

DESCRIPTION

THREE-DIMENSIONAL SHAPE MEASURING APPARATUS

5 **TECHNICAL FIELD**

[0001]

Embodiments described herein relate generally to a three-dimensional shape measuring apparatus which measures a three-dimensional shape of an object by using a confocal
10 optical system.

BACKGROUND ART

[0002]

As one of the methods for measuring a three-dimensional
15 shape, such as a surface shape of an object, there is a method in which the surface shape of an object is measured by acquiring information on the height of each point on the surface of the object by using a confocal optical system. In the measurement using a confocal optical system, the
20 measurement is performed, in principle, for each point, and hence a special contrivance is necessary to measure a surface area.

[0003]

As this type of technique for measuring a surface area,
25 such as the surface of an object, by using a confocal optical system, a technique is disclosed in Japanese Patent Laid-Open

No. H9-329748 (Patent Document 1).

[0004]

Patent Document 1 discloses a confocal microscope provided with a light source and a Nipkow disk in which a plurality of apertures are formed. Each of the apertures functions as a point light source and a detector. A plurality of light beams respectively having passed through the plurality of apertures are converged by an objective lens to respectively corresponding converging positions on the side of a measurement object. Therefore, when the Nipkow disk is rotated, each of the light beams (hereinafter referred to as spots) having passed through the plurality of apertures and converged at the plurality of converging positions on the side of the measurement object can be easily scanned at high speed on the surface of the measurement object.

[0005]

Furthermore, in the method of scanning a spot on the surface of a measurement object using a Nipkow disk, it is difficult to prevent adverse effects caused by the rotation of the Nipkow disk. One adverse effect of the rotation of the Nipkow disk is that the curvature of the curve traced by the trajectory of an aperture (i.e., a pinhole) as the Nipkow disk rotates varies depending on the distance from the center of the disk. Since the curvature of the trajectory differs for each aperture, variations occur, such as different scanning speeds for each aperture. Furthermore, vibrations caused by

continuous rotation, including rotational wobble due to disk eccentricity, are unavoidable. To address these issues, Japanese Patent Laid-Open No. 2013-160612 (Patent Document 2) discloses a three-dimensional shape measuring apparatus
5 capable of linearly scanning a plurality of spots on the surface of a measurement object.

PRIOR ART DOCUMENTS

PATENT DOCUMENT

10 [0006]

Patent Document 1: Japanese Patent Laid-Open No. H9-329748

Patent Document 2: Japanese Patent Laid-Open No. 2013-160612

SUMMARY OF THE INVENTION

15 **PROBLEMS TO BE SOLVED BY THE INVENTION**

[0007]

In pinhole array scanning using a confocal optical system of a pinhole array-type three-dimensional shape measuring apparatus with a plurality of apertures in an
20 aperture plate, the timing at which light passes through each pixel varies. Therefore, if the object to be measured moves due to vibration or other factors, the uniformity of the scan deteriorates. In addition, manufacturing aperture plates is difficult, and individual differences in the diameter of the
25 apertures can occur. As a result, the uniformity of the scan also deteriorates, making accurate measurements difficult.

[0008]

The embodiments have been made in consideration of the above circumstances, and aim to provide a three-dimensional shape measuring apparatus that can perform accurate

5 measurements in pinhole array scanning using a confocal optical system.

MEANS FOR SOLVING THE PROBLEMS

[0009]

10 A three-dimensional shape measuring apparatus using a confocal optical system according to embodiments includes: an aperture plate including a transparent substrate, the aperture plate being provided with a plurality of confocal apertures which respectively allow light beams from a light source to
15 pass therethrough and which are two-dimensionally arranged to have a predetermined arrangement period on one surface of the transparent substrate; an objective lens configured to converge each of the light beams having passed through the plurality of confocal apertures, at an object side focused
20 point, and again converge each of reflected light beams formed by reflection of converged light beams at a measurement object, at respectively corresponding confocal apertures; a focus position changing unit including a rotating member provided thereon with a plurality of parallel plate type
25 members different from each other at least in one of refractive index and thickness and arranged along a rotation

direction so as to cross an optical axis of the objective lens, and a driving portion configured to continuously rotate the rotating member at a predetermined speed, the focus position changing unit being configured to discretely change a position of the object side focused point in an optical axis direction each time the parallel plate type member crossing the optical axis is changed by rotation of the rotating member; a photo-detector group including a plurality of photo-detectors each of which outputs a signal corresponding to an intensity of a reflected light beam having again passed through the confocal aperture; an aperture plate displacement unit configured to displace the aperture plate at a constant speed in a predetermined direction perpendicular to the optical axis direction so as to change a relative positional relationship between the position of the object side focused point and a position of the measurement object in the direction perpendicular to the optical axis direction; an imaging control unit configured to make the photo-detector group perform exposure a plurality of times in a period of constant speed movement of the aperture plate in the predetermined direction perpendicular to the optical axis direction, and to make the photo-detector group perform each of the exposures each time an imaging target region is included in the parallel plate type member, and to control a moving speed of the aperture plate, a rotation speed of the rotating member, and an exposure time and exposure timing of

the photo-detector group so that the exposure time of the photo-detector group coincides with a time during which the aperture plate is moved by a distance obtained by multiplying the predetermined arrangement period by an integer n equal to or greater than 2; a height determination unit configured to, based on the signal of the photo-detector for each of the positions of the object side focused points discretely changed in the optical axis direction by the focus position changing unit, estimate the position of the measurement object at which the intensity of the reflected beam incident on each of the photo-detectors becomes a maximum; a cover member provided on one surface of the transparent substrate of the aperture plate and is displaced integrally with the aperture plate by the aperture plate displacement unit, the cover member including a transparent member and a support member, the transparent member transmitting light from the light source and irradiates the light onto the plurality of confocal apertures, the support member supporting an entire peripheral edge of the transparent member and is provided on one surface of the transparent substrate of the aperture plate so as to surround the plurality of confocal apertures; and an imaging optical system designed in consideration of optical properties of a whole optical system including the transparent member of the cover member, the imaging optical system being configured to guide the reflected light beams having again passed through the confocal apertures to the photo-detector. The cover

member is provided on the one surface of the aperture plate via the support member such that the plurality of confocal apertures are positioned apart from the transparent member within the closed space, and that the transparent member is positioned between the light source and the aperture plate, the closed space being formed by the transparent member and the support member of the cover member and the transparent substrate of the aperture plate.

In the three-dimensional shape measuring apparatus, it is preferable that the imaging control unit is configured to switch between control in which the exposure time of the photo-detector group coincides with the time during which the aperture plate moves a distance obtained by multiplying the predetermined arrangement period by an integer n of 2 or more, and control in which the exposure time of the photo-detector group coincides with the time during which the aperture plate moves a distance obtained by multiplying the predetermined arrangement period by 1.

In the three-dimensional shape measuring apparatus, it is preferable that the imaging control unit is configured to make the exposure time in the control in which the exposure time of the photo-detector group coincides with the time during which the aperture plate moves a distance obtained by multiplying the predetermined arrangement period by an integer n of 2 or more, coincide with the exposure time in the control in which the exposure time of the photo-detector group

coincides with the time during which the aperture plate moves a distance obtained by multiplying the predetermined arrangement period by 1.

5 **ADVANTAGEOUS EFFECT**

[0010]

The three-dimensional shape measuring apparatus according to the embodiments makes it possible to reduce measurement errors and perform accurate measurements in pinhole array
10 scanning using a confocal optical system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

[FIG. 1] FIG. 1 is a schematic overall view showing a
15 configuration example of a three-dimensional shape measuring apparatus according to a first embodiment of the present invention.

[FIG. 2] FIG. 2 is a top view showing a configuration example of the aperture plate that constitutes the three-
20 dimensional shape measuring apparatus according to the first embodiment of the present invention.

[FIG. 3] FIG. 3 is a top view showing a first control example of the aperture plate that constitutes the three-
25 dimensional shape measuring apparatus according to the first embodiment of the present invention.

[FIG. 4] FIG. 4 is a top view showing a second control

example of the aperture plate that constitutes the three-dimensional shape measuring apparatus according to the first embodiment of the present invention.

[FIG. 5] FIG. 5 is a diagram for explaining the second control example of the aperture plate that constitutes the three-dimensional shape measuring apparatus according to the first embodiment of the present invention.

[FIG. 6] FIG. 6 is a perspective view showing a configuration example of the focus position changing portion.

[FIG. 7] FIG. 7 is a block diagram schematically showing an example of an internal configuration of the image processing apparatus.

[FIG. 8] Division (a) of FIG. 8 is a side view of the aperture plate provided with the cover member according to the example shown in FIG. 1, and division (b) is a perspective view of the aperture plate provided with the cover member.

[FIG. 9] FIG. 9 is an illustration showing an example of a timing chart for acquiring clear images.

[FIG. 10] FIG. 10 is a perspective view showing a configuration example of a reaction force mechanism.

[FIG. 11] FIG. 11 is a schematic overall view of a configuration example of a three-dimensional shape measuring apparatus according to a second embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

[0012]

Hereinbelow, a description will be given of a three-dimensional shape measuring apparatus according to embodiments of the present invention with reference to the drawings.

5 [0013]

A three-dimensional shape measuring apparatus according to an embodiment of the present invention is a pinhole array (PHA) type three-dimensional shape measuring device. The three-dimensional shape measuring apparatus measures the shape of a measurement object by using a confocal optical system having a confocal aperture array of a two dimensional array type. The confocal aperture array is provided in such a manner that apertures are two-dimensionally arranged in an aperture plate so as to have a predetermined arrangement period.

10

15 Examples of the measurement object include an electrode terminal (having a size of, for example, several ten to several hundred microns) of a component, such as an IC package, produced in mass production.

[0014]

20 First Embodiment

FIG. 1 is a schematic overall view showing a configuration example of a three-dimensional shape measuring apparatus according to a first embodiment of the present invention. Note that, in the following description, the case where the optical axis direction is set as the Z-axis direction, and where the directions perpendicular to the

25

optical axis direction are set as the X-axis direction and the Y-axis direction is described as an example.

[0015]

A three-dimensional shape measuring apparatus 10 includes an illumination optical system 11 having a light source 11a, an aperture plate (pinhole array) 12 arranged so that the main surface thereof is perpendicular to the optical axis direction, an objective lens 13, a focus position changing portion 14, a mount base 16 for mounting thereon a measurement object 15. The three-dimensional shape measuring apparatus 10 further includes a photo-detector group 17 having a plurality of photo-detectors 17a for receiving light beams reflected from the measurement object 15, a mount base driving portion 18 for moving the mount base 16 in each of the XYZ directions, a support base 19 supporting the mount base 16 and the mount base driving portion 18, and an image processing apparatus 20. The mount base driving portion 18 includes a mount base Z displacement portion 21 and a mount base XY displacement portion 22.

[0016]

As the light source 11a, for example, a halogen lamp, laser, and the like, can be used. The light emitted from the light source 11a is formed into a planar illumination luminous flux via an illumination lens 23. This light illuminates the aperture plate 12 via a polarizing beam splitter 24.

[0017]

FIG. 2 is a top view showing an example configuration of the aperture plate 12. The upper part of FIG. 2 is a top view of the aperture plate 12, and the lower part is an enlarged top view of a partial region W shown in the upper part. The aperture plate 12 is provided with a plurality of confocal apertures (hereinafter simply "apertures" 25) arranged two-dimensionally. The plurality of apertures 25 are arranged such that: (1) with respect to a plurality of apertures 25 arranged in a row along the X-axis, the row of apertures adjacent in the positive Y-axis direction is regularly shifted in the positive X-axis direction; and (2) with respect to a plurality of apertures 25 arranged in a row along the X-axis, the row separated by a predetermined distance Δd in the positive Y-axis direction is arranged without being shifted in the X-axis direction. That is, the aperture plate 12 is formed such that the plurality of apertures 25 are arranged two-dimensionally with a predetermined arrangement period Δd . The aperture plate 12 is driven by the aperture plate displacement unit 26 (shown in FIG. 1) and displaced in the Y-axis direction, which is one of the predetermined directions perpendicular to the optical axis. In the following description, the predetermined distance Δd is taken as the distance in the Y-axis direction, and an example is shown in which the aperture plate 12 moves in the positive and negative Y-axis directions.

[0018]

Generally, in order to reduce crosstalk between the light beams, it is necessary that the adjacent apertures 25 of the aperture plate 12 that is the aperture array of the two dimensional arrangement type of apertures 25 arranged two-
5 dimensionally are provided so as to be separated from each other by a predetermined separation distance. For this reason, in the confocal optical system having the aperture array of the two dimensional arrangement type, the resolution in the in-plane direction perpendicular to the optical axis is
10 restricted by this separation distance. On the other hand, in recent years, as for the two-dimensional image sensor using a solid-state imaging element, an image sensor having a very large number of pixels (for example, 5000×5000, and the like) has been developed.

15 [0019]

To cope with this, one aperture 25 is made to correspond to a plurality of pixels by linearly scanning the aperture plate 12 in the state where the photo-detector group 17 is exposed.

20 [0020]

As shown in the partially enlarged view of the lower part of FIG. 2, when the aperture plate 12 is displaced by the predetermined arrangement period (period interval) Δd by scanning the aperture plate 12, the inside of an imaging
25 target region 27 can be uniformly scanned once by the apertures 25. In the lower part of FIG. 2, the positions of

the photo-detectors (pixels) 17a configuring the photo-detector group 17 are virtually represented by broken lines as a virtual photo-detector 17a'.

[0021]

5 When the exposure time of the photo-detector 17a is controlled to coincide with the time during which the aperture plate 12 is moved by the distance obtained by multiplying the arrangement period Δd by a positive integer m , the time can be made uniform during which the light beam is irradiated to each
10 of the photo-detectors 17a via each of the apertures 25. This control is performed by the image processing apparatus 20.

[0022]

Each of the apertures 25 of the aperture plate 12 functions as a point light source. The light beam having
15 passed through each of the apertures 25 is irradiated by the objective lens 13 onto the measurement object 15 via the focus position changing portion 14 so as to be converged at a spot (object side focused point) conjugate with the point light source. Each of the object side focused points is located on
20 the surface (hereinafter referred to as object side focused plane) which is arranged at a predetermined position in the Z-axis direction and which is perpendicular to the optical axis direction. Note that the objective lens 13 may be configured by a plurality of lenses and diaphragms, so as to form, for
25 example, a both-side telecentric optical system.

[0023]

The aperture plate displacement portion 26 displaces the aperture plate 12 in the direction perpendicular to the optical axis direction. However, when the constant speed property of the aperture plate 12 is poor, unevenness is formed at random in an image, so as to deteriorate the shape measurement accuracy. To cope with this, it is preferred that the aperture plate displacement portion 26 is subjected to closed-loop control using a linear motor or a voice coil motor which is highly controllable and can perform direct driving.

10 [0024]

The mount base Z displacement portion 21 is configured by a common drive device, such as a stepping motor, a servo motor or a piezo motor, and displaces the mount base 16 in the optical axis direction. The amount, the direction, and the timing of the displacement are controlled by the image processing apparatus 20 via a Z-axis driver 30. The mount base Z displacement portion 21 roughly displaces the mount base 16 in the optical axis direction, for example, before the start of measurement.

20 [0025]

As described above, by controlling the exposure time of the photo-detector 17a to match the time during which the aperture plate 12 moves a distance obtained by multiplying the arrangement period Δd by a positive integer m , the irradiation time of light to each photo-detector 17a through each aperture 25 can be made uniform. On the other hand, if the exposure

time of the photo-detector 17a is controlled to match the time during which the aperture plate 12 moves a distance of one arrangement period Δd ($m = 1$), the timing at which light passes through each pixel differs. Consequently, if the measurement object 15 moves due to vibration or other factors, the uniformity of scanning deteriorates. Furthermore, the manufacturing of the aperture plate 12 is difficult, and individual differences in the diameter of the plurality of apertures 25 may occur. As a result, the uniformity of scanning deteriorates, making accurate measurement difficult.

[0026]

Therefore, the control method of the aperture plate 12 shown in FIG. 2 is modified so that scanning is performed over multiple periods for acquiring one image. This allows the reduction of measurement errors caused by deviations in measurement timing and individual differences in aperture diameter. Specifically, the imaging processing apparatus 20 controls the exposure time of the photo-detector 17a to match the time during which the aperture plate 12 moves a distance obtained by multiplying the arrangement period Δd by an integer n equal to or greater than 2. The value of n is determined according to the diameter of the apertures 25.

[0027]

FIGS. 3 and 4 are diagrams for explaining the control method of the aperture plate 12. FIG. 3 shows an example in which the exposure time of the photo-detector 17a matches the

time during which the aperture plate 12 moves a distance equal to one arrangement period Δd ($m = 1$). FIG. 4 shows an example in which the exposure time of the photo-detector 17a matches the time during which the aperture plate 12 moves a distance of Δd multiplied by n (e.g., $n = 2$).

[0028]

The left side of FIG. 3 shows an imaging target region 27 located at a predetermined position within the partial region W shown in the upper part of FIG. 2. If the exposure time of the photo-detector 17a is controlled to match the time during which the aperture plate 12 moves a distance equal to $\Delta d \times 1$ ($m = 1$), the state shown on the right side of FIG. 3 is obtained. The range A shown in FIG. 3 indicates the region through which the center of one pixel passes during exposure.

[0029]

The left side of FIG. 4, similar to FIG. 3, shows an imaging target region 27 located at a predetermined position within the partial region W. If the exposure time is controlled to match the time during which the aperture plate 12 moves a distance equal to $\Delta d \times 2$ ($n = 2$), the state shown on the right side of FIG. 4 is obtained. The range B indicates the region through which the center of one pixel passes during exposure.

[0030]

By scanning over n periods (multiple cycles) to acquire one image, deviations in measurement timing and errors caused

by aperture diameter variations can be reduced.

Multiple-period scanning can be realized by either of the following control methods:

(1) Keeping the scanning speed (movement speed of the aperture plate 12) unchanged and increasing the exposure time by n times.

(2) Keeping the exposure time unchanged and increasing the scanning speed by n times.

[0031]

As a result, n times as many apertures 25 pass over a given pixel, and the effective measurement timing becomes the average over n cycles. Thus, the measurement timing variation within an acquired image becomes $1/n$ of that of single-period scanning. Furthermore, because the movement of the aperture plate 12 causes n times as many apertures 25 to pass, manufacturing errors of the apertures 25 can also be averaged out. Although scanning time increases, aperture manufacturing errors may also be averaged simply by increasing exposure time by n times without performing multi-period scanning.

[0032]

FIG. 5 is a diagram explaining the amount of measurement timing deviation between single-period scanning and two-period scanning. FIG. 5 explains an example of the above control method (2).

[0033]

In single-period scanning, light passes through the

first pixel at the exposure-start timing (solid circle), and
as the aperture plate 12 moves, light passes through the
adjacent second pixel immediately before the exposure-end
timing (open circle). In contrast, in two-period scanning,
5 light passes through the first pixel at the exposure-start
timing (solid circle) and again at the next timing (solid
circle). For the adjacent second pixel in two-period scanning,
light passes at the timing immediately before the first
pixel's light-passing timing (open circle), and again
10 immediately before the exposure-end timing (open circle).
[0034]

Thus, the measurement timing deviation in two-period
scanning becomes half ($1/2$) that of single-period scanning (or
 $1/n$ for n -period scanning). Accordingly, aperture
15 manufacturing errors can be averaged. In control method (2),
since the movement speed of the aperture plate 12 becomes
twice as fast, the exposure time can remain nearly unchanged.
[0035]

Further, by control performed by the imaging control
20 unit 541, which will be described later, switching can be made
between single-period scanning and multi-period scanning. For
example, based on an instruction input by the operator via the
input portion 51, the imaging control unit 541 can switch
between single-period scanning and multi-period scanning
25 according to the above control method (1), between
single-period scanning and multi-period scanning according to

the above control method (2), among single-period scanning and multi-period scanning according to the above control method (1) and multi-period scanning according to the above control method (2), or between multi-period scanning according to the above control method (1) and multi-period scanning according to the above control method (2).

[0036]

FIG. 6 is a perspective view showing a configuration example of the focus position changing portion 14.

[0037]

When a parallel plate-shaped transparent member 31 is arranged in the optical path of the objective lens 13, the position of the object side focused plane of the objective lens 13 is moved in the Z direction. The range of this movement can be controlled by the refractive index and the thickness of the transparent member 31.

[0038]

For this reason, as shown in FIG. 6, the transparent members 31 are arranged on a rotating member 32 at regular intervals along the rotation direction of the rotating member 32. Each of the transparent members 31 is configured to have a different movement range of the position of the object side focused plane of the objective lens 13. When the rotating member 32 is continuously rotated at a predetermined speed by a driving portion 33, such as a motor, the position of the object side focused plane of the objective lens 13 can be

moved discretely (stepwise) in the Z direction each time each of the transparent members 31 crosses the optical axis of the objective lens 13.

[0039]

5 The rotating state of the rotating member 32 is detected by a timing sensor 34. The output of the timing sensor 34 is transmitted to the image processing apparatus 20. The information, which associates each of the transparent members 31 with the Z-axis coordinate of the object side focused
10 point, is stored beforehand in the image processing apparatus 20. When, on the basis of the output of the timing sensor 34, the image processing apparatus 20 repeats the exposure of the photo-detector group 17 at the timing at which each of the transparent members 31 crosses the optical axis, the imaging
15 can be performed easily and at high speed at each of the positions of the plurality of discrete object side focused points.

[0040]

20 Note that the driving portion 33 may be configured to be controllable by the image processing apparatus 20. In this case, the image processing apparatus 20 can control the rotation speed of the rotating member 32.

[0041]

25 Among the light beams reflected by the measurement object 15, particularly the light beam reflected at the object side focused point is converged by the objective lens 13 at the

point (hereinafter referred to as image side focused point) having an optically conjugate relationship with the object side focused point. The aperture 25 serving as a point light source corresponds to the object side focused point one to one.

[0042]

In the present embodiment, an example in the case where the image side focused point coincides with the aperture 25 serving as a point light source is described. In this case, the light beam having passed through the aperture 25 is converged at the object side focused point, and is reflected at the object side focused point, so as to again enter the aperture 25.

[0043]

The light beam having again entered the aperture 25 is deflected by the polarizing beam splitter 24, so as to enter an imaging optical system 35 and to enter the photo-detector 17a forming the photo-detector group 17. Here, the imaging optical system 35 is configured so that an image at the aperture 25 is formed on the photoelectric conversion surface of the photo-detector group 17. The aperture 25 (image side focused point) and the photo-detector 17a arranged at the position corresponding to the aperture 25 are in an optically conjugate relationship with each other by the polarizing beam splitter 24 and the imaging optical system 35.

[0044]

The photo-detector group 17 is a so-called two-dimensional image sensor. The photo-detector 17a configuring the photo-detector group 17 is configured by a CCD (Charge Coupled Device) image sensor or a CMOS (Complementary Metal Oxide Semiconductor) image sensor, and outputs, to the image processing apparatus 20, a signal corresponding to the intensity of an irradiated light beam. Further, the timing of photo-detection by the photo-detector group 17 is controlled by the image processing apparatus 20.

[0045]

The image processing apparatus 20 can receive the signals outputted from the photo-detector group 17 and use the received signals as image data (hereinafter referred to as confocal image data) for generating an image (hereinafter referred to as confocal image). Further, the image processing apparatus 20 may generate, for example, for each exposure, a confocal image based on the confocal image data. In the present embodiment, an example in the case where the image processing apparatus 20 generates a confocal image for each exposure of the photo-detector group 17 is described. In addition, when the image processing apparatus 20 can obtain output signals of the photo-detector group 17 for each exposure of the photo-detector group 17, it is possible to perform three-dimensional shape measurement on the basis of the output signals, and hence the confocal image is not necessarily generated.

[0046]

The mount base XY displacement portion 22 of the mount base driving portion 18 displaces the mount base 16 in the direction perpendicular to the optical axis direction. For example, the mount base XY displacement portion 22 is used for moving the measurement target region in the XY surface in each interval between the measurements.

[0047]

The mount base XY displacement portion 22 includes an X-axis displacement mechanism 41 and a Y-axis displacement mechanism 42 which respectively perform the positioning of the mount base 16 in the X-axis direction and the Y-axis direction. Each of the X-axis displacement mechanism 41 and the Y-axis displacement mechanism 42 is configured by a servo motor for example. And the amount, the direction, and the timing of displacement of each of the X-axis displacement mechanism 41 and the Y-axis displacement mechanism 42 are controlled by the image processing apparatus 20 via an XY-axis driver 45.

[0048]

FIG. 7 is a block diagram schematically showing an example of an internal configuration of the image processing apparatus 20. The image processing apparatus 20 can be configured, for example, by a desktop type personal computer, a notebook type personal computer, or the like. The image processing apparatus 20 includes an input portion 51, a

display portion 52, a memory portion 53, and a control circuit 54.

[0049]

The input portion 51 includes an input device operable
5 by the operator and an input circuit that receives signals
from the input device. The input device may be realized by a
trackball, switch, mouse, keyboard, touchpad for touch-based
operations, touchscreen integrating a display and touchpad,
non-contact input device using an optical sensor, voice input
10 device, or the like. When the operator manipulates the input
device, the input circuit generates a signal corresponding to
the manipulation and outputs it to the control circuit 54.

[0050]

The display portion 52 is configured by a common display
15 output device, such as, for example, a liquid crystal display
or an OLED (Organic Light Emitting Diode) display, and
displays a variety of information according to the control of
the control circuit 54.

[0051]

20 The memory portion 53 includes semiconductor memory
elements such as RAM or flash memory, a hard disk, optical
disk, or the like. The memory portion 53 may include portable
media such as USB memory or DVD. The memory portion 53 stores
various processing programs used by the control circuit 54
25 (including application programs and OS), and data required for
execution of the programs. The OS may include a GUI (Graphical

User Interface) enabling basic operations through the input portion 51 and using graphics for display on the display portion 52. The memory portion 53 stores, in advance, information associating each parallel-plate transparent member 31 with the Z-axis coordinate of the object-side focused point.

[0052]

The control circuit 54 is configured by the CPU, storage media including a RAM, and a ROM, and the like. The CPU of the control circuit 54 loads, to the RAM, a linear scanning program stored in the memory portion 53 including the ROM, and data required for the execution of the program and stored in the storage media, and executes processing to linearly scan the surface of the measurement object.

[0053]

The memory portion 53 may be configured by including a CPU-readable recording medium, such as a magnetic recording medium, an optical recording medium, or a semiconductor memory, so that a part or all of the program and the data stored in the storage media are downloaded via an electronic network. Here, the electronic network means, as a whole, an information communication network using an electric communication technique, and includes a telephone communication network, an optical fiber communication network, a cable communication network, satellite communication network, and the like, in addition to a wireless or wired LAN

(Local Area Network), and the Internet network.

[0054]

The control circuit 54 executes the linear scanning program to thereby function at least as an imaging control
5 portion 541, a height determination portion 542, and an image generation portion 543. Each of the portions 541 to 543 uses a required work area of the RAM as a temporary storage area of the data. Each of the portions 541 to 543 realizing the respective functions may also be configured by using a
10 hardware logic such as an ASIC (Integrated Circuit) or an FPGA (Field Programmable Gate Array).

[0055]

The imaging control portion 541 controls the focus position changing portion 14, the photo-detector group 17, and
15 the aperture plate displacement portion 26. The image control portion 541 thereby makes the photo-detector group 17 perform exposure (imaging) for each period in which the imaging target region 27 is included in the parallel plate-shaped transparent member 31 while the aperture plate 12 is displaced in the Y-axis direction at a constant speed by the aperture plate
20 displacement portion 26. In that case, the imaging control portion 541 controls the moving speed of the aperture plate 12, the rotation speed of the rotating member 32, and the exposure time and the exposure timing of the photo-detector
25 group 17 so that the exposure time of the photo-detector group 17 coincides with the time in which the aperture plate 12 is

moved by the distance obtained by multiplying the arrangement period Δd by n (n is an integer equal to or greater than 2).

[0056]

The height determination portion 542 acquires the present
5 Z-axis coordinate of the object side focused point
(information on the transparent member 31 currently crossing
the optical axis) from the imaging control portion 541 and
also acquires the outputs of the photo-detector group 17. On
the basis of the signal of the photo-detector 17a for each
10 position of the object side focused point discretely changed
in the optical axis direction, the height determination
portion 542 calculates, for each of the photo-detectors 17a,
the position of the measurement object 15 in the optical axis
direction, at which position the intensity of the reflected
15 light beam entering the photo-detector 17a becomes a maximum.
[0057]

Here, when the coordinate system (mount base coordinate
system) is considered whose origin is set at the center of the
mount base 16, the XY coordinates of the measurement target
20 region (imaging target region 27) in the mount base coordinate
system can be uniquely obtained from the present position of
the mount base XY displacement portion 22. For this reason,
the XY coordinates in the mount base coordinate system, which
correspond to each of the photo-detectors 17a, are uniquely
25 determined in correspondence with the present position of the
mount base XY displacement portion 22.

[0058]

Conventionally, various methods have been known as methods being such that the Z-axis coordinate of the measurement object 15, at which coordinate the intensity of the reflected light beam becomes a maximum, is calculated on the basis of the intensity of a plurality of signals discretely acquired from the outputs of the photo-detectors 17a in the shape measuring technique using the confocal optical system. Among these methods, any method can be used.

10 [0059]

The optical axis direction position of the measurement object 15 is calculated for each of the photo-detectors 17a by the height determination portion 542. On the basis of the optical axis direction position of the measurement object 15, the image generation portion 543 generates a shape image of the measurement object 15 so as to enable the shape image to be displayed by the display portion 52.

[0060]

Note that the number of positions of the object side focused points (optical axis direction measurement positions), which are necessary for one measurement (processing for generating one shape image) and which are discretely changed in the optical axis direction, may be set to a fraction of a positive integer (for example, $\frac{1}{2}$, $\frac{1}{3}$, or the like) of the number of the transparent members 31 of the rotating member 32. For example, in the case where the number of the optical

25

axis direction measurement positions coincides with the number of the transparent members 31 of the rotating member 32, one measurement can be performed by one rotation of the rotating member 32. Further, the number of the periods of the apertures 5 25 provided in the aperture plate 12 may be set to a number with which at least one measurement can be performed while the aperture plate 12 is moved at a constant speed in a predetermined direction (one of the positive and negative direction) of the Y-axis direction.

10 [0061]

Further, the measurement may also be performed in such a manner that at least one measurement is performed while the aperture plate 12 is moved at the constant speed in the predetermined direction (one of the positive and negative 15 direction) of the Y-axis direction, and that, after the moving direction of the aperture plate 12 is reversed and then the aperture plate 12 is moved at the constant speed, the next measurement is performed. Furthermore, at this time, in the period in which the aperture plate 12 is accelerated and 20 decelerated for movement direction inversion, or the like, of the aperture plate 12, the measurement target region may also be changed by moving the measurement object 15 in the XY axis direction. In this case, the time required for a plurality of times of the measurement as a whole can be reduced.

25 [0062]

Note that the confocal "microscope" is mainly used for

observation, and hence is required to perform continuous imaging. In this respect, it can be said that the confocal microscope using the Nipkow disk is convenient because, with it, confocal images can be continuously obtained as long as the Nipkow disk is rotated. However, in the surface shape measurement, there is an interval between each of the measurements (each of the visual fields), and hence it is not necessary to continuously perform the imaging. Therefore, there is no problem as long as one measurement is completed during the period in which the aperture plate 12 is moved at a constant speed even when a discrete scanning method such as the method using the movement of the aperture plate 12 according to the present embodiment is used instead of the continuous scanning method, such as the scanning method using the rotation of the Nipkow disk.

[0063]

The three-dimensional shape measuring apparatus 10 according to the present embodiment can linearly scan the aperture plate 12. Therefore, when, while the photo-detector group 17 is exposed, the aperture plate 12 is linearly scanned, one aperture 25 can be made to correspond to a plurality of pixels, so that high resolution can be realized. Further, the scanning trajectory of the object side focused point can be made to follow a strict straight line, and hence the scanning region (measurement target region) on the surface of the measurement object 15 can be formed in a rectangular

shape. Therefore, the compatibility with the two-dimensional image sensor can be improved as compared with the case where the Nipkow disk is used.

[0064]

5 In the present embodiment, an example of the case where the aperture plate 12 is a pinhole array type provided with a plurality of apertures 25 is described. In this case, it is only necessary that the apertures are arranged to have a predetermined arrangement period Δd , and hence a slit array
10 type aperture plate may also be used. In the case where a slit array type aperture plate is used as the aperture plate 12, with the long side of each slit being set in the direction perpendicular to the moving direction of the aperture plate 12, the predetermined arrangement period can be handled as Δd
15 when a plurality of slits are arranged so that the interval in the moving direction between the centers of the slits adjacent to each other is a positive integer fraction of Δd .

[0065]

 In the case where the aperture plate 12 having such
20 slits is used, a minimum scan width required to acquire a confocal image is equal to the interval (pitch) between the centers of the slits adjacent to each other. That is, when the aperture plate 12 is moved by the pitch of the slit, the confocal data can be obtained by all the photo-detectors 17a
25 configuring the photo-detector group 17. For this reason, when the slit array type aperture plate 12 is used, the moving

distance of the aperture plate 12 required to acquire one confocal image can be reduced as compared with the case where the pinhole array type aperture plate 12 is used.

[0066]

5 Next, a detailed configuration of the aperture plate 12 and a dust-proof method of the aperture plate 12 will be described.

[0067]

 The aperture 25 is formed in the aperture plate 12 so as
10 to have a diameter size of one to several μm . For this reason, a dust-proof measure is taken for at least the region (hereinafter referred to as aperture region) in which a plurality of the apertures 25 is formed. When a method of closing the whole optical system of the three-dimensional
15 shape measuring apparatus 10 with housing, or a method of closing the aperture plate 12 and the aperture plate displacement portion 26 with housing is adopted as a dust-proof measure of the aperture region, any of the methods needs a large-scale configuration and also dust may be generated
20 from the driving portion, such as the aperture plate displacement portion 26, so as to adhere to the aperture array region.

[0068]

 To cope with this, the three-dimensional shape measuring
25 apparatus 10 according to the present embodiment includes a cover member 60 for protecting the aperture plate 12 from

dust. The cover member 60 is used for protecting both sides of the aperture region of the aperture plate 12 from dust. FIG. 1 schematically shows an example of a configuration of the cover member 60. Further, division (a) of FIG. 8 is a side view of the aperture plate 12 provided with the cover member 60 according to the example shown in FIG. 1, and division (b) of FIG. 8 is a perspective view of the aperture plate 12 provided with the cover member 60.

[0069]

In the configuration example of the cover member 60 shown in FIG. 1 and FIG. 8, the aperture plate 12 is configured by a transparent substrate 12a. This configuration is suitable for the case where the light source-side surface of the transparent substrate 12a is chromium-etched to form the apertures 25. In this case, the objective lens-side surface of the aperture region is protected from dust by the transparent substrate 12a. For this reason, only the light source-side surface of the aperture region needs to be protected from dust by the cover member 60. Therefore, as shown in FIG. 1 and FIG. 8, it is only necessary that the cover member 60 is detachably provided on the light source side of the aperture plate 12 (on the side surface on which the apertures 25 are formed) so as to cover the apertures 25 and to protect the light source-side surface of the aperture region from dust. The configuration of the aperture plate 12 and the cover member 60 in this case will be described in more

detail below.

[0070]

The cover member 60 includes a transparent member 61, a support member 62 of the transparent member 61, and an intermediate plate 63. On the other hand, the aperture plate 12 includes an aperture region in which a plurality of the apertures 25 is formed on the light source-side surface of the transparent substrate 12a.

[0071]

Each of the support member 62 and the intermediate plate 63 is provided with an opening for transmitting the light beam from the light source 11a. The entire circumference of the transparent member 61 is bonded to the inner side or the outer side of the opening of the support member 62. The support member 62 is screwed to the intermediate plate 63 so that the center of the opening of the support member 62 substantially coincides with the center of the opening of the intermediate plate 63. Moreover, when a packing 64, such as an O-ring, is provided on the contact surface between the support member 62 and the intermediate plate 63 so as to surround the opening of the intermediate plate 63, a dust-proof effect can be further improved.

[0072]

Further, to the side surface of the intermediate plate 63, which side surface is opposite to the fixing side of the support member 62, the entire periphery of the aperture plate

12 is welded so that the forming surface 65 of the apertures 25 and the opening of the intermediate plate 63 face each other. As a result, the aperture region, in which a plurality of the apertures 25 are formed, can be provided in the closed space formed by the aperture plate 12, the transparent member 61, the support member 62, and the intermediate plate 63. Further, the aperture plate 12 and the cover member 60 are integrally displaced in the Y-axis direction by the aperture plate displacement portion 26.

10 [0073]

Note that the entire periphery of the aperture plate 12 need not be welded to the intermediate plate 63, and the aperture plate 12 may be detachably screwed to the intermediate plate 63 via a packing, such as an O ring. In this case, the cover member 60 is detachably attached to the aperture plate 12. In the case where the aperture plate 12 is detachably press-fitted to the cover member 60, the exchange and maintenance of the aperture plate 12 can be easily performed.

20 [0074]

The intermediate plate 63 is screwed to the longitudinal portion of an L-shaped jig 66 so that the aperture plate 12 is mounted in the opening of the L-shaped jig 66. The lateral portion of the L-shaped jig 66 is screwed to an aperture plate mounting portion 67. The aperture plate mounting portion 67 is displaced in the Y-axis direction along a linear guide 68a by

a linear motor 68 controlled by the imaging control portion 541. The drive control of the linear motor 68 is performed by using output signals from a sensor group 69 of various sensors provided in the vicinity of the linear guide 68a. An origin
5 sensor, a limit sensor, and the like, are included in the sensor group 69.

[0075]

The cover member 60 is provided on the light source side forming surface 65 of the apertures 25 of the aperture plate
10 12 so as to cover the aperture region and to protect the light source side of the aperture region from dust. Thereby, as compared with the case where the whole aperture plate displacement portion 26 is covered with housing, or the case where the whole optical system of the three-dimensional shape
15 measuring apparatus 10 is covered with housing, dust-proof can be attained by a very light-weight and simple configuration, and also the adverse effect of dust generated by the motor can be prevented.

[0076]

20 Each of the transparent member 61 and the transparent substrate 12a prevents dust from adhering to the aperture region of the aperture plate 12, but cannot prevent dust from adhering to each of the transparent member 61 and the transparent substrate 12a itself. However, when each of the
25 transparent member 61 and the transparent substrate 12a has a sufficient thickness, dust adhering to the surface of each of

the transparent member 61 and the transparent substrate 12a is separated from the position of the aperture plate 12. This position of the aperture plate 12 is the image forming position of the imaging optical system 35 and of the objective lens 13. Hence, the diameter of the image forming luminous flux is large at the position of dust adhering to the surface of each of the transparent member 61 and the transparent substrate 12a. Therefore, the image forming luminous flux cannot be thoroughly blocked by the dust, and hence the influence of the dust is small.

[0077]

However, when the thick transparent member 61 is inserted into the optical path, the influence of the transparent member 61 on the image forming performance of the imaging optical system 35 cannot be neglected. Therefore, the imaging optical system 35 needs to be designed in consideration of the thickness of the transparent member 61. Of course, optical glass having no striae and having sufficiently high surface accuracy and parallelism needs to be used as the transparent member 61.

[0078]

Note that an example of the case where the apertures are formed on the light source side of the transparent substrate 12a, and where the cover member 60 protects the light source side of the aperture region from dust is shown in FIG. 1 and FIG. 8, but the aperture plate 12 and the cover

member 60 may be arranged so as to be inverted as a whole on the optical path. That is, the apertures 25 may be formed on the objective lens side of the transparent substrate 12a, and the objective lens side of the aperture region may be

5 protected from dust by the cover member 60.

[0079]

Further, it is only necessary that the cover member 60 has a configuration in which both sides of the aperture region of the aperture plate 12 are protected from dust. Therefore, 10 the configuration of the cover member 60 is not limited to the configuration as shown in FIG. 1 and FIG. 8. In the configuration example shown in FIG. 1 and FIG. 8, one side surface of the aperture region of the aperture plate 12 is protected from dust by the transparent substrate 12a, and 15 hence it is only necessary that the cover member 60 is configured so as to be able to protect the other side surface of the aperture region from dust. On the other hand, for example, when the aperture plate 12 is formed of a plate having high light-shielding properties (including a metal 20 plate, a plastic plate coated with light-shielding paint, and the like), and when the apertures 25 are formed by providing holes in the plate, it is preferred that the cover member 60 is configured so as to cover both the light source side and the objective lens side of the aperture region of the aperture 25 plate 12. In that case, it is preferred that the cover member 60 includes, for example, two sets of the transparent member

61 and the support member 62 which are shown in FIG. 1, and that each of the sets is detachably provided on each of the light source side and the objective lens side of the aperture region of the aperture plate 12 formed of the plate having
5 high light-shielding properties.

[0080]

Next, the imaging control method by the imaging control portion 541 will be described.

[0081]

10 The imaging control portion 541 controls the focus position changing portion 14, the photo-detector group 17, and the aperture plate displacement portion 26. The imaging control portion 541 thereby controls the moving speed of the aperture plate 12, the rotation speed of the rotating member
15 32, and the exposure time and the exposure timing of the photo-detector group 17 so that the exposure time of the photo-detector group 17 coincides with the time in which the aperture plate 12 is moved by the distance obtained by multiplying the arrangement period Δd by n (n is an integer
20 equal to or greater than 2).

[0082]

For example, consider a control case (shown in FIG. 3) in which the exposure time of the photo-detector group 17 matches the time required for the aperture plate 12 to move a
25 distance equal to one arrangement period Δd . Assume that the arrangement period Δd is 100 μm , the constant movement speed v

of the aperture plate 12 is 10 mm/s, and the time Δt required to move the distance Δd is 10 ms. In a control case (shown in FIG. 4) where the exposure time matches the time required for the aperture plate 12 to move a distance of Δd multiplied by n , and using control method (1), the movement time Δt is set to $(10 \times n)$ ms while keeping the movement speed v at 10 mm/s. In this case, the exposure time Δt_1 of the photo-detector group 17 is controlled to exactly match $\Delta t \times n$. Alternatively, when adopting control method (2), the movement time Δt is kept at 10 ms, while the constant movement speed v is set to $(10 \times n)$ mm/s. In this case as well, the exposure time Δt_1 is controlled to match exactly $\Delta t = 10$ ms. When adopting control method (2), if the aperture diameter is 1-several micrometers, it is preferable that n is 2-4, i.e., that the constant movement speed of the aperture plate 12 is 20-40 mm/s.

[0083]

However, even in the case where the exposure time Δt_1 accurately coincides with $\Delta t \cdot n$ (the above control method (1)) and Δt (the above control method (2)), when there is a subtle error in the exposure time Δt_1 , a pattern generated in an image. The pattern is determined by the positions of the apertures 25 at the exposure start time. That is, underexposure or overexposure occurs in the pixels in the vicinity of the positions of the apertures 25 at the exposure start time, so as to appear as a pattern. Further, in the case where the arrangement direction of the apertures 25 and the

moving direction of the aperture plate 12 do not accurately coincide with each other and are inclined toward each other, even when the inclination is minute, a similar pattern appears. This pattern is also determined by the positions of the apertures 25 at the exposure start time. Therefore, when the apertures 25 are positioned at random at the exposure start time, the pattern is also changed at random.

[0084]

Meanwhile, the exposure start timing is determined according to the trigger timing of the timing sensor 34 of the focus position changing portion 14. For this reason, for example, when the number of revolutions of the rotating member 32 is determined completely independently of the aperture plate displacement portion 26, the above-described pattern is changed almost at random for each image acquisition, so as to be reflected as noise components in the on-axis response curve used for the measurement operation. Thereby, the measurement accuracy is deteriorated.

[0085]

In order to avoid such problem, it is necessary that the exposure is prevented from starting at a random timing, and that the exposure is allowed to be started only at the interval corresponding to an integer multiple of the time ((10×n) ms or 10 ms in the above-described example) during which the aperture plate 12 is moved by n arrangement period $\Delta d \cdot n$. Thereby, the random generation of the pattern is

prevented, so that clearer images can be obtained.

[0086]

FIG. 9 is an illustration showing an example of a timing chart for acquiring clear images. FIG. 9 explains the above control methods (1) and (2) using an example. Note that in the case of control method (2), simply replace $\Delta t \cdot n$ with Δt in FIG. 9.

[0087]

As shown in FIG. 9, the imaging control portion 541 makes the photo-detector group 17 perform exposure each time the transparent member 31 of the rotating member 32 crosses the optical axis. In that case, the imaging control portion 541 makes the exposure time Δt_1 of the photo-detector group 17 coincide only with the time $\Delta t \cdot n$ required for the aperture plate 12 to be moved by n (n is an integer equal to or greater than 2) arrangement period $\Delta d \cdot n$. In that case, the imaging control portion 541 controls the moving speed v of the aperture plate 12 so that the moving speed v is set as $v = \Delta d / \Delta t$. Further, the imaging control portion 541 makes the interval between the exposure start times adjacent to each other coincide with the time $\Delta t \cdot k$ obtained by multiplying Δt by a positive integer k that is greater than n .

[0088]

Next, a method for reducing the influence of the force generated by acceleration and deceleration of the aperture plate 12 will be described.

[0089]

It is preferred that the aperture plate 12 is accelerated to a constant speed as quickly as possible. However, it is considered that, when the aperture plate 12 is quickly accelerated and decelerated, the aperture plate 12 may be vibrated by the force generated by the acceleration and deceleration, so as to lower the measurement accuracy. In order to reduce the effect of the force generated by the acceleration and deceleration of the aperture plate 12, it is preferred to provide a reaction force mechanism.

[0090]

FIG. 10 is a perspective view showing a configuration example of a reaction force mechanism 70. The reaction force mechanism 70 includes a movable member 71 which is displaced by the linear motor 68 in the Y-axis direction along the linear guide 68a, and an adjusting member 72 which is provided on the movable member 71 so as to be displaced integrally with the movable member 71.

[0091]

The movable member 71 is driven by the linear motor 68 controlled by the imaging control portion 541 and thereby reduces (cancels) the influence of the force generated by the acceleration and deceleration of the aperture plate 12. For example, when the weight of the adjusting member 72 is selected so that the weight of articles placed on the aperture plate mounting portion 67 plus the weight of the aperture

plate mounting portion 67 itself coincides with the weight of the reaction force mechanism 70, the center of gravity of the aperture plate mounting portion 67 and the reaction force mechanism 70 exists in the middle between the aperture plate mounting portion 67 and the movable member 71. In this case, for example, when the movable member 71 and the aperture plate mounting portion 67 are respectively accelerated or decelerated at the same rate in the opposite directions so as to be positioned symmetrically with respect to the center of gravity described above, the influence of the force generated by the acceleration or deceleration of the aperture plate 12 can be reduced.

[0092]

Second Embodiment

Next, a second embodiment of a three-dimensional shape measuring apparatus according to the present invention will be described.

[0093]

FIG. 11 is a schematic overall view of a configuration example of a three-dimensional shape measuring apparatus 10A according to a second embodiment of the present invention.

[0094]

The three-dimensional shape measuring apparatus 10A shown as the second embodiment is different from the three-dimensional shape measuring apparatus 10 shown as the first embodiment in that the focus position changing portion 14 is

provided on the side of the aperture plate 12 with respect to the objective lens 13. Since the other configurations and operations of the three-dimensional shape measuring apparatus 10A are not substantially different from those of the three-dimensional shape measuring apparatus 10 shown in FIG. 1, the same components and configurations are denoted by the same reference numerals and characters, and their explanation is omitted.

[0095]

A microscope is used in such a manner that the (observation) accuracy is improved by increasing the magnification by exchanging the objective lens, and on the contrary, the (observation) accuracy is lowered to observe a whole object in a large visual field. In this way, a microscope enables an optimum enlargement magnification to be selected according to an observation purpose, and hence has high flexibility.

[0096]

It is desired that the three-dimensional shape measuring apparatus has such flexibility. However, as in the case of the three-dimensional shape measuring apparatus 10 according to the first embodiment, when the focus position changing portion 14 including the rotating member 32 is inserted on the side of the measurement object 15 (between the measurement object 15 and the objective lens 13), such flexibility cannot be obtained. This is because the thickness pitch of the

transparent member 31 on the rotating member 32 is determined so that the value of three or more points can be sampled in the central mountain-shaped portion of the confocal on-axis response curve (curve representing the output change of the detector when the object side focused point is moved in the Z direction), though the NA (numerical aperture) of the objective lens 13 on the side of the measurement object 15 is changed when the objective lens 13 is exchanged.

[0097]

The width of the central mountain-shaped portion is determined by the NA on the side of the measurement object 15. For this reason, when the objective lens 13 is exchanged, it is also necessary to change the pitch of the transparent member 31 provided on the rotating member 32. That is, it is necessary to exchange not only the objective lens 13 but also the rotating member 32 itself.

[0098]

Therefore, as shown in FIG. 11, when the rotating member 32 is located in the space on the image side (the side of the aperture plate 12), the sampling pitch in the image side space, which sampling pitch is determined by the thickness pitch of the transparent member 31, is inversely proportional to the longitudinal magnification (square of transverse magnification) of the lens in the space on the side of the measurement object 15. For this reason, even when the objective lens 13 is exchanged to change the magnification,

not only the width of the central mountain-shaped portion but also the sampling pitch on the side of the measurement object 15 are similarly automatically changed so as to be inversely proportional to the square of the transverse magnification.

5 Therefore, as shown in FIG. 11, in the case where the rotating member 32 is located in the image side space (on the side of the aperture plate 12), even when the objective lens 13 is exchanged, it is not necessary to exchange the rotating member 32. Of course, the object side space in the optical axis
10 direction (the measurement range in the Z axis direction), in which space the measurement can be actually performed, is also changed inversely proportional to the square of transverse magnification. However, a smaller object is usually observed at higher magnification, and hence such change is reasonable.

15 [0099]

Therefore, with the three-dimensional shape measuring apparatus 10A according to the second embodiment, the magnification of the objective lens 13 can be easily changed. Further, as compared with the case where the focus position
20 changing portion 14 is provided on the side of the measurement object 15, the working distance in the space on the side of the measurement object 15 can be sufficiently secured, so that workability can be improved, and also auxiliary illumination, such as oblique incident illumination, can be easily provided.

25 [0100]

According to control methods (1) and (2) of the

three-dimensional shape measuring apparatuses 10 and 10A of the present invention, measurement errors can be reduced in pinhole array scanning using a confocal optical system, enabling accurate measurement. Specifically, control methods (1) and (2) reduce deterioration in scanning uniformity caused by vibration and allow accurate measurement regardless of individual differences in aperture diameter. In particular, control method (2) produces these effects without extending the exposure time. The type of measurement object 15 is not particularly limited; however, in the case of control method (2), it is preferable to narrow the measurement range. Thus, it is preferable that the measurement object 15 is, for example, a bump-shaped connection electrode formed on a semiconductor chip or wiring lead.

[0101]

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

[0102]

For example, the focus position changing portion 14 is not limited to the configuration shown in FIG. 6 as long as it can move the position of the object side focused point of the objective lens 13 in the Z direction. For example, the focus position changing portion 14 may also be configured by an optical path length adjusting member which is formed of a transparent member having a predetermined refractive index and a thickness variable in the optical axis direction, and an adjusting member driving portion which changes the thickness of the transparent member in the optical axis direction. In this case, the focus position changing portion 14 can change the position of the object side focused point in the optical axis direction in such a manner that the optical path length of the light beam passing through the optical path length adjustment member is changed by changing the optical-axis-direction thickness of the transparent member crossing the optical axis. The optical path length adjustment member can be configured, for example, by two parallel plane glass plates arranged in parallel with each other, and a liquid filled between the glass plates. In this case, the adjusting member driving portion can change the optical path length by changing the volume of the liquid.

REFERENCE SIGNS LIST

[0103]
10 and 10A ... Three-Dimensional Shape Measuring Apparatus

11 ... Illumination Optical System
 11a ... Light Source
 12 ... Aperture Plate
 13 ... Objective Lens
 5 14 ... Focus Position Changing Portion
 15 ... Measurement Object
 16 ... Mount Base
 17 ... Photo-Detector Group
 18 ... Mount Base Driving Portion
 10 20 ... Image Processing Apparatus
 21 ... Mount Base Z Displacement Portion
 22 ... Mount Base XY Displacement Portion
 25 ... aperture
 26 ... Aperture Plate Displacement Portion
 15 27 ... Imaging Target Region
 31 ... Transparent Member
 32 ... Rotating Member
 34 ... Timing Sensor
 35 ... Imaging Optical System
 20 541 ... Imaging Control Portion
 542 ... Height Determination Portion
 60 ... Cover Member
 61 ... Transparent Member
 62 ... Support Member
 25 63 ... Intermediate Plate
 64 ... Packing

- 67 ... Aperture Plate Mounting Portion
- 68 ... Linear Motor
- 70 ... Reaction Force Mechanism

CLAIMS

1. A three-dimensional shape measuring apparatus using a confocal optical system, comprising:

5 an aperture plate including a transparent substrate, the aperture plate being provided with a plurality of confocal apertures which respectively allow light beams from a light source to pass therethrough and which are two-dimensionally arranged to have a predetermined arrangement period on one
10 surface of the transparent substrate;

an objective lens configured to converge each of the light beams having passed through the plurality of confocal apertures, at an object side focused point, and again converge each of reflected light beams formed by reflection of
15 converged light beams at a measurement object, at respectively corresponding confocal apertures;

a focus position changing unit including a rotating member provided thereon with a plurality of parallel plate type members different from each other at least in one of
20 refractive index and thickness and arranged along a rotation direction so as to cross an optical axis of the objective lens, and a driving portion configured to continuously rotate the rotating member at a predetermined speed, the focus position changing unit being configured to discretely change a
25 position of the object side focused point in an optical axis direction each time the parallel plate type member crossing

the optical axis is changed by rotation of the rotating member;

a photo-detector group including a plurality of photo-detectors each of which outputs a signal corresponding to an intensity of a reflected light beam having again passed through the confocal aperture;

an aperture plate displacement unit configured to displace the aperture plate at a constant speed in a predetermined direction perpendicular to the optical axis direction so as to change a relative positional relationship between the position of the object side focused point and a position of the measurement object in the direction perpendicular to the optical axis direction;

an imaging control unit configured to make the photo-detector group perform exposure a plurality of times in a period of constant speed movement of the aperture plate in the predetermined direction perpendicular to the optical axis direction, and to make the photo-detector group perform each of the exposures each time an imaging target region is included in the parallel plate type member, and to control a moving speed of the aperture plate, a rotation speed of the rotating member, and an exposure time and exposure timing of the photo-detector group so that the exposure time of the photo-detector group coincides with a time during which the aperture plate is moved by a distance obtained by multiplying the predetermined arrangement period by an integer n equal to

or greater than 2;

a height determination unit configured to, based on the signal of the photo-detector for each of the positions of the object side focused points discretely changed in the optical axis direction by the focus position changing unit, estimate the position of the measurement object at which the intensity of the reflected beam incident on each of the photo-detectors becomes a maximum;

a cover member provided on one surface of the transparent substrate of the aperture plate and is displaced integrally with the aperture plate by the aperture plate displacement unit, the cover member including a transparent member and a support member, the transparent member transmitting light from the light source and irradiates the light onto the plurality of confocal apertures, the support member supporting an entire peripheral edge of the transparent member and is provided on one surface of the transparent substrate of the aperture plate so as to surround the plurality of confocal apertures; and

an imaging optical system designed in consideration of optical properties of a whole optical system including the transparent member of the cover member, the imaging optical system being configured to guide the reflected light beams having again passed through the confocal apertures to the photo-detector, wherein

the cover member is provided on the one surface of the

aperture plate via the support member such that the plurality of confocal apertures are positioned apart from the transparent member within the closed space, and that the transparent member is positioned between the light source and the aperture plate, the closed space being formed by the transparent member and the support member of the cover member and the transparent substrate of the aperture plate.

2. The three-dimensional shape measuring apparatus

according to claim 1, wherein

the imaging control unit is configured to switch between control in which the exposure time of the photo-detector group coincides with the time during which the aperture plate moves a distance obtained by multiplying the predetermined arrangement period by an integer n of 2 or more, and control in which the exposure time of the photo-detector group coincides with the time during which the aperture plate moves a distance obtained by multiplying the predetermined arrangement period by 1.

3. The three-dimensional shape measuring apparatus according to claim 2, wherein

the imaging control unit is configured to make the exposure time in the control in which the exposure time of the photo-detector group coincides with the time during which the aperture plate moves a distance obtained by multiplying the

predetermined arrangement period by an integer n of 2 or more,
coincide with the exposure time in the control in which the
exposure time of the photo-detector group coincides with the
time during which the aperture plate moves a distance obtained
5 by multiplying the predetermined arrangement period by 1.

4. The three-dimensional shape measuring apparatus
according to any one of claims 1 to 3, wherein the cover
member is detachably attached to the aperture plate.

10

5. The three-dimensional shape measuring apparatus
according to any one of claims 1 to 3, wherein
the imaging control unit is further configured to
control the moving speed of the aperture plate, the rotation
15 speed of the rotating member, and the exposure time and the
exposure timing of the photo-detector group so that, in the
plurality of times of exposures, a period from any exposure
start time to a next exposure start time coincides with a time
required for the aperture plate to be moved by a distance
20 obtained by multiplying the predetermined arrangement period
by a second positive integer larger than the first positive
integer.

6. The three-dimensional shape measuring apparatus
25 according to any one of claims 1 to 3, wherein
the focus position changing unit is arranged between the

aperture plate and the objective lens so that the plurality of parallel plate type members cross the optical axis of the objective lens on a side of the aperture plate.

5 7. The three-dimensional shape measuring apparatus according to any one of claims 1 to 3, further comprising:
a mount base on which the measurement object is mounted;
and

a mount base displacement unit configured to displace
10 the mount base in the direction perpendicular to the optical axis direction, so as to change the relative positional relationship between the position of the object side focused point and the position of the measurement object in the direction perpendicular to the optical axis, wherein

15 the mount base displacement unit changes the relative positional relationship between the position of the object side focused point and the position of the measurement object in the direction perpendicular to the optical axis direction in a period except a period in which the aperture plate is
20 displaced at the constant speed in the predetermined direction perpendicular to the optical axis direction, and

the period except the period in which the aperture plate is displaced at the constant speed in the predetermined direction perpendicular to the optical axis direction is a
25 period in which the aperture plate is accelerated and decelerated by the aperture plate displacement unit in the

predetermined direction, and a time or a period when a direction of movement of the aperture plate is reversed by the aperture plate displacement unit in the predetermined direction.

5

8. The three-dimensional shape measuring apparatus according to any one of claims 1 to 3, wherein the aperture plate displacement unit includes:

an aperture plate mounting unit on which the aperture
10 plate is mounted; and

a linear motor controlled by the imaging control unit and configured to displace the aperture plate mounting unit in the predetermined direction perpendicular to the optical axis direction.

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9. The three-dimensional shape measuring apparatus according to claim 8, wherein

the aperture plate displacement unit further includes a reaction force mechanism which is displaced in the
20 predetermined direction perpendicular to the optical axis direction, and

the imaging control unit operates the reaction force mechanism so as to reduce influence of a force generated by acceleration and deceleration of the aperture plate mounting
25 unit by the linear motor.

10. The three-dimensional shape measuring apparatus
according to any one of claims 1 to 3, wherein

the focus position changing unit comprises, instead of
the rotating member and the driving portion,

5 an optical path length adjusting member formed of
a transparent member provided at a position crossing the
optical axis of the objective lens and having a predetermined
refractive index and a variable thickness in the optical axis
direction, and

10 an adjusting member driving unit configured to
change a thickness of the transparent member in the optical
axis direction, and

the focus position changing unit is configured to change
the position of the object side focused point in the optical
15 axis direction in such a manner that an optical path length is
changed by changing the optical axis direction thickness of
the transparent member crossing the optical axis.