

OBJECT INSPECTION SYSTEM

Field of Invention

5 The present invention relates generally to systems for inspection of objects. More specifically, the present invention relates to a optical media or lens inspection system.

Background

10 Early techniques for inspecting lenses typically relied on human inspectors to visually examine the lenses for defects (hereinafter referred to as lens defects) usually by placing the lenses under magnification or projection onto a screen whereupon the human inspectors then visually search for lens defects. However, the labour intensive and subjective nature of human operated inspections prompted interest in automating the inspection process. Numerous methods have been investigated, foremost of which are those whereby an image
15 of a lens is acquired and the image then being electronically evaluated for lens defects. Commonly, these methods take advantage of the fact that light, under certain circumstances when encountering a lens irregularity, scatters in a manner that can be qualitatively assessed. These methods generally operate by manipulating a light beam before and/or after passing through a lens in order to extract optical information that is
20 subsequently analysed to assess for flaws.

US Patent No. 5,500,732 to Ebel et al and US Patent No. 6,134,342 to Duke et al describe a conventional system and method for lens inspection. The conventional system and method as described by Ebel and Duke transport lenses using a holder, such as a curvette.
25 However, the conventional system and method is only suited for inspecting lenses that are dry and cannot be applied to inspect ophthalmic or contact lenses that are transported in a medium such as saline solution. Most contact lenses in the market are packaged in saline solution. This causes technical challenges for obtaining high definition images of contact lenses in saline solution for inspection thereof.

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As demands for detecting defects of smaller dimension increases, it is necessary to use images of higher resolution to detect such defects. US Patent No. 6,301,005 to Epstein et al describes a conventional system and method for high resolution lens inspection. However, such high resolution lens inspection requires cameras that are costly and subject to

availability. It is therefore difficult to obtain high definition images of the lenses without the use of the foregoing cameras.

5 Additionally, lens characteristics such as lens power and lens thickness are typically determined after the lenses have been examined for defects. Conventionally, inspection stations are along the lens manufacturing lines in which each inspection station independently measures and determines the corresponding lens characteristics. However, the time spent to transfer the lenses from one inspection station to another adversely affects
10 the efficiency of the lens manufacturing process and hence lowers the overall yield of lens production. Moreover, the need for human intervention during the transferring of lenses from one inspection station to another potentially creates opportunities for human-related mistakes to occur.

15 Accordingly, there exists a need for a system for addressing the foregoing problems of existing lens inspection systems by minimizing the need to physically transfer the lenses between inspection stations thereby improving the overall efficiency for lens manufacturing.

20 **Summary**

The present embodiments of the invention disclosed herein provide a high-resolution object inspection system for performing object inspection.

In accordance with a first aspect of the invention, there is disclosed an object inspection
25 system for inspecting an object, comprising a first station, a second station and a third station. The first station captures a first image of the object in which the first image is processable to determine one of presence and absence of at least one defect on the object. The second station captures at least one second image in which the at least one second image is a magnified view of at least one portion of the object. The at least one second
30 image is processable to determine quality of the at least one defect and the quality of the at least one defect is one of acceptable and unacceptable. The third station determines optical property such as the object power and thickness of the object upon one of absence of the at least one defect and the quality of the at least one defect being determined as acceptable from the at least one second image.

In accordance with a second aspect of the invention, there is disclosed an object inspection method comprising capturing a first image of an object by a first station. The first image is processable to determine one of presence and absence of at least one defect on the object.

- 5 The method also comprises capturing at least one second image by a second station in which the at least one second image is a magnified view of at least one portion of the object. The at least one second image is processable to determine quality of the at least one defect and the quality of the at least one defect is one of acceptable and unacceptable. Lastly, the method comprises determining optical property such as the object power and
10 thickness of the object by a third station upon one of absence of the at least one defect and the quality of the at least one defect being determined as acceptable from the at least one second image.

Brief Description Of The Drawings

- 15 Embodiments of the invention are disclosed hereinafter with reference to the drawings, in which:

FIG. 1 shows a high-resolution lens inspection system according to an embodiment of the invention;

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FIG. 2 shows a lens defect inspection subsystem of the high-resolution lens inspection system of FIG. 1 in which the lens defect inspection subsystem comprises a Full Field-of-View (FOV) station and a Magnified Field-of-View (FOV) station;

- 25 FIG. 3 shows an image of a lens captured by the Full FOV station of FIG. 2 being magnified by the Magnified FOV station of FIG. 2 for producing a magnified image in which the magnified image is partitioned into reference image portions;

FIG. 4 shows a photograph of a lens captured by the Full FOV station of FIG. 2;

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FIG. 5 shows a photograph of a portion of the lens captured by the Magnified FOV station of FIG. 2 in which the portion of the lens containing the defects is identified from the photograph of FIG. 4;

FIG. 6 shows a lens characteristic measurement subsystem of the high-resolution lens inspection system of FIG. 1 in which the lens characteristic measurement subsystem comprises a lens power meter station and a lens thickness meter station; and

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FIG. 7 shows a flowchart illustrating a lens inspection process performed by the high-resolution lens inspection system of FIG. 1.

Detailed Description

10 A high-resolution lens inspection system for performing object inspection is described hereinafter for addressing the foregoing problems.

For purposes of brevity and clarity, the description of the invention is limited hereinafter to lens inspection. This however does not preclude various embodiments of the invention
15 from other applications of similar nature or from applications in inspection of other types of objects. The fundamental inventive principles of the embodiments of the invention are common throughout the various embodiments.

Exemplary embodiments of the invention described hereinafter are in accordance with
20 FIGs. 1 to 7 of the drawings, in which like elements are numbered with like reference numerals.

FIG. 1 shows a high-resolution object inspection system 100 according to an embodiment of the invention. The high-resolution object inspection system 100 is suitable for
25 inspecting objects such as lens or other manufactured products for detecting defects on the objects. The following description of the embodiments of the invention applies but is not limited to inspection of lenses.

The high-resolution object inspection system 100 comprises three subsystems: a lens
30 defect inspection subsystem 102, a lens placement subsystem 130 and a lens characteristic measurement subsystem 150. The lens defect inspection subsystem 102 serves to assess and detect defects on lenses, such as aberration defects. The lens defect inspection subsystem 102 comprises two inspection stations: a Full Field-of-View (FOV) station 104 and a Magnified Field-of-View (FOV) station 106.

At the Full FOV station 104, an image of a lens is captured and electronically evaluated to detect any defects on the lens. Thereafter, regardless whether defects are detected by the Full FOV station 104, high-resolution images of different portions of the lens are captured using the Magnified FOV station 106 for further inspection of the lens. The multiple high-resolution images of the lens are preferably captured using a device that comprises two mirror galvanometers for focusing different portions of the lens for allowing the high-resolution images to be captured. The mirror galvanometers are preferably variable speed mirror galvanometers. If no defects are detected, the lens is then transferred to the lens placement subsystem 130. However, if defects have been detected, the severity and complexity of the defects determine whether the lens should be accepted or discarded. If the lens is accepted, the lens will be transferred to the lens placement subsystem 130.

Preferably, the object inspection system 100 determines the severity and complexity of detected defects. Alternatively, a human inspector may be alerted to inspect the lens if the high-resolution object inspection system 100 is unable to make a judgement on whether to discard or accept the lens. The Full FOV station 104 comprises a first detection means 108 and a first illumination source 110. Separately, the Magnified FOV station 106 comprises a second detection means 112, a mirror galvanometer 114 and a second illumination source 116. The first and second illumination sources 110/116 are, for example, laser beam emitting sources.

The lens placement subsystem 130 serves to transfer the lens from the lens defect inspection subsystem 102 to the lens characteristic determination subsystem 150. As shown in FIG. 1, the lens placement subsystem 130 comprises a bottom pickup unit 132, a top pickup unit 134, a curvette 136 and actuator motors 138. The bottom pickup unit 132 picks up and rotates the lens by 180° prior to transferring the lens to the lens characteristic determination subsystem 150. This action results in the lens facing the top pickup unit 134. The bottom pickup unit 132 then transfers the lens to the top pickup unit 134 and moves away to allow the top pickup unit 134 to place the lens in the curvette 136. Alternatively, the lens is picked up by the bottom pickup unit 132 without rotation thereto. Additionally, the actuator motors 138 displace and position the bottom pickup unit 132 and top pickup unit 134 along a plane parallel to the optical axis of the lens.

At the lens characteristic determination subsystem 150, the lens power and thickness of the lens are determined. Lens power essentially measures the focal length of a lens. The lens is first transferred from the curvette 136 onto a lens holder 152. The lens holder 152 is operated by an actuator motor 154 and is movable perpendicular to the optical axis of the lens. The measurement of the lens thickness is performed using a third detection means 156 and a third illumination source 158. Independently, the measurement of the lens power is performed using a fourth detection means 160 and a fourth illumination means 162. The fourth detection means 160 is movable along a plane parallel to the optical axis of the lens and is driven by an actuator motor 164.

Additionally, the first illumination source 110, second illumination source 116 and fourth illumination means 162 provide backlighting to illuminate the lens at the respective subsystems of the high-resolution object inspection system 100. Further, the first illumination source 110, second illumination source 116 and fourth illumination means 162 are preferably operable for varying the amount of illumination to thereby enable images of the lens to be captured under and inspected under different lighting conditions. The first detection means 108, second detection means 112, third detection means 156 and fourth detection means 160 are preferably one of complementary metal-oxide semiconductor (CMOS) sensor and a charge-coupled device (CCD) to provide lens imaging. Typically, digital cameras equipped with either the CMOS sensor or the CCD are used for taking images of the lenses. In addition, the first detection means 108 and the second detection means 112 are preferably of similar pixel resolutions. Alternatively, the first detection means 108 and the second detection means 112 are of different pixel resolutions.

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Details with respect to the Full FOV station 104 and the Magnified FOV station 106 are as shown in FIG. 2. The setup at the Full FOV station 104 shows a lens 200 enclosed in a protective casing 202 that is positioned on a support 204. Illumination is provided by the first illumination source 110 to enable the first detection means 108 to capture a clear image of the lens 200. The image is then digitally processed and evaluated for detecting defects on the lens. If defects are detected, the lens 200 is transferred to the Magnified FOV station 106 for further assessment in which portions of the lens 200 containing the defects are magnified by the second detection means 112. The magnification is performed preferably by taking high-resolution images of the required portions of the lens 200.

In addition, the Full FOV station 104 might not be able to detect very fine defects on the lens. Under such conditions, it is still necessary for the lens to undergo inspection at the Magnified FOV station 106 to ensure that the lens is defect-free. Hence, there are situations in which the defects are only detectable by the Magnified FOV station 106 and not by the Full FOV station 104.

To selectively capture images of any portion of the lens 200, usage of the mirror galvanometer 114 in conjunction with the second detection means 112 is required. The mirror galvanometer 114 comprises a steering-mirror 206 that is rotatable for bringing a portion of the lens 200 into focus to thereby facilitate taking images thereof. Notably, the steering-mirror 206 is preferably rotatable through an angle of ninety degrees in a plane parallel to the optical axis of the lens 200. Consequently, the Magnified FOV station 106 is able to resolve defects on lenses that are as small as $2.5\text{ }\mu\text{m}$ in size.

Before magnification is performed on any portion of a lens 302, the lens 302 is partitioned into reference image portions 304 as shown in FIG. 3. Each reference image portion 304 is tagged with an identification number, as shown in FIG. 3, to facilitate identification and referencing. The lens 302 is then magnified by the Magnified FOV station 106 together with use of the mirror galvanometer 114 to produce a magnified image 306 of the lens 302. The magnified image 306 contains magnified images of portions of the lens 302. Depending on the camera resolution employed by the Magnified FOV station 106, the resolution of the magnified image 306 attainable could reach or exceed nine times the resolution of the reference image portion 304.

Although the magnified image 306 is shown in FIG. 3 as being partitioned into nine segments, the magnified image 306 can be partitioned into any number of segments depending on the specifications of the defects to be inspected. The camera resolutions employed by both the Magnified FOV station 106 and the Full FOV station 104 are preferably similar. Alternatively, the camera resolutions employed by both the Magnified FOV station 106 and the Full FOV station 104 are different. Thus, using the magnified images of the portions of the lens 302, further inspection is performable on the portions of the lens 302 containing the defects.

Alternatively, instead of providing a magnified image 306 of the entire lens 302, only required reference image portions 304 of the lens 302 are magnified. Magnifying and capturing images of only the reference image portions 304 of the lens 302 can then provide
 5 specific details of the defects on the portions of the lens 302 that require further inspection.

FIG. 4 shows an image 400 of a sample lens captured by the Full FOV station 104 whereas FIG. 5 shows an image 402 of a portion of the sample lens magnified by the Magnified FOV station 106. Defects present on the portion of the sample lens were identified after
 10 digitally processing and evaluating the image 400 to determine whether the defects are acceptable or unacceptable.

FIG. 6 shows the lens characteristic determination subsystem 150, which comprises two stations for measuring the lens power and lens thickness. A first station for measuring the lens power comprises the fourth detection means 160 and the fourth illumination means
 15 162. The lens power of a lens 600 is measured by providing a test image 602 to thereby enable the fourth detection means 160, together with the usage of an imaging lens 604, to capture a virtual image (not shown) of the test image 602. Equations for determining the lens powers and magnification ratio of a lens are expressed as:

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$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad (1a)$$

$$M = \frac{u}{v} \quad (1b)$$

25 in which u is the distance of the virtual image from the lens, v is the distance of the object from the lens, f is the focal length of the lens and M is the magnification ratio of the lens.

Equations (1a) and (1b) are known as the Thin Lens formula and the Magnification formula respectively, as well known to practitioners in the art. Hence, by adjusting the
 30 position of the fourth detection means 160 until a virtual image of the test image 602 is captured by the fourth detection means 160, both the focal length and the magnification ratio of the lens 600 are then computable using equations (1a) and (1b).

A second station for determining the lens thickness comprises the third detection means 156 and the third illumination source 158. The third illumination source 158 emits beams which are directed at an angle towards the lens 600. The beams are preferably one of laser beams and light beams. Subsequently, the beams refracted by the lens 600 is received by the third detection means 156 and further processed for obtaining a set of optical information. Equations (2a) and (2b) are then used in conjunction with the set of optical information for determining the lens thickness of the lens 600:

$$t = \left(\left(\frac{D}{2} \right)^{2P} \right) / [2000(n-1)] + 1.5mm \quad (2a)$$

$$n = \frac{c}{v_{phase}} \quad (2b)$$

in which t is the thickness of a lens, D is the diameter of the lens, P is the lens power, n is the refractive index, c is the speed of light in a reference medium and v_{phase} is the speed of light in a subject medium.

FIG. 7 shows a flowchart illustrating a lens inspection process 700 performed by the high-resolution object inspection system 100. Firstly in step 702, the Full FOV station 104 captures an image of a lens under inspection. The image is then digitally processed and evaluated to detect defects on the lens. If defects are detected, the lens is then transferred to the Magnified FOV station 106. Optionally, even if no defects are detected by the Full FOV station 104, the lens is still transferred to the Magnified FOV station 106 for further inspection to detect defects that are not detectable by the Full FOV station 104.

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At the Magnified FOV station 106, magnified images of portions of the lens containing the defects are captured in step 704. The magnified images are then further inspected to determine whether the lens can be accepted. If the lens is acceptable, the lens is subsequently transferred to the lens characteristic measurement subsystem 150 for measuring the lens power and lens thickness of the lens in the last step 706. Conversely, if no defects are detected on the lens, the step 704 is omitted, and the lens is directly

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transferred to the lens characteristic measurement subsystem 150 for measuring the lens power and lens thickness of the lens in the step 706.

- 5 In the foregoing manner, a high-resolution inspection system for performing object inspection is described according to various embodiments of the invention for addressing the foregoing disadvantages of conventional lens inspection systems. Although a few embodiments of the invention are disclosed, it will be apparent to one skilled in the art in view of this disclosure that numerous changes and/or modifications can be made without
10 departing from the scope and spirit of the invention.

Claims

1. An object inspection system for inspecting an object comprising:
 - a first station for capturing a first image of the object, the first image being processable to determine one of presence and absence of at least one defect on the object;
 - a second station for capturing at least one second image, the at least one second image being a magnified view of at least one portion of the object, the at least one second image being processable to determine quality of the at least one defect, the quality of the at least one defect being one of acceptable and unacceptable; and
 - a third station for determining optical property of the object upon one of absence of the at least one defect and the quality of the at least one defect being determined as acceptable from the at least one second image.
2. An object inspection system as in claim 1, wherein the first station comprises:
 - a light source for illuminating the object; and
 - an image capture means for capturing the first image of the object illuminated by the light source.
3. An object inspection system as in claim 2, wherein the detection means is one of a complementary metal-oxide semiconductor (CMOS) sensor and a charge-coupled device (CCD).
4. An object inspection system as in claim 1, wherein the second station comprises:
 - a light source for illuminating the object;
 - an image capture means for capturing the at least one second image of the object illuminated by the light source; and
 - an optical scanner being operable for magnifying view of the at least one portion of the object and for directing the magnified view of the at least one portion of the object towards the image capture means.
5. An object inspection system as in claim 4, wherein the optical scanner is a mirror galvanometer.

6. An object inspection system as in claim 4, wherein the detection means is one of a complementary metal-oxide semiconductor (CMOS) sensor and a charge-coupled device (CCD).
- 5 7. An object inspection system as in claim 1, wherein the optical property of the object being determined is at least one of the thickness of the object and the focal length of the object.
- 10 8. An object inspection method comprising:
 - capturing a first image of the object by a first station, the first image being processable to determine one of presence and absence of at least one defect on the object;
 - capturing at least one second image by a second station, the at least one second image being a magnified view of at least one portion of the object, the at least one second image being processable to determine quality of the at least one defect, the quality of the at least one defect being one of acceptable and unacceptable; and
 - determining optical property of the object by a third station upon one of absence of the at least one defect and the quality of the at least one defect being determined as acceptable from the at least one second image.
- 20 9. An object inspection method as in claim 8, wherein the first station comprises:
 - providing a light source for illuminating the object; and
 - 25 capturing the first image of the object illuminated by the light source by an image capture means.
10. An object inspection method as in claim 9, wherein the light source is a laser beam emitting source and the detection means is one of a complementary metal-oxide semiconductor (CMOS) sensor and a charge-coupled device (CCD).
- 30 11. An object inspection method as in claim 8, wherein the second station comprises:
 - providing a light source for illuminating the object;

capturing the at least one second image of the object illuminated by the light source by an image capture means; and

5 magnifying view of the at least one portion of the object and for directing the magnified view of the at least one portion of the object towards the image capture means by an optical scanner.

12. An object inspection method as in claim 11, wherein the optical scanner is a variable speed mirror galvanometer.
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13. An object inspection method as in claim 11, wherein the light source is a laser beam emitting source and the detection means is one of a complementary metal-oxide semiconductor (CMOS) sensor and a charge-coupled device (CCD).
- 15 14. An object inspection method as in claim 8, wherein the optical property of the object being determined is at least one of the thickness of the object and the focal length of the object.