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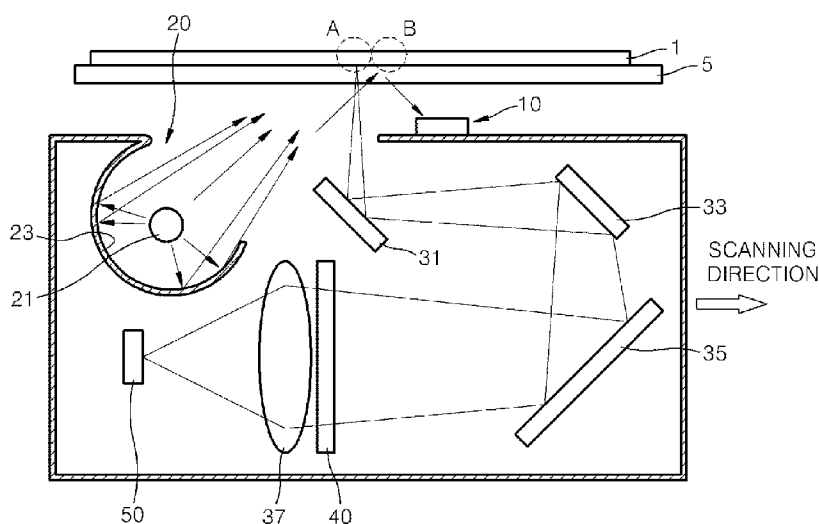
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(54) Title: **IMAGE READING APPARATUS AND METHOD**

FIG. 2



(57) **Abstract:** Provided is an image reading apparatus and method which may read images beyond the maximum depth of focus without substantial image deterioration. The image reading apparatus includes a light source unit radiating light to a scan region of a scan object placed on a transparent plate, an image sensor converting a light signal obtained by reading the scan region of the scan object into an electric signal, a focus state detecting unit detecting a focus state of the scan object, and a wavefront coding unit. The wavefront coding unit modulates a wavefront of the light reflected from the scan region of the scan object in order to input light that is made insensitive to defocus to the image sensor. This is done when it is determined by the focus state detection unit that the light is radiated to the scan object in an improper focus state on the scan object.

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Description

IMAGE READING APPARATUS AND METHOD

Technical Field

- [1] The present invention generally relates to an image reading apparatus and method, and more particularly, to an image reading apparatus and method capable of improving scanned image quality.

Background Art

- [2] An image reading apparatus reads a scan object by radiating light. Examples of an image reading apparatus may include a scanner, a facsimile, a copier, and a multi-functional scanner/facsimile/copier device, a digital camera, or the like.
- [3] An image reading apparatus includes flat glass, on one side of which an object to be scanned may be placed, and a scanning system located on the other side of the flat glass for reading the scan object. The scanning system may include a light source unit for radiating light to the scan object, an image sensor for converting a light signal obtained from light reflected from the scan object into an electric signal, a light path forming unit for delivering the light reflecting from the scan object to the image sensor and an imaging lens for condensing the light delivered to the image sensor. The light path forming unit may include, e.g., a plurality of mirrors.
- [4] For example, a scanning system generally in use may have a maximum depth of focus of about ± 2 mm. When a scan object is beyond the maximum depth of focus, image blurring may occur, resulting in deterioration of image. For example, when the scan object is a unfolded bound book, the distance between the flat glass and the book at the binding portion of the book where two leaves meet may become large, and may exceed the maximum depth of focus, the scanned image of the fold portion being blurred and distorted
- [5] FIG. 1 illustrates a state where the bound book is put face down on the flat glass, in which d_0 indicates a distance between a reference plane and an edge page portion contacting the flat glass 5, and d_1 and d_2 indicate distances between the reference plane and page portions near the binding portion where 2 leaves meet. It is assumed that a scan object exists in the page portions. When $d_1 - d_0$ or $d_2 - d_0$ is greater than the depth of focus of the scanning system, a scan image obtained from the corresponding page portion may become blurred and/or distorted, resulting in deterioration of the scan image.

Disclosure of Invention

Advantageous Effects

- [6] Signal light obtained by reading a scan object may be made insensitive to defocus by

using wavefront coding and may be input to an image sensor. A signal obtained by the image sensor may then be decoded by signal processing, thereby reducing image blurring.

Description of Drawings

- [7] FIG. 1 illustrates a state where an unfolded book is put face down on flat glass;
- [8] FIG. 2 schematically illustrates a structure of an image reading apparatus according to an embodiment of the invention;
- [9] FIG. 3 schematically illustrates the structure of a focus state detecting unit according to an embodiment of the invention;
- [10] FIGS. 4A through 4C illustrate various examples of arrangements of a plurality of light-amount detecting sensors across a scanning direction, according to various embodiments of the invention;
- [11] FIGS. 5A and 5B schematically illustrate an active wavefront coding element according to an embodiment of the invention;
- [12] FIGS. 6A and 6B schematically illustrate an active wavefront coding element according to another embodiment of the invention;
- [13] FIG. 7 schematically illustrates a light source unit according to an embodiment of the invention;
- [14] FIGS. 8A and 8B schematically illustrate additional examples of a wavefront coding element according to an embodiment of the invention;
- [15] FIG. 9 is a flowchart illustrating an image reading method using an image reading apparatus according to an embodiment of the invention; and
- [16] FIG. 10 illustrates graphs for comparing modulation transfer function (MTF) before and after wavefront coding.

Mode for Invention

- [17] In the following description, the same drawing reference numerals are used for the same elements in all drawings. The matters defined in the description, such as detailed construction and elements, are provided to assist in a comprehensive understanding of the invention. Thus, it should be apparent that embodiments of the invention can be carried out without those specifically detailed matters. Also, well-known functions or constructions are not described in detail so as to avoid obscuring the description with unnecessary detail.
- [18] Referring to FIG. 2, in one embodiment of the invention, an image reading apparatus may include a light source unit 20, which radiates light to a scan object 1 placed on a transparent plate 5, an image sensor 50, which converts the signal light obtained by reading a scan region A of the scan object 1 from the light radiated by the light source unit 20 into an electric signal, a focus state detecting unit (including a light-amount

detecting sensor 10), which detects the focus state of the scan object 1, and a wavefront coding unit 40 which applies wavefront coding to the signal light in order to make the signal light insensitive to defocus, i.e., to lessen the effect of defocus condition on the signal light.

- [19] The image reading apparatus may further include a light path forming unit which forms a light path for delivering the light reflected from the scan region A of the scan object 1 to the image sensor 50, and may include a plurality of mirrors 31, 33, and 35.
- [20] The image reading apparatus may further include an imaging lens 37, which condenses the light signal delivered to the image sensor 50. The image reading apparatus typically reads an image in the unit of a line by simultaneously radiating light to the scan region A. The scan region A means a line-based region of the scan object 1 on which image reading is performed. The line-based region to which light is simultaneously radiated corresponds to the main scanning direction of an image forming apparatus such as a printer while the scanning direction of the image reading apparatus corresponds to the sub-scanning direction of the image forming apparatus. The image reading apparatus according to an embodiment of the present invention may perform image reading while moving the entire scanning optical system or a portion thereof in the scanning direction of the image reading apparatus.
- [21] The image sensor 50 may be a charge-coupled device (CCD) sensor, a CMOS sensor, a contact image sensor (CIS), or another equivalent device capable of converting a light signal into an electric signal.
- [22] The transparent plate 5 may accept the scan object 1, which for example may be a document, manuscript or a book to be scanned, and may contact the scan object 1. The transparent plate 5 may be made of flat glass or another substantially flat transparent material.
- [23] In one embodiment of the invention, the light source unit 20 may include a lamp light source 21 which generates light in a line shape. For example the lamp light source 21 may be a halogen lamp or similar device. In this case, the light source unit 20 may further include a reflective mirror 23 in order to direct light radiated from the lamp light source 21 towards the scan object 1. The reflective mirror 23 may be a curved-surface mirror whose cross section forms a portion of an oval or a circle, and whose length corresponds to the length of the lamp light source 21.
- [24] An image reading apparatus typically reads an image in linear units, e.g., a line at a time, by simultaneously radiating light to the scan region A. In an embodiment of the invention, scan region A may denote a line-based region of the scan object 1 on which an image reading operation is to be performed. The line-based region to which light is simultaneously radiated may correspond to a main scanning direction of an image forming apparatus such as a printer, and a scanning direction of the image reading

apparatus may correspond to a sub-scanning direction of the image forming apparatus. According to an embodiment of the invention, the image reading apparatus may perform image reading while moving the entire scanning optical system or a portion thereof in the scanning direction of the image reading apparatus.

- [25] The focus state detecting unit may detect a focus state of the scan object 1. In one embodiment of the invention, the focus state detecting unit may do so by checking whether light is radiated with focus or defocus to a particular region of the scan object 1 from which an image is read.
- [26] Light may be radiated from the light source unit 20 to a particular region of the scan object 1 instead of being radiated in a line shape. As a result, some light may be radiated to a neighboring region B that is located adjacent to, and in front of, the scan region A. By monitoring the amount of light reflected from the neighboring region B, the focus state of the scan object 1 may be obtained.
- [27] Referring to FIG. 3, in one embodiment of the invention the focus state detecting unit may include a light amount detecting sensor 10, which detects the amount of light reflected from the neighboring region B of the scan object 1. The focus state detecting unit may further include a focus state judging unit 60, which may judge whether light is radiated with correct focus on the scan object 1 based on a detection signal obtained by the light-amount detecting sensor 10. A light-amount detecting sensor 10 may include, for example, a photodiode capable of producing varying levels of output signals based on the amount of light received. The focus state judging unit 60 may include, for example, an analog comparator having an input coupled to the output of the light-amount detecting sensor 10, another input for receiving a reference value, and an output for outputting a signal indicative of whether the output from the light-amount detecting sensor 10 is larger or smaller than the reference value. The active wavefront coding unit will be described in more detail later.
- [28] The scan object 1 is placed on the transparent plate 5, and the change in the focus occurs in the direction moving further away from the transparent plate 5. The light-amount change may also occur according to the surface state of the scan object 1. For example, a difference may exist in the amount of light generated between scanning of a dark portion of the scan object 1 and scanning of a bright portion of the scan object 1. Thus, in order to distinguish the surface reflection difference influenced by the scan object 1 from the surface reflection difference as a result of defocus, it is possible to compare the amounts of light by using a plurality of light-amount detecting sensors 10. These light-amount detecting sensors 10 may be spaced apart from each other across the scanning direction as illustrated in FIGS. 4A through 4C. This spacing may enable the focus state detecting unit to distinguish a light-amount difference originating from a scan surface state and a light-amount difference originating from

defocus.

- [29] FIG. 4A illustrates an embodiment where two light-amount detecting sensors 10 (S1 and S2) are arranged. FIG. 4B illustrates an embodiment where three light-amount detecting sensors 10 (S1, S2, and S3) are arranged. FIG. 4C illustrates an embodiment where n light-amount detecting sensors 10 (S1, S2, ..., Sn) are arranged.
- [30] When all detection light amounts obtained by the plurality of light-amount detecting sensors 10 are less than a threshold level, a scan region of the scan object 1 is in a defocused state. In this case the wavefront coding unit 40 (see FIG. 3) may operate to apply wavefront coding. If only some of the detection light amounts are less than the threshold level, a light-amount difference may have originated from the scan surface state, and wavefront coding is not used. When all the detection light amounts are greater than the threshold level, the scan object 1 is in a focused state. In this state the scan object 1 may properly be scanned to form the scanned image. To this end, the wavefront coding unit 40 may include a controller (not shown), which may be, e.g., a microprocessor, a microcontroller or the like, that includes a CPU to execute one or more computer instructions to implement the operations of controlling the wavefront coding unit 40 as described herein, and may further include a memory device, e.g., a Random Access Memory (RAM), Read-Only-Memory (ROM), a flash memory, or the like, to store the one or more computer instructions. According to an embodiment, the controller may serve as the main controller for the image reading apparatus, and perform other aspects of controlling the image reading apparatus.
- [31] The threshold level may be a reference level that is set by the light-amount detecting sensors 10 by defocusing the scan object 1 during scan unit initial setting. The reference level may be a detection value obtained by the light-amount sensor 10 when the scan region of the scan object 1 is spaced d_0 from the reference plane illustrated in FIG. 1 or is located within the depth of focus of light radiated from the light source unit 20 for d_0 . When the scan region of the scan object 1 is spaced d_1 or d_2 from the reference plane beyond the depth of focus, the light-amount detecting sensor 10 may detect a smaller light-amount than the reference level. Thus, the light-amount sensor 10 may be able to determine whether or not the scan region of the scan object 1 is in a defocused state by comparing the detection value with the threshold level.
- [32] Assuming that the surface of the scan object 1 is a Lambertian surface, scattered light may be imaged to form a scan image. However, since the surface of the scan object 1 may not be a perfect Lambertian surface, specular reflection components may exist. Thus, in one embodiment of the invention, the light-amount detecting sensor 10 may be disposed in a position where the specular reflection components may reach. In this case, reflection from the surface of the transparent plate 5 may become an issue. In one embodiment of the invention, by applying anti-reflection coating to the surface of the

transparent plate 5 and keeping the angle between the direction vector of light radiated from the light source unit 20 and the vector normal to the surface of the transparent plate 5 to be 50° or less, the amount of light reflected from the surface of the transparent plate 5 may be reduced to be less than the amount of specular reflection components from the scan object 1, according to the Fresnel reflection equation. Therefore, by using light reflected from the scan object 1, the focus state of the scan object 1 can be determined.

- [33] When the focus state detecting unit determines that light is radiated without correct focus on the scan object 1, the wavefront coding unit 40 may modulate the wavefront of the light signal reflected from the scan region A in order to deliver a light signal to the image sensor 50 that is insensitive to the defocus. In one embodiment of the invention, the wavefront coding unit 40 may be disposed in front of the imaging lens 37 as shown in FIG. 2.
- [34] The wavefront coding unit 40 may be an active wavefront coding element 40' or 40'' as illustrated in FIGS. 5A through 6B. FIGS. 5A and 5B illustrate the active wavefront coding element 40' according to an embodiment of the invention while FIGS. 6A and 6B illustrate the active wavefront coding element 40'' according to another embodiment of the invention.
- [35] Referring to FIGS. 5A through 6B, the active wavefront coding element 40' (or 40'') may include a first transparent substrate 41, a second transparent substrate 44, an active double refraction layer 43 (or 43'), which is disposed between the first transparent substrate 41 and the second transparent substrate 44, and which may have an effective refractive index that changes according to whether or not an electric field is applied, and a refractive index correcting plate 42 (or 42') whose interface with the active double refraction layer 43 (or 43') has a shape corresponding to phase distribution for wavefront coding. By controlling the refractive index of the active double refraction layer 43 (or 43') such that the refractive index is the same as or different from that of the refractive index correcting plate 42 (or 42'), the wavefront of incident light can be actively modulated.
- [36] The active double refraction layer 43 (or 43') of the active wavefront coding element 40' (or 40'') may be made of liquid crystal or other materials capable of active control. FIGS. 5A through 6B illustrate embodiments where the active double refraction layer 43 (or 43') is a liquid crystal layer.
- [37] Referring to FIGS. 5A and 6A, when a switch 47 is closed to connect the power source 45, the active double refraction layer 43 (or 43') undergoes a refractive index change and thus serves as a wavefront coding phase element. The refractive index change is due to a change of liquid crystal arrangement caused by the electric field applied to the active double refraction layer 43 (or 43'). In FIGS. 5B and 6B, when the

switch 47 is open, the liquid crystal arrangement returns to its original state and thus the active double refraction layer 43 (or 43') does not serve as a wavefront coding phase element.

[38] The active wavefront coding element 40' (or 40'') may also be structured such that a voltage may be applied to both of the first transparent substrate 41 and the second transparent substrate 44, and the refractive index correcting plate 42 (or 42') may be made of a material which, when in a state where the electric field is not applied to the liquid crystal (as illustrated in FIGS. 5B and 6B), has the same refractive index as that of the active double refraction layer 43 (or 43').

[39] When the refractive indices of the refractive index correcting plate 42 (or 42') and the active double refraction layer 43 (or 43') are different from each other, light passing through the active double refraction layer 43 (or 43') undergoes a phase change corresponding to the shape of the interface between the refractive index correcting plate 42 (or 42') and the active double refraction layer 43 (or 43'). Therefore, by applying an electric field to the active double refraction layer 43 (or 43'), the wavefront coding element 40' (or 40'') can be actively driven.

[40] A wavefront coding element capable of optically changing a phase may use one of the following 2 methods to cause the phase change.

[Table 1]

[Table]

Phase change	Asymmetric shape	Phase function $a(X^3+Y^3)$, a optimization
	Symmetric shape	Zernike coefficient optimization

[41] For example, in the wavefront coding element 40' illustrated in FIGS. 5A and 5B, the refractive correcting plate 42 is structured to cause a phase change in an asymmetric shape while, in the wavefront coding element 40'' illustrated in FIGS. 6A and 6B, the refractive correcting plate 42' is structured to cause a phase change in a symmetric shape.

[42] The material used for the active double refraction layer 43 (or 43') may be liquid crystal that reacts to polarized light or liquid crystal that reacts to non-polarized light. When liquid crystal that reacts to polarized light is used for the active double refraction layer 43 (or 43'), a polarization aligner 25 (see FIG. 7) may be further included in the emitting side of the light source unit 20. In one embodiment of the image reading apparatus, the polarization aligner 25 may be disposed at the exit side through which light is emitted from the lamp light source 21 and the reflective mirror 23, e.g., shown in FIG. 2.

[43] Referring to FIG. 7, the polarization aligner 25 may include a polarization beam

splitter array 26 which transmits or reflects incident light according to polarization, reflective mirrors 28, each of which is disposed in front of one of a set of polarization beam splitters in order to reflect the incident light, and 1/2 wave plates 27, each of which is disposed at the rear of a polarization beam splitter adjacent to one of the set of polarization beam splitters to change a linearly polarized light into another linearly polarized light.

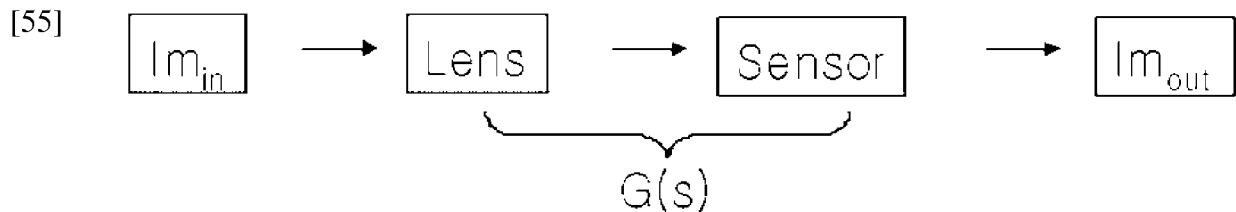
- [44] While the examples of the wavefront coding unit 40 are shown in FIGS. 5A through 6B to include an active wavefront coding element 40' (or 40"), as illustrated in FIGS. 8A and 8B, in an alternative embodiment, a wavefront coding unit 40 may include a fixed wavefront coding phase element 140 (or 140') and a driving unit 145. The fixed wavefront coding phase element 140 (or 140') includes a pair of medium layers of different refractive indices which have a mutual interface in a shape corresponding to phase distribution for wavefront coding. The driving unit 145 may insert the fixed wavefront coding phase element 140 (or 140') into a light path or remove the fixed wavefront coding phase element 140 (or 140') from the light path. FIG. 8A illustrates an embodiment in which the wavefront coding phase element 140 is structured to cause a phase change in an asymmetric shape while FIG. 8B illustrates an embodiment in which the wavefront coding phase element 140' is structured to cause a phase change in a symmetric shape.
- [45] Referring to FIG. 8A, the fixed wavefront coding phase element 140 may include a first optical member 142 corresponding to the refractive index correcting plate 42 and a second optical member 143 corresponding to the active double refraction layer 43 in order to cause a phase change in an asymmetric shape. The first optical member 142 may have the same structure as that of the refractive index correcting plate 42 and the second optical member 143 may be a transparent substance or a liquid crystal layer having a different refractive index than that of the first optical member 142. When the second optical member 143 is a liquid crystal layer, a transparent substrate (not shown) may further be included on the second optical member 143.
- [46] Referring to FIG. 8B, the fixed wavefront coding phase element 140' may on the other hand include a first optical member 142' corresponding to the refractive index correcting plate 42' and a second optical member 143' corresponding to the active double refraction layer 43' in order to cause a phase change in a symmetric shape. The first optical member 142' may have the same structure as that of the refractive index correcting plate 42' and the second optical member 143' may be a transparent substance or a liquid crystal layer having a different refractive index than that of the first optical member 142'. When the second optical member 143' is a liquid crystal layer, a transparent substrate (not shown) may further be included on the second optical member 143'.

- [47] FIG. 9 is a flowchart illustrating an image reading method, which may be practiced by an image reading apparatus according to an embodiment of the invention. The described operations may be performed by a controller (not shown) of the image reading apparatus, which may be the same controller previously described above, or may be a separate controller that may be, e.g., a microprocessor, a microcontroller or the like, that includes a CPU to execute one or more computer instructions to implement the operations as described herein, and may further include a memory device, e.g., a Random Access Memory (RAM), Read-Only-Memory (ROM), a flash memory, or the like, to store the one or more computer instructions.
- [48] The scan object 1 may be placed on the transparent plate 5 in operation S10, and scanning may begin by radiating light to the scan object 1 placed on the transparent plate 5 in operation S20.
- [49] In order to check the focus state of the scan object 1, light reflected from a neighboring region B of a scan region A of the scan object 1 is detected by the light-amount detecting sensor 10 in operation S30, and it is determined whether a detection value obtained by the light-amount detecting sensor 10 is less than the threshold level in operation S40.
- [50] When the detection value obtained by the light-amount detecting sensor 10 is less than the threshold level, the wavefront coding unit 40 is driven to apply wavefront coding to the signal light obtained by image reading in operations S50 and S60, and the scanning continues in this state in operation S70. Once the wavefront coding unit 40 is driven, the signal light read from the scan object 1 is made insensitive to defocus, and is then input to the image sensor 50. In order to obtain the scanned image, the electric signal produced by the image sensor 50 is decoded in operation S80. The decoding will be described in more detail later. A scanned image is formed from the image data obtained during the decoding in operation S90, which may then be output in operation S100.
- [51] On the other hand, if the detection value obtained by the light-amount detecting sensor 10 is greater than the threshold level in operation S40, the wavefront coding unit 40 is not operated so as not to perform wavefront coding in operation S110, and the scanning continues in this state in operation S120. A signal light obtained by reading an image of the scan object 1 during scanning is input to the image sensor 50. A scanned image is formed by using an electric signal obtained by the image sensor 50 in operation S90, which is output in operation S100.
- [52] In some embodiments of the invention, a plurality of light-amount detecting sensors 10 are used. The light-amount detecting sensors 10 are spaced apart from each other across the scanning direction of the image reading apparatus. In these embodiments, wavefront coding is applied only when all detection light amounts obtained by the

plurality of light-amount detecting sensors 10 are less than the threshold level.

[53] If one of the detection values obtained by the plurality of light-amount detecting sensors 10 is not less than the threshold level, the discrepancy may be due to the surface reflection difference in the scan object 1 rather than the state of focus. In this case a scan image is directly output without wavefront coding.

[54] In the following description, wavefront coding of the type that may be used in an embodiment of the invention will be briefly described. Wavefront coding is modulation of an optical wavefront emitted from an optical system. Wavefront coding may allow the optical system to form an emitting wavefront regardless of focus, and the resulting image obtained may be clearly produced with signal processing even when defocus occurs. Imaging and reconstruction may be described with reference to the diagram below.



[56] In the above diagram,

Im_{in}

indicates an input image and

Im_{out}

indicates an output image produced by the sensor, which had received the image through the optical system. When the output image and the performance of the optical system are known, the input image may be calculated as follows:

[57]

$$Im_{out} = G(s) \otimes Im_{in}$$

$$Im_{in} = G^{-1}(s) \otimes Im_{out}$$

..... (1),

[58] where

$G^{-1}(s)$

indicates an inverse fast Fourier transformation (inverse FFT) of the lens.

[59] Generally, when defocus occurs, a frequency component may be lost if its

modulation transfer function (MTF) value is 0. The lost frequency component cannot be reconstructed even by signal processing. Thus, optical modulation which does not result in a frequency component having an MTF value of 0 despite defocus condition may be used to allow reconstruction by signal processing. Such optical modulation is a wavefront coding operation.

[60] The wavefront coding operation can be expressed as Equation (2) where

$$G(s)'$$

indicates a product of an imaging optical system and a function of a phase plate for modulating an emitting wavefront.

[61]
$$G(s)' = G(s) \otimes P(s)$$

$P(s)$: Phase plate

[62]
$$\text{Im}_{out} = G(s)' \otimes \text{Im}_{in}$$

=> Encoding

[63]
$$\text{Im}_{in} = G^{-1}(s)' \otimes \text{Im}_{out}$$

=> Decoding (2),

[64] where encoding indicates an optical result and decoding indicates image reconstruction by signal processing.

$$G^{-1}(s)'$$

indicates a result of performing an inverse FFT on a function of the product of the lens and the phase plate, which may be a point spread function (PSF) of the optical system, and can be obtained by CODE V. A PSF may need to be obtained for every wavelength, every defocus, and every field.

[65] FIG. 10 illustrates graphs for comparing MTF changes caused by defocus before and after the performance of wavefront coding.

[66] In the left graph illustrated in FIG. 10, (a) indicates a case corresponding to a defocus of 0, (b) indicates a case corresponding to a defocus of $\pi/2$, and (c) indicates a case corresponding to a defocus of π . In the right graph illustrated in FIG. 10, MTF curves for the 3 cases overlap after wavefront coding. In (c) of the left graph illustrated in FIG. 10, a frequency component having an MTF value of 0 cannot be reconstructed. However, when wavefront coding is performed as in the right graph illustrated in FIG. 10, there is no frequency component with an MTF value of 0 notwithstanding defocus, and thus reconstruction is possible by using signal processing. The amount of defocus

and a minimum MTF (%) for signal processing may vary according to the performance of an optical system and the capability of signal processing reconstruction.

- [67] As mentioned previously, wavefront coding may be implemented as an asymmetric phase change or as an axially-symmetric phase change. The asymmetric phase change may optimize a wavefront coding phase element such that focus changes in a top-to-bottom direction and the axially-symmetric phase change may optimize a wavefront coding phase element such that focus changes in a radial direction.
- [68] According to an embodiment of the invention, by detecting and checking the focus state of the scan object 1, wavefront coding may be applied when the scan object 1 is not in proper focus. This may be done in order to make a signal light obtained by reading the scan object 1 insensitive to defocus and to detect the signal light by using the image sensor 50. By decoding a detection signal obtained by the image sensor 50, a clear scan image can be obtained.
- [69] In sum, according to embodiments of the invention, signal light obtained by reading a scan object may be made insensitive to defocus by using wavefront coding and may be input to an image sensor. A signal obtained by the image sensor may then be decoded by signal processing, thereby reducing image blurring.
- [70] The foregoing embodiments are merely examples and are not to be construed as limiting the present invention. The present teaching can be readily applied to various other embodiments. Also, the description of the embodiments of the present invention is intended to be illustrative, and not to limit the scope of the claims, and many alternatives, modifications, and variations will be apparent to those skilled in the art.

Claims

- [1] An apparatus for acquiring an image of an object, comprising:
a light source disposed in the apparatus, the light source being configured to direct light toward the object;
a focus state detecting unit configured to produce an indication of a state of focus of the light on the object;
an image sensor configured to receive an input light, and to convert the received input light into an electric signal; and
a wavefront coding unit disposed in an optical path between the object and the image sensor to receive reflected light, the reflected light being at least a portion of the light from the light source reflected by the object, the wavefront coding unit being configured to produce the input light, by modulating a wavefront of the reflected light when the indication by the focus state detecting unit indicates an out-of-focus condition, and by allowing the reflected light to pass substantially unchanged when the indication by the focus state detecting unit indicates an in-focus condition.
- [2] The apparatus of claim 1, wherein the input light, when produced by the wavefront coding unit modulating the wavefront of the reflected light, has no frequency component having a modulation transfer function (MTF) value of substantially zero.
- [3] The apparatus of claim 1, wherein the wavefront coding unit comprises:
a first transparent substrate and a second transparent substrate;
an active double refraction layer disposed between the first transparent substrate and the second transparent substrate, the active double refraction layer having an effective refractive index that changes when subjected to an electric field; and
a refractive index correcting plate disposed adjacent the double refraction layer, the refractive index correcting plate having a surface facing the double refraction layer, the surface having a shape corresponding to phase distribution for wavefront coding, the refractive index correcting plate having a first refractive index.
wherein the effective refractive index of the active double refraction layer is variable between the first refractive index and a second refractive index different from the first refractive index.
- [4] The apparatus of claim 3, wherein the active double refraction layer is a liquid crystal layer.
- [5] The apparatus of claim 1, wherein the wavefront coding unit comprises:
a wavefront coding phase element comprising a first light passing medium layer

having a first refractive index and a second light passing medium layer having a second refractive index different from the first refractive index, an interface between the first and second light passing medium layers being in a shape corresponding to phase distribution for wavefront coding; and
a driving unit configured to move the wavefront coding phase element in and out of the optical path.

- [6] The apparatus of claim 1, wherein the focus state detecting unit comprises:
a light-amount detecting sensor disposed at a location within the apparatus such that the light-amount detecting sensor is capable of receiving a second reflected light, the second reflected light being a portion of light from the light source that is reflected from a neighboring region of the object adjacent to an image region of the object, from which the image is being acquired, the light-amount detecting sensor having an output for an output signal based on the received second reflected light,
wherein the focus state detecting unit being configured to produce the indication indicating the out-of-focus condition when the output signal is less than a reference level.
- [7] The apparatus of claim 6, wherein the light-amount detecting sensor comprises a plurality of sensors spaced apart from each other across a scanning, and
wherein the focus state detecting unit being configured to produce the indication indicating an out-of-focus condition when each output signal of the plurality of detecting sensors is less than the reference level.
- [8] The apparatus of claim 1, further comprising:
a optical path forming unit having one or more mirrors to change a direction of travel of the reflected light in the optical path, and thereby to direct the reflected light toward wavefront coding unit; and
an imaging lens condensing the input light received by the image sensor.
- [9] The apparatus of claim 4, wherein the liquid crystal layer is one that reacts to polarized light, the apparatus further comprising:
a polarization aligner disposed in between the light source and the object, the polarization aligner having an incident side on upon which the light from the light source is incident and an light emitting side opposite the incident side, a polarization of the light emitting from the light emitting side of the polarization being aligned.
- [10] The apparatus of claim 9, wherein the polarization aligner comprises:
a plurality of beam splitters arranged linearly, each of the beam splitters transmits or reflects the light according to the polarization of the light incident thereupon;

a plurality of reflective mirrors each disposed on the incident side of one of a first set of beam splitters; and

a plurality of half-wave plates each disposed on the emitting side of one of a second set of beam splitters non-overlapping with the first set.

- [11] A method of acquiring an image of an object, comprising:
 radiating light from a light source unit to a scan region of the object;
 detecting an amount of light reflected from a neighboring region adjacent to the scan region of the object;
 determining whether the detected amount of light is less than a reference amount;
 converting by an image sensor a reflected light into electrical signal, the reflected light being a portion of the light from the light source reflected by the scan region of the object, the electrical signal being representative of at least a portion of the image at the scan region; and
 modulating a wavefront of the reflected light prior to the image sensor receiving the reflected light if it is determined that the detected amount of light is less than the reference amount.

- [12] The method as set forth in claim 11, wherein the step of detecting comprises:
 detecting the amount of light with a plurality of sensors,
 wherein the step of determining comprises determining whether the amount of light detected by each of the plurality of sensors is less than the reference amount, and
 wherein the step of modulating is performed only if the amount of light detected by each of the plurality of sensors is less than the reference amount.

- [13] The method as set forth in claim 11, further comprising:
 if the amount of light detected is determined to be less than the reference amount,
 processing at least the electrical signal to reconstruct at least a portion of the image by performing an operation according to an equation,

$$\text{Im}_{in} = G^{-1}(s)' \otimes \text{Im}_{out}$$

,

wherein

$$\text{Im}_{in}$$

indicates the at least the portion of the image to be constructed,

$$\text{Im}_{out}$$

indicating an output image based on the electrical signal from the image sensor,

and

wherein

$$G^{-1}(s)'$$

indicates a result of performing an inverse FFT on a function of at least an optical performance characteristics of an wavefront coding unit that performs the modulating step.

- [14] The method as set forth in claim 13, wherein:
the optical performance characteristics comprises a point spread function (PSF) of an optical system being used.
- [15] The method as set forth in claim 11, wherein the step of modulating comprises:
allowing the reflected light to pass through an interface between a double refraction layer and an refractive index correcting plate, and onto the image sensor, the double refraction layer having an effective refractive index, and being disposed adjacent the refractive index correcting plate, the refractive index correcting plate having a refractive index that is different from the effective refractive index of the double refraction layer.
- [16] The method as set forth in claim 15, wherein the step of modulating further comprises:
subjecting the double refraction layer to an electric field to change the effective refractive index thereof.
- [17] The method as set forth in claim 15, wherein the double refraction layer comprises a liquid crystal layer.
- [18] The method as set forth in claim 17, further comprises:
aligning a polarization of the light from the light source before the light reaches the object.
- [19] The method as set forth in claim 11, further comprises:
condensing the reflected light before being received by the image sensor.

FIG. 1

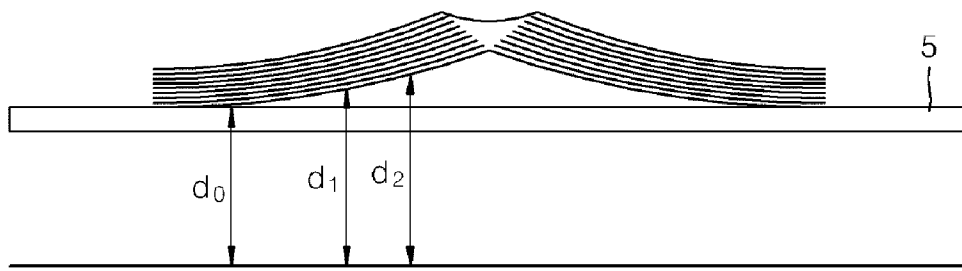


FIG. 2

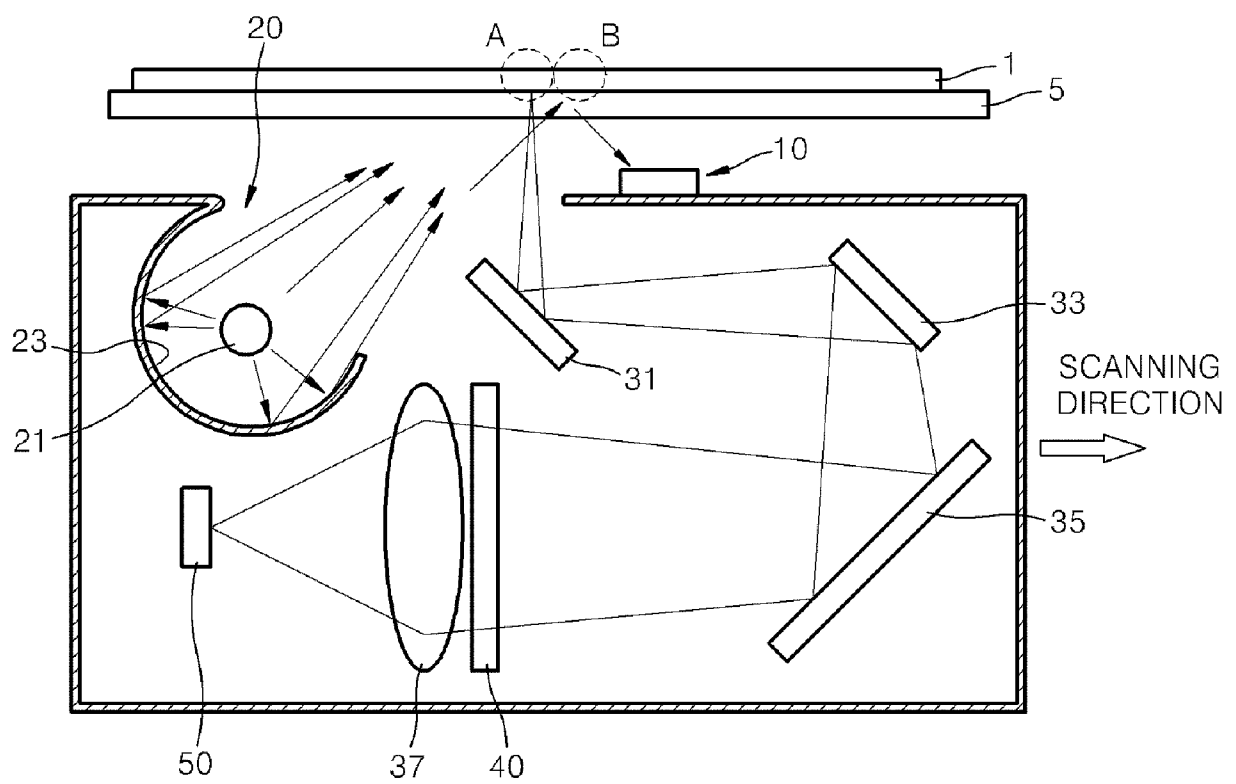


FIG. 3

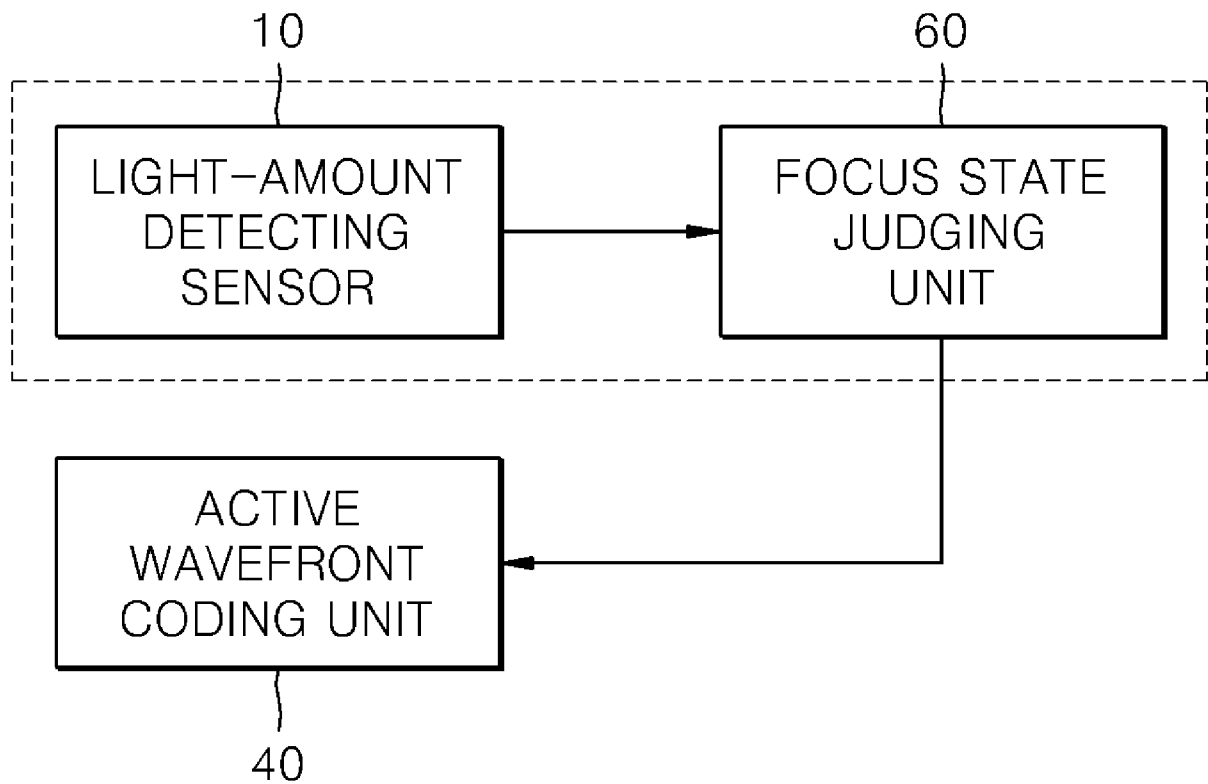


FIG. 4A

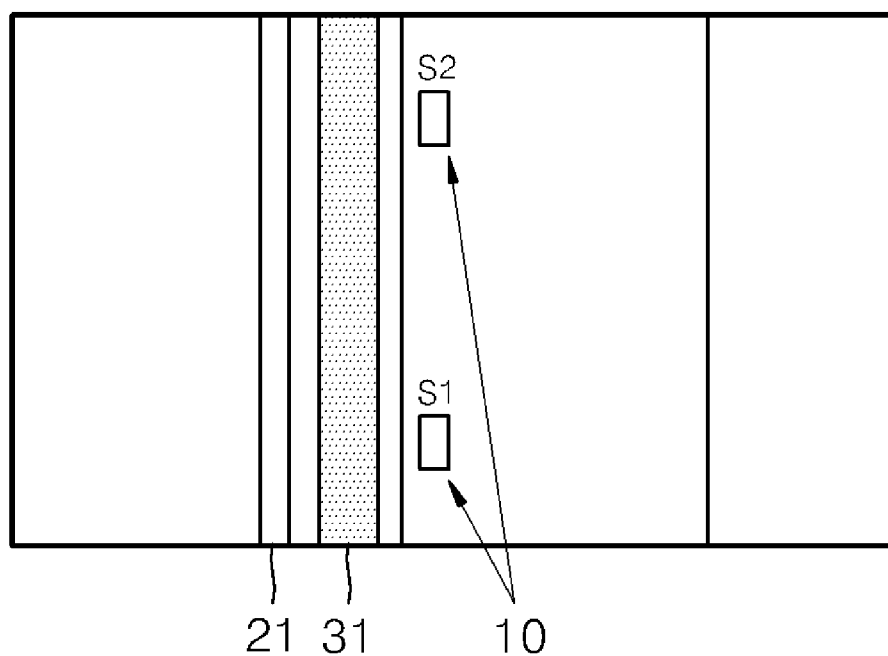


FIG. 4B

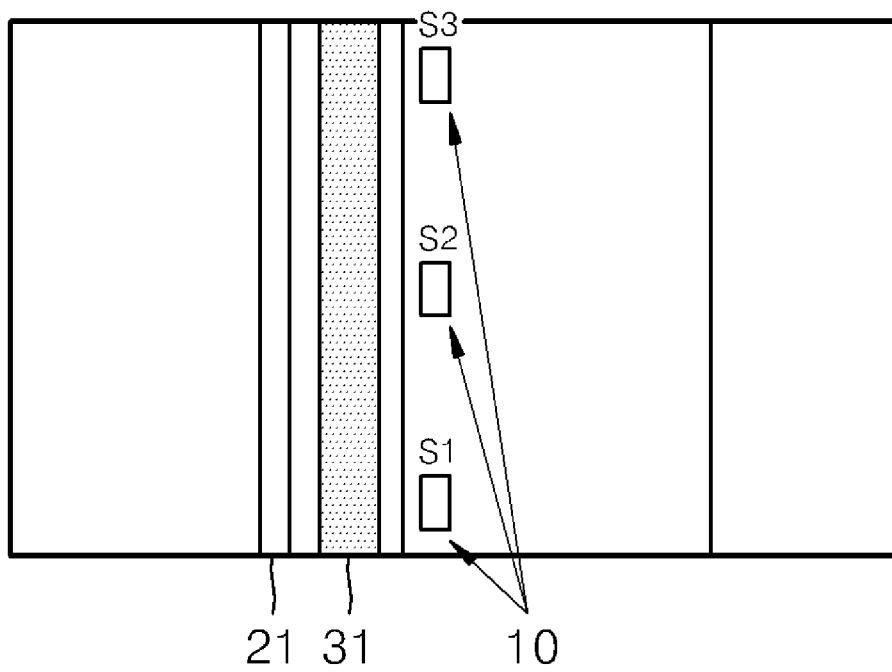


FIG. 4C

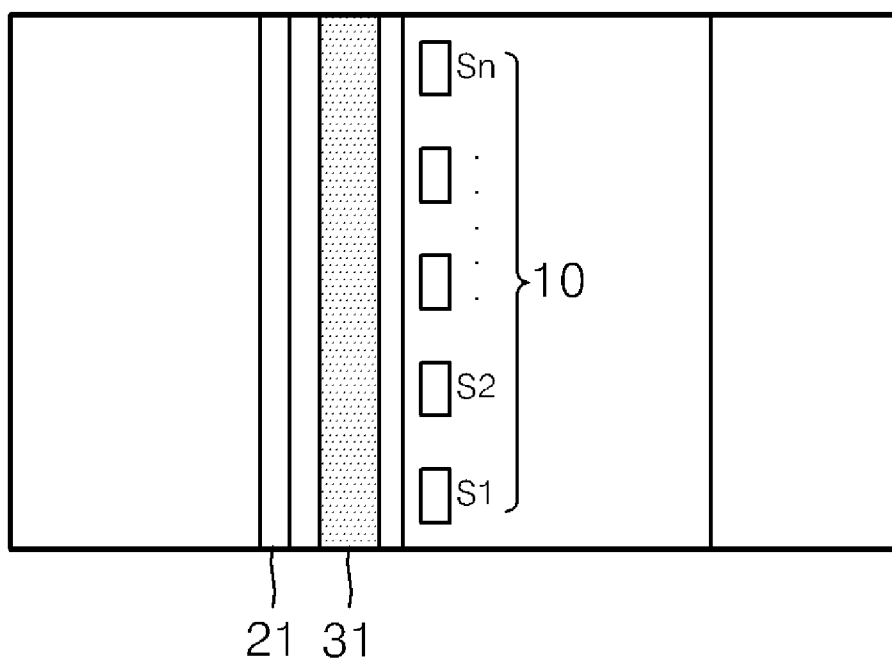


FIG. 5A

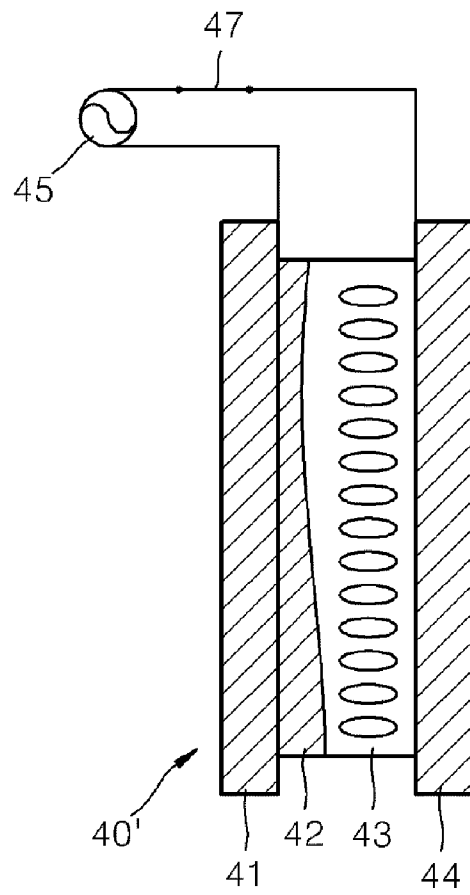


FIG. 5B

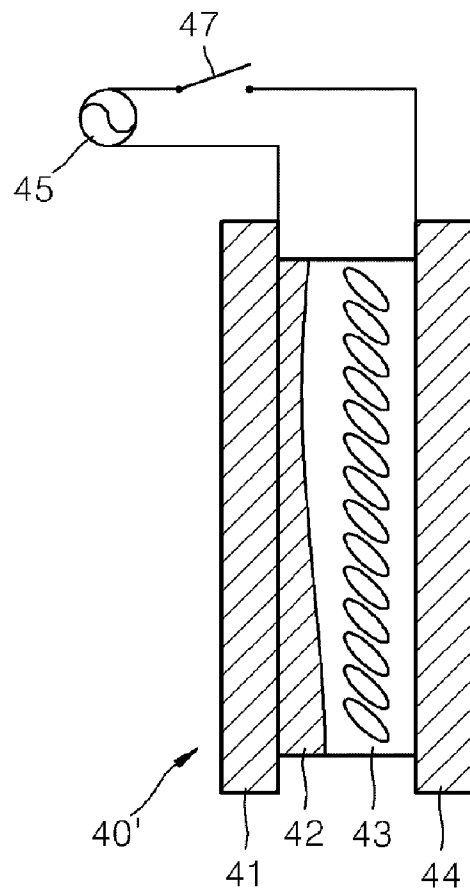


FIG. 6A

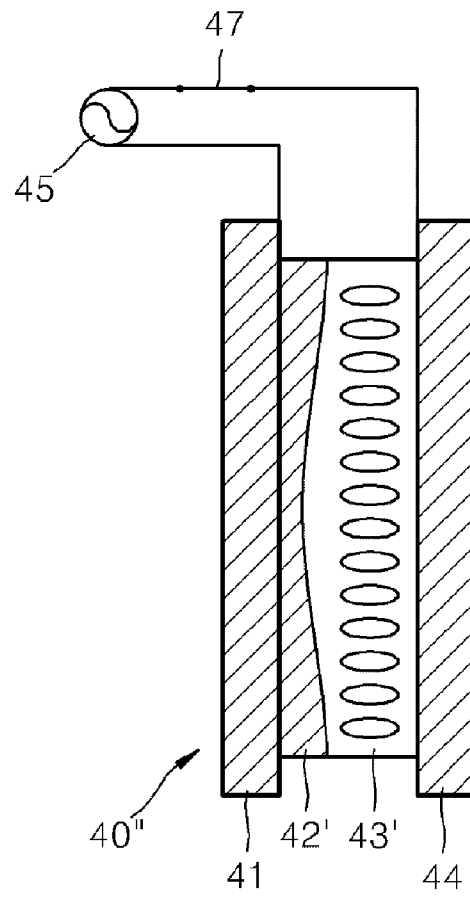


FIG. 6B

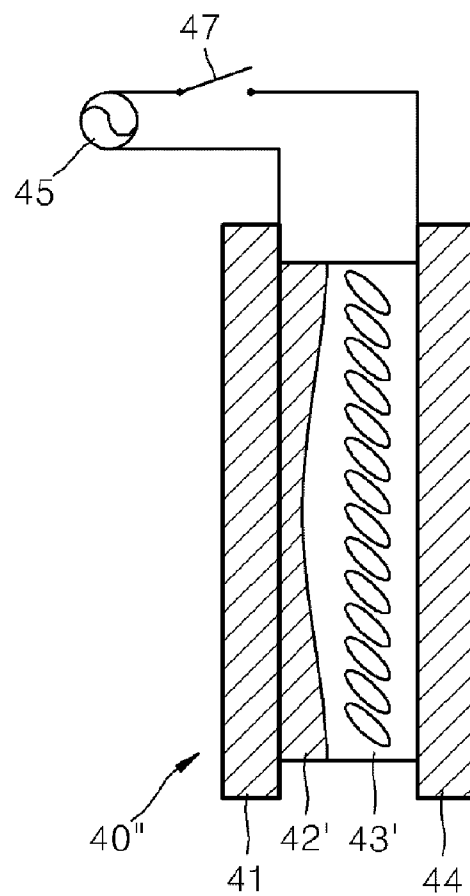


FIG. 7

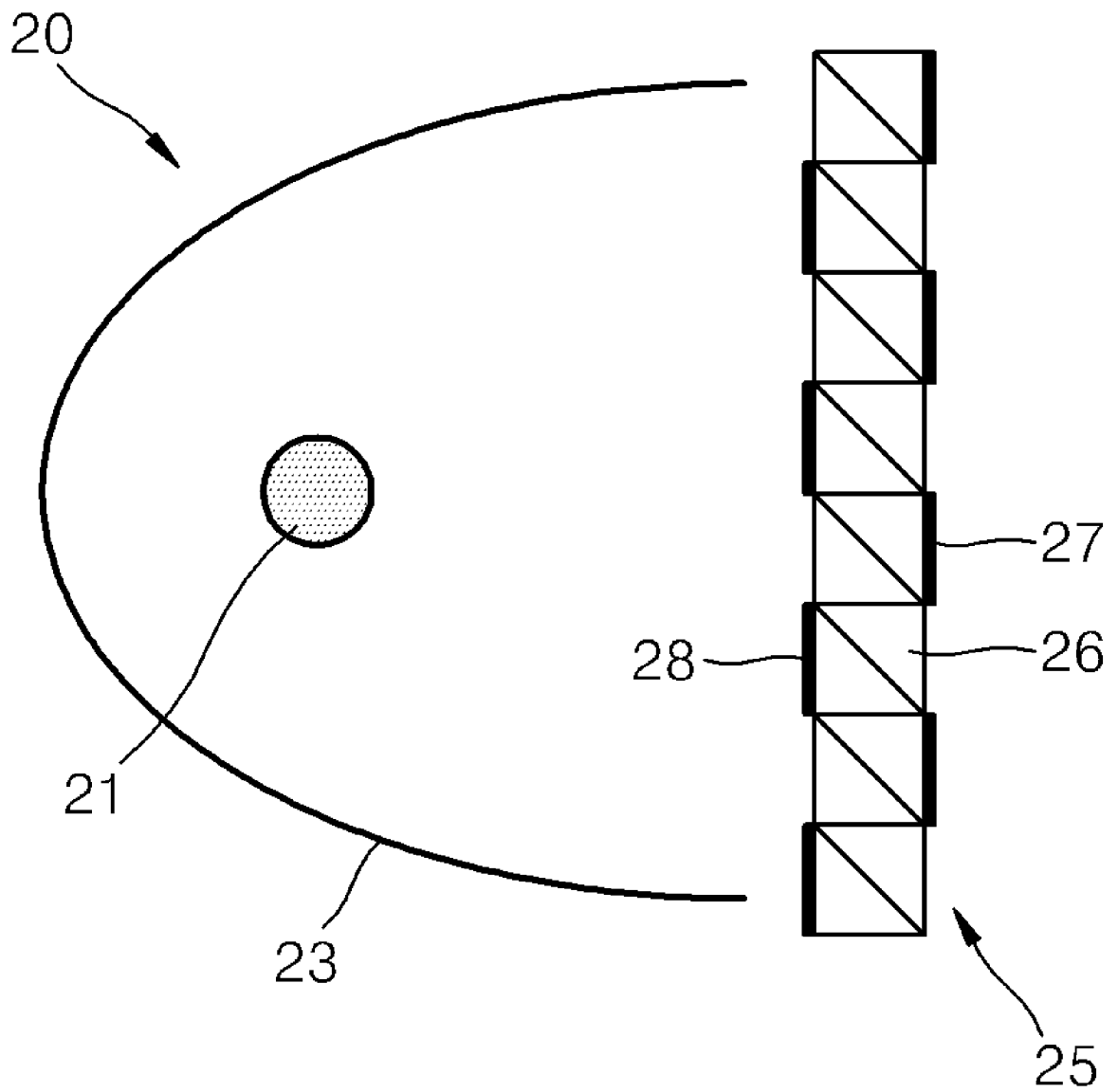


FIG. 8A

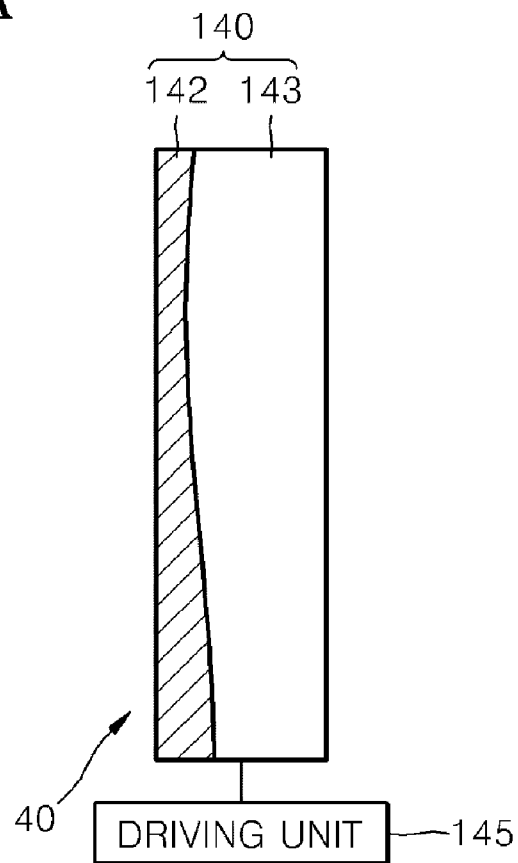


FIG. 8B

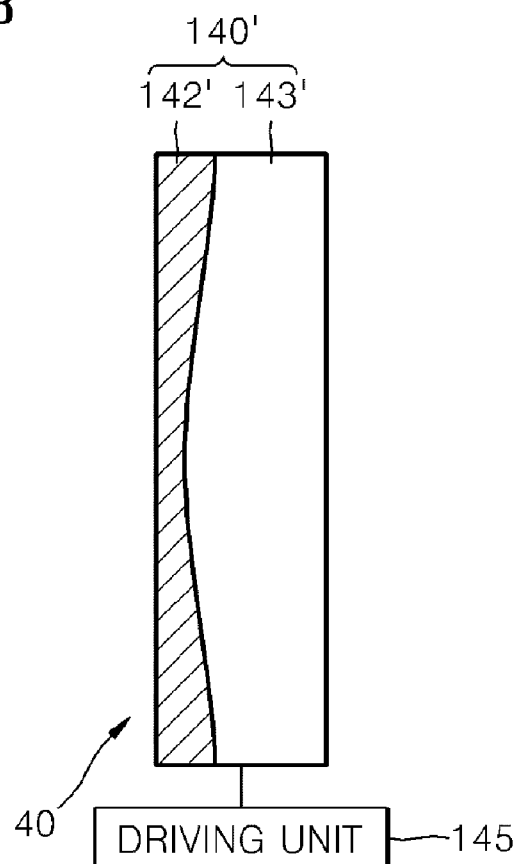


FIG. 9

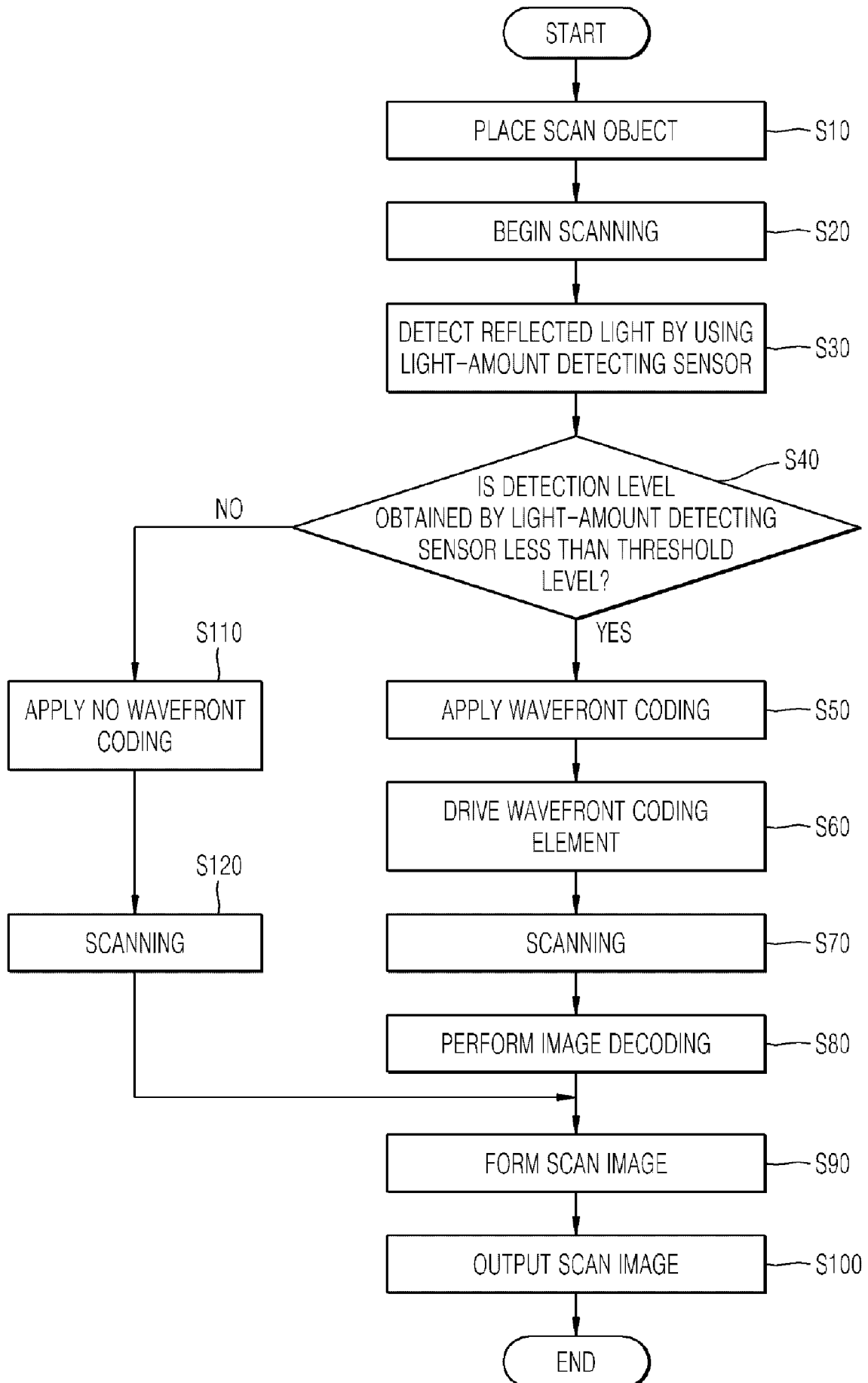
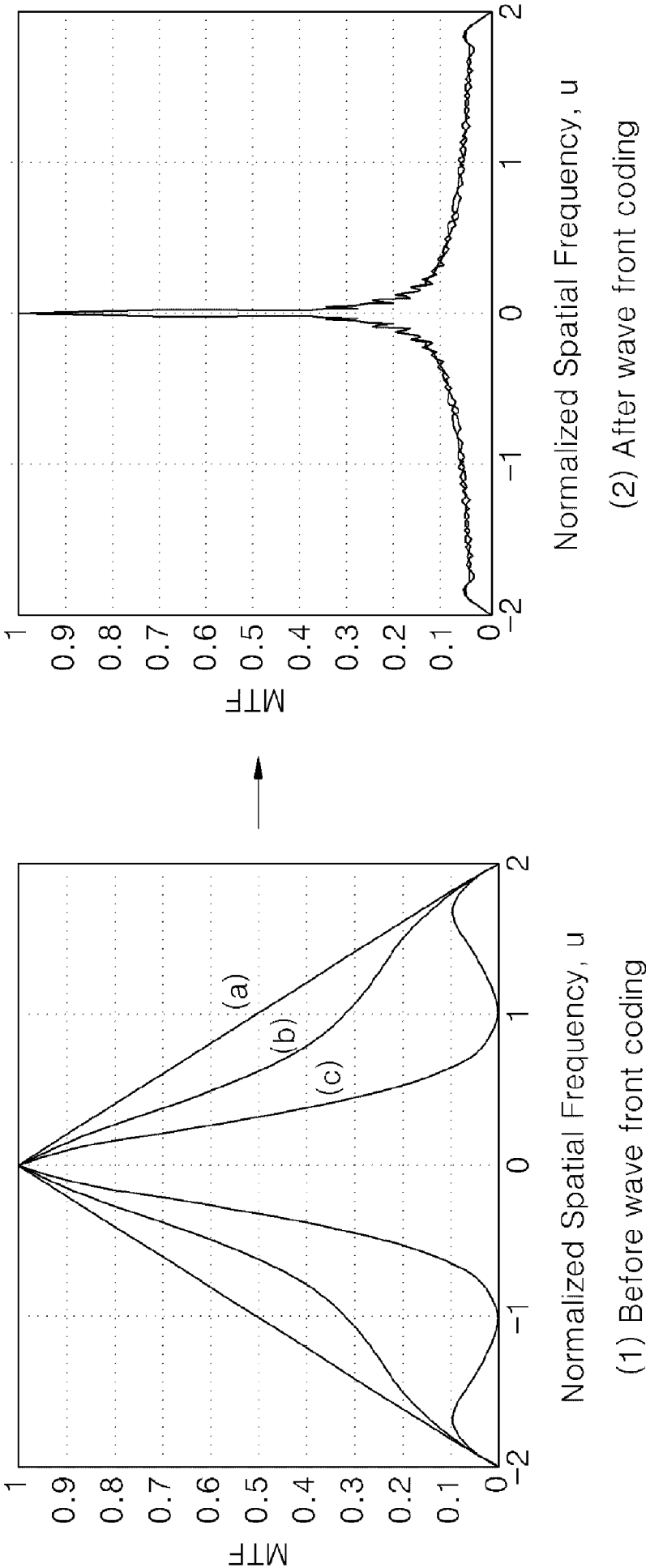


FIG. 10



A. CLASSIFICATION OF SUBJECT MATTER**G06K 15/00(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC : G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility models since 1975

Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS(KIPO Internal)

"Keywords : light, focus, detect, sensor, image, wavefront, coding, modulation, transfer, transparent, refraction "

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5548403 A (GARY E. SOMMARGREN) 20 August 1996 See column 2, line 20-column 6, line 14 and figure 1	1-19
A	US 6360012 B1 (JUSTIN L. KREUZER) 19 March 2002 See abstract and figures 1-6	1-19
A	WO 2005-069280 A2 (THOMSON LICENSING S.A.) 28 July 2005 See pages 6-7 and figure 2	1-19
A	US 2004-0227944 A1 (TATSUO FUKUI et al.) 18 November 2004 See abstract and figure 1	1-19



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

17 FEBRUARY 2009 (17.02.2009)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2008/005318

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