2(T) = \alpha_{20} + \alpha_{21} \cdot T + \alpha_{22} \cdot T^2.$$

[0017] According to the above configuration, a required current amount I is calculated by simply applying the information corresponding to the temperature T at the installation location of the light-emitting element and the target value Φ of the light output to the control function specified by the second degree polynomial with two variables. Therefore, an amount of arithmetic operation is significantly reduced, whereby the responsiveness is extremely improved, and the light output can be controlled in real-time.

[0018] Besides the configuration described above, one of the first variable or the second variable may correspond to the independent variable x, another one may correspond to the dependent variable z, the third variable may correspond to the independent variable y, and the arithmetic processing unit may transform the control function represented by mathematical formula (1) into a transformation formula for calculating the independent variable y, and determine the supply current amount to the light-emitting element using a value of the independent variable y calculated by an arithmetic operation that applies the temperature T and the target value Φ to the corresponding independent variable x and dependent variable z in the transformation formula.

[0019] In this case, both k and j in mathematical formula (1) may be 2, and the arithmetic processing unit may determine the supply current amount using a current amount I obtained by an arithmetic operation based on following mathematical formula (3).

$$I = \frac{-\alpha_1(T) + \sqrt{\alpha_1(T)^2 - 4 \cdot \alpha_2(T) \cdot (\alpha_0(T) - \Phi)}}{2 \cdot \alpha_2(T)} \qquad (3)$$

where $\alpha_0(T)$, $\alpha_1(T)$, and $\alpha_2(T)$ correspond to formulas below, respectively:

$$\alpha_0(T) = \alpha_{00} + \alpha_{01} \cdot T + \alpha_{02} \cdot T^2$$

$$\alpha_1(T) = \alpha_{10} + \alpha_{11} \cdot T + \alpha_{12} \cdot T^2$$

$$\alpha_2(T) = \alpha_{20} + \alpha_{21} \cdot T + \alpha_{22} \cdot T^2.$$

[0020] The control unit may include an input port receiving an input of information regarding a value of the coefficient α_{ts}.

[0021] According to the configuration described above, even in a case where, for example, the light-emitting element is replaced, the information regarding the coefficient α_{ts} corresponding to the light-emitting element is transmitted to the control unit through the input port, whereby the light output control using the control function recorded in the first storage unit can be performed. In addition, even in a case where the value of the coefficient α_{ts} is reviewed with the deterioration of the light-emitting element over time, the value of the coefficient α_{ts} after the review is also transmitted to the control unit through the input port, whereby light output control using the control function recorded in the first storage unit can be performed.

[0022] In the above configuration, the light source apparatus may include a drive unit on which the drive circuit and the control unit are mounted and which is detachable from the light-emitting element, wherein

the light-emitting element may include a second storage unit in which information regarding the value of the coefficient α_{ts} uniquely assigned to the light-emitting element is recorded, and
when the drive unit and the light-emitting element are connected, information regarding the value of the coefficient α_{ts} recorded in the second storage unit may be input to the control unit via the input port.

[0023] According to the above configuration, information regarding the value of the coefficient α_{ts} is recorded in the light-emitting element. Therefore, even when, for example, the light-emitting element is replaced, the value of the coefficient α_{ts} recorded in the first storage unit of the control unit is automatically updated, whereby light output control for the replaced light-emitting element can be accurately performed.

[0024] A plurality of the light-emitting elements having different wavelengths may be provided, and
the first storage unit may record the control function differently for each of the light-emitting elements.

[0025] It is conceivable that the light source apparatus includes light-emitting elements of red (R), green (G), and blue (B) to generate white illumination light. In the light-emitting element, a degree of influence on the light output with respect to the temperature changes according to the emission wavelength. Therefore, when an amount of current is equally adjusted for the light-emitting elements of different wavelength bands (color bands), the color balance of the illumination light may change. On the other hand, according to the above configuration, control functions corresponding to the light-emitting elements having different wavelengths are recorded in the control unit, and thus, the light output can be controlled with high accuracy with the color balance being maintained.

[0026] A calibration device according to the present invention performs a calibration process for the above light source apparatus. The calibration device includes an information updating unit that creates update information of the coefficient α_{ts} in the control function and performs update processing on the first storage unit included in the light source apparatus, wherein

the information updating unit

determines, by arithmetic processing, an update control function represented by mathematical formula (4) in which a first actual measurement value correlated with a light output from the light-emitting element, a second actual measurement value correlated with an amount of current supplied to the light-emitting element, and a measured temperature value correlated with a temperature of the installation location of the light-emitting element are associated with any of an independent variable X, an independent variable Y, and a dependent variable Z under a light-emitting state of the light-emitting element, and
outputs information regarding a coefficient α_{TS} in the update control function to the first storage unit as the update information:

$$Z = \sum_{T=0}^{k} \left(\sum_{S=0}^{j} \alpha_{TS} \cdot Y^{S} \right) \cdot X^{T} \tag{4}$$

where values of k and j in mathematical formula (4) coincide with the values of k and j in mathematical formula (1), respectively.

[0027] In the calibration device, the update control function represented by mathematical formula (4) may be determined using a least-square method. In detail, the information updating unit may acquire coordinate information including the first actual measurement value, the second actual measurement value, and the measured temperature value for at least $(k + 1) \times (j + 1)$ points, and may determine the update control function by a least-square method based on a plurality of pieces of the coordinate information.

[0028] As the light source apparatus has been used, the relationship between the temperature of the light-emitting element mounted in the light source apparatus and the light output may vary over time. According to the above calibration device, the value of the coefficient α_{TS} corresponding to the light-emitting element at present can be derived by performing the calibration process at a predetermined timing, and by having the information regarding this coefficient α_{TS} recorded in the first storage unit in the control unit, high controllability over the light output can be maintained.

[0029] The light source apparatus may include a light-receiving sensor that receives light emitted from the light-emitting element, and the information updating unit of the calibration device may acquire the first actual measurement value based on a light amount detected by the light-receiving sensor, may acquire the second actual measurement value based on a controlled amount of a current by the control unit, and may acquire the measured temperature value based on a temperature detected by the temperature detector.

[0030] According to the above configuration, it is only sufficient that the calibration device is provided with a function (information updating unit) for performing arithmetic processing based on input information. That is, a general-purpose computer may be used as the calibration device, for example. Furthermore, in a case where the light source apparatus has a communication function, the calibration device can be implemented by a computer located at a position distantfrom the installation location of the light source apparatus or a communication device equipped with an arithmetic processing function.

[0031] The calibration device may include an instruction signal output unit that outputs, to the control unit of the light source apparatus, an instruction signal indicating execution of light emission with an amount of current supplied to the light-emitting element being changed for the calibration process,

wherein the information updating unit may acquire the first actual measurement value, the second actual measurement value, and the measured temperature value from the light-emitting element that is in a light emission state in response to the instruction signal.

[0032] According to the present invention, a light source apparatus capable of performing light output control with high responsiveness is achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033]

Fig. 1 is a diagram schematically illustrating an example of a structure of a light source apparatus according to a first embodiment;

Fig. 2 is a functional block diagram schematically illustrating an example of a configuration of the light source apparatus;

Fig. 3 is a graph illustrating an example of a result obtained by measuring a light output P and a temperature T with a current amount I being varied;

Fig. 4 is a graph visually indicating a control function obtained by fitting a plurality of coordinate groups obtained in Fig. 3;

Fig. 5 is a graph showing a result obtained by comparing a calculated value of a current amount calculated using a control function obtained based on the result of Fig. 4 with an actually measured current amount;

Fig. 6A is a graph showing a result in a case where control is performed by a method (feedback) according to a comparative example and shows a temporal change in a target value of a light output, an actual measurement value of an actual light output, and difference between the target value and the actual measurement value;

Fig. 6B is a graph showing a result in a case where control is performed by the method (feedback) according to the comparative example and shows a temporal change in an amount of current supplied to the light-emitting element and a temperature of an installation location of the light-emitting element;

Fig. 7A is a graph showing a result in a case where control is performed by a method (feedforward using a control function) according to an example and shows a temporal change in a target value of a light output, an actual measurement value of an actual light output, and difference between the target value and the actual measurement value;

Fig. 7B is a graph showing a result in a case where control is performed by the method (feedforward using a control function) according to the example and shows a temporal change in an amount of current supplied to the light-emitting element and a temperature of an installation location of the light-emitting element;

Fig. 7C is an enlarged graph of a partial region in Fig. 7B;

Fig. 8 is a functional block diagram schematically illustrating an example of another configuration of the light source apparatus;

Fig. 9 is a diagram schematically illustrating configurations of a calibration device and the light source apparatus;

Fig. 10 is a functional block diagram schematically illustrating configuration examples of the calibration device and the light source apparatus;

Fig. 11 is a functional block diagram schematically illustrating another configuration examples of the calibration device and the light source apparatus; and

Fig. 12 is a functional block diagram schematically illustrating another configuration examples of the calibration device and the light source apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] Embodiments of a light source apparatus and a calibration device according to the present invention will be described with reference to the drawings as appropriate.

[First embodiment]

[0035] Fig. 1 is a diagram schematically illustrating an example of a structure of a light source apparatus according to a first embodiment. The light source apparatus 1 includes a housing 10, a substrate 11 on which a light-emitting element 12 is mounted, a heat sink 16 for cooling, and a fan 17. The substrate 11, the heat sink 16, and the fan 17 are housed in the housing 10. The light-emitting element 12 emits light L12 when supplied with an electric current.

[0036] The light source apparatus 1 includes a temperature detector 19 that detects the temperature of an installation location of the light-emitting element 12. Fig. 1 illustrates a case where the temperature detector 19 detects the temperature of the substrate 11, but the installation location is not limited as long as the temperature of at least an area correlating with the temperature of the light-emitting element 12 can be detected.

[0037] Fig. 2 is a block diagram schematically illustrating an example of a configuration of the light source apparatus 1. In Fig. 2, a solid arrow indicates a flow of information, a one-dot chain line arrow indicates a flow of light, and a two-dot chain line arrow indicates a flow of current supplied to the light-emitting element 12. The same applies to the drawings referred to below.

[0038] The light source apparatus 1 includes a drive circuit 21, a control unit 22, and a target light output receiving unit 31. The drive circuit 21 is connected to a power supply (not illustrated) and supplies a current to the light-emitting element 12. The control unit 22 is a functional unit that controls an amount of current supplied from the drive circuit 21 to the light-emitting element 12.

[0039] The target light output receiving unit 31 is a unit that receives an input of an instruction signal for adjusting the light output of the light source apparatus 1 in response to an instruction from a user. As an example, a target light output input unit 35 attached to the light source apparatus 1 or provided at a position away from the light source apparatus 1 is operated by the user. The target light output input unit 35 includes, for example, an operation button, a knob, a dial, a scroll bar on a touch panel, an input form, etc. When intending to increase or decrease the light output of the light L12 at present, the user operates the target light output input unit 35 to instruct a desired light output. When receiving the input of information regarding the desired light output (information corresponding to a target value Φ) input from the target light output input unit 35, the target light output receiving unit 31 outputs the information to the control unit 22.

[0040] The control unit 22 includes an arithmetic processing unit 25, a first storage unit 26, and an input/output port 27. The input/output port 27 is an interface that receives an input of information from the outside of the control unit 22 and outputs information to the outside of the control unit 22. For example, the information corresponding to the target value Φ may be input to the control unit 22 via the input/output port 27. In the present embodiment, an input port having no output function may be used instead of the input/output port 27.

[0041] In the first storage unit 26, information regarding a control function to be described later is recorded. The first storage unit 26 includes a storage medium such as a hard disk or a flash memory. The arithmetic processing unit 25 applies information regarding a temperature T of the installation location of the light-emitting element 12 input from the temperature detector 19 and information regarding the target value Φ of the light output input from the target light output receiving unit 31 to the control function recorded in the first storage unit 26, thereby calculating a supply current amount I (hereinafter sometimes abbreviated as "current amount I") necessary for obtaining the light output of the target value Φ under the temperature T by arithmetic processing. The arithmetic processing unit 25 is implemented by software or dedicated hardware capable of executing such arithmetic processing.

[0042] Information regarding the current amount I determined by the arithmetic processing unit 25 is output from the control unit 22 to the drive circuit 21. The drive circuit 21 supplies an amount of current corresponding to the current amount I to the light-emitting element 12. In Fig. 2, information regarding the current amount I output from the control unit 22 to the driver circuit 21 is represented by the symbol "I", while the amount of current corresponding to the amount of current I supplied from the drive circuit 21 to the light-emitting element 12 is also represented by the symbol "I". This is intended to prevent misunderstandings caused by the use of different symbols for the two. The same notation is used in Fig. 8, Fig. 10 to Fig. 12, which will be described later.

[0043] The temperature detector 19 outputs information regarding the temperature T of the installation location of the light-emitting element 12 to the control unit 22 (arithmetic processing unit 25) at intervals of, for example, several milliseconds to several ten seconds. The arithmetic processing unit 25 calculates the supply current amount I by performing arithmetic processing every time the information regarding the temperature T is input. The drive circuit 21 adjusts an amount of current supplied to the light-emitting element 12 every time the information regarding the supply current amount I is updated from the control unit 22.

[0044] Next, the control function recorded in the first storage unit 26 will be described.

[0045] The light source apparatus 1 is subjected to a process of deriving a control function, for example, before shipment, and the light source apparatus 1 is shipped in a state in which information regarding the control function determined by this process is recorded in the first storage unit 26.

[0046] Specifically, the light output P of the light L12 and the temperature T detected by the temperature detector 19 are obtained while the amount of current supplied from the drive circuit 21 to the light-emitting element 12 is intentionally changed, and the obtained light output P and temperature T are associated with the current amount I. Thus, a plurality of coordinates (P, T, I) is obtained. Then, a function (control function) in which the obtained coordinate group can be present is derived by fitting processing.

[0047] Here, the information regarding the light output P can be detected on the basis of an amount of light received by a light-receiving sensor installed outside the light source apparatus 1, for example. Furthermore, in a case where a light-receiving sensor 41 (see Fig. 10) capable of receiving a part of the light L12 is mounted in the light source apparatus 1 as will be described later, the information regarding the light output P may be detected based on an amount of light received by the light-receiving sensor 41. In addition, the information regarding the current amount I may be acquired based on information output from the control unit 22 to the drive circuit 21 or may be acquired based on information obtained by actually measuring an amount of current supplied from the drive circuit 21 to the light-emitting element 12 using a current sensor or the like.

[0048] Fig. 3 is a graph illustrating an example of a result obtained by measuring the light output P of the light L12 and the temperature T detected by the temperature detector 19 with the current amount I being varied. In Fig. 3, the size of a circle corresponds to the magnitude of the current amount I. It is understood that the light output P fluctuates according to the temperature T despite the current amount I being the same, and there is regularity in the fluctuation manner. In addition, it is understood that the light output P fluctuates according to the current amount I despite the temperature T being constant, and there is regularity in the fluctuation manner.

[0049] Fig. 4 is a graph visually indicating a control function obtained by fitting a plurality of coordinate groups obtained in Fig. 3. In the example of Fig. 4, the control function is defined by an approximate curved surface.

[0050] More specifically, the control function defined in mathematical formula (1) mentioned above is fitted to the measurement result (x_i, y_i, z_i) (where i = 0, 1,..., n) obtained by assigning the light output P to the variable x, the temperature T to the variable y, and the current amount I to the variable z using, for example, the least-square method. Formula (1) is described again below. In mathematical formula (1), at least one of k or j is an integer of 2 or more, and the other is an integer of 1 or more.

$$z = \sum_{t=0}^{k} \left(\sum_{s=0}^{j} \alpha_{ts} \cdot y^{s} \right) \cdot x^{t} \qquad (1)$$

[0051] A case where k = 2 and j = 2 will now be described in detail as a specific example. In this case, mathematical formula (1) is specifically defined by mathematical formula (5) below.

$$z = \alpha_{00} + \alpha_{01} \cdot y + \alpha_{02} \cdot y^2 + \alpha_{10} \cdot x + \alpha_{11} \cdot x \cdot y + \alpha_{12} \cdot x \cdot y^2 + \alpha_{20} \cdot x^2 + \alpha_{21} \cdot x^2 \cdot y + \alpha_{22} \cdot x^2 \cdot y^2 \quad (5)$$

[0052] When expressed as a vertical vector C, a coefficient α_{ts} to be obtained can be defined by mathematical formula (6) below.

$$\boldsymbol{C} = \begin{pmatrix} \alpha_{00} \\ \vdots \\ \alpha_{22} \end{pmatrix} \quad (6)$$

[0053] When expressed as a vertical vector B, the measurement result z_i (where i = 0, 1, ..., n) regarding the current amount I can be defined by mathematical formula (7) below.

$$\boldsymbol{B} = \begin{pmatrix} z_0 \\ \vdots \\ z_n \end{pmatrix} \quad (7)$$

[0054] A matrix A expressed by mathematical formula (8) below is defined using the measurement resultxi regarding the light output P and the measurement result y_i (where i = 0, 1, ..., n) regarding the temperature T.

$$\boldsymbol{A} = \begin{pmatrix} 1 & y_0 & {y_0}^2 & x_0 & x_0 \cdot y_0 & x_0 \cdot {y_0}^2 & x_0^2 & {x_0}^2 \cdot y_0 & {x_0}^2 \cdot {y_0}^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & y_n & {y_n}^2 & x_n & x_n \cdot y_n & x_n \cdot {y_n}^2 & x_n^2 & {x_n}^2 \cdot y_n & {x_n}^2 \cdot {y_n}^2 \end{pmatrix} \quad (8)$$

[0055] In this case, the coefficient α_{ts} defined by the vertical vector C in mathematical formula (6) is calculated by an arithmetic operation based on mathematical formula (9) below. In mathematical formula (9), A^T is a transpose of the matrix (vertical vector) A, and $(A^T \cdot A)^{-1}$ is an inverse matrix of the matrix $(A^T \cdot A)$.

$$\boldsymbol{C} = (\boldsymbol{A}^T \cdot \boldsymbol{A})^{-1} \cdot \boldsymbol{A}^T \cdot \boldsymbol{B} \quad (9)$$

[0056] Each element of the matrix C obtained by mathematical formula (9) corresponds to the coefficient α_{ts} (t = 0, 1, 2; s = 0, 1, 2). That is, a formula obtained by applying each coefficient α_{ts} to mathematical formula (5) corresponds to the control function. This control function is a function obtained by fitting the measurement result (x_i, y_i, z_i) (where i = 0, 1, ..., n) using a least-square method, and corresponds to a curved surface function in the present embodiment. That is, each coefficient α_{ts} is a factor for determining the shape of the curved surface function.

[0057] Information regarding the control function calculated in advance using such a method is recorded in the first storage unit 26. Taking the control function defined by mathematical formula (5) as an example, the information regarding the control function is recorded in the first storage unit 26 with the values of the coefficients α_{ts} (t = 0, 1, 2; s = 0, 1, 2) being already recorded. The arithmetic processing unit 25 of the control unit 22 performs the arithmetic operation by applying the information regarding the target value Φ of the light output input from the target light output receiving unit 31 to the variable x of the control function defined by mathematical formula (5), and the temperature T of the installation location of the light-emitting element 12 input from the temperature detector 19 to the variable y of the same function, and determines the supply current amount I based on the obtained value of z.

[0058] Fig. 5 is a graph showing a result obtained by comparing a calculated value of the current amount calculated using the control function obtained based on the result of Fig. 4 with an actual current amount. The plots on the graph indicate actual measurement values of the current, and the horizontal axis corresponds to a calculated value of the current calculated based on the values of the light output P and the temperature T at a location corresponding to the actual measurement. In addition, the vertical axis represents a difference between the calculated value and the actual measurement value of the current.

[0059] According to the result of Fig. 5, it is understood that the actual measurement value and the calculated value substantially correspond to each other, and the value of the difference is also extremely small. That is, it can be seen that the characteristics (relationship among temperature, current, and light output) of the light-emitting element 12 can be expressed by the control function derived based on the actual measurement value.

[0060] As a comparative example, Figs. 6A and 6B illustrate control results in a case where the light-receiving sensor receives the light L12 emitted from the light-emitting element 12 and feedback control is performed based on the amount of received light. Fig. 6A is a graph illustrating a temporal change in the output of the actually received light L12 (corresponding to (a) in Fig. 6A) and difference (corresponding to (c) in Fig. 6A) between the target value of the light output (corresponding to (b) in Fig. 6A) and the output of the actually received light L12, in a case where the target value of the light output changes from moment to moment. In addition, Fig. 6B is a graph illustrating a temporal change in the current flowing through the light-emitting element 12 (corresponding to (a) in Fig. 6B) and the temperature detected by the temperature detector 19 (corresponding to (b) in Fig. 6B).

[0061] On the other hand, the case where the current control for the light-emitting element 12 was performed by the control unit 22 in the manner described above was taken as an example. That is, in the example, with the control function recorded in the first storage unit 26, the arithmetic processing unit 25 of the control unit 22 calculated the value of z by applying the target value Φ of the light output and the temperature T of the installation location of the light-emitting element 12 input from the temperature detector 19 to the control function, respectively, and a current corresponding to the current amount I determined based on the obtained value of z was supplied from the drive circuit 21 to the light-emitting element 12.

[0062] Figs. 7A to 7C show the result of control of the example. Fig. 7A is a graph illustrating a temporal change in the output of the actually received light L12 (corresponding to (a) in Fig. 7A) and difference (corresponding to (c) in Fig. 7A) between the target value of the light output (corresponding to (b) in Fig. 7A) and the output of the actually received light L12, in a case where the target value of the light output changes from moment to moment. In addition, Fig. 7B is a graph illustrating a temporal change in the current flowing through the light-emitting element 12 (corresponding to (a) in Fig. 7B) and the temperature detected by the temperature detector 19 (corresponding to (b) in Fig. 7B). Fig. 7C is an enlarged graph of a region A in Fig. 7B.

[0063] Comparing Fig. 6A with Fig. 7A, it can be seen that, in the comparative example, about three to seven seconds is spent until the actual light output reaches the target value after the instruction regarding the target value of the light output is given. Therefore, regarding the light output, a certain degree of difference occurs between the target value and the actual measurement value. On the other hand, in the example, a time taken until the actual light output reaches the target value after the instruction regarding the target value of the light output is given is extremely short. This is indicated in Fig. 7A in which the curve of (a) and the curve of (b) substantially overlap each other and the value of the difference is nearly zero at all times.

[0064] This can also be understood by comparing Fig. 6B and Fig. 7B. It is understood that the current flowing through the light-emitting element 12 in the comparative example has a larger variation amount during control than the current flowing through the light-emitting element 12 in the example. This indicates that, in the control method used in the comparative example, the light output is separated from the target value, so that the control for constantly changing the current amount is performed. It is to be noted that, in the example, the current amount also varies a little according to the temperature change, and this is indicated in Fig. 7C that is an enlarged graph of a portion of the graph in Fig. 7B.

[0065] As described above, according to the light source apparatus 1 of the present embodiment, even when an instruction to change the target value Φ of the light output is given, an amount of current necessary for achieving the target value Φ is determined by arithmetic operation by the control unit 22, and a current in the calculated amount is supplied to the light-emitting element 12. Therefore, it is possible to perform control with high responsiveness. In addition, since the control function is defined by a multidimensional polynomial of degree two or more, it is possible to perform control with high accuracy.

[0066] The light-emitting element 12 may include a second storage unit 42 in which information regarding the coefficient α_{ts} in the control function corresponding to the light-emitting element 12 is recorded (see Fig. 8). For example, there is a case where the light-emitting element 12 is to be replaced in the light source apparatus 1. In this case, the coefficient α_{ts} of a certain light-emitting element 12 (hereinafter referred to as a "light-emitting element 12A" for convenience) and the coefficient α_{ts} of another light-emitting element 12 (hereinafter referred to as a "light-emitting element 12B" for convenience) are not necessarily the same. Therefore, when the light-emitting element 12A is replaced with the light-emitting element 12B and the light-emitting element 12B is attached to the light source apparatus 1, the control unit 22 may read the information regarding the coefficient α_{ts} recorded in the second storage unit 42 of the light-emitting element 12B and record the read information in the first storage unit 26.

[0067] As a more specific example, the light-emitting element 12 may be detachable from the drive unit 20 including the drive circuit 21 and the control unit 22, and the information recorded in the second storage unit 42 of the light-emitting element 12 may be read from the drive unit 20 (control unit 22) by connecting the light-emitting element 12 and the drive unit 20. Furthermore, as another example, the second storage unit 42 includes, for example, an IC tag, and the drive unit 20 has a function of reading the IC tag. When the light-emitting element 12A is replaced with the light-emitting element 12B, the drive unit 20 (control unit 22) reads the IC tag attached to the light-emitting element 12B to be newly attached, and information regarding the coefficient α_{ts} corresponding to the light-emitting element 12B is recorded in the first storage unit 26.

[Second embodiment]

[0068] When the light source apparatus 1 is continuously used for a long period of time, the light output decreases even if the same amount of current is supplied to the light-emitting element 12. In this case, even when the output control is performed on the light-emitting element 12 using a control function defined based on, for example, the information measured in a test before shipment, the light output may not reach the target light output in a short time.

[0069] In view of this, a calibration device 50 for correcting the control function corresponding to the light-emitting element 12 may be used as illustrated in Figs. 9 and 10. Fig. 10 is a functional block diagram schematically illustrating configurations of the calibration device 50 and the light source apparatus 1.

[0070] The calibration device 50 illustrated in Fig. 10 includes an information updating unit 51 that creates update information of the coefficient α_{ts} in the control function, and an instruction signal output unit 52 for instructing the start of a calibration process.

[0071] When the calibration process is performed, the instruction signal output unit 52 outputs an instruction signal cs instructing the calibration process to the light source apparatus 1. When confirming the input of the calibration instruction signal cs, the control unit 22 performs control to cause the light-emitting element 12 to emit light while intentionally changing the amount of current supplied from the drive circuit 21 to the light-emitting element 12. Then, information regarding coordinates (P, T, I) in which the light output P (corresponding to a "first actual measurement value") obtained by receiving the light L12 obtained at this time by the light-receiving sensor 41 and the temperature T (corresponding to a "measured temperature value") detected by the temperature detector 19 are associated with the current amount I (corresponding to a "second actual measurement value") is output to the information updating unit 51. The information updating unit 51 derives a function (control function) in which a given coordinate group can be present by arithmetic processing using fitting processing, and determines a new coefficient α_{TS}. The information regarding the coordinates (P, T, I) is acquired for (k + 1) × (j + 1) points or more and output to the information updating unit 51. The k and j herein are the same as k and j in mathematical formula (1). That is, in a case where k = 2 and j = 2 as in the above example, the information regarding the coordinates (P, T, I) for nine or more points is acquired.

[0072] The method of the fitting processing may be similar to the method of determining the control function performed before shipment. Specifically, the control function defined in mathematical formula (4) similar to mathematical formula (1) is fitted to the measurement result (X_i, Y_i, Z_i) (where i = 0, 1,..., n) obtained by assigning the light output P to the variable X, the temperature T to the variable Y, and the current amount I to the variable Z using, for example, the least-square method, whereby an update control function is determined. Note that the values of k and j in mathematical formula (4) are the same as the values in mathematical formula (1), and at least one of k or j is an integer of 2 or more and the other is an integer of 1 or more.

$$Z = \sum_{T=0}^{k} \left(\sum_{S=0}^{j} \alpha_{TS} \cdot Y^{S} \right) \cdot X^{T} \qquad (4)$$

[0073] As described above, the information regarding the control function derived by performing a light emission test on the light-emitting element 12 before shipment is recorded in the first storage unit 26 included in the control unit 22. The calibration device 50 according to the present embodiment has a function of performing a process of deriving a control function corresponding to the light-emitting element 12 at present by performing a test similar to that performed before shipment after the light source apparatus 1 is started to be used. Then, the calibration device 50 outputs the derived update control function to the first storage unit 26 as update information. Note that, at this time, the update information may be only information related to the coefficient α_{TS} obtained for determining the update control function, or may be information of the function itself.

[0074] As illustrated in Fig. 11, the calibration device 50 may be incorporated in the light source apparatus 1. In this case, a process for reviewing the control function (that is, the calibration process) can be frequently performed, and thus, the accuracy of the light output control is further improved.

[0075] Furthermore, in the example illustrated in Fig. 10, the light source apparatus 1 includes the light-receiving sensor 41, and the information regarding the light output P based on an amount of light received by the light-receiving sensor 41 is transmitted to the calibration device 50. However, in a case where the calibration device 50 includes a light-receiving sensor 53 as illustrated in Fig. 12, the light-receiving sensor 53 in the calibration device 50 may receive a part or all of the light L12 emitted from the light-emitting element 12, and the information updating unit 51 may perform the process of deriving the control function using the light output P based on the received light amount. Note that, in the configuration illustrated in Fig. 12, the light source apparatus 1 may include the light-receiving sensor 41 as in Fig. 10.

[Another embodiment]

[0076] Another embodiment will be described below.

[0077] <1> The light source apparatus 1 may include a plurality of light-emitting elements 12 having different wavelengths. In this case, information regarding different control functions may be recorded in the first storage unit 26 for each of light-emitting elements 12 having different wavelengths. For example, in a case where the light-emitting element 12 includes a light-emitting element 12R that emits red light, a light-emitting element 12G that emits green light, and a light-emitting element 12B that emits blue light, a control function used for controlling the light-emitting element 12R, a control function used for controlling the light-emitting element 12G, and a control function used for controlling the light-emitting element 12B are recorded in the first storage unit 26.

[0078] Due to the control unit 22 controlling an amount of current supplied to the light-emitting element 12 based on the control functions set according to the wavelengths as described above, the light output can be controlled with the color balance being maintained. For example, the present invention exhibits a high effect in an application requiring maintenance of color balance and controllability of light output, such as a solar simulator.

[0079] <2> In the present invention, the type of light-emitting element 12 is not limited. The present invention is applied to the light source apparatus 1 including the light-emitting element 12 having a light output that can be controlled by a supplied amount of current and that is affected by the temperature near the light-emitting element 12. It is to be noted, however, that the light-emitting element 12 is typically a semiconductor light-emitting element such as an LED or a laser diode (LD).

[0080] <3> In the present invention, the structure of the light source apparatus 1 is not limited. However, the present invention exhibits a high effect particularly when the light source apparatus 1 is used with the output of the light L12 emitted from the light-emitting element 12 being frequently changed. Examples thereof include a light source for an endoscope. The present invention also exhibits a high effect in a case where an object is repeatedly irradiated with a constant dose, and examples thereof include an exposure device and a printing machine.

[0081] <4> The above embodiments describe the case using a control function that uses the information regarding the light output P and the temperature T as the independent variable (x, y) and the information regarding the current amount I as the dependent variable z. However, the format of the control function recorded in the first storage unit 26 is not limited thereto. For example, a control function using information regarding the light output P and the temperature T as the variable (x, z) and information regarding the current amount I as the variable y in mathematical formula (1) may be recorded in the first storage unit 26. In this case, the arithmetic processing unit 25 transforms the control function represented by mathematical formula (1) into a form of obtaining the value of the variable y and then applies the information regarding the target value Φ of the light output and the temperature T to the transformation formula to determine the supply current amount I of the current supplied to the light-emitting element 12, for example.

[0082] As a specific example, when the supply current amount I to be obtained corresponds to the variable y, the light output P corresponds to the variable x, and the temperature T corresponds to the variable z in mathematical formula (5) above, the supply current amount I is obtained using the transformation formula indicated by mathematical formula (3) above. Formula (3) is described again below.

$$I = \frac{-\alpha_1(T) + \sqrt{\alpha_1(T)^2 - 4 \cdot \alpha_2(T) \cdot (\alpha_0(T) - \Phi)}}{2 \cdot \alpha_2(T)} \qquad (3)$$

where $\alpha_0(T)$, $\alpha_1(T)$, and $\alpha_2(T)$ correspond to formulas below, respectively:

$$\alpha_0(T) = \alpha_{00} + \alpha_{01} \cdot T + \alpha_{02} \cdot T^2$$

$$\alpha_1(T) = \alpha_{10} + \alpha_{11} \cdot T + \alpha_{12} \cdot T^2$$

$$\alpha_2(T) = \alpha_{20} + \alpha_{21} \cdot T + \alpha_{22} \cdot T^2.$$

[0083] <4> The above embodiments describe the case of using a least-square method as a method of the processing (fitting processing) of deriving the control function from the coordinates (P, T, I) constituted by the light output P, the temperature T, and the current amount I. However, the fitting processing may be performed by a method other than the least-square method. As an example, a control function serving as a reference is set by optionally setting the value of the coefficient α_{ts} (or the coefficient α_{TS}), and the deviation between the set control function and the coordinates (P, T, I) is evaluated. Next, the control function set by changing the value of the coefficient α_{ts} (or the coefficient α_{TS}) is changed, and the deviation is evaluated similarly. This process is repeatedly performed to change the value of the coefficient α_{ts} (or the coefficient α_{TS}) until the deviation becomes sufficiently small, and the control function represented by mathematical formula (1) or (4) may be specified by the determined value of the coefficient α_{ts} (or the coefficient α_{TS}).

Claims

1. A light source apparatus (1) comprising:

a light-emitting element (12);
a temperature detector (19) that detects a temperature of an installation location of the light-emitting element (12);
a drive circuit (21) that supplies a current to the light-emitting element (12);
a control unit (22) that controls the current supplied from the drive circuit (21) to the light-emitting element (12); and
a target light output receiving unit (31) that receives an input of information corresponding to a target value Φ of a light output of the light-emitting element (12),
wherein
the control unit (22) includes:

a first storage unit (26) in which a control function is recorded for obtaining a third variable correlated with the current supplied to the light-emitting element (12) from a first variable correlated with the temperature of the installation location of the light-emitting element (12) and a second variable correlated with the light output of the light-emitting element (12); and
an arithmetic processing unit (25) that determines a supply current amount to the light-emitting element (12), which is the third variable, by reading the control function from the first storage unit (26), substituting a temperature T detected by the temperature detector (19) for the first variable, and substituting the target value Φ for which the target light output receiving unit has received input for the second variable,

the control function is a curved surface function specified in mathematical formula (1) below that includes an independent variable x, an independent variable y, and a dependent variable z, the control function being a function converted into a formula for obtaining the third variable by assigning the first variable, the second variable, and the third variable to one of the independent variable x, the independent variable y, and the dependent variable z, and
the curved surface function has a shape determined by a coefficient α_{ts} in mathematical formula (1) below:

$$z = \sum_{t=0}^{k} \left(\sum_{s=0}^{j} \alpha_{ts} \cdot y^s \right) \cdot x^t \qquad (1)$$

where α_{ts} ($0 \le t \le k$, $0 \le s \le j$) is the coefficient, one of k or j is an integer of 2 or more, and another one is an integer of 1 or more.

2. The light source apparatus (1) according to claim 1, wherein

the first variable corresponds to the independent variable x, the second variable corresponds to the independent variable y, the third variable corresponds to the dependent variable z, and
the arithmetic processing unit (25) determines the supply current amount to the light-emitting element (12) by a value of the dependent variable z in the control function which is obtained by an arithmetic operation based on mathematical formula (1) with applying the temperature T to the independent variable x in the control function and applying the target value Φ to the independent variable y in the control function.

3. The light source apparatus (1) according to claim 1, wherein

one of the first variable and the second variable corresponds to the independent variable x, the other to the dependent variable z, the third variable corresponds to the independent variable y, and
the arithmetic processing unit (25) transforms the control function represented by mathematical formula (1) into a transformed formula for calculating the independent variable y and determines the supply current amount to the light-emitting element (12) by a value of the independent variable y calculated by an arithmetic operation that applies the temperature T and the target value Φ to the corresponding independent variable x and dependent variable z, respectively, in the transformed formula.

4. The light source apparatus (1) according to claim 2, wherein

in mathematical formula (1), both k and j are 2, and
the arithmetic processing unit (25) determines the supply current amount by a current amount I obtained by an arithmetic operation based on mathematical formula (2) below:

$$I = \alpha_0(T) + \alpha_1(T) \cdot \Phi + \alpha_2(T) \cdot \Phi^2 \qquad (2)$$

where $\alpha_0(T)$, $\alpha_1(T)$, and $\alpha_2(T)$ correspond to formulas below, respectively:

$$\alpha_0(T) = \alpha_{00} + \alpha_{01} \cdot T + \alpha_{02} \cdot T^2$$

$$\alpha_1(T) = \alpha_{10} + \alpha_{11} \cdot T + \alpha_{12} \cdot T^2$$

$$\alpha_2(T) = \alpha_{20} + \alpha_{21} \cdot T + \alpha_{22} \cdot T^2.$$

5. The light source apparatus (1) according to claim 3, wherein

in mathematical formula (1), both k and j are 2, and
the arithmetic processing unit (25) determines the supply current amount by a current amount I obtained by an arithmetic operation based on mathematical formula (3) below:

$$I = \frac{-\alpha_1(T) + \sqrt{\alpha_1(T)^2 - 4 \cdot \alpha_2(T) \cdot (\alpha_0(T) - \Phi)}}{2 \cdot \alpha_2(T)} \qquad (3)$$

where $\alpha_0(T)$, $\alpha_1(T)$, and $\alpha_2(T)$ correspond to formulas below, respectively:

$$\alpha_0(T) = \alpha_{00} + \alpha_{01} \cdot T + \alpha_{02} \cdot T^2$$

$$\alpha_1(T) = \alpha_{10} + \alpha_{11} \cdot T + \alpha_{12} \cdot T^2$$

$$\alpha_2(T) = \alpha_{20} + \alpha_{21} \cdot T + \alpha_{22} \cdot T^2.$$

6. The light source apparatus (1) according to any one of claims 1 to 5, wherein the control unit (22) includes an input port (27) receiving an input of information regarding a value of the coefficient α_{ts}.

7. The light source apparatus (1) according to claim 6, further comprising

a drive unit (20) on which the drive circuit and the control unit are mounted and which is detachable from the light-emitting element (12),
wherein

the light-emitting element (12) includes a second storage unit (42) in which information regarding the value of the coefficient α_{ts} uniquely assigned to the light-emitting element (12) is recorded, and
when the drive unit (20) and the light-emitting element (12) are connected, information regarding the value of the coefficient α_{ts} recorded in the second storage unit (42) is input to the control unit (22) via the input port (27).

8. The light source apparatus (1) according to any one of claims 1 to 7, wherein

a plurality of the light-emitting elements (3, 3,...) having different wavelengths is provided, and
the first storage unit (26) records the control function different for each of the light-emitting elements (3, 3,...).

9. A calibration device (50) that performs a calibration process for the light source apparatus (1) according to any one of claims 1 to 8, the calibration device (50) comprising

an information updating unit (51) that creates update information of the coefficient α_{ts} in the control function and performs update processing on the first storage unit (26) included in the light source apparatus (1),
wherein

the information updating unit (51)

determines, by arithmetic processing, an update control function represented by mathematical formula (4) in which a first actual measurement value correlated with a light output from the light-emitting element (12), a second actual measurement value correlated with an amount of current supplied to the light-emitting element (12), and a measured temperature value correlated with a temperature of the installation location of the light-emitting element (12) are associated with any of an independent variable X, an independent variable Y, and a dependent variable Z under a light-emitting state of the light-emitting element (12), and
outputs information regarding a coefficient α_{TS} in the update control function to the first storage unit (26) as the update information:

$$Z = \sum_{T=0}^{k} \left(\sum_{S=0}^{j} \alpha_{TS} \cdot Y^S \right) \cdot X^T \tag{4}$$

where values of k and j in mathematical formula (4) coincide with the values of k and j in mathematical formula (1), respectively.

10. The calibration device (50) according to claim 9, wherein the information updating unit (51) acquires coordinate information including the first actual measurement value, the second actual measurement value, and the measured temperature value for at least (k + 1) × (j + 1) points, and determines the update control function by a least-square method based on a plurality of pieces of the coordinate information.

11. The calibration device (50) according to claim 9 or 10, wherein

the light source apparatus (1) includes a light-receiving sensor (41) that receives light emitted from the light-emitting element (12), and
the information updating unit (51) acquires the first actual measurement value based on a light amount detected by the light-receiving sensor (41), acquires the second actual measurement value based on a controlled amount of a current by the control unit (22), and acquires the measured temperature value based on a temperature detected by the temperature detector (19).

12. The calibration device (50) according to any one of claims 9 to 11, further comprising

an instruction signal output unit (52) that outputs, to the control unit (22) of the light source apparatus (1), an instruction signal indicating execution of light emission with an amount of current supplied to the light-emitting element (12) being changed for the calibration process,
wherein the information updating unit (51) acquires the first actual measurement value, the second actual measurement value, and the measured temperature value from the light-emitting element (12) that is in a light emission state in response to the instruction signal.

Fig. 1

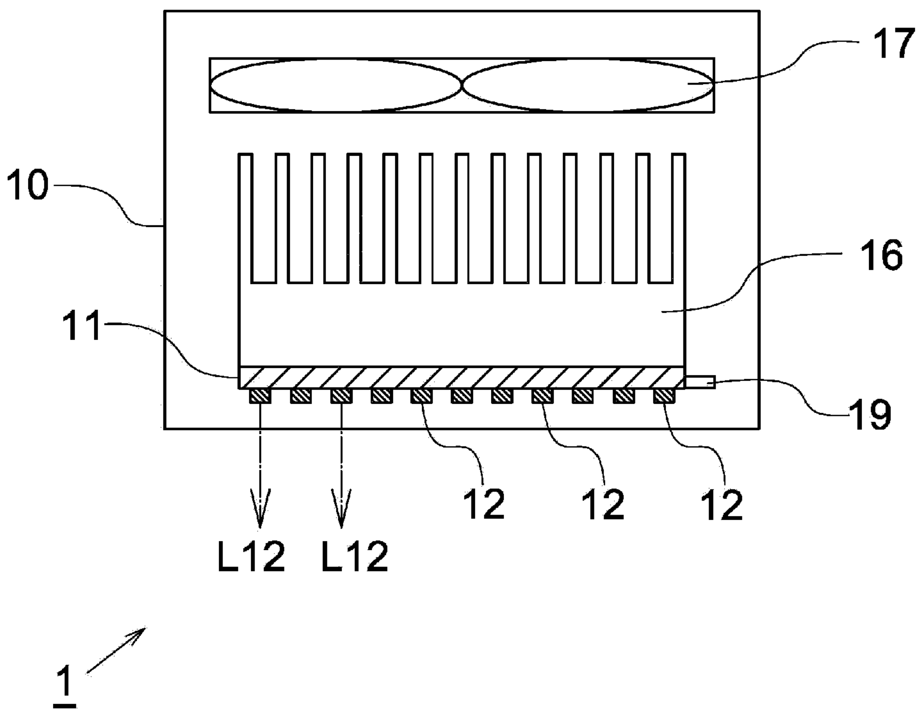


Fig. 2

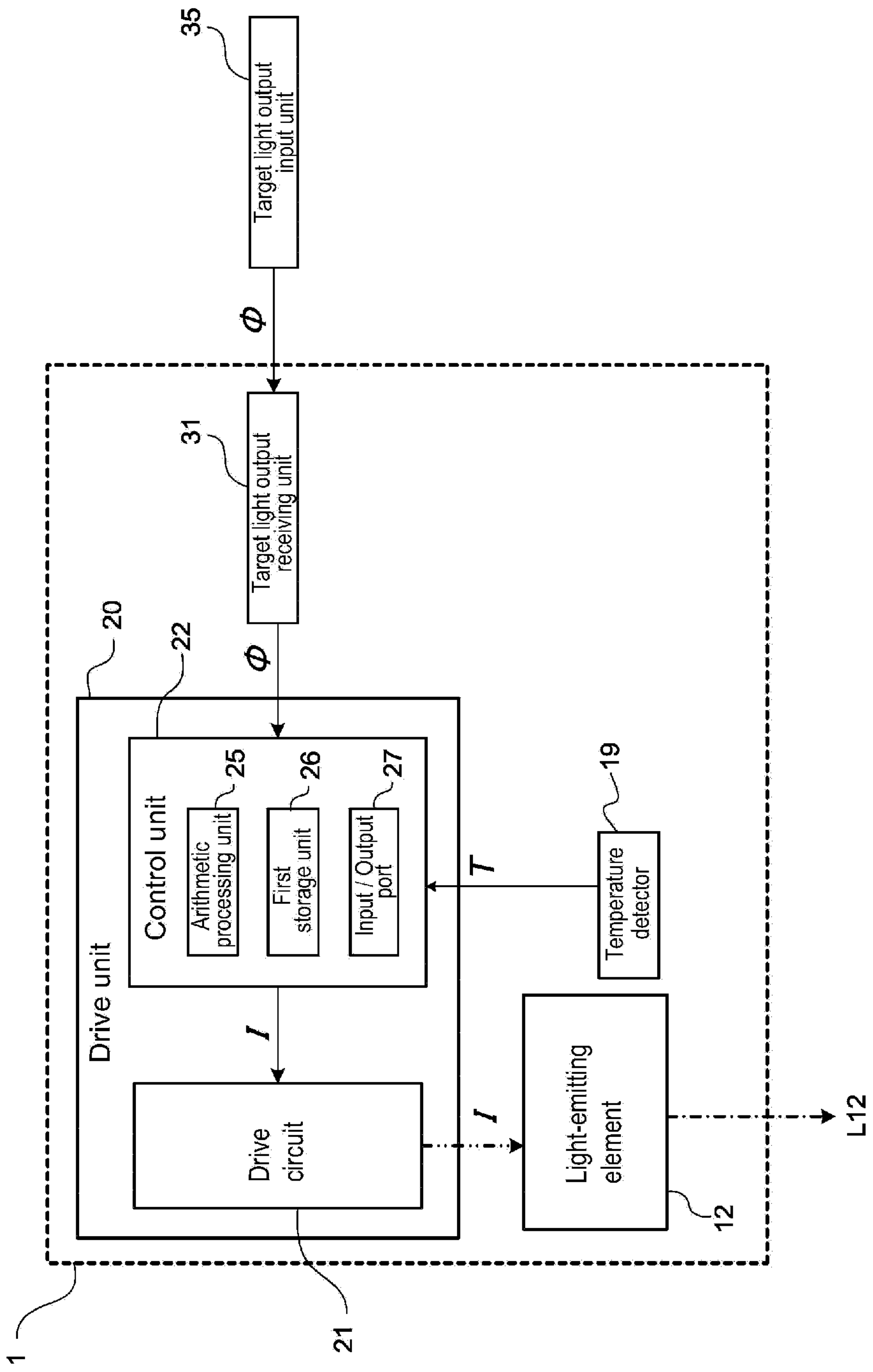
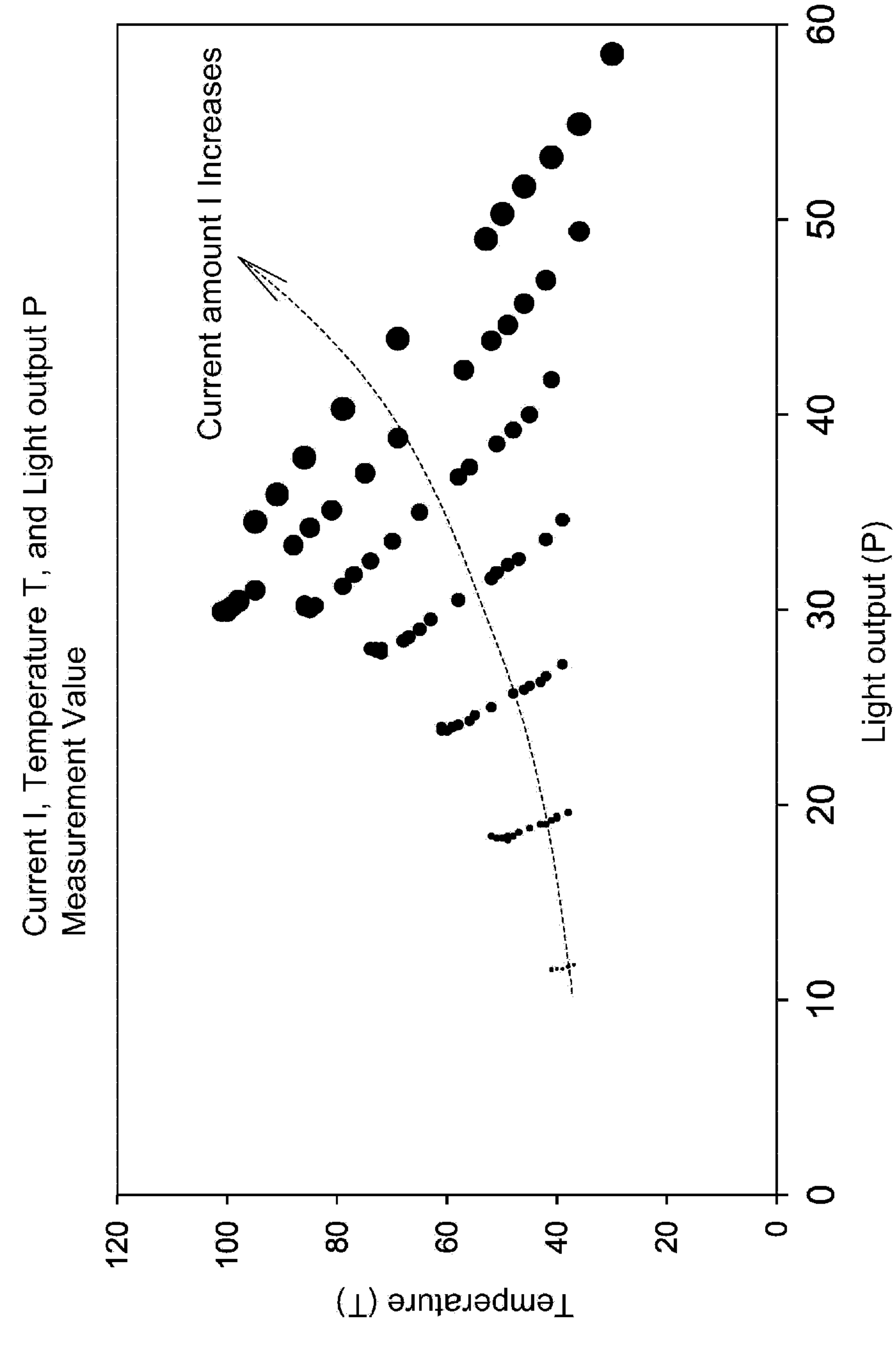

Target light output input unit
35
Φ
Target light output receiving unit
31
Φ
20
22
Drive unit
Control unit
Arithmetic processing unit
25
First storage unit
26
Input / Output port
27
T
Temperature detector
19
I
Drive circuit
21
I
Light-emitting element
12
L12
1

Fig. 3


Current I, Temperature T, and Light output P
Measurement Value
Current amount I Increases
Temperature (T)
Light output (P)
0
20
40
60
80
100
120
0
10
20
30
40
50
60

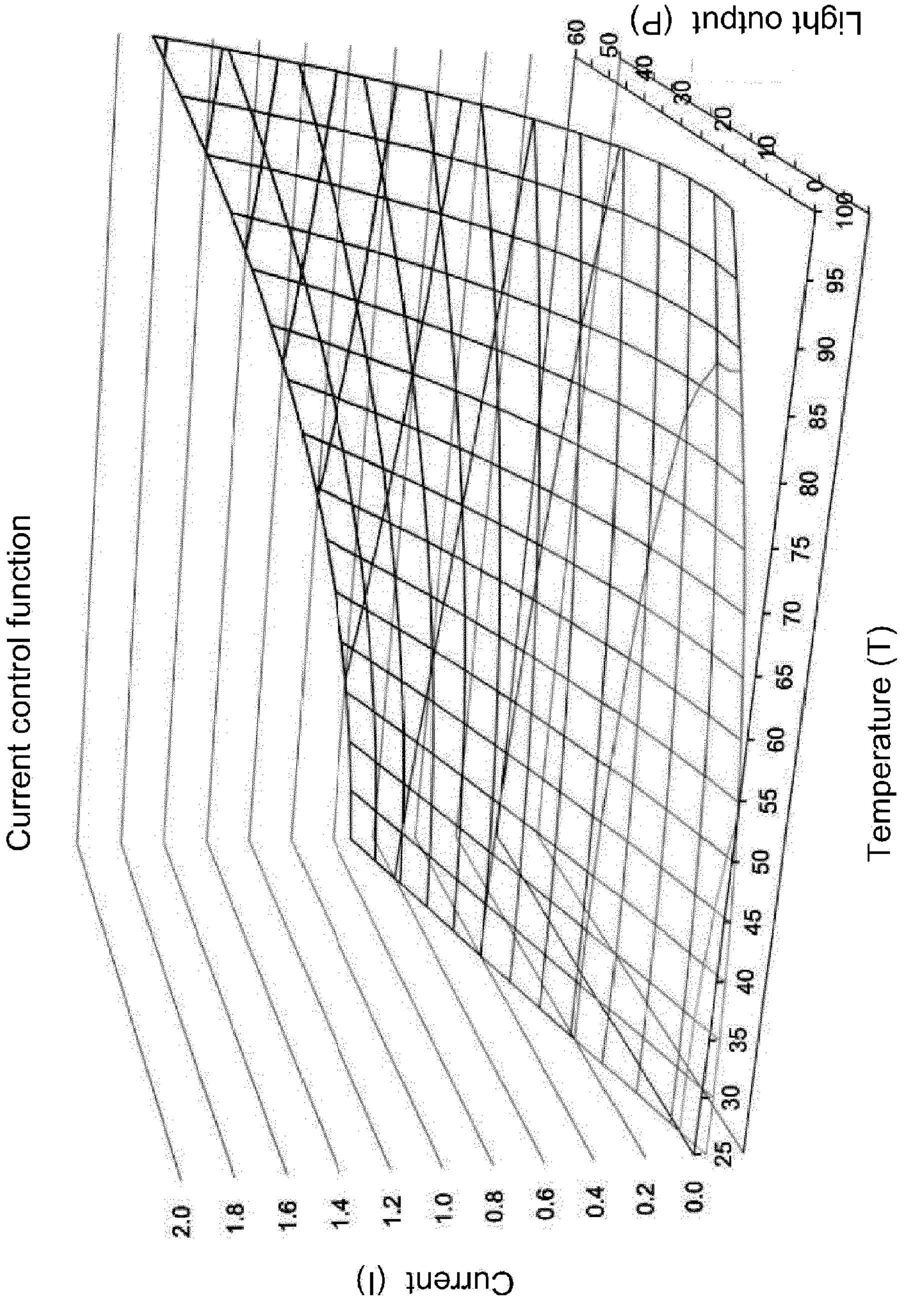

Current control function
Current (I)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Temperature (T)
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Light output (P)
0
10
20
30
40
50
60

Fig. 4

Fig. 5

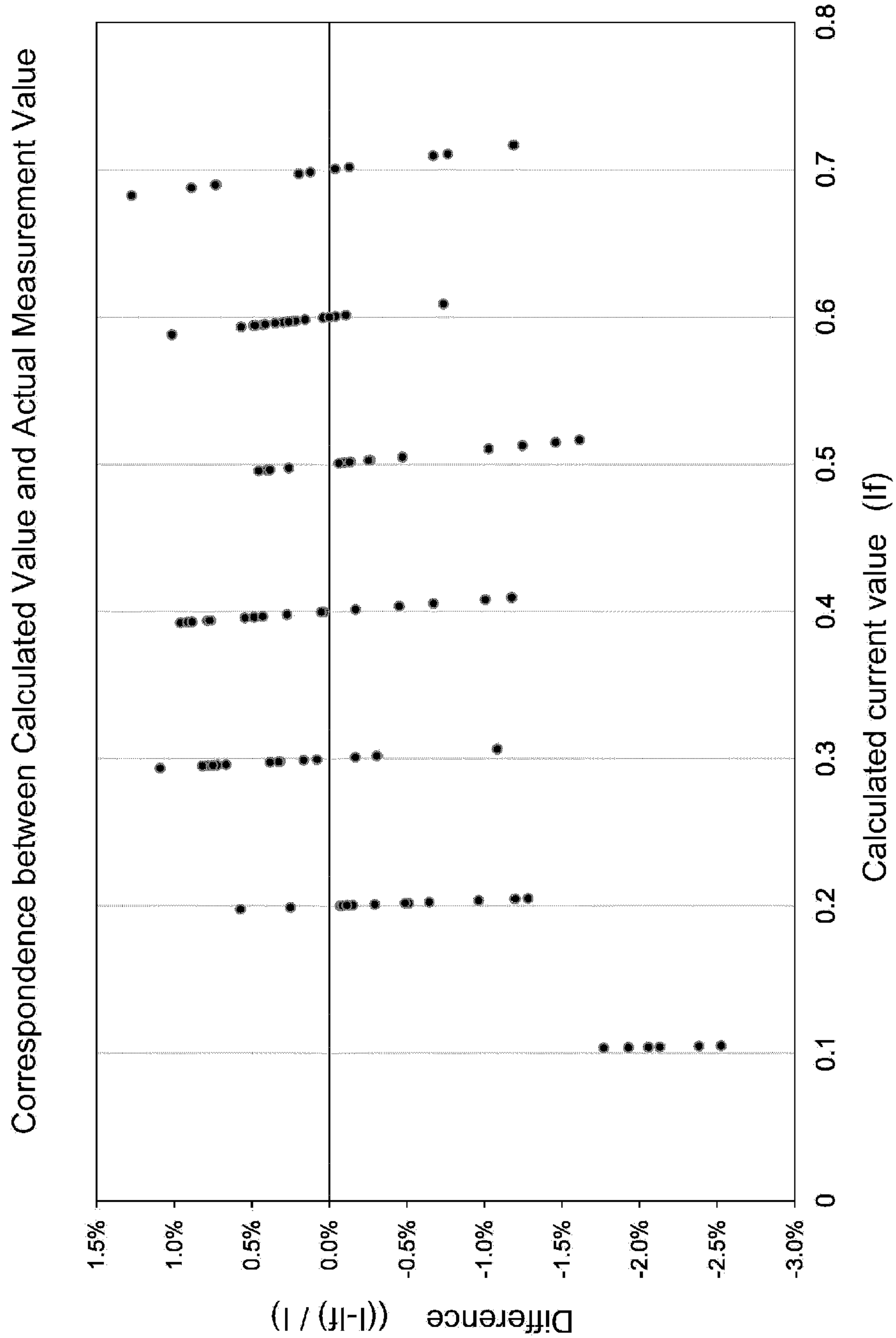

Correspondence between Calculated Value and Actual Measurement Value
Difference ((I-If) / I)
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
-1.5%
-2.0%
-2.5%
-3.0%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Calculated current value (If)

Fig. 6A

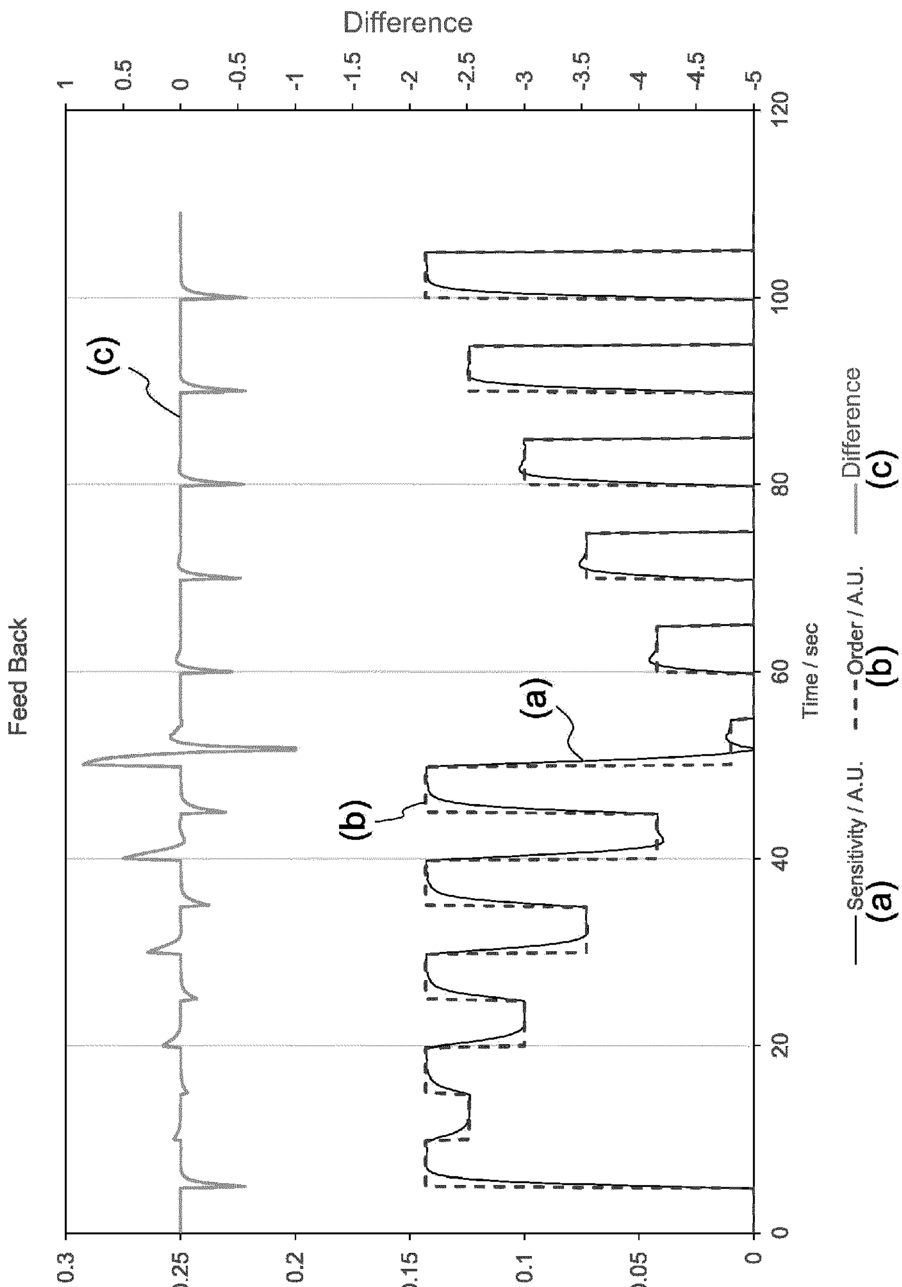

Feed Back
Difference
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
Sensitivity / A.U.
0.3
0.25
0.2
0.15
0.1
0.05
0
Time / sec
0
20
40
60
80
100
120
(a)
(b)
(c)
Sensitivity / A.U.
Order / A.U.
Difference

Fig. 6B

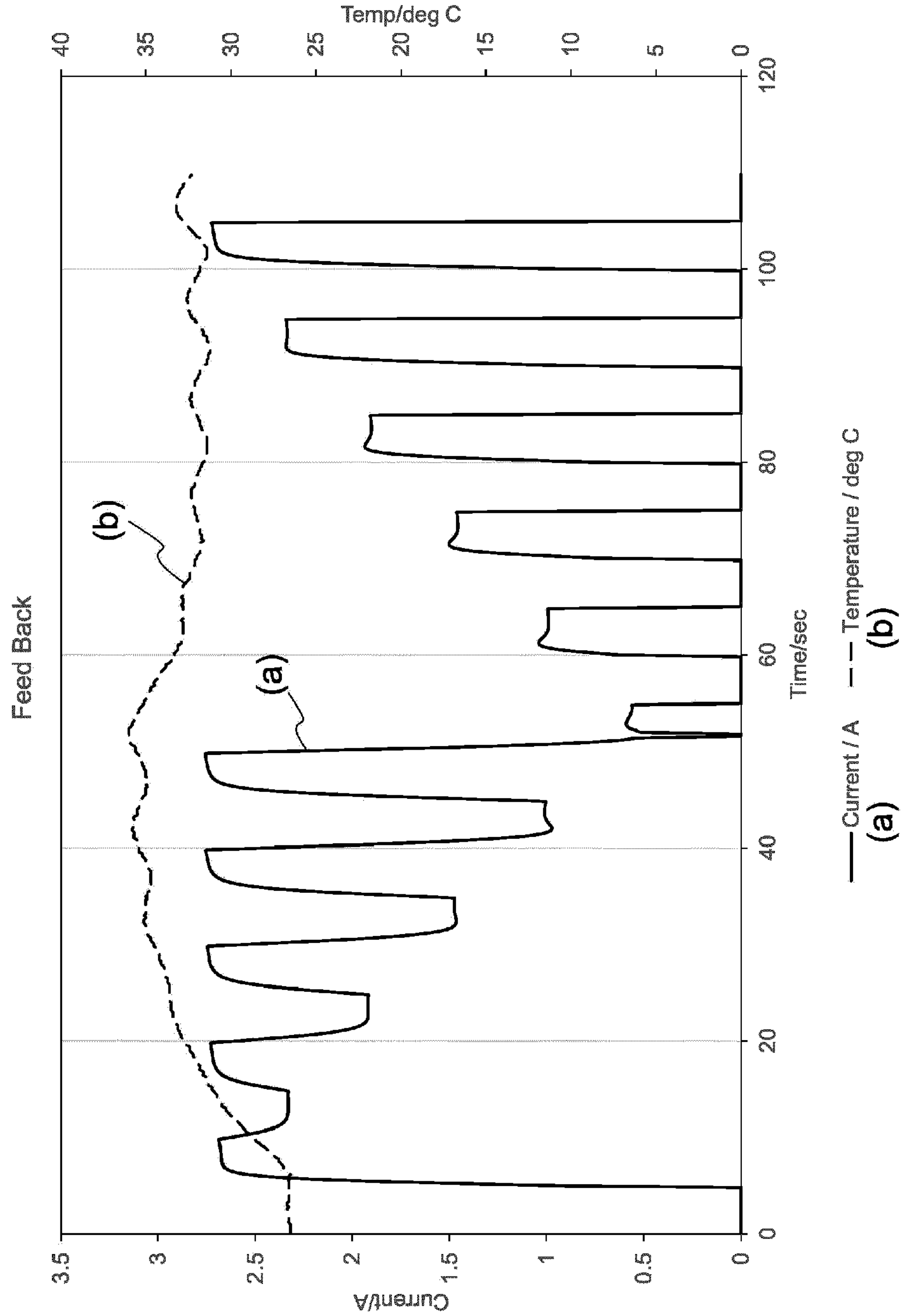

Feed Back
Temp/deg C
Current/A
Time/sec
(a)
(b)
Current / A
Temperature / deg C

Fig. 7A

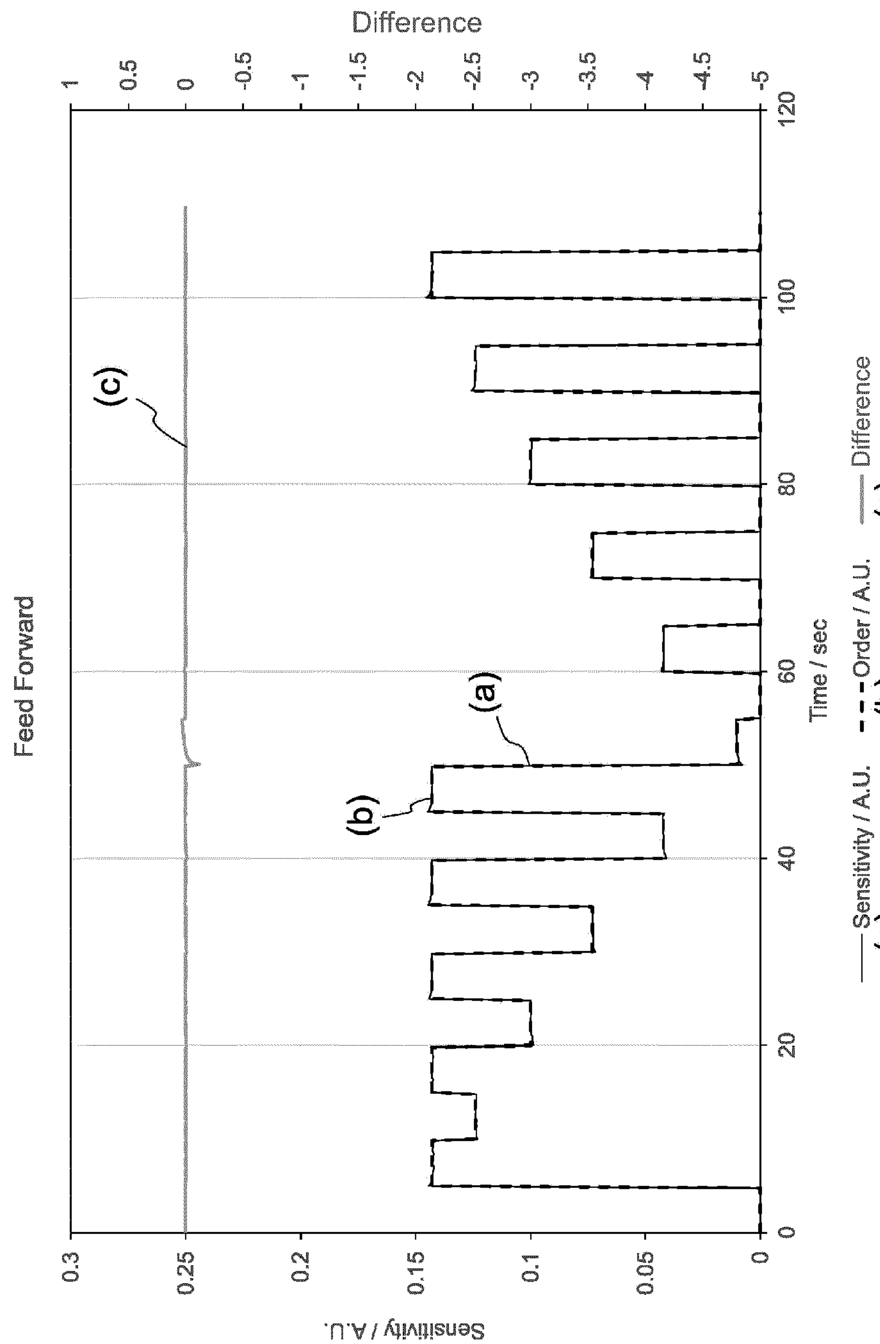

Feed Forward
Difference
Sensitivity / A.U.
Time / sec
(a) Sensitivity / A.U.
(b) Order / A.U.
(c) Difference
(a)
(b)
(c)
0
20
40
60
80
100
120
0
0.05
0.1
0.15
0.2
0.25
0.3
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5

Fig. 7B

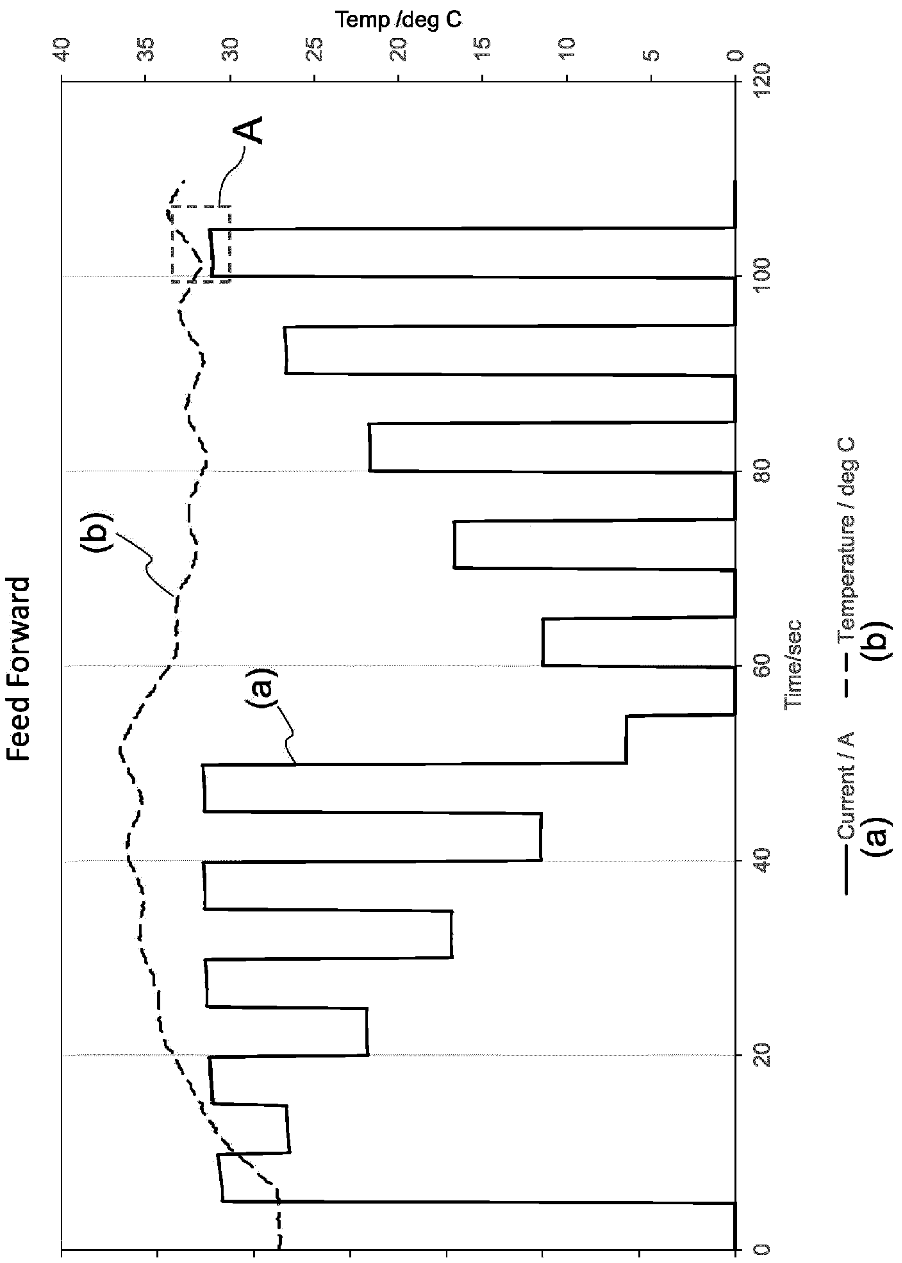

Feed Forward
Temp /deg C
Current / A
Time/sec
(a)
(b)
A
(a) Current / A
(b) Temperature / deg C

Fig. 7C

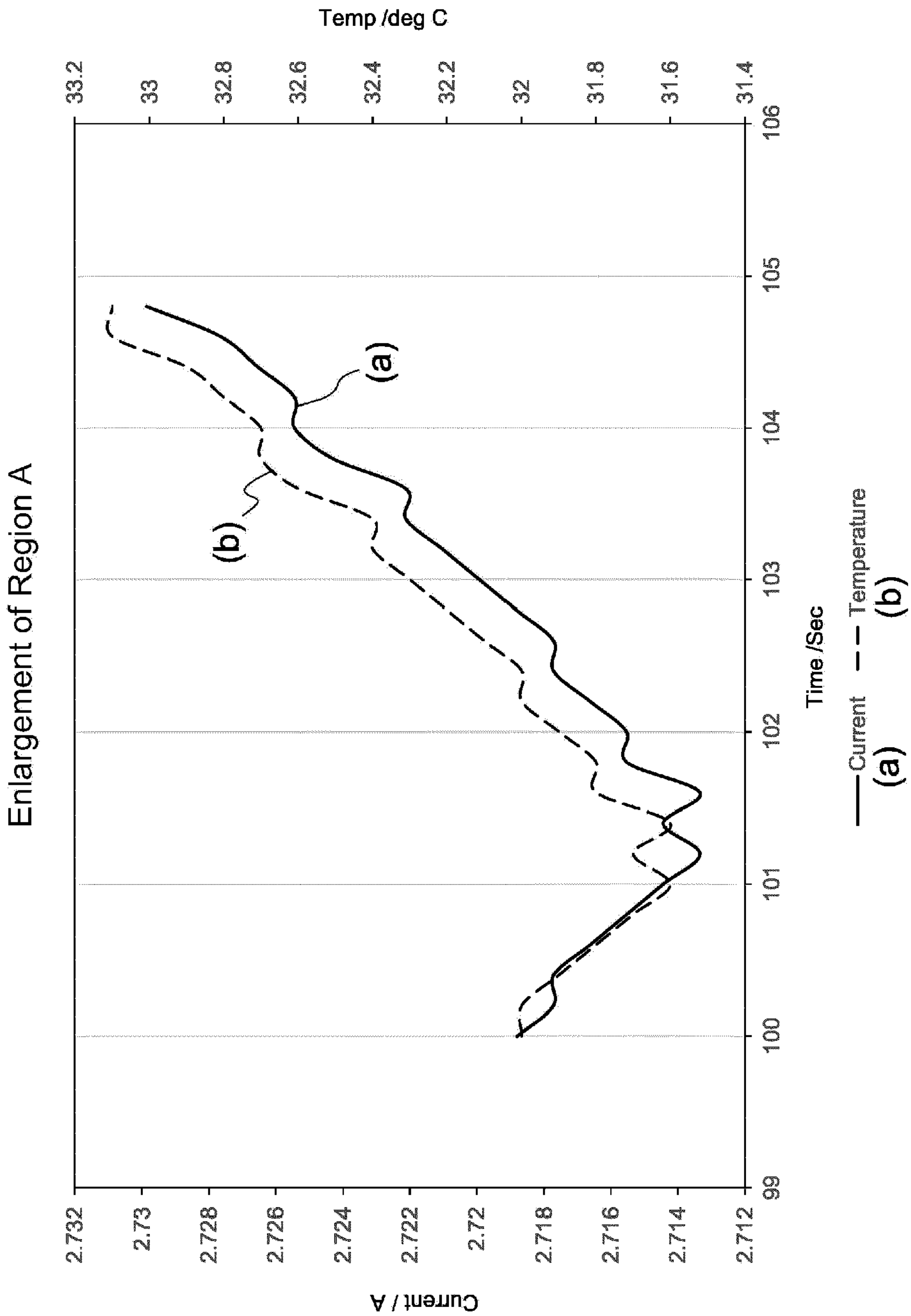

Enlargement of Region A
Temp /deg C
33.2
33
32.8
32.6
32.4
32.2
32
31.8
31.6
31.4
Current / A
2.732
2.73
2.728
2.726
2.724
2.722
2.72
2.718
2.716
2.714
2.712
Time /Sec
99
100
101
102
103
104
105
106
(a)
(b)
(a) Current
(b) Temperature

Fig. 8

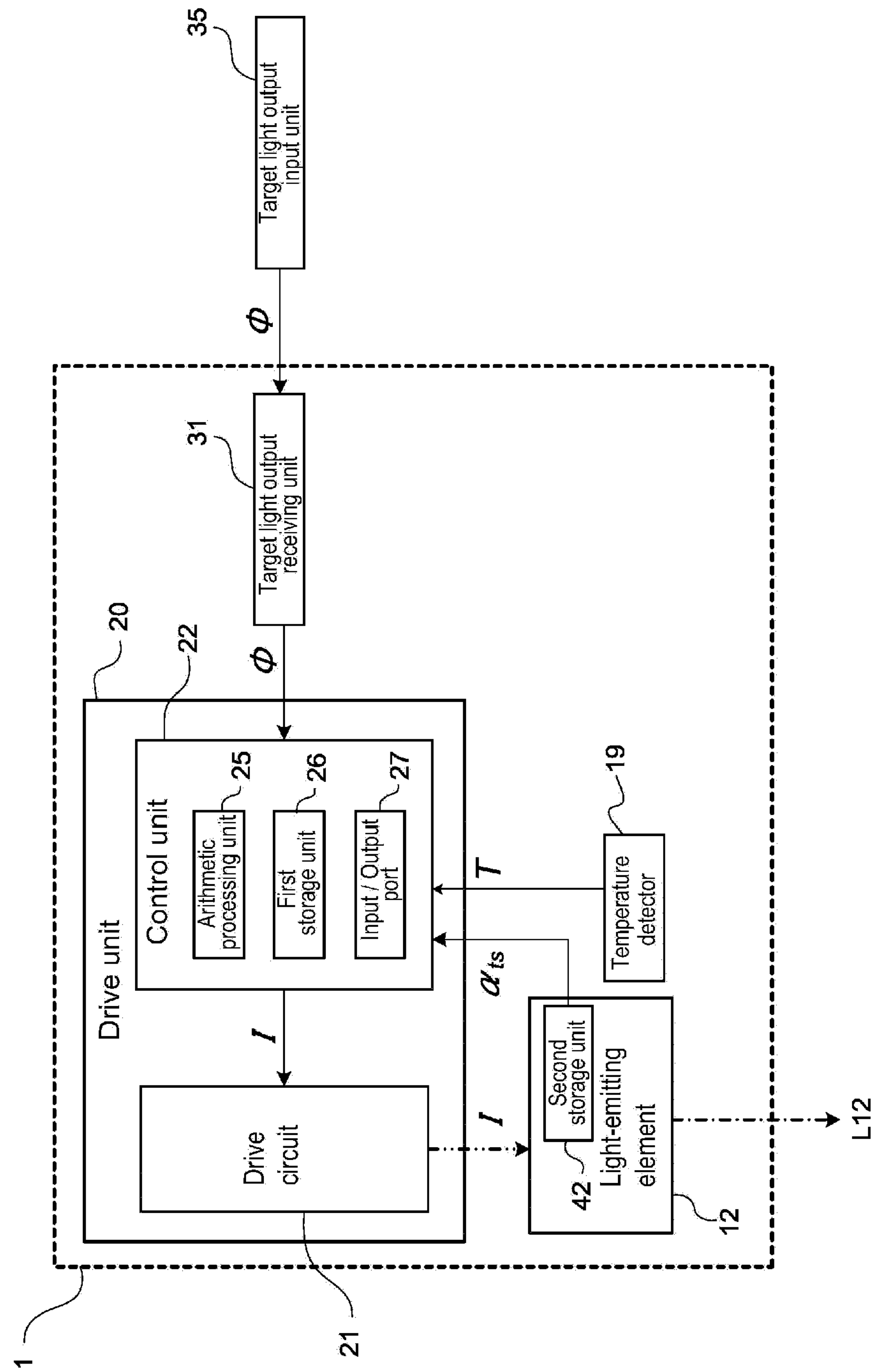

35
Target light output input unit
Φ
31
Target light output receiving unit
Φ
20
22
1
Drive unit
Control unit
25
Arithmetic processing unit
26
First storage unit
27
Input / Output port
T
19
Temperature detector
α_{ts}
I
Drive circuit
21
I
Second storage unit
42
Light-emitting element
12
L12

Fig. 9

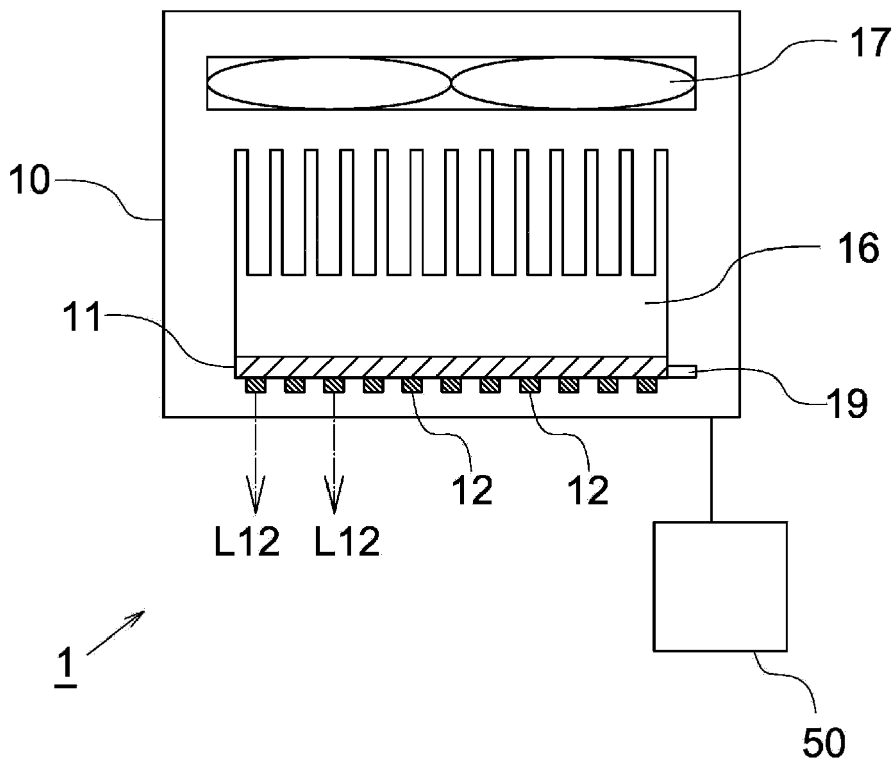


Fig. 10

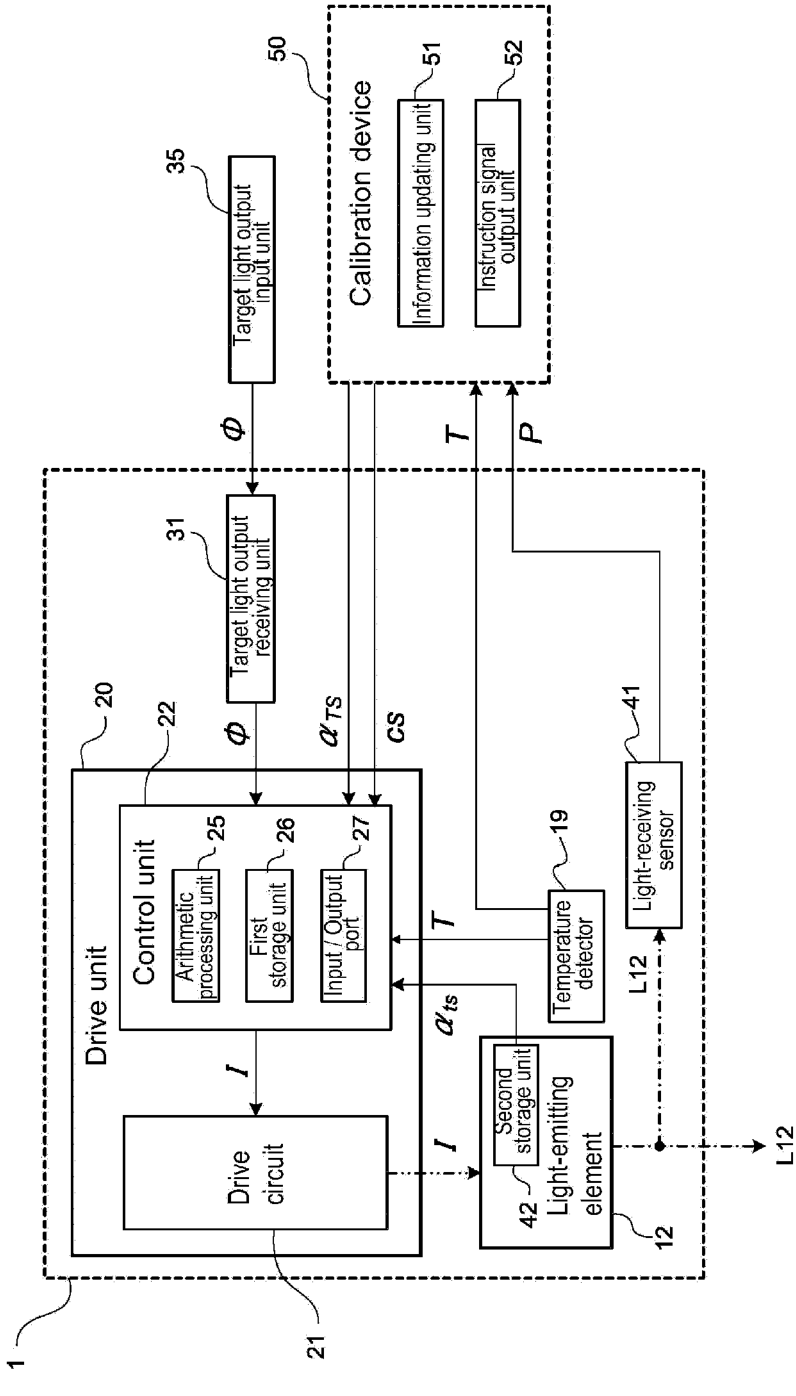

Calibration device
Information updating unit
Instruction signal output unit
Target light output input unit
Target light output receiving unit
Drive unit
Control unit
Arithmetic processing unit
First storage unit
Input / Output port
Drive circuit
Second storage unit
Light-emitting element
Temperature detector
Light-receiving sensor
Φ
α'TS
CS
T
P
I
α'ts
L12
1
12
19
20
21
22
25
26
27
31
35
41
42
50
51
52

Fig. 11

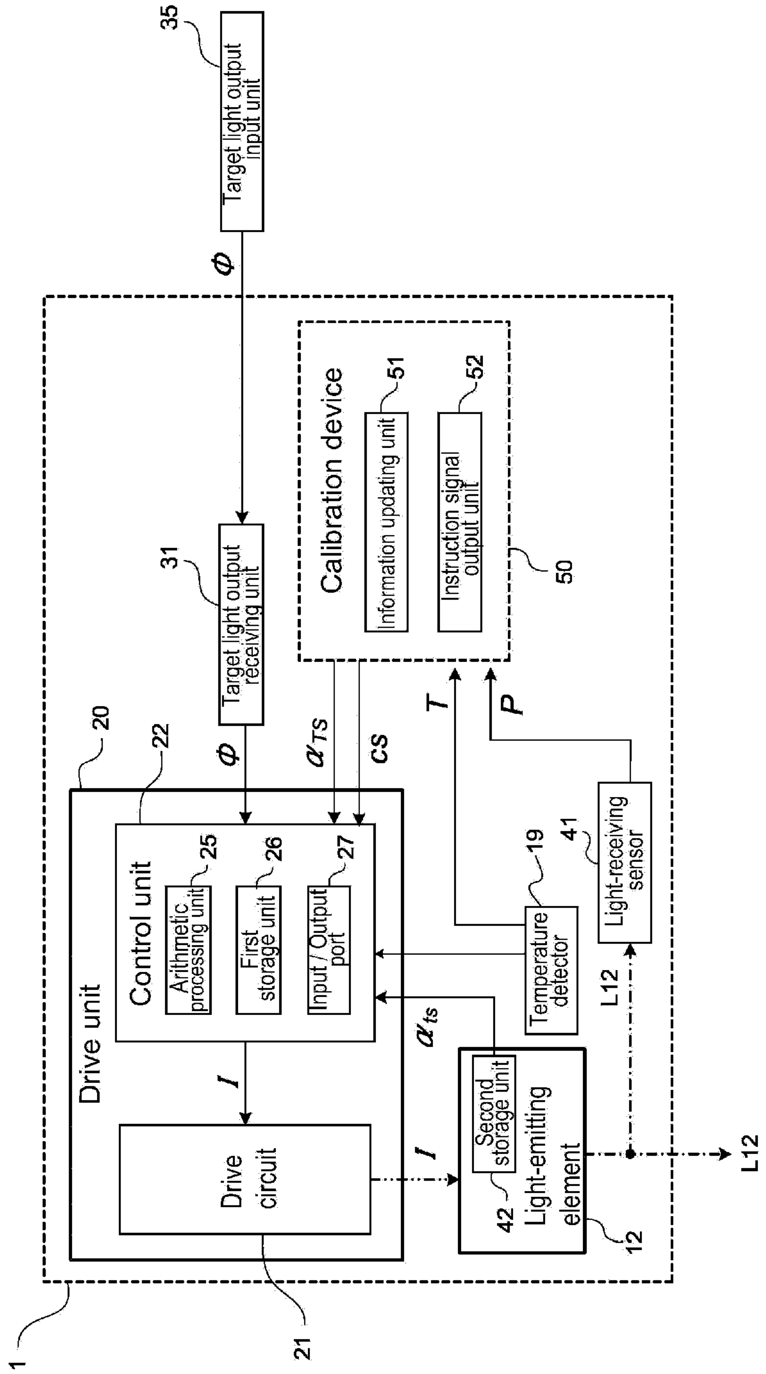
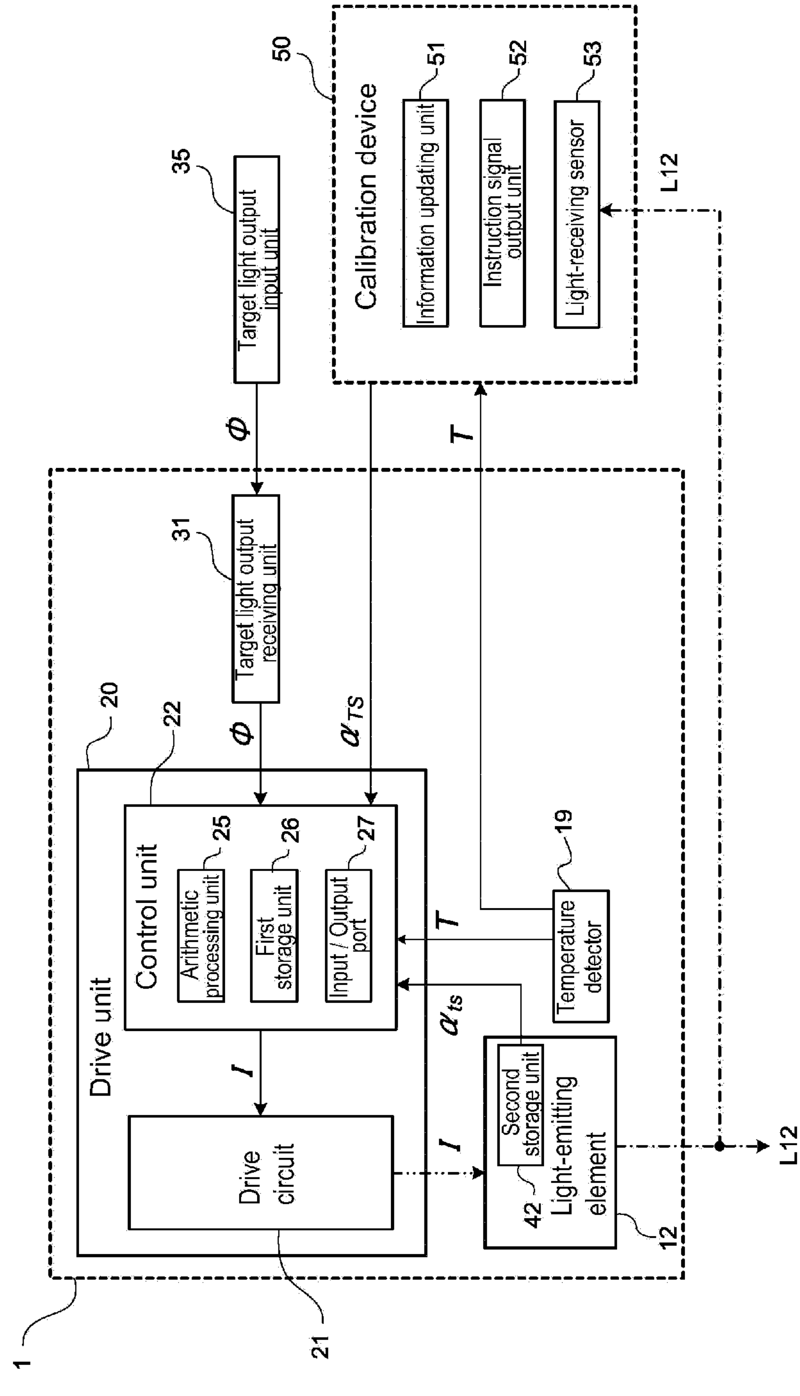

Target light output input unit
35
Φ
31
Target light output receiving unit
Calibration device
Information updating unit
51
Instruction signal output unit
52
50
20
22
Drive unit
Control unit
Arithmetic processing unit
25
First storage unit
26
Input / Output port
27
α_{TS}
CS
T
P
19
Temperature detector
41
Light-receiving sensor
L12
α_{ts}
I
Drive circuit
Second storage unit
42
Light-emitting element
12
1
21

Fig. 12


1
Drive unit
20
21
Drive circuit
22
Control unit
25
Arithmetic processing unit
26
First storage unit
27
Input / Output port
31
Target light output receiving unit
35
Target light output input unit
19
Temperature detector
12
Light-emitting element
42
Second storage unit
50
Calibration device
51
Information updating unit
52
Instruction signal output unit
53
Light-receiving sensor
L12
L12
Φ
Φ
I
I
T
T
α'TS
α'ts

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	DE 10 2007 044556 A1 (ARNOLD & RICHTER KG [DE]) 12 March 2009 (2009-03-12) * paragraphs [0061], [0152]; figures 25,28 * -----	1-12	INV. H05B45/18
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TECHNICAL FIELDS SEARCHED (IPC)
H05B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	21 September 2022	Boudet, Joachim

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