FLEXIBLE VISION INSPECTOR

[0001] The present application relates to a Flexible Vision Inspector (FVI). The application also relates to methods of using, installing, uninstalling, modifying, upgrading, assembling, disassembling, configuring and programming the Flexible Vision Inspector. The Flexible Vision Inspector is also known as a Flexible Machine Vision Inspector.

[0002] Machine vision (MV) is the technology used to provide imaging-based analysis for automatic inspection, process control, and robot guidance. Typically, 90% of the success of any machine vision application is achieved through proper lighting. Known machine vision inspectors usually provide fixed and task-specific lighting and camera arrangements for capturing images of interest. However, if various aspects of an object are required to be captured for manufacturing process control, several known machine vision inspectors are deployed for checking the different aspects of the objects, which make an inspection line both expensive and bulky.

[0003] The present invention(s) aim(s) to provide new and useful device(s). The invention also aims to provide new and useful methods for using, installing, uninstalling, modifying, upgrading, assembling, disassembling, configuring and programming the device(s). Essential features of the invention(s) have been provided by one or more independent claims, whilst advantageous features are offered by their dependent claims. The present application claims priority of Singapore patent application 2013090378 that was filed on 29 November 2013. All content of this earlier application is hereby incorporated by reference.

[0004] According to a first aspect, the present application provides a flexible vision inspector that comprises a first type of illuminator for illuminating an object under machine or computer vision inspection. The flexible vision inspector also comprises a second type of illuminator for projecting light onto the same object from another angle. The flexible vision inspector additionally a housing that encloses the first type of illuminator, the second type of illuminator or both for preventing interference of illumination or shielding the first type of illuminator, the second type of illuminator, or a combination of both to the object.

[0005] Since appropriate lighting or illumination greatly influences results of machine or computer vision, the flexible vision inspector projects suitable light with frequency, photon intensity and wavelength onto the object for inspection. The two or more types of lighting/illumination may be sequentially and concurrently projected onto the object such that the camera (i.e. vision camera) can capture images of the object with excellent contrast. For example, halogen light as a single type of lighting typically provides bright white and yellow light. A typical halogen lamp is inexpensive and can normally last 200~3,000 hours. However, the typical halogen lamp generates excessive heat and cannot be switched on/off frequently. In contrast, a LED lamp or an array of LEDs can produce various spectrum of light stably, and long life (e.g. up to 100,000 hours). When combined, either one type of illuminator can be switched on for inspecting objects, such as clear/transparent glasses, plastic colored (opaque) trays, or shining/reflective cutlery items (e.g. chrome knife).

[0006] The camera provides machine vision that has wide Field Of View (FOV) or Field Of Vision for inspecting multiple sides of the object with fewer cameras. For example, the single camera can capture top and side views of the object, or bottom and inside views of the object simultaneously with one shot. In a first embodiment, the camera has one or more pericentric lenses (known as PC series) that can capture 360° top and lateral view with just one camera. In a second embodiment, the camera has a catadioptric lens (known as PCCD series) for 360° top and lateral view with just one camera. In a third embodiment, the camera has a lens of hole inspection optics for 360° inside view in perfect focus, known as PCHI series. In a fourth embodiment, the camera has one or more boroscopic probes (known as PCBP series) for panoramic cavity imaging and measurement from inside of the object. In a fifth embodiment, the camera has a lens of micro-polyview optics (known as PCMP series) for 3D measurement and imaging of small parts. In a sixth embodiment, the camera has a lens of polyview optics (known as PCPW series) for multiple views of the same objects with one shot. In a seventh embodiment, the camera has a lens of bi-telecentric system (known as TCCAGE series) for multiple side imaging and measurement at 90°. The camera may further comprise a 3D camera that includes a range camera for producing a 2D image showing the distance to points in a scene from a specific point. The 3D camera comprises a stereo camera that has two or

more lenses with separate image sensors or film frame for each of these lens, which allows the camera to simulate human binocular vision, and therefore capture three-dimensional images.

[0007] Each of the two types of illuminators may adopt one of the lighting techniques, such as partial bright field, dark field, back lighting, diffuse dome, axial diffuse and flat diffuse. The selection of illuminator and its lighting technique depends on the vision-inspected object's surface texture, shape, size and surface reflectivity.

[0008] The housing protects the illuminator, the camera or both. The housing can prevents unwanted light (e.g. ambient light) from interfering stable and consistent illumination to the object. For example, the housing that has side boards or shell(s) can reflect or absorb the unwanted light such that external light cannot enter the lens of the camera when conducting vision inspection. The housing further keeps foreign items (e.g. falling screw, water droplets) from damaging the illuminators, the camera and their electrical wires/cables. Accordingly, the flexible vision inspector provides a modular solution/device such that the flexible vision inspector can be installed or transferred to any designated position for plug-and-play (i.e. quick & easy setup). Since the housing further encloses the illuminator(s), the camera or both, components of the flexible vision inspector are protected against accidental damages or disturbances. The various types of the illuminators and their different lighting techniques offer flexibility for adapting to diverse types, colors, shapes and textures of objects for inspection. If repair or upgrading is required, all parts of the flexible vision inspector may simply be taken away for maintenance. The housing is further useful for protecting components of the flexible vision inspector (e.g. camera, lens, electronic circuit boards, cables) from interference, especially when installed in a wet, steamy, dusty or vibrating environments. The housing or the flexible vision inspector can have damper (shock absorber) or sealing of high ingress protection marking according to IP Code of International Protection Marking (e.g. IPX8).

[0009] The Flexible Vision Inspector can further comprise one or more types of camera for capturing an image of the object. The one or more types of camera are enclosed by the housing. The camera is also known as vision camera, smart camera or smart sensor. The camera further includes various types of lenses (e.g. biconvex

lens) and filters (e.g. polarizer, diffusion filter). The camera can provide machine vision in 2D with visible light, image capturing in various infrared bands, line scan imaging, 3D imaging of surfaces and X-ray imaging. For example, the camera is a X-Ray CCD camera (e.g. xiRAY model MH110XC-KK-FA by XIMEA™) that provides high resolution direct phosphor imaging. Alternatively, the camera is or comprises X-ray line-scan camera (e.g. XR8800 and XRH8800 by AMS Technologies™) that has high image resolution for detecting tiny defects in food and non-food items (e.g. resolutions range from 50-µm to 0.8-mm pitch for the XR and 50-µm to 1.6-mm for the XRH). With the help of X-Ray camera, the flexible vision inspector can detect failure in concealed inflight set meal packages. For example, fractured biscuits can be detected from their sealed sachets. Internal cracks of glasses can be readily recognized such that these glasses can be prevented from being packaged into inflight set meals. Additionally, the camera may be partially or completely shielded by the housing such that the camera is secure and safely protected.

[0010] The one or more types of cameras can take or multiple shots for capturing one or more images of the object. When multiple images of the object are taken simultaneously or sequentially, these different images of the object are then joined or stitched together into one unwrapped image such that vision tools (computer software packages) are then applied to verify inspection criteria for passing or failing the object. In one embodiment, passed objects continue on down a conveyor for inflight set meal packaging while failed objects are removed from the conveyor by a rejector (e.g. industrial robot). Accordingly, the Flexible Vision Inspector prevents food allergen and reduce liability of inflight set meal provider. ◦Mislabeled food and non-food items are greatly avoided for achieving increased customer satisfaction.

[0011] In an embodiment, the flexible vision inspector provides accurate 360° inspection in a single image such that part orientation of the object is not required. The flexible vision inspector offers non-contact 100% inspection at high speed such that an inflight se meal packaging line is not slowed down. The flexible vision inspector has simple vision setup and product changeover, which further allows wide range of vision tools for customization. The flexible vision inspector additionally facilitates label content verification, date-lot code verification, bar code and data matrix reading, gauging (e.g. without a telecentric lens) and verifies lid logo contents.

[0012] The housing may comprise one or more panels for blocking external light from interfering illumination of the object. In production, external lighting may interfere with desired lighting condition for inspecting the object. One or more panels may reside next to or around the object such that only light from the illuminator(s) provide dominant lighting to the object for vision. For example, any of the panels may include a wall or other parts of neighboring equipment(s).

[0013] The one or more panels can comprise a light absorber, a light reflector, a light refractor, a light diffuser, a light polarizer, a lens or a combination of any of these, which may be also known as light transformer(s) or manipulator(s). Moreover, a portion of entire piece of any of these panels can comprise light transformer(s) or manipulator(s). These light transformer(s) or manipulator(s) can help to focus, diffuse, scatter, reflect or divert light from the one or more types of illuminators. They can also reflect ambient or external light such that lighting condition of the vision-inspected object (i.e. object) is stable, consistent and under control. These light transformer(s) or manipulator(s) can further enhance, diminish, combine or separate light from the one or more illuminators such that the flexible vision inspector can be adopted for inspecting diverse types of objects having different shapes, colors, translucencies or sizes.

[0014] The light polarizer, polarizer or polariser is an optical filter that passes light of a specific polarization and prevents waves of other polarizations. The lolarizer can convert a beam of light of undefined or mixed polarization into a beam with well-defined polarization, polarized light. The polarizer includes linear polarizer and circular polarizer (e.g. homogenous circular polarizer). The linear polarizer includes wire-grid polarizer, absorptive polarizer, beam-splitting polarizer, birefringent polarizer and thin film polarizer.

[0015] The one or more panels may comprise a front panel that is in the form of an optic diffuser or ground glass diffuser. In fact, a portion or entire front panel may be in the form of ground glass diffuser. The diffuser or ground glass diffuser may diffuse, spread out or scatters light for giving soft or uniform. Diffuse light can be easily obtained by making light to reflect diffusely from a white surface, such as ground

glass. Alternatively, the diffuser may be more compact by adopting translucent objects, including Teflon diffusers, holographic diffusers, opal glass diffusers, and greyed glass diffusers. For example, the first type of illuminator includes a xenon flash light bulb, whilst the front panel comprises a flash diffuser spreads in front of the xenon flash light bulb such that light from the xenon flash light bulb (as concentrated light source like a spotlight) spreads out, bounce from reflective panels or walls. Harsh light and hard shadows are removed from the vison-inspected object.

[0016] The front panel, the diffuser or the ground glass diffuser can comprise one or more clear portions for exposing lens of the one or more types of camera. For example, the panels of the flexible vision inspector form an enclosure in the form of a rectangular prism. The one or more cameras are enclosed by the housing such that only portion of opening(s) or clear glass exposes lens(es) of the cameras for capturing images of the object. Hence, most components of the flexible vision inspector are protected against intrusion or infiltration. The flexible vision inspector can achieve protection against intrusion by meeting relevant IP Code (International Protection Marking) of level 1 to 6. For example, the flexible vision inspector has level 1 protection for blocking any large surface of the body (e.g. the back of a hand). The can achieve level 6 protection by being dust tight.

[0017] The housing may comprise one or more rails for mounting the two or more types of the illuminators, the one or more cameras, or both. The one or more rails not only provide fixed mounting positions, but also offer adjustable or mobile fixtures. In use or configuration, the one or more rails provide one or tracks for shifting positions or angles of the illuminator(s) or camera(s) in order to capture desired images. The one or more illuminators or cameras may be propelled by electric motor(s) (step motor) and belts such that the illuminator(s) or camera(s) can flexibly work in cooperation. Any of the rails may be straight, curved in 2D, curved in 3D or in combination of any of these such that the illuminator(s) or camera(s) may be locked, dislodged, fixed or detachably mounted at any place inside the housing or near the housing. Various effects of illumination can either be statically or dynamically provided for inspecting objects by machine or computer vision.

[0018] The one or more rails can comprise a first rail, a second rail or both for mounting the one or more cameras and the two or more types of the illuminators separately or together. The one or more rails can be installed into the housing when required. Any of the one or more rails can be pliable, resilient, stiff or in combination of any of these such that the one or more rails can be adjusted or improvised by technician or user onsite. Any of the rails can be a continuous track, which is propelled by an electric motor. Accordingly, the illuminators, the camera or both move around for inspecting one or more the objects.

[0019] The one or more rails may comprise a first rail and a third rail that are joined together for moving the one or more of the cameras, the two or more types of the illuminators or both the two rails and the camera. Multiple rails that are connected together enable the illuminator(s) or camera(s) to move around a larger area as compared to that of a single rail. Any of the rails may also carry or support cables/wires that are connected to the camera(s) or illuminator(s). Multiple rails may be joined to form a 3D geometry or 2D geometry, either in regular shape (e.g. circular, square) or irregular shapes. The one or more rails may be made of same or different materials, such as aluminum, steel, stainless steel, plastic or in combination of any of these.

[0020] The Flexible Vision Inspector can further comprise a hub connector on or inside the housing or on the unitary framework for combining/collecting/bundling electrical connections. Since the illuminators and camera(s) can require external power supply and control, power cables and signal wires are often useful for connecting these components. However, scattered strands (wires or cables) and their connections are complex and hazardous for handling, especially by machine users/operators. The hub connector fasten several strands together and gather their electrical connections to a same site such that the multiple electrical connections can be achieved by a hub plug for coupling with a hub socket (e.g. plug & socket together known as connector). If service maintenance is required for the flexible vision inspector, the hub connector can be disconnected such that the flexible vision inspector can be easily carried away for repair, instead of disconnecting the many strands. In other words, the flexible vision inspector is made modular for easy configuration and upgrading offsite.

[0021] The hub connector may comprise a signal wire connector, a power cable connector or both for providing detachable electrical connections. The signal wire connector and power cable connector can located within one hub connector, or separately into two or more hub connectors. For example, the hub connector is mounted on a panel of the housing, which provides robust support to the hub connector. A plug and a socket of the hub connector may be detached for moving the Flexible Vision Inspector to another location.

[0022] The housing can comprise one or more openings for receiving the object into the housing. Hence, the object can be inspected inside or outside (e.g. neighboring the housing) the Flexible Vision Inspector. Multiple objects can be simultaneously or sequentially inspected by the Flexible Vision Inspector inside or outside the housing. For example, an industrial robot (i.e. robotic arm) can hold a mug from its interior (e.g. bottom surface by suction cup) into the housing for vision-inspecting exterior surfaces (e.g. bottom) of the mug. Upon completion, another industrial robot can reach the mug from an opposite opening on the housing such that the other industrial robot can grab the mug from the already inspected exterior surface (e.g. bottom), allowing interior surfaces of the mug to be examined by the Flexible Vision Inspector again. Consequently, both interior and exterior of the mug are vision-inspected. Alternatively, the two industrial robots can exchange an object (e.g. a saucer) outside and near the Flexible Vision Inspector such that both interior and exterior surfaces of the object can be vision-inspected. In other words, the Flexible Vision Inspector facilitates complete inspection of an object, avoiding blind spots when examining the object.

[0023] The one or more openings may comprise a first opening and a second opening such that the object can be transferred between two robotic arms by accessing through the two openings. The two openings may be provided on the same panel, different panel or opposite panels. Additional openings may be provided for allowing further robotic arms to cooperate together for inspecting the object. In fact, multiple robotic arms that carry several objects can be transferred around the Flexible Vision Inspector for simultaneous or sequentially vision-inspection either inside, or near the housing.

[0024] The housing can comprise one or more layers of anti-fogging coating or anti-static coating for resisting moisture. Alternatively, other exposed components of the flexible vision inspector can have one or more layers of anti-fogging coating or anti-static coating for working in a wet or steamy environment. Particularly, the flexible vision inspector can be deployed in an industrial dishwasher, which utilizes water and steam throughout the industrial dishwasher. For example, the housing that encloses the flexible vision inspector partially or fully can have IPX1~8 protection for having reliable operation in a hazardous environment.

[0025] The flexible vision Inspector may further comprise a wiper (also known as windscreen wiper or windshield wiper) for preventing fluid or dust accumulation on any part of the flexible vision inspector. In practice, the wiper can remove accumulated liquid intermittently, continuously, periodically or on-demand (when required). For example, a moisture sensor can be installed for detecting presence of unwanted liquid (e.g. water droplets) such that the wiper can swiftly remove the unwanted liquid. In a steamy ambient, the wiper can remove condensate from a screen before a lens of the camera so that vision inspection is not affected. In fact, any part of the flexible vision inspector may be installed with a fan or heater for driving away moisture from the flexible vision inspector.

[0026] The flexible vision inspector can further comprise one or more fans inside or near the housing for cooling components (e.g. illuminator) of the Flexible Vision Inspector. The one or more fans circulate or suck into air so that heat of the Flexible Vision Inspector is dissipated for providing a stable environment. Life span, consistency and reliability of the Flexible Vision Inspector are improved. For example, the housing has numerous orifices that permit hot air in the Flexible Vision Inspector to escape to the ambient environment. More advantageously, the orifices are not located at a top surface of the Flexible Vision Inspector such that dust or water cannot enter into the housing easily under gravity.

[0027] The flexible vision inspector may further comprise a distance sensor mounted onto the unitary framework for detecting distance between the object and the one or more camera. Although the distance sensor may be in the form of two or more cameras separated part, the distance sensor may also be simply implemented by a

laser rangefinder. If an industrial robot is installed with the distance sensor, an object that is carried by the industrial robot may be consistently transported to the Flexile Vision Inspector to a fixed place (e.g. with predetermined stance from the FVI). The Flexible Vision Inspector can inspect the object speedily, without demanding much time and computer resource (e.g. RAM usage). The distance sensor has many forms readily for implementation.

[0028] The present application further provides a vision inspection station that comprises the Flexible Vision Inspector, and one or more robotic arms for fetching the object to the Flexible Vision Inspector. The one or more robotic arms can fetch diverse types of objects to Flexible Vision Inspector for vision examination. Hence, the Flexible Vision Inspector or the vision inspection station can suit specific industrial requirements, relieving human from continuous, exhausting and monotonous quality inspection.

[0029] The one or more robotic arms can comprise a first robotic arm and second robotic arm that are positioned next to the Flexible Vision Inspector for transferring the object. Any of the robotic arms can be floor-mounted or ceiling mounted such that the entire vision inspection station becomes compact, requiring less factory floor. The two or more robotic arms can share the same workspace by entering the shared workspace sequentially, without interfering each other.

[0030] The vision inspection station may further comprise a conveyor for transporting the object. Examples of the conveyor include gravity roller conveyor, gravity skate-wheel conveyor, belt conveyor, wire mesh conveyor, plastic belt conveyor, bucket conveyor, flexible conveyor, vertical conveyor, spiral conveyor, vibrating conveyor, pneumatic conveyor, electric track vehicle system, belt driven live roller conveyor, line-shaft roller conveyor, chain conveyor, screw conveyor aka Auger conveyor, chain driven live roller conveyor, overhead conveyor, dust proof conveyor, pharmaceutical conveyor, automotive conveyor, overland conveyor and drag conveyor. Depending on specific task requirements, any of these conveyors may be combined for working with the flexible vision inspector.

[0031] In the present application, the single flexible visible inspector or vision inspection station provides an adaptable and versatile automatic vision inspection solution for examining inflight set meal packages. In purpose or task specific machine vision apparatuses, illuminator(s) and camera(s) are often uniquely or peculiarly chosen and positioned for inspecting particular surface textures, shapes or dimensions. In other words, these machine vision apparatuses have rigid system configuration and cannot be switched or transferred to machine vision inspection of different objectives. In contrast, the present flexible visible inspector or vision inspection station has one or types of illuminators, and one or more types of cameras such that these illuminators or cameras can be sequentially or concurrently deployed for inspecting diverse types of objects with varying sizes, shapes or textures with high efficiency, without building several machine vision inspection apparatuses. In other words, the one flexible vision inspector can replace several single task specific vision inspection setup such that the overall cost of vision inspection is reduced, with added advantages of flexibility of inspecting diverse types of objects, textures and shapes.

[0032] Since the flexible visible inspector or vision inspection station has a housing that comprises one or more panels, light noise (e.g. ambient light or neighboring flashing) is prevented from interfering image capturing of the camera. Whether partially or completed enclosed, the camera is able to obtain consistent, stable and clear object images with little external light interference. Additionally, the housing can prevent intrusion or damage from fluid spillage, dust accumulation, pest trespassing, knocking or other unwanted disturbance to the flexible visible inspector or vision inspection station.

[0033] The camera of the flexible visible inspector or vision inspection station is alternatively known as portable visible inspector or portable vision inspection station because both illuminator(s) and camera(s) can be transported together on the unitary framework. In practice, the flexible visible inspector or vision inspection station sometimes needs to be repaired, maintained, configured or updated. When required, a faulty flexible vision inspector is replaced by a proper faulty flexible vision inspector such that an inflight set packaging line with the flexible vision inspector is not unduly delayed for operation. The faulty flexible vision inspector is repaired offline while the inflight set packaging line operates continuously without interference. After repair, the

restored flexible vision inspector can be reinstated into its original place such that disruption to the inflight set packaging line is minimized. In use, purchasers or users of the flexible vision inspector can readily installed the flexible vision inspector at a suitable location of production floor without engaging experts for setting up the entire flexible vision inspector because the flexible vision inspector can work independently, possibly with ports connected to external power supply and data communication via one or more hub connectors. In other words, the flexible vision inspector becomes modular in design, construction and usage, can be easily move around on a manufacturing line or a factory floor for different tasks of vision inspection, known to be plug-and-play.

[0034] The unitary framework has fixtures or components that can be flexibly dislodged, replaced or installed. Diverse types or models of illuminators or cameras can be fixed onto or removed from the unitary framework on demand. Accordingly, the flexible visible inspector or vision inspection station may be adopted by wide variety machines for vision inspection. In fact, one manufacturing line can hold several flexible visible inspectors or vision inspection stations at various places for different types of vision inspection, although the flexible visible inspectors or vision inspection stations are essentially similar. Mass production or deployment of the flexible visible inspector or vision inspection station becomes feasible for cost reduction, easy deployment or standard configuration.

[0035] In the application, the housing (also known as box) can be water-proof or splash-proof for wash down, which is useful in food industries or pharmaceutical/medical industry for keeping excellent hygiene condition. The housing or parts of the housing prevent external lighting (known as noise illumination) from interfering accurate or sensitive machine vision inspection. For example, panels of the housing hinder the external lighting (e.g. sunlight or flashlight) and eliminate unwanted reflection. Multiple pieces of the flexible visible inspectors or vision inspection stations are thus allowed to be installed at close vicinity without worry of their mutual light interference. The housing further accidental disturbance to the flexible visible inspector or vision inspection station by unintentional intrusion, such as by a factory operator.

[0036] According to the application, the flexible vision inspector or vision inspection station can be easily mounted onto a ceiling, a wall, a floor or pole via the unitary framework. Hence, the flexible vision inspector or vision inspection station can be installed on any part of a machine or inflight set meal packaging line for providing compactness of the line/machine, reliability or ease of access. The housing can further include one or more mirrors (reflectors) or magnifying glasses for capturing multiple or enhanced images of the object without unduly adding more cameras. The flexible vision inspector or vision inspection station has one or more cameras for 2D and 3D surfaces inspection such that both curved and flat surfaces are examined for quality compliance. For example, the flexible vision inspector or vision inspection station can check both an internal surface and an external surface of the object simultaneously. According to embodiments of the invention(s), an end-effector of a robot can move a cup into the housing or in front of (outside) the housing for capturing both internal and external images of the cup.

[0037] According a second aspect, the present application provides a method for inspecting an object by machine or computer vision. The method comprises a first step of providing a robotic arm, two or more types of illuminators, on or more cameras and an object for machine vision/visual examination. The method further comprises a second of moving the object to the one or more types of illuminator and the one or more cameras by the robotic arm. The method additionally comprises a third step of projecting light onto the object for vision inspection by the one or more cameras. Some of these steps may be changed in sequence. The method is adaptable to various types of objects for machine vision inspection. For example, the robotic arm can fetch objects of diverse types of material, shape, weight, colour and translucency for inspecting. The method thus can be easily adopted for inflight set meal packaging, where only manual operation exist worldwide at present. When inspecting the object, an image captured by the flexible vision inspector can be analyzed for determining the object's position such that a next object may be more accurately placed before the camera by eliminating position/location errors, such as according to 6 axes of Cartesian coordinate system.

[0038] The method may further comprise a step of receiving the object by another robotic arm, and vision inspection by the same camera or another camera. In other

words, two or more Flexible Vision Inspectors can collaborate with one robotic arm. Alternatively, two or more cameras of a Flexible Vision Inspector can cooperate with the same robotic arm. Multiple robotic arms, multiple cameras of one Flexible Vision Inspector or multiple Flexible Vision Inspectors can join forces for inspecting one or more objects. The method can be easily configured and adapted to diverse types of vision inspection requirements, with little compromising in speed, quality, reliability and consistency.

[0039] According to a third aspect, the present application provides a Flexible Vision Inspector that comprises a first type of illuminator for illuminating an object, a second type of illuminator for projecting light onto the object, and a first type of camera for capturing an image of the object under the lighting of the first type of illuminator, the second type of illuminator, or both.

[0040] The Flexible Vision Inspector utilizes machine vision for automatic quality inspection and assurance. The Flexible Vision Inspector adopts various imaging techniques for checking quality compliance of washed cutlery items and trays. When installed close to an industrial dishwasher, the FVI inspect if the washed cutlery items and trays are stained or broken such that only quality-compliant (e.g. free from stain and deformation) cutlery items and trays are accepted for sorting, storing or packaging. The Flexible Vision Inspector can use 2D visible light imaging, infrared light imaging, line scan imaging, 3D imaging of surfaces and X-ray imaging techniques.

[0041] Instead of only capturing specific type of feature, the FVI has multiple types of illuminators for providing lighting to the object either sequentially or simultaneously. Multiple vision inspection stations are avoided such that vision inspection of the object with numerous features can be realized within a compact device and short duration. In use, the flexible vision inspector can examine both dry and wet surface of an object. Since water droplets will alter surface reflection of the object, the flexible vision inspector employs different types of illuminators for capturing images of the same object sequentially at short interval in-between such that quality of vision inspection is not compromised by variation of surface texture/condition, colour or roughness of the object. Actually, the flexible vision inspector can check washing quality of wet plates

or other food utensils when deployed in an industrial dishwasher. The housing of the flexible vision inspector can protect intrusion of moisture, dust, liquid or pests. The flexible vision inspector may also be adopted by inflight meal packaging line that is generally dry and clean.

[0042] For example, the first type of illuminator is a DOAL (Diffuse On-Axis Light) illuminator that has wide selection of colors and lengths. The DOAL illuminator offers continuous or strobed operation modes. Light from the DOAL illuminator enables inspection and analysis of reflective components (e.g. chromed coated table spoon). The DOAL illuminator provides a bright, diffuse spot at a distance of greater than 25mm, which is ideal for precision inspection.

[0043] The second type of illuminator may be a CDI® (Cloudy Day Illuminators) illuminator, which provides self-contained continuous diffuse lighting. Light projected by the CDI® (illuminator) suits machine vision inspection of highly faceted and undulating reflective surfaces.

[0044] In view of the fact that 90% of the success of any machine vision application is through proper lighting, usage of lamps or illuminators are of critical importance for the effectiveness and efficiency of machine vision. According to the present application, when the two types of illuminators are installed inside one machine vision inspector, the single object can be illuminated by two lamps of different types of lighting conditions. Accordingly, different features of interest can be correctly and accurately captured by the camera such that two separate vision inspector are avoided, resulting in saving in cost, factory floor and inspection time. The two types of light may be sequentially or simultaneously casted onto the object such that the vision inspection can be performed orderly and efficiently.

[0045] Types of light for machine vision may be classified by wavelength of the light, such as red, white, blue, UV (ultraviolet) and infrared light. The types of light may be further classified by illumination pattern of the lamps, such as edge-to-edge backlight, large area backlight, focused light and diffused light.

[0046] The Flexible Vision Inspector may further comprise a third type of illuminator for providing light to the object. Having another type of light, more features of the object can be detected for complete inspection. For example, the third type of illuminator is dark field illuminator 56 that casts light onto the object sidewise with a low angle, not shining top down. Edges of the object, contrast of surface features and surface defects are emphasized. Non-compliance of geometry contours on the object (e.g. edge crack) is easily noticed by the Flexible Vision Inspector.

[0047] The Flexible Vision Inspector can further comprise a fourth type of illuminator for shining light onto the object. Accordingly, the Flexible Vision Inspector is provided with a further type of capability for exposing more features of the object within the same inspection site. For example, the fifth type of illuminator is a ring light illuminator 58 of low-cost that provides diffuse illumination of surfaces. Surface defects (e.g. scratch mark) on a bowl can be easily observed by the camera under the diffuse illumination.

[0048] Similarly, the Flexible Vision Inspector can comprise a Fifth type of illuminator or further types of illuminators. For example, the fifth type of illuminator is a Large Area Backlight illuminator. The Large Area Backlight illuminator provides stark contrast to outline the object's shape, which enables a vision enabled machine to find edges and view openings.

[0049] The further types of illuminator include a Dome illuminator that provides an economical source of diffused, uniform light. The Dome illuminator projects light with a wide and solid angle which support imaging of curved, shiny or bumpy surfaces. The Dome illuminator is a cost-effective alternative to CDI® illuminators for applications not requiring an on-axis lighting component. Two colors are available for the Dome illuminator and it is an economical solution for widely-used general purpose designs. The Dome illuminator is easily integrated and can provide continuous, or strobed diffused LED illumination.

[0050] Further types of illuminator comprise an Area Array illuminator that provides general purpose lighting, and enables unidirectional and adjustable mounting position. The Area Array illuminator may be used for dark field lighting, which creates shadows

and specular reflection. The Area Array illuminator can further provide bright field lighting for diffused surfaces. Subtle adjustments to working distance and angle of light delivery can deliver good image contrast for minimal investment. The Area Array illuminator may be provided in three colors, ultraviolet & infrared light. Multiple arrays may be combined into a single Area Array illuminator for addressing large field of view applications.

[0051] The first type of camera is an imaging device that can either be separated from the main image processing unit or combined with it in which case the combination is generally called a smart camera or smart sensor. When separated, the connection may be made to specialized intermediate hardware, a frame grabber using either a standardized (Camera Link, CoaXPress) or custom interface. The first type of camera can also be a digital camera capable of direct connections (without a frame-grabber) to a computer via FireWire, USB or Gigabit Ethernet interfaces.

[0052] The Flexible Vision Inspector can further comprise a second type of camera for obtaining an image of the object. Various types of the camera include analogue cameras, CCD cameras, CMOS cameras, DSP cameras, FireWire cameras, Gigabit Ethernet cameras, Camera Link Cameras and USB2.0/3.0 cameras. These types of cameras provide many advantages for capturing images of different resolutions at different speed.

[0053] The Flexible Vision Inspector may further comprise one or more housings for blocking ambient light of the Flexible Vision Inspector. Since the object is ideally inspected within controlled environment (e.g. predetermined lighting conditions), ambient disturbance is blocked by the housing for keeping the controlled environment within the housing. For example, lighting condition of the object can be affected by walking operators near the Flexible Vision Inspector. Accordingly, the FVI provides consist inspection quality for reliable and continuous operations. The housing may mounted onto spring supports such that vibration of the factory floor will affect the cameras and lamps on the housing. The housing may form an enclosure in the form of a box that minimizes dust collection on the surface of the cameras lens. In some critical inspection situation, one or more mini-HEPA filters are installed onto the housing such that air within the housing is dust-free. The box openings can be

constructed according to IP67 (Ingress Protection) splash proof opening so that all lighting/cameras can be protected during operation and/or washing in harsh operating conditions.

[0054] The Flexible Vision Inspector can include flexible mounting brackets that are pre-mounted around the object of inspection. The cameras and lamps can be mounted around the object for taking snap shots of the object sequentially such that multiple object-of-interest may be captured. The construction of FVI requires short time for capturing different images of one or more objects. Different types of objects/products (bowls, spoons, trays) can be vision-inspected in the same box without having to shut down the production for low turnover rate. The FVI is compact and requires little space working space for ease of handling.

[0055] The Flexible Vision Inspector can further comprise a first rail for mounting one or more of the cameras. The first rail allows a mounted camera to move along the first rail, or to rotate around the first rail or locking of the camera onto the first rail. The first camera may be fixed to the first rail at various angles, positions and orientations such that ideal image-capturing positions may be realized for effective inspection.

[0056] The Flexible Vision Inspector may further comprise a second rail for mounting one or more of the cameras. The second rail supports one or more of the cameras for obtaining the image at another angle. The second rail and the first rail may be connected or detached for coordinated camera movements. For example, the first rail has a straight profile for enabling linear translation, whilst the second rail has a semi-circular profile that enables rotary displacement, even around the object.

[0057] One or more of the rails can comprise a transmission for adjusting position or orientation of the cameras. The transmission includes a gearbox type, a conveyor belt type and other types of mechanism, such as kinetic pairs, gear and gear trains, cam and follower mechanism, as well as linkages.

[0058] The Flexible Vision Inspector may further comprise a holder for supporting one or more of the illuminators. The holder enables the lamps to be fixed at predetermined positions and angle for light projection according to predetermined pattern.

[0059] The holder can comprise a locking mechanism for detachably attaching or releasing the at least one of the illuminators. Some of the lamps or illuminators can thus be removed or added for adjusting lighting condition of the FVI.

[0060] The holder may further comprise an angle adjustment mechanism for regulating an orientation of the one or more of the illuminators. Light is not just directly projected, but also reflected onto the object by adjusting the angle such that more variety of illumination patterns can be obtained for inspecting diverse types of features.

[0061] The Flexible Vision Inspector can further comprise one or more mirrors for reflecting light, replicating light, projecting images or projecting light. Images or light reflected by the one or more mirrors assist machine vision inspection of an object from multiple angles, under different lighting conditions or various distances in a simultaneous routine or sequential manner. The Flexible Vision Inspector can thus be made more compact and efficient.

[0062] Alternatively, the Flexible Vision Inspector may comprise one or more lenses for expanding certain features such that machine vision inspection can be made more accurate for examining minute parts of an object.

[0063] The mirror can comprise one or more portions of structural support of the Flexible Vision Inspector. For example, parts or the entire sidewall of the Flexible Vision Inspector has mirror-finish stainless board such that the sidewall acts as structural support, as well as mirror.

[0064] The Flexible Vision Inspector may further comprise one or more fixtures for mounting the Flexible Vision Inspector to a ceiling, a pillar or a wall. The fixtures include smooth surface(s) for vacuum suction, slot(s) for screw mounting, strut(s) for bolt attachments, or hole(s) for fastening. The fixtures provide structural mounting structure for fasteners.

[0065] The Flexible Vision Inspector can further comprise one or more fences, partitions, dividers, walls, pillars or other structure division elements for forming an

enclosure. These fences, partitions, dividers, walls, pillars or other structure division elements may be transparent, semi-transparent or opaque such that they form a container structure for blocking dust, water spillage or other external disturbances, including light or sound interferences. For example, external shadow or lighting in a production line will not affect accurate vision inspection based on previously calibrated settings of the Flexible Vision Inspector.

[0066] The Flexible Vision Inspector may further comprise one or more hub connectors for combining electrical connections. The one or more hub connectors can integrated multiple signal wires or sockets into one united connection base/plug/socket such that the Flexible Vision Inspector is able to connect to an external device (e.g. computer or power socket) neatly via the single connection. Loose wires or scattered plugs are avoided, which makes electrical connection of the Flexible Vision Inspector neat and easy. The hub connector can incorporate signal wire connections, power line connections or in combination. Accordingly, the Flexible Vision Inspector becomes convenient for connecting to external devices via the hub connectors, instead of multiple wires, plugs or sockets, known as plug & play.

[0067] The Flexible Vision Inspector can further comprise one or more electric controllers (e.g. Programmable Logic Controller) that are connected to the one or more hub connectors. The electric controllers may alternatively be replaced or combined with one or more microprocessors such that the Flexible Vision Inspector can provide one or more electrical control functions or image processing locally at the Flexible Vision Inspector. In other words, the Flexible Vision Inspector itself becomes automatic or semi-automatic for performing vision inspection or lighting, in response to incoming objects, lighting conditions or loading duties.

[0068] The present application also provides vision inspection station that comprises the Flexible Vision Inspector and one or more of the robotic arm for fetching the object into or out of the Flexible Vision Inspector. The robotic arm is versatile for transferring objects of various shapes, weight, hardness, surface texture and sizes for vision inspection.

[0069] The one or more robotic arms may comprise a first robotic arm and a second robotic arm that are positioned at opposite sides of the housing for feeding and retrieving the object respectively. In other words, the two robotic arms cooperate with each other such that they avoid idling time spent on waiting for a next vision inspection object.

[0070] The Vision inspection station can further comprise a belt conveyor for transporting the object into or out of the Flexible Vision Inspector. The belt conveyor provides an alternative for feeding the FVI continuously with objects for vision inspection. Since the belt conveyor has a generally flat surface for carrying objects, diverse types of cutlery items and trays can be transported efficiently.

[0071] The vision inspection station may comprise one or more fixtures for mounting the Flexible Vision Inspector to a ceiling or any other physical locations, such as pillar, wall or corner. For example, the vision inspection station or the Flexible Vision Inspector may be fastened to a ceiling. Accordingly, cameras on the lateral sides of the Flexible Vision Inspector are not exposed to water dripping from the ceiling. In case that inspection objects/targets (e.g. a mug) misses gripping by a robotic arm, the dropping inspection object/target (e.g. a mug) will not fall onto cameras mounted onto sidewalls of the Flexible Vision Inspector.

[0072] The vision inspection station can further comprise one or more mirrors for reflecting light or images. The cameras can be attached internally to the Flexible Vision Inspector, shared by neighboring Flexible Vision Inspectors, or fastened to parts of the vision inspection station.

[0073] The vision inspection station may further comprise one or more fixtures for mounting the Flexible Vision Inspector to a ceiling, a pillar or a wall. Accordingly, the Flexible Vision Inspector can be mounted in any desired orientation, regardless locations or types of the fixtures (e.g. fasteners).

[0074] The present application provides a Flexible Vision Inspector and a Vision Inspection Station for carrying out vision inspection substantially as hereinbefore described with reference to or as illustrated in any of the accompanying drawings.

[0075] The accompanying Figures (Figs.) illustrate embodiments and serve to explain principles of the disclosed embodiments. It is to be understood, however, that these Figs. are presented for purposes of illustration only, and not for defining limits of relevant inventions.

[0076] Fig. 1 illustrates a first flexible vision inspector with two robotic arms;
Fig. 2 illustrates a second flexible vision inspector with a belt conveyor; and
Fig. 3 illustrates a third flexible vision inspector.

[0077] Exemplary, non-limiting embodiments of the present application will now be described with references to the above-mentioned Figs.

[0078] Fig. 1 relates to a first embodiment of the present application. In particular, Fig. 1 illustrates a first Flexible Vision Inspector (FVI) 30 with a first robotic arm 32 and a second robotic arm 34. The two robotic arms 32, 34 are placed at opposite sides 36, 38 of the first FVI 30 for loading and unloading square saucers 40. Each of the first robotic arm 32 and the second robotic arm 34 has a laser rangefinder 33, 35 attached to its forearm respectively. A first laser rangefinder 33 on the first robotic arm 32 measures distances of objects from an end effector 72 for the first robotic arm 32 for accurate picking up. Similarly, a second laser rangefinder 35 on a forearm of second robotic arm 34 detects distances continuously between an end effector 76 of the second robotic arm 34 and its object 82 for picking. In particular, the first robotic arm 32 is located at a first side 36 of the first FVI 30, whilst the second robotic arm 34 is positioned at a second side 38 of the first FVI 30. A first basket 42 containing the square saucers 40 are placed next to the first robotic arm 34, whilst a second basket 44 holding other square saucers 40 is sited adjacent to the second robotic arm 34.

[0079] The first FVI 30 comprises a housing 46 that encloses cameras 48, 50 and lamps 52-58. The cameras 48, 50 and the lamps 52-58 are supported on rails 60, 62 and holders 64-70 that are further mounted to the housing 46. The lamps 52-58 are also known as illuminators, which comprise a DOAL illuminator 52, a CDI® illuminator 54, a dark field illuminator 56 and a ring light illuminator 58. The cameras 48, 50 comprise a CCD camera 48 with a Kodak® KAI-11002 Image Sensor and a CMOS

camera 50 with a MT9P031 image sensor. The CCD camera 48 is installed onto the housing 46 via a linear rail 60, whilst the CMOS camera 50 is attached to the housing 46 via a circular rail 62. Correspondingly, the DOAL illuminator 52, the CDI® illuminator 54, the dark field illuminator 56 and the ring light illuminator 58 are mounted to the housing 46 via a first holder 64, a second holder 66, a third holder 68 and a fourth holder 70 respectively. In particular, the first holder 64 and the fourth holder 70 are attached to the first side 36, whilst the second holder 66 and the third holder 68 are attached to the second side 38.

[0080] The first robotic arm 32 has a first suction cup 72 and a DSP camera 74 with an interline CCD solid-state image sensor (ICX285AL). The DSP camera 74 is fixed above the first basket 42, whilst the first suction cup 72 (as an end effector) is attached to an end of the first robotic arm 32. Similarly, the second robotic arm 34 comprises a second suction cup 76 at an end of the second robotic arm 34.

[0081] The housing 46 is made of flat panels that form an enclosure for protecting the illuminators 52-58 and the cameras 48, 50. The panels also keep off ambient light such that a vision-inspected object 80 inside the housing 46 has little exposure to the ambient light. Accordingly, changing of factory floor lighting and passing-by operators will have no noticeable influence on illuminating condition of the vision-inspected object 80. Nevertheless, the housing 46 has openings for receiving or retrieving the vision-inspected object 80 by the robotic arms 32, 34 from the two sides 36, 38. On a backside 84 of the housing 46, a Large Area Backlight illuminator 78 is affixed for providing an additional source of lighting to the first FVI 30. The housing 46 further includes blowers having spray nozzles (not shown) for dispersing dirt or particles from any vision-inspected article 80.

[0082] Functionally speaking, the DOAL (Diffuse On-Axis Light) illuminator 52 provides diffuse, uniform illumination for flat specular surfaces. With the coaxial lighting approach, specular surfaces perpendicular to an image capturing camera appear bright, while surfaces which are marked or embossed absorb light and appear dark. By providing greater uniformity than conventional sources, DOALs increase machine vision accuracy and repeatability. The DOAL illuminator 52 can project three colors and Infrared light. The DOAL illuminator 52 further has built-in controller for

operating with continuous and high output strobe modes. The DOAL illuminator 52 provides superior uniformity throughout an illumination envelope. The DOAL illuminator 52 is also compact and of light weight.

[0083] The CDI® (Cloudy Day Illuminators) illuminator 54 provides self-contained continuous diffuse lighting performance. The CDI® illuminator 54 provides lighting condition that critical applications involving inspection of highly faceted and undulating reflective surfaces, such as CD artwork verification and the inspection of solder patterns on circuit boards. The CDI® illuminator 54 enables the vision-inspected object 80 to be inspected in the package, including blister-packaged pharmaceutical products and computer chips inside a clear packaging tube. The CDI® illuminator 54 provides outstanding uniformity in lighting, which is known as self-contained cloudy day lighting for highly complex applications.

[0084] The dark field illuminator 56 provides effective low-angle lighting to targeted regions, which enhance the contrast of surface features such as laser embossed or engraved marks or surface defects. The dark field illuminator 56 particularly suits applications such as BGA ball placement, reading laser-etched symbologies and inspecting surfaces with geometric contours. The dark field illuminator 56 uses three tiers of LEDs mounted at 75° to their optical axis.

[0085] The ring light illuminator 58 is a cost-effective, easily integrated solution for diffuse illumination of surfaces. With subtle adjustments to working distance and angle of light delivery, the ring light illuminator 58 delivers good image contrast for a minimal cost. The ring light illuminator 58 is robust and versatile for use. The ring light illuminator 58 can provide both ultraviolet & infrared light. The ring light illuminator 58 has an in-built controller for operating with continuous and high output strobe modes. The ring light illuminator 58 is economical and widely-adopted general purpose illuminator with an adapter for easy, direct attachment to camera lens. A detachable Fresnel lens is provided for providing the illumination to be focused at various distances.

[0086] The Large Area Backlight illuminator 78 provides sharp contrast to outline a part's shape, find edges and view openings such as drilled holes. The Large Area

Backlight illuminator 78 has a low-profile industrial package for optimal thermal management, in addition to its capability of providing highly intensive and uniform lighting. The Large Area Backlight illuminator 78 provides continuous or strobe duty cycles to support static or high speed applications. The Large Area Backlight illuminator 78 can provide three colors (Red, Green and Blue) and Infrared light. M12 connectors (not shown) are installed on the Large Area Backlight illuminator 78 for easy connections to drivers or advanced controllers.

[0087] The linear rail 60 comprises two parallel straight bars whose opposite ends are attached to the two sides respectively 36, 38. The CCD camera 48 is propelled by a linear motor (not shown) on the linear rail 60 such that the CCD camera 48 can move along the linear rail 60 for adjusting its position. The linear rail 60 can further rotate around its axis such that the CCD camera 48 is carried to tilt for regulating its image-capturing (viewing) angle. The linear rail 60 further comprises a stopper (not shown) for locking the position of the CCD camera 48.

[0088] The circular rail 62 comprises a track bent into a semicircular profile, whilst both ends of the track are tightened to the second side (wall, flat panel) 38. The CMOS camera 50 has a stand (not shown) integrated with a transmission (not shown), which includes gearbox and linear motor. Gears (not shown) of the transmission match teeth (not shown) on the circular rail 62 such that the CMOS camera 50 can be shifted along the circular rail 62 for changing its location. The stand further allows the CMOS camera 50 to revolve around a central axis (not shown) of the circular rail 62 such that the CMOS camera 50 can capture images at different angles. In the applications, the housing 46, the rails 60, 62, the holders 64-70, panels 222-232 and other fixtures 252, 256, 258, 260 are parts or components of an unitary framework 47 that supports the illuminators 52-58, 78, 240-248 and cameras 48, 50, 74.

[0089] In use, the DSP camera 74 captures images of the first basket 42. Orientations and positions of the square saucers 40 are identified for guiding the first robotic arm 32. Following the guidance and distance measurement by the first laser rangefinder 33, the first robotic arm 32 extends its arms and bends such that the first suction cup 72 reaches a bottom surface of a square saucer 80 for picking. After securing the square saucer 80, the first robotic arm 32 raises the square saucer 80 and insert it

into a first opening 88 on the first side wall 36 such that the square saucer 80 is exposed to the lamps 52-58, 78 and cameras 48, 50. Under the control of a computer (not shown), the lamps 52-58, 78 project light onto the square saucer 80 (i.e. vision-inspected object) sequentially such that both the CCD camera 48 and the CMOS camera 50 capture images of the square saucer 80 under different lighting conditions. The computer (not shown) further processes the images for examining surface quality (e.g. free from water stains), structure integrity (e.g. free from fracture and deformation) and hygiene quality (e.g. free from discoloring due to mold).

[0090] After a first round of vision inspection as mentioned above, the second robotic arm 34 reaches the square saucer 80 from a second opening 90 on the second side wall 38, and grabs the square saucer 80 from an opposite side of the vision-inspected object 80. Accordingly, the first suction cup 72 releases the square saucer 80, whilst the second suction cup 72 seizes the square saucer 80 for a second round of vision inspection. Both the first vision camera 48 and the second vision camera 50 have shifted their positions and angles along the rails 60, 62 for conducting the second round of vision inspection. Similarly, the illuminators 52-58 are activated sequentially such that the images under dissimilar lighting conditions are taken by the cameras 48, 50. Captured images of the vision-inspected object 80 are further processed for investigating surface quality (e.g. free from water stains), structure integrity (e.g. free from fracture and deformation) and hygiene quality (e.g. free from discoloring due to mold).

[0091] Quality-compliant objects (e.g. square saucer 80) is taken out the housing 46, whilst quality-non-compliant objects (e.g. having sharp edges on side walls) are dropped into a reject bin (not shown) under the housing 46. In the present example, the Quality Control (QC) compliant square saucer 80 is transferred into the second basket 44, and stacked neatly following a predetermined packaging pattern.

[0092] Fig. 2 relates to a second flexible vision inspector 200 with a belt conveyor 202. Fig. 2 illustrates parts that have reference numerals similar or identical to those of Fig. 1. Relevant description of the parts is hereby incorporated where appropriate.

[0093] Instead of using the two robotic arms 32, 34, the second flexible vision inspector 200 utilizes the belt conveyor 202 for transporting the vision-inspection objects 80, namely square saucers 40a, 40b. The belt conveyor 202 is placed below the second vision inspector 200 such that a square saucer 80 is illuminated by lamps 52-58 of the second vision inspector 200. Vision cameras 48, 50 further capture images of the square saucer 80 when corresponding lamps 52-58 are activated for projecting light onto the square saucer 80.

[0094] Fig. 2 further illustrates a reject basket 204 for containing quality non-compliant square saucers 206a-c. Although vision inspection process is carried out by the second flexible vision inspector 200 similar to that of the first vision inspector, the quality non-compliant square saucers 206a-c are transported by a robotic arm (not shown) to the reject basket 204, not dropped below the second flexible vision inspector 200. Nevertheless, quality-compliant square saucers 40 are conveyed directly to the second basket 44 at an end of the belt conveyor 202. Another robotic arm (not shown) is placed at the end of the belt conveyor 202, which arranges the square saucers 40 neatly according to predetermined formation.

[0095] Fig. 3 illustrates a third flexible vision inspector 220. Fig. 3 depicts parts or components that are similar or identical to those of Figs. 1 and 2. The third flexible vision inspector 220 is a part of vision inspection station 236 that further includes a third robotic arm 32. The similar or identical parts or components are labelled with the same or comparable reference numerals. Description of the similar or identical parts or components is hereby incorporated where appropriate.

[0096] Particularly, the third vision inspector 220 comprises a housing 46 that have six flat panels 222~232 in forming sides of a rectangular prism enclosure. The six flat panels consist of a front panel 222, a back panel 224, a left panel 226, a right panel 228, a top panel 230 and a bottom panel 232. The front 222 and back 224 panels are opposite to each other. Similarly, the left panel 226 and the right panel 228 face each other, whilst the top panel 230 and the bottom panel 232 opposes each other as well. The back panel 224, the left panel 226, the right panel 228, the top panel 230 and the bottom panel 232 are solid and opaque boards that have black exterior surfaces. In contrast, interior surfaces of the back panel 224, the left panel 226, the right panel

228, the top panel 230 and the bottom panel 232 have reflectors (e.g. metal, glass). Differing from others 224~232, the front panel 222 is a ground glass diffuser that has a clear circular portion 234 at its center, although the front panel 222 is also a board joining other panels 224~232. A lens of the CCD camera 48 is exposed by the clear portion 234 such that the CCD camera 48 can capture images of objects in front of the third vision inspector 220.

[0097] The third vision inspector 220 has additional illuminators 240~248 installed inside. In detail, the third vision inspector 220 has a machine vision fiber optic illuminator 240, a xenon flash lamp 242, a LED (Light-Emitting Diode) lamp 244, a fluorescent lamp 246 and a phosphor-coloured neon lamp 248 (not shown) fixed at corners or walls of the third vision inspector 220. These lamps/illuminators 240~248, 52~58 collectively, individually or in combination provide diverse types of illumination to an objection 250 for machine vision inspection.

[0098] Some of the lamps 240~248 are held by rails 252, 254 inside the third vision inspector 220. Particularly, the top panel 230 has a linear rail 60 and a bar 252 that are joined together in forming a cross. The two rails 60, 252 enable the ring light illuminator 58 to move along the top panel 230 for adjusting angle or position of light projection. Similarly, the rails 252, 254 include a shaft 254 attached to the right panel 228 from inside. The fluorescent lamp 246 may travel along the shaft 254 for shifting its location or orientation.

[0099] Cables (not shown) of the illuminators 52~58 240~248 and the CCD camera 48 are bundled up and secured to connectors 256, 258 on the right panel 228. Specifically, signal wires of the illuminators 52~58 240~248 and the CCD camera 48 are fastened together and joined to the signal wire connector 256 on the right panel 228. In contrast, power supply cables of the illuminators 52~58 240~248 and the CCD camera 48 are clipped together and linked to a power (cable) connector (e.g. multi-pin connector) on the right panel 228.

[0100] The third vision inspector 220 further comprises electric fans and ventilation slots/holes (not shown) for dissipating heat of the third vision inspector 220. The ventilation slots/holes are provided on the front panel 222, the back panel 224, the left

panel 226, the right panel 228 and the bottom panel 232, but not the top panel 230 such that dust or water cannot enter the third vision inspector 220.

[0101] When in use, jaws 260 of the third robotic arm 32 grasp a mug 262 from its bottom end. The mug 262 is picked from a stack of mugs (not shown) in a basket 42. Together with lifting, the jaws 260 of the third robotic arm 32 rotate back and forth (e.g. clockwise & counterclockwise) such that another mug (not shown) below the picked mug 262 detaches away from the mug 262. The jaws 260 additionally vibrate within range of 2~5mm and 10~20Hz such that the other mug (not shown) cannot stick to the picked mug 262.

[0102] Once picked, the third robotic arm 32 moves the mug 262 to the third flexible vision inspector 220 such that an external bottom surface of the mug 262 is exposed in front of the CCD camera 48. Depending on colour, material and surface texture of the mug 262, for example, the LED (Light-Emitting Diode) lamp 244 is switched on such that the ground glass diffuser 222 illuminates the mug 262 with uniform white light. The CCD camera 48 captures one or more images of the bottom surface for image data processing. If detecting cracks, scratches, stains or other quality defects, the third robotic arm 32 will move the mug 262 to a reject basket 204. In contrast, if the mug 262 is found having no defects, another robotic arm (not shown) will grasp the mug 262 such that the third robotic arm 32 releases. Accordingly, the other robotic arm carries the mug 262 to another flexible vision inspector (not shown) such that internal surfaces of the mug 262 are further exposed for machine vision inspection. Additional flexible vision inspectors or robotic arms are installed for examine cylindrical surfaces of the mug 262 or other objects (e.g. saucer, plate/dish). Multiple flexible vision inspectors may be installed, connected together and/or synchronized for examining or recognizing shape, profile, texture, colour, stain or other features of the mug 262 automatically.

[0103] In the application, unless specified otherwise, the terms "comprising", "comprise", and grammatical variants thereof, intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, non-explicitly recited elements.

[0104] As used herein, the term "about", in the context of concentrations of components of the formulations, typically means +/- 5% of the stated value, more typically +/- 4% of the stated value, more typically +/- 3% of the stated value, more typically, +/- 2% of the stated value, even more typically +/- 1% of the stated value, and even more typically +/- 0.5% of the stated value.

[0105] Throughout this disclosure, certain embodiments may be disclosed in a range format. The description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

[0106] It will be apparent that various other modifications and adaptations of the application will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the application and it is intended that all such modifications and adaptations come within the scope of the appended claims.

Reference Numerals

30	first Flexible Vision Inspector
32	first robotic arm
34	second robotic arm
36	first side
38	second side
40	square saucers
42	first basket
44	second basket
46	housing
47	unitary framework
48	CCD camera
50	CMOS camera
52	DOAL illuminator
54	CDI illuminator
56	dark field illuminator
58	ring light illuminator
60	linear rail
62	circular rail
64	first holder
66	second holder
68	third holder
70	fourth holder
72	first suction cup
74	DSP camera
76	second suction cup
78	large area backlight illuminator
80	vision-inspected object
82	object
84	backside
86	vision inspection station
88	first opening
90	second opening

200 second flexible vision inspector
202 belt conveyor
204 reject basket
206 quality non-compliant square saucers
220 third flexible vision inspector
222 front panel
224 back panel
226 left panel
228 right panel
230 top panel
232 bottom panel
234 center portion
236 vision inspection station
240 machine vision fiber optic illuminator
242 xenon flash lamp
244 LED (Light-Emitting Diode) lamp
246 fluorescent lamp
248 phosphor-coloured neon lamp
250 object
252 bar
254 shaft
256 signal wire connector
258 power cable connector
260 jaws

Claims

1. Flexible Vision Inspector comprising
   - a first type of illuminator for illuminating an object,
   - a second type of illuminator for projecting light onto the object,
   - at least one type of camera for capturing an image of the object, and
   - an unitary framework that is connected to the first type of illuminator and the at least one type of camera for holding the first type of illuminator and the least one type of camera together at predetermined positions.

2. Flexible Vision Inspector of Claim 1, wherein
the unitary framework comprises a housing that encloses the first type of illuminator, the second type of illuminator, the at least one type of camera or a combination of any of these types of illuminators or camera for preventing interference of illumination to the object.

3. Flexible Vision Inspector of Claim 1 or 2, wherein
the unitary framework further comprises at least one panel for preventing external light from interfering illumination of the object.

4. Flexible Vision Inspector of Claim 3, wherein
the at least one panel comprises a light absorber, a light reflector, a light refractor, a light diffuser, a light polarizer, a lens or a combination of any of these.

5. Flexible Vision Inspector of Claim 3 or 4, wherein
the at least one panel comprises a front panel that is in the form of ground glass diffuser.

6. Flexible Vision Inspector of Claim 5, wherein
the front panel comprises a clear portion for exposing lens of the at least one type of camera.

7. Flexible Vision Inspector of any of the preceding Claims, wherein
the unitary framework comprises at least one rail for mounting at least one of these types of illuminators, the at least one camera or both.

8. Flexible Vision Inspector of Claim 7, wherein
the at least one rail comprises a first rail and a second rail for mounting the at least one of the cameras and any of these types of illuminators separately.

9. Flexible Vision Inspector of Claim 7 or 8, wherein
the at least one rail comprises a first rail and a third rail that are joined together for moving the at least one of the cameras, the types of the illuminators or both one the two rails.

10. Flexible Vision Inspector of any of the preceding claims 2 to 9, wherein
the unitary framework comprises a hub connector on the housing for bundling electrical connections.

11. Flexible Vision Inspector of Claim 10, wherein
the hub connector comprises a signal wire connector, a power cable connector or both for providing detachable electrical connectors.

12. Flexible Vision Inspector of Claim 2 or 10, wherein
the housing comprises a first opening and a second opening such that the object can be transferred between two robotic arms by accessing through the two openings.

13. Flexible Vision Inspector of Claim 2, 10 or 12, wherein
the housing further comprises a layer of anti-fogging coating for resisting moisture.

14. Flexible Vision Inspector of any of the preceding Claims 1 to 13 further comprising
a wiper for preventing fluid accumulation on the flexible vision inspector intermittently, continuously, periodically or on-demand.

15. Flexible Vision Inspector of any of the preceding Claims further comprising:
a fan mounted onto the unitary framework for cooling components of the flexible vision inspector.

16. Flexible Vision Inspector of any of the preceding Claims further comprising:
a distance sensor connected to the at least one type of camera for detecting distance between the object and a lens of the at least one type of camera.

17. Vision inspection station comprising
the flexible vision inspector of any of the preceding claims, and
at least one robotic arm for fetching the object to the at least one type of camera.

18. Vision inspection station of Claim 17, wherein
the at least one robotic arm comprises a first robotic arm and second robotic arm that are positioned next to the flexible vision inspector for transferring the object.

19. Vision inspection station of Claim 17 or 18 further comprising
a belt conveyor for transporting the object.

20. Method for inspecting an object by machine or computer vision, the method comprising:
- providing a robotic arm, a first type of illuminator, a second type of illuminator, a camera and an object for examination,
- moving the object to the at least one type of illuminator and the camera by the robotic arm,
- projecting light onto the object from the first type of illuminator or the second type of illuminator for vision inspection by the camera.

21. Method of Claim 20 further comprising:
receiving the object by another robotic arm via vision inspection by the camera or another camera.

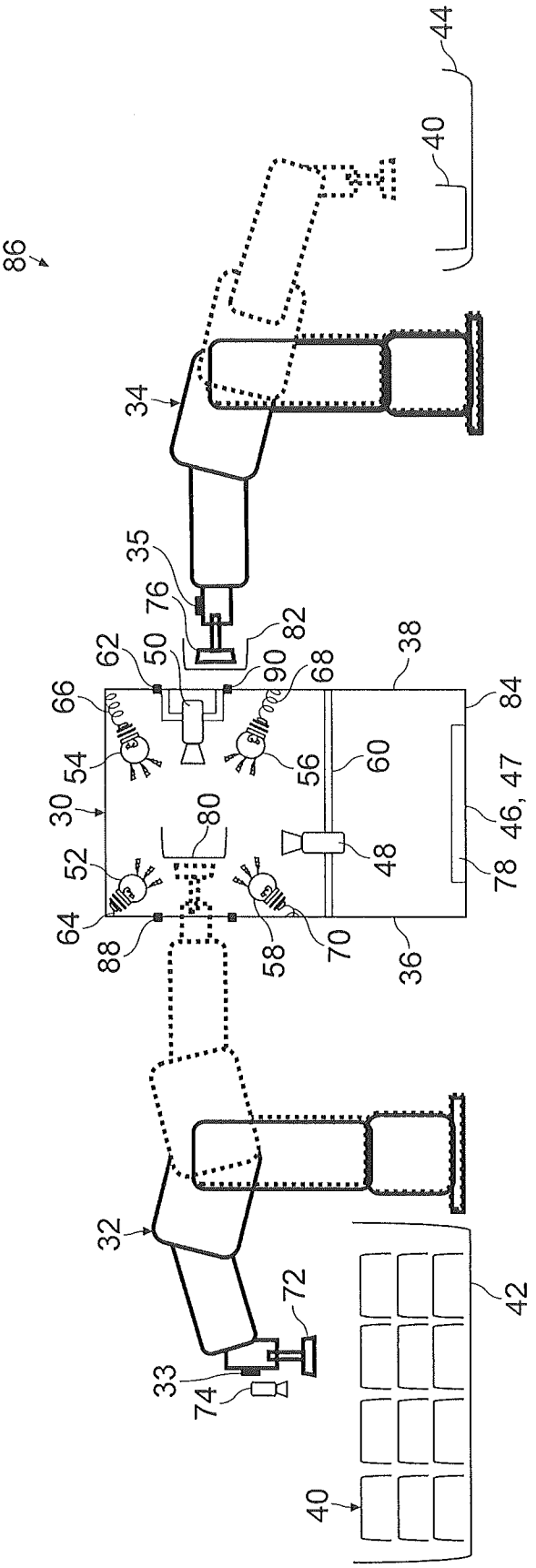

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54
56
60
30
80
46, 47
52
48
78
64
88
58
70
36
32
72
42
33
74
40

FIG. 1

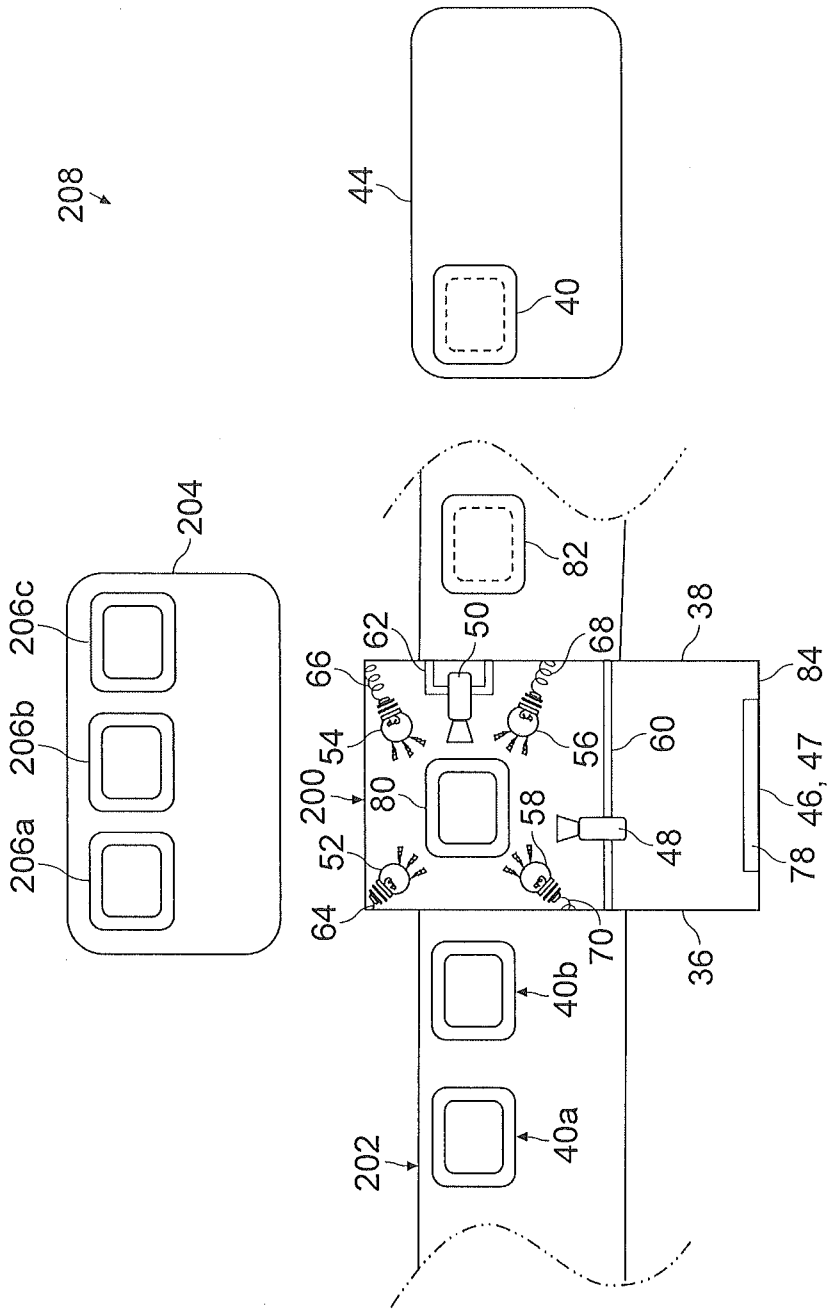

208
44
40
204
206c
206b
206a
82
62
50
68
38
66
84
54
56
60
200
80
58
46, 47
52
48
78
64
70
36
40b
40a
202

FIG. 2

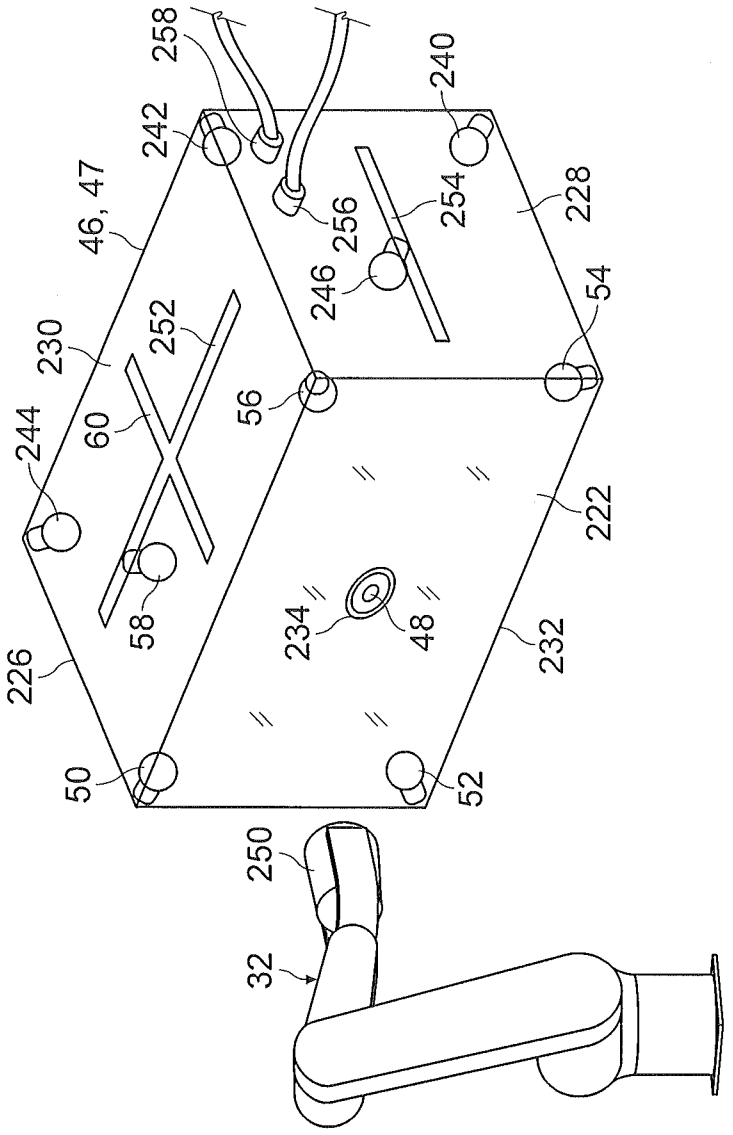

258
240
242
46, 47
254
228
256
246
54
230
252
56
60
244
222
58
234
48
232
226
50
52
250
32

FIG. 3