

ADAPTIVE LIGHTING SYSTEM AND METHOD FOR INSPECTION OF COMPLEX OBJECTS

Field Of Invention

5

The present invention generally relates to electronically controlled LED based illumination systems coupled with illumination transmitting light guides to propagate light to inaccessible areas of a multidimensional object. The invention is particularly applicable for inspection of multidimensional objects comprising angular surfaces requiring special illumination and positioning techniques for enhanced inspection.

10

Background

15

Conventional light sources are typically bulky and complex if they are designed to illuminate multiple surfaces, especially if the objects have angular surfaces. In prior art US 8,100,552, the illuminating device is designed using multiple light emitting components mounted in specific orientations to match the profile of an object. If the profile of the object to be inspected changes, a new illuminating module is required to be designed to achieve uniform illumination across the object, making the approach complex, time consuming and expensive. They are neither flexible nor scalable which makes them difficult to scale and adapt to new types of objects with different surface profiles.

20

25

Typical solid state LEDs are commonly used in various configurations to enable the light distribution to be uniform across the object. The final configurations for a specific object may still have uneven intensities of illumination across the area of the object, resulting in inconsistencies and unreliable measurement of defects. Moreover, they are bulky and occupy precious real estate within the inspection system.

30

The current technology lacks the apparatus and methodology to uniformly illuminate the complex three dimensional object without compromising on the quality and accuracy of defect inspection and related measurements.

Summary

The invention relates to an efficient and flexible illumination system consisting of a illumination module suitably coupled with a set of light guides that are planar, rectangular or
5 circular made from acrylic or other light transmitting material mounted with appropriate retractable springs and suitably arranged on a platform comprising at least two parallel plates, that allows free movement of the light guides along its vertical axis. When the object to be inspected is positioned under the camera, they are positioned to rest on the light guides, which move, adjust and orientate themselves to the profile of the object at the point of contact at one
10 end with the other end exposed to the Backlight illumination module. With this arrangement, when the Backlight illumination is energised the light guides transmit the light towards the object resulting in uniform distribution of the light at every point of the three dimensional object. The camera captures multiple images at different positions and angles of the object for inspection. On completion of the inspection, the object is moved away from the light guides,
15 and simultaneously the light guides move back to their home position or reference position.

The object is next illuminated from the Top using the Top light illumination module followed by capture of multiple images of different areas of the object at different angles.

20 The camera may also be used by an operator to view the illuminated object surface, to perform measurements of defects or features. Typical case of manual inspection or viewing is used during the process of setup and configuration of the inspection system.

One of the main advantages of such an arrangement enables easy adaptation of the illumination
25 modules to a variety of complex objects with three dimensional features or defects on their surfaces. The flexible adaptation of moving light guides coupled with the programmability of the illumination systems makes the illumination system very flexible and scalable, resulting in quick reconfiguration of the illumination setup during product changeovers.

30 The next advantage of the invention is in reliably illuminating angular surfaces of the object, which has not been possible with current art. Features on angular surfaces can also be reliably

inspected when the object is appropriately tilted using integrated motors that are coupled to the inspection assembly, so an optimum view is presented to the camera.

Another advantage of the invention is the positioning of the backlight module that may be achieved using the air cylinders that are mechanically coupled to the backlight module. Enhanced images of the object captured by the camera under multiple lighting conditions enables measurement of fine defects and features that are more pronounced.

Other aspects of the invention include various combinations of one or more of the foregoing aspects of the invention, as well as the combinations of one or more of the various embodiments thereof as found in the following detailed description or as may be derived therefrom. It should also be understood that other embodiments of the invention may be derived by those of ordinary skill in the art both from the following detailed description of a particular embodiment of the invention.

Description Of The Drawings

The specific features, aspects, and advantages of the invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

FIG 1 represents a system of all the elements making up a preferred embodiment of this invention.

FIG 2 is an illustration of the three dimensional object's top surface.

FIG 3 is an illustration of the three dimensional object's bottom surface.

FIG 4 is an illustration of one aspect of the preferred embodiment of this invention.

Fig 4a is an image of an area of the object with the backlight illumination turned ON in **Fig 4**.

FIG 4b is an exploded view of the image area enclosed in Fig 4.

FIG 5 is an illustration of another aspect of the preferred embodiment of this invention.

5 **Fig 5a** is the image of an area of the object with the Front light illumination turned ON in **Fig 5**.

FIG 6 represents a system of all the elements making up another embodiment of this invention. The system is designed to rotate the object in two different axes, to enable inspection of the
10 object at different angles using either a top light illumination or Backlight illumination.

FIG 7 is an illustration of the system showing an aspect of the embodiment in **Fig 6**.

FIG 7a illustrates an image of a top light illuminated area of the object **50** in **Fig 7**.
15

FIG 8 is an illustration of the system showing another aspect of the embodiment in **Fig 6**.

FIG 8a illustrates an image of a Backlight illuminated area of the object **50** in **Fig 8**.

20 **FIG 9** is an illustration of the system showing yet another aspect of the embodiment in **Fig 6**.

FIG 9a illustrates an image of a Top light illuminated area of a slope in the object **50** of **Fig 9**.

FIG 10 is an illustration of the system showing yet another aspect of the embodiment in **Fig 6**.
25

FIG 10a illustrates an image of a backlight illuminated area of a slope in the object **50** of **Fig 10**.

FIG 11 represents an image of a top light illuminated area of an object in **Fig 2**.

30 **FIG 12** represents an image of a Back light illuminated area of an object in **Fig 2**.

Detailed Description Of The Drawings

In the following description of the preferred embodiments of the present invention, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

A first embodiment of the system and method according to the invention is shown in **FIG. 1**.

The system **100** shows, in pictorial form, an embodiment of a first aspect of the present invention which is an apparatus for inspecting defects in complex three dimensional objects including their angular surfaces. Defects such as dimension of holes, markings on their surfaces, absence and presence of molded features, scratches, contaminants & all edge defects around the object may be measured.

The first embodiment **100** in **Fig 1** comprises a high resolution camera **30**, mounted on a XY motorised table **25** (Motors not shown), at least two illuminating light sources, a ring light or Top light **22** and a flat LED backlight **8**. The backlight **8** is mechanically and optically coupled to a set of light guides **10** or otherwise referred to as arrays of light transmitting elements which are preferably made of efficient light dispersing material. The light guide assembly is designed with two metal plates **18** and **20** drilled with identical and symmetrical holes. Every aligned hole in plates **18** and **20** are configured to hold a spring loaded unit **12** and **14** respectively, through which a set of light guides **10** is mounted and held in a position **P1** referred to as Home position or a reference position, which may be adjustable depending upon the application. The number of light guides **10** used is determined by the application. The set of light guides **10** are vertically displaceable through the mechanism of a set of spring loaded bearings **12** and **14**. The light guides **10** may be fabricated using acrylic resin, polycarbonate or similar material with high dispersion characteristics to enable the illumination of the object around the angular surfaces as well as uneven surfaces at different locations and different depths. The set of light guides **10** may also be designed with different angles, thickness or profiles to adapt to different types of objects making them scalable and cost effective.

When the Backlight sub assembly **102** is moved to position **P2** in the vertical direction **16**, the set of light guides **10** are appropriately displaced to take the profile of the top surface of the object **50**. The Backlight sub-assembly **102** comprising elements **8, 10, 12, 14, 18** and **20** are mechanically integrated together, and driven by a motor (not shown). The motor is driven to vertically move the Backlight illumination module between position **P1** and **P2** shown in **Fig 1**.

It is important to note that people skilled in the art know that several different vertical positions may be programmed to suit different types of object profiles. A separate Front illumination module **22** is suitably coupled to another Motor (not shown) to enable it to be positioned at different positions below the object. The Backlight illumination module **8** and Front illumination module **22** are fabricates using a segmented design, with different wavelength LEDs and electronically coupled to a strober (not shown), that may be programmable to trigger the illumination at different time intervals, with different pulse duration, different intensities and different light spectrum for enhancing the defect features of the object **50** and aid image capture under different illumination conditions.

Fig 2 and **Fig 3** illustrate the Top view and Bottom view of a typical object **50**, respectively. As evident, the object **50** has multiple three dimensional profiles and may be porous or comprise cutouts suitable for particular application. It may also comprise various angular surfaces around the object.

Fig 4 illustrates an inspection technique in the first embodiment of the invention for inspecting defects on the object **50**. In this technique, the Backlight illumination sub assembly **102** is moved down to position **P2** while simultaneously displacing the set of light guides **10** to touch the top surface of the object **50**. A magnified image of the box **B1** enclosing the area in **Fig 4** is shown in **Fig 4b**. The displacement of the set light guides **10** is clearly visible in **Fig 4b**.

The Backlight illumination **8** as earlier explained, is fabricated with LEDs that may be segmented to illuminate every light guide individually or simultaneously, allowing for a highly complex illumination control mechanism. At the position **P2** in **Fig 4**, the Backlight **8** and camera **30** are triggered or strobed to illuminate the set of light guides **10**, and simultaneously

capture an image of the area of interest in object **50**, as illustrated in **Fig 4a**. Subsequently the XY table **25** is moved from one area of interest to the next, until the surface area of the object has been imaged by Camera **30**. The images are then assembled appropriately to arrive at the full image of the object **50** for further analysis and classification. Subsequently the results of the inspection are communicated through an external interface for segregation and sorting.

Fig 5 illustrates an inspection technique of the invention for inspecting defects at the bottom surface of the object **50**. In this technique, the Backlight illumination sub assembly **102** is moved up to the reference position **P1**, while simultaneously displacing the set of light guides **10** to move away from the top surface of the object **50** by the spring loaded bearings **12** and **14**. At position **P1**, the Backlight **8** is turned OFF and the Ring light **22** is turned ON to illuminate the bottom surface of the object **50**. The Ring light **22** and camera **30** are triggered or strobed to illuminate the bottom surface, and simultaneously capture an image of the area of interest in object **50**, as illustrated in **Fig 5a**. Subsequently the XY table **25** is moved from one area of interest to the next, until the surface area of the object has been imaged by Camera **30**. The images are then assembled appropriately to arrive at the full image of the object **50** for further analysis and classification. Subsequently the results of the inspection are communicated through an external interface for segregation and sorting.

Fig 6 illustrates an inspection technique in a second embodiment of the invention for inspecting defects on the object **50**. In this embodiment **110**, the Backlight illumination sub assembly **102** is the same as in **Fig 1**, but mounted in reverse with the set light guides **10** facing up. The Backlight illumination sub assembly **102** further comprises a pair of air cylinders **40** and **42** mechanically mounted on plates **18** and **20** to drive the backlight **8** up and down. is further coupled to another motor **39**. The backlight illumination sub assembly **102** is further mounted on another mechanism that is suitably coupled to another motor **37**. Motors **39** and **37** enable the movement of **110** in two different axes. Motor **39** is utilised to rotate **110** along with the object **50**, in the rotary axis **44** and motor **37** is utilised to move **110** along with the object **50**, in the rotary axis **40**. The set of air cylinders **40** and **42** provided, enable displacement of Backlight **8** vertically, between two or more positions which may be preprogrammed. The air cylinders **40** and **42** also serve to displace the set light guides **10** to a position as determined by

the software program. The Ring light **22** in **Fig 6** illuminates the top surface of object **50** and Back light **8** illuminates the bottom surface of object **50** through the set of light guides **10**. Camera **30** mounted on XY table **25** is positioned to capture images of the top surface of the object **50** in **Fig 6**.

5

The first process step of inspection in the second embodiment shown in **Fig 7**, is initiated with the object **50** moved down from position **P3** to position **P4**, towards the light guides **10**. The light guides **10** position themselves at their respective points at the bottom surface of the three dimensional object **50**. As earlier explained, the light guides **10** are integrated to the plates **20** and **18** through spring loaded guiding units **12** and **14** respectively, allowing them to move freely along the vertical axis. After the object **50** is positioned at the predetermined location **P4** as shown in **Fig 7**, the Camera **30** captures the image of a predetermined area of interest on the top surface of the object **50** when it is synchronously strobed with the Ring light **22** for illumination. An image of a typical area of interest is illustrated in **Fig 7a**, where the symbols printed on the surface of the object **50** are enhanced. Subsequently the XY table **25** is moved from one area of interest to the next, until the surface area of the object has been imaged by Camera **30**. The images are then assembled appropriately to arrive at the full image of the object **50** for further analysis and classification. Subsequently the results of the inspection are communicated through an external interface for segregation and sorting.

15
20

Ring Light **22** in **Fig 7**, is mechanically integrated to the XY table **25**, and appropriately positioned and strobed during image capture, to enhance defects such as surface scratches, stains, symbols, markings..etc on the object **50**.

25

In the second process step shown in **Fig 8**, the Ring light is turned OFF and the Backlight **8** is strobed for the camera **30** to capture an image of an area of interest in object **50**. An image of a typical area of interest is illustrated in **Fig 8a**, where the symbols printed on the object **50** are clearly visible along with the enhanced perforations or holes. The captured image with the Backlight **8** illuminated, aids in detecting missing holes, damaged holes, incorrect dimension holes and other defects visible in the backlit image. Subsequently the XY table **25** is moved from one area of interest to the next, until the surface area of the object has been imaged by Camera **30**. The images are then assembled appropriately to arrive at the full image of the

30

object **50** for further analysis and classification. Subsequently the results of the inspection are communicated through an external interface for segregation and sorting.

In the third process of inspection in the second embodiment is shown in **Fig 9**. It is initiated with the object **50** moved down from position **P3** to position **P4**, towards the light guides **10** as in **Fig 7**. After the object **50** is positioned at the predetermined location **P4** as shown in **Fig 7**, the motor **37** rotates to a preprogrammed angle to present the elevated and angular sides of the object **50** to the Camera **30**. The camera **30** captures the image of a predetermined area of interest of the object **50** while synchronously strobing the top light or Ring light **22** for illumination. An image of a typical area of interest is illustrated in **Fig 9a**, where the surface features at the angular surfaces of the elevated structures on the object **50** are enhanced. The Ring Light **22** which is also integrated to the XY table **25**, is appropriately positioned and strobed, to enhance defects such as surface scratches, stains, symbols..etc on the object **50**. In the next step, the motor **39** rotates to position the object **50** to the next area of interest as programmed in the software. The process continues until the entire area of the object **50** is imaged. The images are then assembled appropriately to arrive at the full image of the relevant angular surface of the object **50** for further analysis and classification. Subsequently the results of the inspection are communicated through an external interface for segregation and sorting.

A fourth process step includes repositioning the object **50** at a different preprogrammed angle by rotating motor **37**, and repeating the entire third process again until all the preprogrammed angles are executed.

In the fifth process step shown in **Fig 10**, the Ring light is turned OFF and the Backlight **8** is turned ON or strobed. After the object **50** is positioned at the predetermined location **P4** as shown in **Fig 7**, the Camera **30** captures the image of a predetermined area of interest of the object **50** while synchronously strobing the Backlight **8** for illumination.

An image of a typical area of interest is illustrated in **Fig 10a**, wherein the perforations located at the angular surface of the object **50** is clearly visible. The process continues until the entire area of the object **50** is imaged. The images are then assembled appropriately to arrive at the full image relevant angular surface of the object **50** for further analysis and classification.

Subsequently the results of the inspection are communicated through an external interface for segregation and sorting.

The captured images in the fifth process step aids in detecting missing holes, damaged holes, incorrect dimension holes and other defects visible in the backlit image at the angular surfaces of the object **50**.

In a sixth process step with the Backlit **8** illuminated, the XY table is moved from one area of interest to the next as programmed in the software. Subsequently, the motor **39** rotates to position the object **50** at different points around it, for capturing images with Backlit illumination. The process continues until the angular surfaces of the entire area of the object **50** is imaged. The images are then assembled appropriately to arrive at the full image relevant angular surface of the object **50** for further analysis and classification. Subsequently the results of the inspection are communicated through an external interface for segregation and sorting.

It is very important to note that a skilled person can change the angle of the object and modify the illumination sequence and characteristics such as intensity, wavelength and strobing pulse duration, and also utilise segmented illumination to highlight different features on the surface of the object **50**.

Fig **11** is an illustration of a Top light or Ring light illuminated surface to show how the enhancement of markings and surface defects such as **56** and **54 & 55** are achieved respectively.

Fig **12** is an illustration of a Backlight illuminated surface to show how the enhancement of perforations such as **58** and **60** are achieved. It is evident that the perforation diameter is easily and accurately measured in a Backlit image apart from detecting missing perforation **52** or inaccurately spaced perforations.

Having now described a few embodiments of the invention, it should be apparent to those skilled in the art that the foregoing is merely illustrative and not limiting, having been presented by way of example only. Numerous modifications and other embodiments are within the Scope

of one of ordinary skill in the art and are contemplated as falling within the scope of the invention as defined by the appended claims and equivalents thereto.