11. Inspection Technologies

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11.1 Introduction

Inspection is the means by which poor quality is detected and good quality is assured in products that are produced in a production process. Inspection is usually carried-out manually via the use of various technologies that examine specific variables (quality characteristics of the product), or product attributes (to ensure product conformance to previously-set standards). The major steps in inspection include:

BULLETLIST
Presentation of the item for inspection
Examination of the item for non-conformance on certain product attributes
Decision-making, based on the results of the examination, whether the item passes the quality standards required, and assigning the product to a quality grade
Action, based upon the decision reached, such as accepting or rejecting the item
ENDLIST

KEYPOINT
Inspection is the process of presenting, examining, deciding-upon, and acting-upon an item to ensure that poor quality is detected in product attributes, and good quality is assured.
END KEYPOINT

Various technologies support the inspection procedure, enabled by various sensors, instruments, and gauges. Some inspection techniques use manually-operated devices such as micrometers, callipers, protractors, and go/no-go gauges; whilst other techniques are based upon modern technologies such as
co-ordinating measuring machines (CMM) and machine vision, which use computer-controlled systems that allow the inspection procedure to be automated. This unit focuses on automated inspection techniques.

Some general characteristics of measuring instruments, used in the inspection procedure, may be noted. These are outlined briefly in Table 11.1. These characteristics are used to determine the correct choice of inspection equipment for a particular inspection procedure.

Table 11.1: Characteristics of measuring instruments

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy and Precision</td>
<td>Accuracy is the degree to which the measured value agrees with the true value that has been pre-defined for the item. Precision is a measure of repeatability in a measurement process, such that precision reflects the consistency of the measurement results achieved.</td>
</tr>
<tr>
<td>Resolution and Sensitivity</td>
<td>This aspect of a measuring instrument is its capacity to distinguish very small differences in the quantity of interest. The indication of this characteristic is the smallest variation of the quantity that can be detected by the instrument.</td>
</tr>
<tr>
<td>Speed of response</td>
<td>Measures the time required for the measuring device to indicate the quantity measured. Ideally, the time lag should be zero, but this is obviously impossible.</td>
</tr>
<tr>
<td>Wide operating range</td>
<td>This is the capability of a measuring instrument to measure the physical variable throughout the entire span of practical interest to the user.</td>
</tr>
<tr>
<td>High reliability</td>
<td>A measure of the absence of frequent malfunction and failures of the measurement device.</td>
</tr>
<tr>
<td>Cost</td>
<td>The expense of purchasing and operating the measuring device, plus the expense of training on the measuring device.</td>
</tr>
</tbody>
</table>

KEYPOINT
Characteristics of measuring instruments that are used to ensure correct device selection include parameters that assess: accuracy and precision; resolution and sensitivity; speed of response; wide operating range; high reliability; and cost.

END KEYPOINT

In this unit inspection technologies, particularly automated inspection technologies, are investigated. We first look at contact versus non-contact inspection techniques, and provide examples of each. Conventional measuring and gauging techniques, which are typically manually-operated, are outlined followed by description of automated techniques for example the co-ordinate measuring machine. Machine vision methodologies are discussed. Finally, other optical inspection methods are outlined.

11.2 Learning Objectives

After completing this unit you will be able to:

BULLET LIST
List the parameters of measuring instruments that are used to ensure correct device selection

Explain the different functions of measuring devices and gauges

Describe the concept of co-ordinate metrology, and its associated equipment

List the components of a co-ordinate measuring machine (CMM)

Define the concept of machine vision

Describe how image acquisition and digitization is performed

Outline image processing and analysis techniques

Specify common methods of interpretation in machine vision

Outline other optical sensing techniques that can be used for inspection

Specify other inspection techniques that are non-contact and non-optical

**11.3 Contact vs. Non-contact Inspection Techniques**

There are two types of inspection techniques - contact and non-contact. See Figure 11.1.

**KEYPOINT**
There are two types of inspection techniques: contact and non-contact.

**END KEYPOINT**

Figure 11.1: Contact and non-contact inspection

**11.3.1 Contact Inspection Techniques**
In contact inspection, physical contact is made between the object to be inspected, and the measurement device. Typically contact is achieved using a mechanical probe or other device that touches the item, and allows the inspection procedure to occur. By its nature, contact inspection is concerned with some physical dimension of the part, and so contact methods are widely used in manufacturing and production industries to assess metal parts, and for electrical circuit testing. Principal contact inspection technologies include:

- Conventional measuring and gauging instruments
- Co-ordinate measuring machines (CMMs) and related techniques to measure mechanical dimensions
- Stylus type surface texture measuring machines to measure surface characteristics such as roughness and waviness
- Electrical contact probes for testing integrated circuits and printed circuit boards

Contact inspection techniques are the most widely-used inspection techniques. As well as possessing considerable accuracy and reliability, in many cases they represent the only methods available to accomplish inspection.

11.3.2 Non-contact Inspection Techniques

Non-contact inspection techniques use sensors instead of a mechanized probe favoured by contact inspection methodologies. The sensor is located at a certain distance from the object to be inspected, to measure or gauge the desired features of the object.

There are two categories of non-contact inspection technologies:
BULLETLIST
Optical inspection technologies—these use light to accomplish the measurement or gauging cycle. The most important technique is machine vision.

Non-optical inspection technologies—these use other forms of energy than light to perform the inspection. Various energies utilized include: electrical fields, radiation, and ultra-sonics.
ENDLIST

The advantages of non-contact inspection techniques over contact inspection techniques include:

BULLETLIST
They avoid possible surface damage that can be caused upon contact

Inspection cycle times are faster as the contact probe must be re-positioned for each new part inspected, while the non-contact sensor remains stationary

Parts handling is lower with non-contact inspection than with contact inspection, as parts in the latter methodology usually require special handling and adjustments so that inspection can occur

It allows for the possibility of 100% automated inspection, for the above reasons
ENDLIST

Figure 11.2: 3-D Non contact inspection probe for robot arm

11.4 Conventional Measuring and Gauging Techniques
Conventional measuring and gauging techniques use manually-operated devices to assess a host of linear dimensions, such as length, depth, and diameter, as well as features such as angles, straightness, roundness and so on. Measuring devices provide a quantitative value of the part features of interest. Gauges determine whether the part feature falls within a certain acceptable range of values. Both techniques are widely used for post-process inspection of piece parts in manufacturing.

**KEYPOINT**
Measuring devices provide a quantitative value of the part features of interest.
**END KEYPOINT**

Measuring devices are typically used for sampling inspection. Some equipment is portable and can be used by hand, while other devices require bench set-ups that are remote from the process, such that the measurement device is set-up on a flat reference surface, called a surface plate. Gauges are used for sampling and for 100% inspection. They are more portable than measuring devices, and can be used on the production line itself. Certain techniques of measuring and gauging can be automated to permit feedback control of the process, or for statistical process control.

Electronic gauges deploy transducers capable of converting linear displacement into a proportional electrical signal, which in turn is amplified and transformed into a suitable data format such as a digital read-out. Advantages of electronic gauges include: good sensitivity, accuracy, precision, repeatability, and speed of response; ability to sense very small dimensions; ease of operation; reduced human error; ability to display electrical signal in various formats; and capability to be interfaced with computer systems for data processing.

**LEARNING ACTIVITY 11.1**
Metrology is the science of measurement, and the institution of inspection techniques is essentially the performance of applied metrology. Investigate the term metrology and associated techniques and technologies using the internet.
**END LEARNING ACTIVITY 11.1**

**11.5 Co-ordinate Measuring Machines**

In co-ordinate metrology the actual shape and dimensions of an item are measured, and compared against desired shape and dimensions, as might be specified on a part drawing. Co-ordinate measuring machines (CMM) is an electromechanical system that has been designed to evaluate relevant dimensions of an item against a required standard.

**KEYPOINT**
A co-ordinate measuring machine (CMM) is an electromechanical system that evaluates relevant dimensions of an item against a required standard.

END KEYPOINT

A CMM consists of a mechanical probe that operates in three dimensions, so that the relative surfaces of a workpart may be inspected. The three dimensions can be co-ordinated by recurrence to relative positions on the x-, y-, and z-axes. The CMM consists of:

BULLETLIST
Probe head and probe to contact workpart surface
Mechanical structure to provide motion of the probe in the three Cartesian axes, and displacement transducers to measure the co-ordinate values of each axis
ENDLIST

Optional components include a drive system and control unit to move each axis, and back-end computing system and associated software.

KEYPOINT
A CMM consists of a mechanical probe that operates in three axial dimensions, a mechanical structure to provide for the motion of the probe, and optional components such as a drive system, and computing hardware and software.

END KEYPOINT

11.5.1 CMM Construction

The overall CMM construction is illustrated in Figure 11.2 and consists of a mechanical structure that supports the probe head and probe, and a worktable that passes underneath the probe, upon which the item to be inspected is placed. To the side we can see the associated computer system that takes and records the probe results as they occur.
The two principal components from this construction are the probe, and its mechanical structure. These are examined in further detail in the sections below.

**KEYPOINT**
The CMM construction consists of a worktable upon which the item to be inspected is placed, and, overhead, is the mechanical structure that supports the probe head and probe. Associated equipment such as the computer system are located remotely.

**END KEYPOINT**

**Section 11.5.2 CMM Probe**

The tip of the probe in the CMM is usually a ruby ball. Ruby is a form of corundum (aluminium oxide) with high hardness for wear resistance, and low density for minimum inertia, thus making it ideal for probing applications. Probes can be single or multiple tip (see Figure 11.3).
KEYPOINT
Probe tips usually consist of ruby balls, which contain ideal physical and mechanical properties for probing operations. Probes can be single- or multi-tip.
END KEYPOINT

The most common probe design is the touch-trigger type, which actuate when the probe makes contact with the item’s surface. Various trigger mechanisms are available, including: high-sensitivity electrical contact switch triggers; contact switch triggers that activate when electrical contact is made between part surface and probe tip; and piezoelectric sensor switch that operates by assessing tension loads on the probe.

After contact between probe and part surface, displacement transducers associated with the three linear axes record the co-ordinate positions of the probe, and pass the results to the CMM controller. Compensation is made for the radius of the probe tip, and over-travel of the probe nib due to momentum is neglected. The probe returns to a neutral position when it leaves the part surface.

KEYPOINT
Probes with touch-trigger mechanisms are the most common probe type: these operate in a variety of ways.
END KEYPOINT

11.5.3 Mechanical Structure

A number of different physical configurations exist for the mechanical structure of the CMM; these are outlined in more detail in Figure 11.4.

Figure 11.4: Cantilever; Moving Bridge; Fixed bridge; Horizontal arm; Gantry; Column
**KEYPOINT**
A number of different physical configurations exist for the mechanical structure of the CMM; these include: cantilever; moving bridge; fixed bridge; horizontal arm; gantry; and column mechanical structures.

**END KEYPOINT**

### 11.5.4 CMM Operation and Programming

Probe positioning may be accomplished using several methods, ranging from manual operation to direct computer control. Computer-controlled CMMs operate much like CNC machine tools, and these machines must be programmed.

CMM control may be accomplished via the methodologies outlined in Table 11.2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual drive</td>
<td>The human operator physically moves the probe along the machine’s axes to make part contact, and take inspection measurements. Equipment is designed so that the probe may move with a minimum amount of friction between directional axes. Measurements are provided by digital read-out for manual recording or paper printout.</td>
</tr>
<tr>
<td>Manual drive with computer-assisted processing</td>
<td>Similar in operational context to the above, but additional data processing and computational capabilities for performing the calculations required to evaluate a given part feature. Types of data processing include: dimensional conversions, and geometric calculations.</td>
</tr>
<tr>
<td>Motor drive with computer-assisted data processing</td>
<td>Here the probe is driven by means of an electric motor along the machine axes, under operator supervision. The operator controls the probe movement with a joystick or similar device. Typically low-power stepping motors and friction clutches prevent probe collision with the workpart. Also, the motor may be disengaged to permit the operator to manually move the probe. Computer-assisted data processing, as outlined above, is also included.</td>
</tr>
<tr>
<td>Direct computer control with computer assisted data processing</td>
<td>This operates like a CNC machine tool. The movements of the probe are accomplished by a motor under the programme control of a dedicated computer. The computer also performs the various data processing and calculation functions required; it compiles a record of the measurements made during inspection. It requires frequent part programming.</td>
</tr>
</tbody>
</table>

**KEYPOINT**
CMM control may be accomplished via methodologies that use manual drive; manual drive with computer-assisted processing; motor drive with computer-assisted data processing; or direct computer control with computer assisted data processing.

**END KEYPOINT**
In the case of CMMs using direct computer control with computer assisted data processing capabilities, two principle methods of programming may be outlined:

**BULLETLIST**

Manual lead-through—where the operator leads the CMM probe through the various motions that are required of it for a particular workpart, while the points and locations are recorded into programme memory.

Off-line programming—where the programme is prepared based on the workpart drawing, and then downloaded to the CMM controller for execution.

**END LIST**

**KEYPOINT**

CMMs using direct computer control with computer assisted data processing capabilities can be programmed using manual lead-through or off-line programming methods.

**END KEYPOINT**

### 11.5.5 Other CMM Software

In addition to CMM part programming software used for programming direct computer control CMMs, other CMM software may be used. These include software in the following categories: core software (other than programming software for direct computer control); post-inspection software; and reverse-engineering and application-specific software.

**KEYPOINT**

Other CMM software that may be used includes core software, post-inspection software, and reverse-engineering and application-specific software.

**END KEYPOINT**

Types of core software that may be deployed are outlined in Table 11.3.

#### 11.3: Core software types for CMMs

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe calibration</td>
<td>Software used to define the parameters of the probe tip (including information such as probe radius, the use of single or multi-probe tips, tip position, and elastic bend co-efficient). Calibrating the probe allows for the repeatability of inspection operations, and avoids many complex probe calculations.</td>
</tr>
<tr>
<td>Part co-ordinate system definition</td>
<td>Software that allows the inspection procedure to occur without a time-consuming alignment operation on the CMM worktable. The measurement axes are aligned to the workpart, not to the CMM worktable.</td>
</tr>
<tr>
<td>Geometric feature construction</td>
<td>Software used for geometric features that require complex measurements of more than one point. Geometries measured include holes, cylinders, extrusions etc.; and the software evaluates such features as flatness, squareness, determining centre points etc.</td>
</tr>
</tbody>
</table>
Tolerance analysis Software that compares measurements taken on the part with specified measurements as stated on the engineering drawing.

**KEYPOINT**
Types of core software include probe calibration; part co-ordinate system definition; geometric feature construction; and tolerance analysis.
**END KEYPOINT**

Types of post-inspection software (i.e. software applied after the inspection procedure) that may be deployed are outlined in Table 11.4.

**Table 11.4: Post-inspection software types for CMMs**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical analysis</td>
<td>Software that carries out statistical analysis on various pieces of data collected by the CMM. An example is part dimensional analysis to determine optimal manufacturing process capabilities. The statistical analysis software application can be located remotely from the CMM, requiring exporting data from the CMM to the computer system containing the software; or the software may be integrated into the CMM itself for instant statistical analysis investigation.</td>
</tr>
<tr>
<td>Graphical data representation</td>
<td>Software used to display the data collected during the CMM procedure in a graphical way, so as to allow for easier troubleshooting of errors, and for overall visualization of the data by the operator.</td>
</tr>
</tbody>
</table>

**KEYPOINT**
Types of post-inspection software that may be deployed include statistical analysis software, and graphical data representation software.
**END KEYPOINT**

Reverse engineering software takes an existing workpart and constructs a computer model, replete with geometries, part dimensions and tolerances, based upon this. The reason that this is done is so that further items with the same attributes may be created. The simplest method for doing this is to use the CMM in manual mode operation, and to allow the operator to use the manual lead-through method so that attributes are stored in the CMM programme memory. This creates a three-dimensional surface model; however it is considered a very time-consuming way of creating a computer model of the part. An alternative is to use automated methods that allow the CMM to explore the workpart surfaces, with little or no human intervention, and construct a three-dimensional model. Exploration time should be minimized, without affect overall model accuracy. Important examples of reverse engineering software are detailed in Table 11.5.

**Table 11.5: Reverse engineering software types for CMMs**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear checking</td>
<td>Software used in CMM to measure geometric features of a gear, such as tooth profile, tooth thickness pitch, and helix angle.</td>
</tr>
<tr>
<td>Thread checking</td>
<td>Software used to inspect cylindrical and conical threads.</td>
</tr>
<tr>
<td>Cam checking</td>
<td>Software used to evaluate the accuracy of physical cams relative to design specifications.</td>
</tr>
</tbody>
</table>
Types of reverse engineering software include software for gear checking, thread checking, cam checking, and automobile body checking.

**KEYPOINT**

11.5.6 Portable CMMs

Recent years have seen advancements, such that traditional CMMs—stationary equipment located in specialised locations of the plant floor—have become portable devices. Leading manufacturers of portable CMMs are FARO (http://www.faro.com/), who produce the FARO gauge and the FARO arm product range.

**LEARNING ACTIVITY 11.2**
Investigate the FARO range of products at:
http://www.faro.com/.

**END LEARNING ACTIVITY 11.2**

Advantages of *in-situ* inspection include:

- Reduction in material handling
- Results of the inspection procedure are known immediately
- Reduction in labour requirements (operators who perform the machining can generally perform the inspection operation)
- As the workpart remains on the CNC during inspection, datum references are not lost; this occurs when the workpart is removed from the machine for inspection, and then replaced

**11.6 Machine Vision**

Machine vision is the creation of an image and the collection of data derived from the image, and the subsequent processing and interpretation of the data by a computer from some useful application. Machine vision is also known as computer vision, and its principal application is in industrial inspection.

**KEYPOINT**
Machine vision is concerned with the creation, and collection of data from an image, all subsequently processed and interpreted by a computer for some useful application.

END KEYPOINT

Machine vision exists in two-dimensional (2D) and three-dimensional (3D) formats, with 2D being most common in industrial applications. Examples of its usage include dimensional measuring and gauging, verifying the presence of components, and checking for features on a flat (or semi-flat) surface. 3D machine vision is used in applications where a 3D analysis of the scene is required. Here we focus on the simpler 2D machine vision system.

Figure 11.5 outlines the basic elements of a machine vision system. The operation of machine vision has three functions: image acquisition and digitization; image processing and analysis; and interpretation.

Figure 11.5: Basic functions of a machine vision system

KEYPOINT
The operation of machine vision has three functions: image acquisition and digitization; image processing and analysis; and interpretation.

END KEYPOINT

LEARNING ACTIVITY 11.3 [CRIT] [WRIT COMM]
Investigate machine vision further at web-site:
http://en.wikipedia.org/wiki/Machine_vision

Also, see machine vision in operation at the following:
http://www.youtube.com/watch?v=RhPD_EqSwCc
http://www.youtube.com/watch?v=j4mSbHineds

Write a one page report on machine vision, and post it to the discussion forum.
11.6.1 Image Acquisition and Digitization

Image acquisition and digitization is typically performed by deploying a video camera to capture the image, and the use of a digitizing system to store the image data for subsequent analysis. The camera is focused upon the surface of the item of interest, and an image consisting of discrete pixel elements is captured in the viewing area; each pixel has a value proportional to the light intensity of that portion of the scene. The intensity value of each pixel is converted into its equivalent digital value by an analogue-to-digital converter. This operation in diagram format is depicted in Figure 11.6.

Figure 11.6: Machine vision: (a) scene presentation; (b) 12 x 12 matrix super-imposed; and (c) creation of pixelated scene and assignment of intensity values, in black or white

KEYPOINT
Image acquisition and digitization is typically performed by using a video camera to capture the scene of interest, the super-imposition of a pixel matrix to the resultant image, and the assignment of intensity values, based on the light intensity of each portion of the scene.

END KEYPOINT

Figure 11.6 outlines the simplest type of machine vision, called binary vision (so called because it can only assign black and white intensity values, and no values in-between). A more sophisticated vision system will add a palette of different representational colours, in grey, that can capture different light intensities as different shades of grey; this system is called the greyscale system. This type of system is used, not only to pick-out dimensional features and the items size and shape, but also the item’s colour, and other surface characteristics. Greyscale vision systems typically use 4, 6, or 8 bits of memory, with each bit
corresponding to $2^8 = 256$ intensity levels—more than either the human eye or the video camera can really distinguish.

Each set of digitized pixel values is referred to as a frame, and each frame is stored in a computer memory device called a frame buffer. The process of reading all the pixel values in a frame is performed with a frequency of 30 times per second. Very-high resolution cameras often operate at slower frequencies.

11.6.2 Cameras

Solid-state cameras have, to a great extent, replaced vidicon cameras (also used as TV cameras) as the prime image-capturing devices used in machine vision. Solid-state cameras operate by focusing the image onto a 2D array of very small, finely spaced photosensitive elements, which subsequently form the matrix of pixels seen in the scene image. An electrical charge is generated by each element according to the intensity of light striking the element; and this charge is subsequently stored by a storage device consisting of an array of storage elements corresponding one-to-one with the photosensitive picture elements. Charge values accumulate, and are ultimately read sequentially in the data processing and analysis function of machine vision.

**KEYPOINT**

Solid-state cameras are the prime device used to capture images in machine vision. They project the image onto an array of photosensitive elements that produce an electrical charge equivalent to the light intensity on each element, subsequently stored and read in the data processing and analysis function.

**END KEYPOINT**

Pixel arrays can be 640 x 480, 1024 x 768, or 1040 x 1392 (horizontal x vertical) picture elements. The higher the number of picture elements the higher the resolution of the camera achieved, where higher resolution can pick-out finer details of the item’s image; however, higher resolution cameras are more expensive, and the time taken to read the resultant images is slower as read-times increase with the increase in the number of pixels.

11.6.3 Illumination

The scene that the camera is focused-upon must be well illuminated if an image of sufficient quality is to be captured. Illumination must be well-placed and constant over the time required to capture the image; this usually means that special lighting must be deployed for a machine vision application, rather than relying upon ambient lighting.
There are five categories of lighting used in machine vision; these are outlined in Table 11.7.

<table>
<thead>
<tr>
<th>Lighting Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>The light source is located on the same side of the object as the camera. This produces a reflected light from the object that allows inspection of various surface features.</td>
</tr>
<tr>
<td>Back</td>
<td>The light source is placed behind the object, so that the object is between the camera and the light source. This creates a dark silhouette of the object that contrasts sharply with the light background. Used in binary vision systems to inspect part dimensions and to distinguish between different part outlines.</td>
</tr>
<tr>
<td>Side</td>
<td>The light source is placed to the side of the object, at an angle to the camera. Creates irregularities in an otherwise plane smooth surface to cast shadows that can be identified by the vision system. Used to inspect for defects and flaws in the surface of an object.</td>
</tr>
<tr>
<td>Structured</td>
<td>The projection of a special light pattern onto the object to enhance certain geometric features. Common structured light patterns include the deployment of a planar sheet of highly-focused light directed against the surface of the object at a certain known angle. The sheet of light forms a bright line where the beam intersects the surface. Used to determine the existence of deviations in the part surface.</td>
</tr>
<tr>
<td>Strobe</td>
<td>The projection of short pulses of high-intensity light that causes a moving object to appear stationary. The moving object, for example, may be a part moving past the vision camera at high speed on a conveyor. The pulse of light can last 5-500 microseconds, which is</td>
</tr>
</tbody>
</table>
sufficient time for the camera to capture the scene. Camera must be synchronized with the strobe light pulse.

KEYPOINT
There are five categories of lighting used in machine vision; these are: front lighting, back lighting, side lighting, structured lighting, and strobe lighting.
END KEYPOINT

11.6.4 Image Processing and Analysis

A number of techniques have been developed so that data produced during the first phase of machine vision may be processed and analysed. These general techniques are called segmentation (a technique intended to define and separate regions of interest within the image), and feature extraction (which follows on from various segmentation processes). Image processing and analysis techniques under these general headings are outlined in Table 11.8.

Table 11.8: Image processing and analysis techniques

<table>
<thead>
<tr>
<th>General category</th>
<th>Sub-category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segmentation</td>
<td>Thresholding</td>
<td>Involves the conversion of each pixel intensity level into a binary value (black or white); performed by comparing each pixel value to a defined threshold value.</td>
</tr>
<tr>
<td>Segmentation</td>
<td>Edge detection</td>
<td>Concerned with determining the location of the boundaries between an object and its surroundings in an image. Accomplished by identifying the contrast in light intensity that exists between adjacent pixels at the borders of the object.</td>
</tr>
<tr>
<td>Feature extraction</td>
<td></td>
<td>Methods that are designed to determine an object’s features based on the area and boundaries of the object (using the above segmentation techniques).</td>
</tr>
</tbody>
</table>

KEYPOINT
Image processing and analysis techniques consist of the segmentation techniques of thresholding and edge detection, as well as feature extraction techniques.
END KEYPOINT
11.6.5 Interpretation

The extracted features of the image are guide from which interpretation of the image emerges; that is, interpretation is concerned with recognizing the object (object recognition), and/or recognizing the major features of the object (pattern recognition). Predefined models or standard values are used to identify the object in the image. Two commonly-used interpretation techniques are:

BULLETLIST
Template matching—a method whereby the features of the image are compared against corresponding features of a model or template stored in the computer memory

Feature weighting—a technique in which several features are combined into a single measure by assigning a weight to each feature according to its relative importance in identifying the object, and where the resultant score is compared against an ideal object score stored in computer memory, to achieve proper identification
ENDLIST

KEYPOINT
Interpretation of the image is concerned with recognizing the object recognition, and/or pattern recognition. Two commonly-used interpretation techniques are template matching and feature weighting.
END KEYPOINT

11.6.6 Machine Vision Applications

Machine vision applications as used in manufacturing come in three categories: inspection; identification; and visual guidance and control. Typical industrial inspection tasks include:

BULLETLIST
Dimensional measurement on parts or products

Dimensional gauging on parts or products

Verification of the presence of components

Verification of hole location and number of holes

Detection of surface flaws and defects

Detection of flaws in a printed label
ENDLIST
11.7 Other Optical Inspection Methods

Other optical sensing techniques can be used for inspection. Conventional optical instruments include optical comparators and microscopes; while laser systems can be used for scanning. In Figure 11.7 a scanning laser device is depicted. The system uses a laser beam that is deflected by a rotating mirror to produce a beam of light that can be focused to sweep past an object; while on the other side of the object, a photo-detector senses the light sweep, except when it is interrupted by the object, and this interruption time may be measured and related to the size and shape of the object with great accuracy.

LEARNING ACTIVITY 11.4 [CRIT] [WRIT COMM]
Investigate and report on optical comparators and microscopes. Use the following web-sites:
http://en.wikipedia.org/wiki/Microscope

Laser devices include the scanning laser, which comes in a number of formats; see:
http://en.wikipedia.org/wiki/Laser_Range_Scanner

Linear array devices may also be used, whereby an array of closely spaced photo diodes are placed behind an object, and used to capture planar light that is directed at the object from the other side (see Figure 11.8). The light that is
blocked by the object may be measured by the photo diode array to indicate the object’s dimension of interest.

Figure 11.8: Linear array measuring device

A variation of this technique uses optical triangulation methods (refer to Figure 11.9). A laser is used to focus a narrow beam at an object to form a spot of light on the object; meanwhile, a linear array of photo diodes is used to determine the location of the spot using triangulation. The resultant angle $A$ and distance $L$ between light source and photo diodes are known; and thus, by means of simple trigonometry, the range of the object ($R$) can be determined by means of the equation:

$$R = L \cot A$$

Figure 11.9: Optical triangulation sensing

KEYPOINT
Other optical sensing techniques can be used for inspection. These include conventional optical instruments (such as optical comparators and microscopes),
Other potential inspection techniques that are non-contact and non-optical are outlined in brief in Table 11.9.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Field</td>
<td>An electrically active probe creates an electrical field which is affected by the proximity of an object to the probe. In typical applications, the object to be inspected is placed at a set proximity to the probe, and the effect on the electrical field is measured. This procedure is repeated at different distances from the probe, and results are compared against each other to complete inspection procedure.</td>
</tr>
<tr>
<td>Radiation</td>
<td>Uses x-ray radiation to accomplish non-contact inspection on metals and weld-fabricated products. The amount of radiation absorbed by the metal is measured and compared against standards. This allows metals that do not absorb sufficient amounts of radiation to be quickly spotted as flawed.</td>
</tr>
<tr>
<td>Ultrasonic Inspection</td>
<td>Uses very high frequency sound as an inspection mechanism. Methods can be either manually-performed or performed automatically. Automated methods include emitting ultrasonic waves from a probe and reflecting them off the object to be inspected, to create a sound pattern. This sound pattern can be compared against the sound pattern produced by an ideal object for inspection purposes. If the produced sound pattern matches the standard pattern the object passes the test; otherwise it fails.</td>
</tr>
</tbody>
</table>

Other potential inspection techniques that are non-contact and non-optical include electrical field techniques, radiation techniques, and ultrasonic inspection techniques.

**11.9 Unit Review**

**BULLETINDEX**  
Inspection is the process of presenting, examining, deciding-upon, and acting-upon an item to ensure that poor quality is detected in product attributes, and good quality is assured.

Characteristics of measuring instruments that are used to ensure correct device selection include parameters that assess: accuracy and precision; resolution and sensitivity; speed of response; wide operating range; high reliability; and cost.
There are two types of inspection techniques: contact and non-contact.

Physical contact occurs between the object to be inspected and the measurement device in contact inspection; this is typically done by means of a mechanical probe or other device that touches the item, which allows the inspection procedure to occur.

Non-contact inspection techniques use a sensor to measure or gauge the desired features of the object.

Conventional measuring and gauging techniques use manually-operated inspection devices.

Measuring devices provide a quantitative value of the part features of interest.

Gauges determine whether the part feature falls within a certain acceptable range of values.

Measuring devices are used for sampling inspection: devices can be both portable and stationary equipment. Gauges are used for sampling and for 100% inspection: devices usually portable, and can be used upon the production line itself.

Electronic gauges represent a recent technological advance on conventional measuring and gauging technology, and are increasing displacing these technologies in manufacturing and production environments.

Co-ordinate metrology measures the actual shape and dimensions of an item and compares them against a desired shape and dimension set. A co-ordinate measuring machine (CMM) is an electromechanical system that has been designed to carry out this function.

A CMM consists of a mechanical probe that operates in three axial dimensions, a mechanical structure to provide for the motion of the probe, and optional components such as a drive system, and computing hardware and software.

The CMM construction consists of a worktable upon which the item to be inspected is placed, and, overhead, is the mechanical structure that supports the probe head and probe. Associated equipment such as the computer system are located remotely.

Probe tips usually consist of ruby balls, which contain ideal physical and mechanical properties for probing operations. Probes can be single- or multi-tip.

Probes with touch-trigger mechanisms are the most common probe type: these operate in a variety of ways.
A number of different physical configurations exist for the mechanical structure of the CMM; these include: cantilever; moving bridge; fixed bridge; horizontal arm; gantry; and column mechanical structures.

CMM control may be accomplished via methodologies that use manual drive; manual drive with computer-assisted processing; motor drive with computer-assisted data processing; or direct computer control with computer assisted data processing.

CMMs using direct computer control with computer assisted data processing capabilities can be programmed using manual lead-through or off-line programming methods.

Other CMM software that may be used includes core software, post-inspection software, and reverse-engineering and application-specific software.

Types of core software include probe calibration; part co-ordinate system definition; geometric feature construction; and tolerance analysis.

Types of post-inspection software that may be deployed include statistical analysis software, and graphical data representation software.

Types of reverse engineering software include software for gear checking, thread checking, cam checking, and automobile body checking.

CMMs are most appropriate for applications where repetitive manual inspection exists; where post-inspection is required; where geometric features are complex and have multiple contact points; where, otherwise, multiple inspection set-ups would have to be used; where there is a wide part variety; and where repeat orders are common.

The advantages offered by CMMs over traditional manual inspection methods include: reduced inspection cycle time; increased flexibility of change-overs; reduced operator errors; greater inherent accuracy and precision; and the avoidance of multiple inspection set-ups.

On-line inspection can occur on CNC machines; it is called in-process inspection. This uses tactile probes, mounted in tool-holders, and handled in the same way as CNC machine tools, to carry out an inspection procedure on the workpart currently being worked upon by the CNC machine.

Disadvantages of using in-process inspection methods include: errors that occur but are not detected by the in-process method owing to the use of the same production machine to perform the inspection test; and increases to overall manufacturing cycle time.
Surface measurements, such as surface roughness, can be measured by commercially available stylus-type instruments that traverse the surface of the workpart at a slow constant speed.

A topographical map of the workpart surface is created by deploying parallel lines of stylus instruments that move at the same speed. This creates a profile ‘map’ of the workpart surface giving indications of surface roughness, waviness, and other measures of surface condition.

Typically an averaging value is calculated that reduces recorded deviations in the workpart surface to a single value of surface roughness.

Calculations for surface roughness must account, and eliminate, waviness deviations that may be apparent in the workpart surface. This is done by setting the cutoff length to being shorter than any existing waviness width, leaving records of roughness deviations only.

Machine vision is concerned with the creation, and collection of data from an image, all subsequently processed and interpreted by a computer for some useful application.

The operation of machine vision has three functions: image acquisition and digitization; image processing and analysis; and interpretation.

Image acquisition and digitization is typically performed by using a video camera to capture the scene of interest, the super-imposition of a pixel matrix to the resultant image, and the assignment of intensity values, based on the light intensity of each portion of the scene.

Solid-state cameras are the prime device used to capture images in machine vision. They project the image onto an array of photosensitive elements that produce an electrical charge equivalent to the light intensity on each element, subsequently stored and read in the data processing and analysis function.

There are five categories of lighting used in machine vision; these are: front lighting, back lighting, side lighting, structured lighting, and strobe lighting.

Image processing and analysis techniques consist of the segmentation techniques of thresholding and edge detection, as well as feature extraction techniques.

Interpretation of the image is concerned with recognizing the object recognition, and/or pattern recognition. Two commonly-used interpretation techniques are template matching and feature weighting.
Machine vision applications as used in manufacturing come in three categories: inspection; identification; and visual guidance and control.

Other optical sensing techniques can be used for inspection. These include conventional optical instruments (such as optical comparators and microscopes), laser scanning systems, and linear array devices with arrays of photo diodes arranged in direct and triangulation methodologies.

Other potential inspection techniques that are non-contact and non-optical include electrical field techniques, radiation techniques, and ultrasonic inspection techniques.

11.10 Self-Assessment Questions

Explain the concept of inspection.

What are the parameters of measuring instruments that are used to ensure correct device selection?

What are the two types of inspection techniques?

What different functions do measuring devices and gauges serve?

What is co-ordinate metrology? What equipment is associated with it?

List the components of a co-ordinate measuring machine (CMM).

Describe the construction of a CMM probe.

What types of CMM physical configuration are there?

What types of methodologies are used to achieve CMM control?

List types of software for the following: core software; post-inspection software; and reverse engineering software.

What is meant by the concept of in-process inspection? Explain how it operates.

Describe how surface measurements of workparts are taken.

How are waviness deviations in surface measurements eliminated from surface roughness measurements?
What is machine vision?

List the three functions of machine vision.

How is image acquisition and digitization performed?

What types of lighting are used in machine vision?

List some image processing and analysis techniques used in machine vision.

Name some common methods of interpretation in machine vision.

What are other optical sensing techniques that can be used for inspection?

List other inspection techniques that are non-contact and non-optical.

11.11 Answers to Self-Assessment Questions

Inspection is the process of presenting, examining, deciding-upon, and acting-upon an item to ensure that poor quality is detected in product attributes, and good quality is assured.

Characteristics of measuring instruments that are used to ensure correct device selection include parameters that assess: accuracy and precision; resolution and sensitivity; speed of response; wide operating range; high reliability; and cost.

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CMM physical configurations include the following mechanical structures: cantilever; moving bridge; fixed bridge; horizontal arm; gantry; and column.

CMM control may be accomplished via methodologies that use manual drive; manual drive with computer-assisted processing; motor drive with computer-assisted data processing; or direct computer control with computer assisted data processing.

Types of core software include probe calibration; part co-ordinate system definition; geometric feature construction; and tolerance analysis. Types of post-inspection software that may be deployed include statistical analysis software, and graphical data representation software. Types of reverse engineering software include software for gear checking, thread checking, cam checking, and automobile body checking.

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END LIST