MULTIPLE SURFACE INSPECTION SYSTEM AND METHOD

FIELD OF THE INVENTION

The invention relates to component inspection systems, and in particular to a system and method for multiple surface inspection that does not require the component being inspected to be placed within the inspection equipment.

BACKGROUND OF THE INVENTION

It is known to inspect multiple surfaces of a component using a single set of image data. However, existing methods and systems for performing such inspections require the component to be placed within the inspection apparatus, such as by lowering or raising the component into position. While some systems and methods allow some inspection processes to be performed using an inspection apparatus that is placed over or under the component being inspected, the image data from the different surfaces of such systems and methods is not in the same focal plane, and is contained within an area that significantly larger than the total surface area of the component being inspected. As such, the resolution of such systems and methods is low, or they require different image data generation systems having different focal lengths.

SUMMARY OF THE INVENTION

In accordance with the present invention, a system and method for performing multiple surface inspection of a component are provided that overcome known problems with systems and methods for performing multiple surface inspection of components.

In particular, a system and method for performing multiple surface inspection of components are provided that provide high resolution and allow a single set of image data to be generated containing image data from each surface using prisms to compensate for different focal lengths.

In accordance with an exemplary embodiment of the present invention, a system for on-the-fly inspection of components is provided. The system includes a prism structure disposed below an inspection item transit path. An image data system is disposed below the prism structure. A lighting assembly provides a first lighting source to

illuminate a plurality of sides of an inspection item and a second lighting source to illuminate a bottom of the inspection item.

The present invention provides many important technical advantages. One important technical advantage of the present invention is an inspection system that utilizes prisms with two reflecting surfaces that compensate for the focal length difference between the different inspection surfaces, where the prism is used to compensate for different refractive indexes through which the light passes and not the difference between different inspection surfaces, and which allow the inspection surfaces to be placed in close proximity with each other, so as to increase the resolution of the image data.

Those skilled in the art will further appreciate the advantages and superior features of the invention together with other important aspects thereof on reading the detailed description that follows in conjunction with the drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIGURE 1 is a diagram of a system for inspecting objects in accordance with an exemplary embodiment of the present invention;

FIGURE 2 is a diagram of optical ray paths for a prism in accordance with an exemplary embodiment of the present invention;

FIGURE 3 is a diagram of a system for inspecting components in accordance with the exemplary embodiment of the current invention;

FIGURE 4 is a diagram of an inspection system in accordance with an exemplary embodiment of the present invention;

FIGURE 5 is a flow chart of a method for inspecting items utilizing a prism inspection system that eliminates the need for the axial movement of inspection pieces in accordance with an exemplary embodiment of the present invention;

FIGURE 6 is a diagram of a light assembly in accordance with an exemplary embodiment of the present invention; and

FIGURE 7 is a diagram of a light assembly in accordance with an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the description that follows, like parts are marked throughout the specification and drawings with the same reference numerals, respectively. The drawings figures might not be to scale, and certain components can be shown in generalized or schematic form and identified by commercial designations in the interest of clarity and conciseness.

Figure 1 is a diagram of a system 100 for inspecting objects in accordance with an exemplary embodiment of the present invention. System 100 allows the top and sides of an object to be inspected using a single set of image data. The term "top" will be used throughout the detailed description and claims to designate the surface of the component that is directly facing the camera or other image data generation system, even though that surface might be the bottom or one of the sides of the component as it is ultimately used.

System 100 includes inspection piece 102 and prism 104. Prism 104 is configured so as to reflect light on the path shown by dashed line 106, such that the side of inspection piece 102 can be seen from the bottom face 118 of prism 104. In this manner, the camera or other device generating image data can generate image data of the top of inspection piece 102 as well as the side of inspection piece 102 as seen from the bottom face 118 of prism 104 in the direction indicated by the arrow of dashed line 106.

While mirrors could also be used to generate such image data, one draw back of mirrors is that the focal length of the path from the side of inspection piece 102 to a position parallel to the bottom face 118 of prism 104 will be longer than the focal length of the path from the top of inspection piece 102 to the viewing frame 116 of the top of inspection piece 102 that is also parallel to bottom face 118 of prism 104. Because prism 104 can be used to adjust the focal length so as to match the focal length of the

direct image from the surface of inspection piece 102 to viewing frame 116, the effective focal length for the side image as seen at the bottom face 118 of prism 104 and the top of inspection piece 102 to viewing frame 116 can be the same, thus allowing a single set of focused image data to be readily generated for use in inspecting inspection piece 102.

In addition, if a mirror was used to generate an image of the sides of inspection piece 102, the field of view would be larger. In that embodiment, a large number of pixels of image data would need to be generated for the space between the top of inspection piece 102 and the image available from a mirror showing the side of inspection piece 102. System 100 thus allows a higher pixel density image to be formed that includes the image data from the top of inspection piece 102 in viewing frame 116 and the side of inspection piece 102 through bottom face 118 of prism 104.

As shown in FIGURE 1, the angle α defines the relationship between the reflecting surfaces 108 and 110 of prism 104. The angle α is measured between the plane parallel to the point of reflection at first reflecting surface 108 and the plane of the inspection piece 102, at the point of reflection. The angular relationship between the plane of first reflecting surface 108 and the plane parallel to the plane of the inspection piece 102 at the point of reflection is $45^o + \alpha$, and the angular relationship between first reflecting surface 108 and second reflecting surface 110 is $45^o - \alpha/2$, such that the typical range for is α is 20^o to 50^o. In addition, it can be seen that there is a lighting gap 112 between the plane containing the top of prism 104 and the plane containing the top of inspection piece 102. Lighting gap 112 needs to be large enough to allow a low angle lighting source 114 to illuminate the top and sides of inspection piece 102. As such, the use of prism 104 provides the additional advantage of increasing lighting gap 112 over that of prior art systems.

FIGURE 2 is a diagram of optical ray paths for a prism 200 in accordance with an exemplary embodiment of the present invention. Unlike prism 104 which is a five sided prism having three obtuse angles and two acute angles, prism 200 is a six sided prism having three obtuse angles, one right angle, and two acute angles. Prism 200 includes a field of view identified by lines 202A and 202B. As shown in FIGURE 2, the points A

and B along the sides of an inspection object would be reflected through prism 204 along the dashed lines shown as 206 and 208. The resultant image at the bottom of prism 204 would invert the position of the points A and B, such that point A would be on the left side of point B. As such, the apparent position of the sides of the inspection item would be opposite that of the apparent position of the sides of the inspection as viewed by a single mirror. Likewise, dashed lines are shown within prism 204 that indicate the relative position of the various sides of prism 204. The angular relationships between the reflecting surfaces of prism 204 are similar to those shown in FIGURE 1.

In operation, prism 204 can be used to generate the image of a side of an inspection object, so as to allow the top and sides of an inspection object to the captured in a single set of image data. Because the focal length of the path from the sides of the image object through the prism 204 can be adjusted to match the focal length of the path from the top of an object under inspection directly to the image data generation system, it is possible to focus on both the side images and the top surface image of the inspection item using a single image data generation system, such as a digital imaging system.

FIGURE 3 is a diagram of systems 300A and 300B for inspecting components in accordance with an exemplary embodiment of the present invention. In system 300A, an inspection piece transportation system such as conveyor 302 moving in the direction shown by arrow A carries inspection pieces 304A through 304D past an inspection area. Prisms 306A through 306D capture image data from the sides of inspection pieces 304A through 304D. Image data generation system 308 is positioned over the viewing area formed by the top surfaces of prisms 306A through 306D and the viewing area directly over inspection pieces 304A through 304D as they move under image data generation system 308.

As previously noted, prisms 306A through 306D have a focal length that is equal to the focal length through air from the surface of inspection pieces 304A through 304D as they pass through the viewing area of image data generation system 308. In another alternative embodiment, another rectangle prism can be introduced on top of inspection piece 304 purely to ensure refractive index is the same as that of 306A-D. In this

manner, image data generation system 308 can generate a set of image data that contains the top of inspection pieces 304A through 304D as well as the sides. Low angle ring lighting system 316 provides lighting to the components under inspection in manner that does not over-illuminate either the sides or the top surface of a given component, such as by use of rows of light-emitting diodes set to different brightness values or in other suitable manners.

Image compensation and inspection system 310 is coupled to image data generation system 308. As used herein, the term "coupled" and its cognate terms such as "couples" or "couple" can include a physical connection (such as a wire, optical fiber, or a telecommunications medium), a virtual connection (such as through randomly assigned memory locations of a data memory device or a hypertext transfer protocol (HTTP) link), a logical connection (such as through one or more semiconductor devices in an integrated circuit), or other suitable connections. In one exemplary embodiment, a communications medium can be a network or other suitable communications media.

Image compensation and inspection system 310 includes side inspection system 312 and top inspection system 314, each of which can be implemented in hardware, software, or a suitable combination of hardware and software, and which can be one or more software systems operating on a general purpose processing platform. As used herein, a hardware system can include a combination of discrete components, an integrated circuit, an application-specific integrated circuit, a field programmable gate array, or other suitable hardware. A software system can include one or more objects, agents, threads, lines of code, subroutines, separate software applications, two or more lines of code or other suitable software structures operating in two or more software applications or on two or more processors, or other suitable software structures. In one exemplary embodiment, a software system can include one or more lines of code or other suitable software structures operating in a general purpose software application, such as an operating system, and one or more lines of code of other suitable software structures operating in a specific purpose software application.

Image compensation and inspection system 310 receives image data from image data generation system 308 and provides the side image data to side inspection 312 and the

top image data to top inspection system 314. In one exemplary embodiment, image data generation system 308 can generate multiple images of an inspection item, such as by using different illumination angles, different illumination colors/wavelengths, different light intensity, or other varying illumination parameters to allow defects to be detected by comparing sets of image data, by using different types of illumination, or in other suitable manners. In one exemplary embodiment, image compensation and inspection system 310 can locate areas having image data of one of inspection piece 304A through 304D, such as by using predetermined templates, image detection techniques or other suitable processes. As shown in system 300B, the exemplary set of image data generated by image data generation system 308 can include a top of inspection piece 304C as well as the sides of inspection piece 304C as seen through prisms 306A through 306D. Image compensation and inspection system 310 isolates the images from the sides of inspection piece 304 using prism 306A through 306D and provides them to side inspection system 312 for analysis, such as by directly transferring pixels, by compensating the image for any distortion generated by the prism associated with the image, or in other suitable manners. Likewise, the top of the inspection piece 304C is provided to top inspection system 314. In this manner, the top and sides of an item under inspection can be generated where the focal length of the path of viewing from image data generation system 308 to the inspection piece 304A through 304D that is being inspected is the same as the sides view. Likewise, top inspection system 314 allows image data for the top of inspection piece 304C to be generated and inspected, such as using pattern matching, location of image data from predetermined areas, masking, pixel histogram data, or other suitable data.

In one exemplary embodiment, side inspection system 312 and top inspection system 314 can use lighting elements emitting light of different wavelengths, such as to allow the sides to be illuminated with a first color light and the top to be illuminated with a second color light, to allow different colors of light to be used to inspect both the sides and the top, to use light wavelengths that are optimized to detect predetermined classes of defects, or in other suitable manners. Side inspection system 312 and top inspection system 314 can also or alternatively use light from different light sources in different locations to enhance detection of defects, damage or other aspects of an inspection item. In this exemplary embodiment, a surface defect can be detected by comparing image

data taken with illumination from two different angles, such as by detecting the shadow cast by a surface defect or in other suitable manners.

FIGURE 4 is a diagram of an inspection system 400 in accordance with an exemplary embodiment of the present invention. Inspection system 400 is shown in views 400A and 400B. As shown in view 400B, image compensation and inspection system 402 includes inspection piece tracking system 404, side inspection system 406, and top inspection system 408. Image data generation system 410 generates image data from the field of view that encompasses a plurality of inspection pieces 414A through 414D, either by directly viewing the tops of inspection pieces such as the exemplary view of inspection pieces 414B and 414C, or by viewing the sides of inspection pieces through prisms 412A through 412D. Low angle ring lighting system 418 provides lighting to the components under inspection in manner that does not over-illuminate either the sides or the top surface of a given component, such as by use of rows of light-emitting diodes set to different brightness values or in other suitable manners.

As shown in 400A, the exemplary view generated by image data generation system 410 includes the tops of inspection pieces 414B and 414C as well as a side of inspection piece 414B, a side of each of inspection pieces 414B and 414C through prism 412C, the side of inspection piece 414C through prism 412A, and the sides of inspection pieces 414B and 414C through prism 412B. Because the image data includes different sides for multiple pieces, inspection piece tracking system 404 identifies and tracks which side image is associated with which inspection piece. In one exemplary embodiment, as inspection pieces are moved by an inspection piece transportation system such as pick and place tool 416 in the direction of arrow A, they are scanned across the field of view of image data generation system 410. Image compensation and inspection system 402 receives the image data and identifies the inspection pieces, the tops, and the sides from prisms 412A through 412D and by direct viewing from the surface of the inspection pieces. Alternatively a prism may be introduced below piece 414 purely to ensure that the refractive index matches with prisms 412A-D. Likewise, suitable compensation processing can be performed to compensate for any image distortion introduced by translation of the side image data by the associated prism. Side inspection system 406 and top inspection system 408 are used to analyze image data to determine whether the

image data indicates that the inspection piece is acceptable. Inspection piece tracking system 404 receives the side image data testing results from side inspection system 406 and the top inspection system 408 results and determines whether a complete set of all four sides and the top of an inspection piece has been generated. Image compensation and inspection system 402 generates indications of unacceptable pieces, such that pieces can be rejected. In one exemplary embodiment, pick and place tool 416 can be controlled so as to release an item that has failed inspection in a predetermined location, an operator notification can be generated so as allow the piece to be manually inspected, or other suitable processes can be used.

FIGURE 5 is a flow chart of a method 500 for inspecting items utilizing a prism or prisms that eliminates the need for movement of inspection pieces in three axes in accordance with an exemplary embodiment of the present invention. Method 500 begins at 502 where inspection pieces are moved either over a plurality of prisms, under the plurality of prisms, or in other suitable manners, depending on whether the inspection pieces are being moved by a pick and place tool, a conveyor, or in other suitable manners. The method then proceeds to 504 where image data is generated. In one exemplary embodiment, the image data can be from a field view that encompasses a set of four prisms and a direct viewing area or other suitable fields of view. The method then proceeds to 506.

At 506 it is determined whether there are multiple pieces being inspected in the field of view. If it is determined that multiple pieces are not being inspected, the method proceeds to 508 where image data of the sides and tops of the inspection piece is generated and one or more image data analysis processes are performed. In one exemplary embodiment, the image data of the sides and tops can be analyzed to determine if the image data contains any indications of defects, histogram data of pixels can be generated, data from predetermined locations within the set of image data can be analyzed, or other suitable processes can be performed. The method then proceeds to 510.

At 510 it is determined whether the piece has passed inspection. If the piece has not passed inspection, the method proceeds to 512 where the piece is rejected. In one

exemplary embodiment, a command can be provided to a pick and place control device to drop the piece into a defect pile, an indication can be generated for an operator to remove the piece and perform manual inspection, or other suitable processes can be used. Likewise, if it is determined at 510 that the piece has passed inspection, the method returns to 502.

If it is determined at 506 that multiple pieces are being inspected, the method proceeds to 514. At 514, image data is generated for the tops and sides of the multiple inspection pieces, and the top and side images are segregated. In one exemplary embodiment, if multiple top images and side images are present, it may be necessary to not only separate the top image data from the side image data, but also to associate the side image data with the proper top image data, so as to form a complete set of side top image data for an inspection piece. The method then proceeds to 516 where inspection of the image data is performed. In one exemplary embodiment, the top and side image data set can be inspected using common inspection processes such as histogram inspections, inspections of predetermined areas, or other suitable data. The method then proceeds to 518 where pass or fail results are tracked. In one exemplary embodiment, a plurality of pieces may be inspected at one time such that any defectively side should be associated with one of the plurality of inspection pieces. In this exemplary embodiment, the tracking of the pass and fail results allows a complete set of image to be generated for each inspection piece as it is moved past the inspection device, thereby allowing on the fly inspection of inspection pieces as they are being moved laterally from one location to a second location without movement of the inspection pieces in a third axis direction relative to the direction of movement, such as into the inspection device. The method then proceeds to 520.

At 520 it is determined whether a complete set of inspection data has been received for an inspection piece. If a complete set of data has not been received, the method returns to 502 and the inspection pieces are moved until a complete set of image data is generated. Otherwise, the method proceeds to 522 where it is determined whether the inspection piece has passed. If the inspection has passed, the method returns to 502. Otherwise, the method proceeds to 524 where the inspection piece that has failed is

rejected, and a suitable process is performed or indication is generated. The method then returns to 502.

In operation, method 500 allows inspection pieces to be inspected as they are moved through a field of view of an inspection device. Unlike prior art systems that require inspection items to be moved in an axial direction so as to place the sides within the field of view of the inspection device, method 500 can be utilized by an inspection device that obtains side and top image data in a single field of view, so as to allow for continuous movement, on the fly inspection, and other suitable processes to be performed.

FIGURE 6 is a diagram of a light assembly 600 in accordance with an exemplary embodiment of the present invention. Light assembly 600 includes lighting elements 602A through 602D, which are located within lighting element supports 606A through 606D, respectively. In one exemplary embodiment, lighting elements 602A through 602D can be provided in a dome lighting support, such as one providing illumination over a range from three degrees to 80 degrees or other suitable ranges. A ring-shaped array of LED lighting elements or other suitable lighting elements 604A through 604D are also located within lighting element supports 606A through 606D, respectively, such as to provide a low angle lighting source. Arrow 608 shows an inspection item 610 transit path through light assembly 600.

In operation, light assembly 600 is used to perform on-the-fly inspection of items, and provides lighting to the sides and bottom of an inspection item using light from light sources in two different configurations. A channel in light assembly 600 allows the inspection items to be moved vertically along a one dimensional transit path (e.g., along a line) through a prism array, which is used to generate image data of the sides and bottom of the inspection item, without requiring movement of the inspection item in other dimensions, such as a two or three dimensional transit path (e.g. without sideways movement and without needing to lower the inspection item into a space contained by prisms or mirrors). Different lighting elements can be used to illuminate the bottom and sides of an inspection item, to provide different wavelengths of light, to provide different illumination angles, or for other suitable purposes. Light assembly 600 can be

used to provide improved corner inspection using illumination pattern 612, such as to improve detection of package defects.

FIGURE 7 is a diagram of a light assembly 700 in accordance with an exemplary embodiment of the present invention. Lighting element support 702 holds light emitting diodes 704A and 704B, or other suitable lighting elements, which illuminate the sides of inspection item 706 as held by support 712, which can use suction or other suitable mechanisms to hold inspection item 706 and to move inspection item 706 through a channel in lighting element support 702. Light emitting diodes 704A and 704B can be disposed at an angle or otherwise configured to concentrate light on the sides of inspection item 706. In one exemplary embodiment, light emitting diodes 704A and 704B can be disposed at an angle of 20 to 35 degrees from horizontal to provide optimal lighting to the sides of inspection item 706, or can otherwise have an angle that is coordinated with prisms 708A and 708B.

Prisms 708A and 708B are disposed below the path of inspection item 706, and are surrounded by a circular array 710 of light emitting diodes or other suitable lighting elements. Circular array 710 is shown in stylized format, as the light emitting diodes or other lighting elements can be disposed on an annular ring so as to provide uniform lighting around the inner periphery of lighting element support 702, and can be angled or otherwise disposed so as to concentrate light on the bottom surface of inspection item 706.

In operation, inspection items are moved through a channel in light assembly 700, such as in a linear fashion without requiring additional motion in a second or third dimension, above prisms that are configured to obtain image data of the side of the inspection item. A first set of lighting elements are used to concentrate light on the sides of the inspection items, and a second set of lighting elements are used to provide illumination to the bottom surface of the inspection item. The inspection items can be held in an inverted position so as to allow a top surface of the inspection items to be inspected, such as by a vacuum pick-and place tool or other suitable supports, which are then moved through the channel and over the prisms. A camera or other suitable device disposed at the opposite end of the prisms is used to generate a single set of image data

that includes all four sides of the inspection item as well as the bottom of the inspection item. The lighting sources can also be used to provide lighting at different angles or wavelengths to allow different sets of image data to be compared to aid in detection of defects or damage, to emphasize different types of damage, such as package defects, or for other suitable purposes.

Although exemplary embodiments of a system and method of the present invention have been described in detail herein, those skilled in the art will also recognize that various substitutions and modifications can be made to the systems and methods without departing from the scope and spirit of the appended claims.

What is claimed is:

1. A system for on- the-fly inspection of components comprising:

a prism structure disposed below an inspection item transit path;

an image data system disposed below the prism structure; and

a lighting assembly for providing a first lighting source to illuminate a plurality of sides of an inspection item and a second lighting source to illuminate a bottom of the inspection item.

2. The system of claim 1 wherein the lighting assembly comprises a channel enclosing the inspection item transit path.

3. The system of claim 1 wherein the first lighting source comprises a dome lighting source.

4. The system of claim 1 wherein the inspection item transit path is one dimensional.

5. The system of claim 1 wherein the inspection item transit path does not require movement in a second dimension.

6. The system of claim 1 wherein the prism structure includes a plurality of prisms.

7. The system of claim 1 wherein the prism structure comprises one or more prisms having a first reflecting surface oriented at an angle between a plane of the first reflecting surface and a plane parallel to the plane of the inspection item at a point of reflection of $45^{o} + \alpha$, where α is approximately 20^{o} to 50^{o}.

8. The system of claim 7 further comprising an angular relationship between the first reflecting surface and a second reflecting surface of $45^{o} - \alpha/2$.

9. The system of claim 1 wherein the first lighting source comprises a plurality of light emitting diodes disposed within the lighting assembly and adjacent to the inspection item transit path.

10. The system of claim 1 wherein the second lighting source comprises an annular array of light emitting diodes below the inspection item transit path.

11. A method for on-the-fly inspection of components comprising:

moving an inspection item through a channel in a lighting assembly;

illuminating a plurality of sides of the inspection item using a first illumination source; and

illuminating a bottom of the inspection item using a second illuminating source.

12. The method of claim 11 wherein moving the inspection item through the channel in the lighting assembly comprises moving the inspection item in only one dimension.

13. The method of claim 11 further comprising:

moving a plurality of inspection items through the channel in the lighting assembly; and

generating image data of the plurality of sides of each of the inspection item as the inspection items pass over a prism assembly.

14. The method of claim 11 wherein illuminating the plurality of sides of the inspection item using the first illumination source comprises illuminating a plurality of side corners of the inspection item using the first illumination source.

15. A prism for inspecting components comprising:

a first end;

a first reflecting surface oriented at an angle between a plane of the first reflecting surface and a plane parallel to the plane of an inspection item beyond the first end at a point of reflection of $45^{o} + \alpha$, where α is approximately 20^{o} to 50^{o};

an angular relationship between the first reflecting surface and a second reflecting surface of $45^{o} - \alpha/2$; and

a second end, wherein the first reflecting surface and the second reflecting surface are disposed between the first end and the second end.

16. The prism of claim 15 further comprising a plurality of prisms according to claim 15.

17. The prism of claim 16 wherein the plurality of prisms are arranged to provide images of a plurality of sides of an inspection item when the plurality of prisms are viewed from a point beyond to the second end.

18. The prism of claim 16 wherein the plurality of prisms comprise:

a first pair of prisms diametrically opposed to each other for providing images of right and left sides of an inspection item; and

a second pair of prisms diametrically opposed to each other for providing images of front and back sides of an inspection item.

19. The prism of claim 18 further comprising a fifth prism oriented in the center of the first pair of prisms and the second pair of prisms to match a refractive index for a focused image.