Inspection Technologies

L-30

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1) Inspection Metrology

- Measurement is a procedure in which an unknown quantity is compared to a known standard, using an accepted and consistent system of units. The measurement may involve a simple linear rule to scale the length of a part, or it may require measurement of force versus deflection during a tension test.
- Metrology is the science of measurement. The science is concerned with seven basic quantities: length, mass, time, electric current, temperature, luminous intensity and matter.

a) Characteristics of Measuring Instruments

(i) Accuracy and Precision

(ii) Resolution and sensitivity

(iii) Analog vs digital instruments

(iv) Calibration

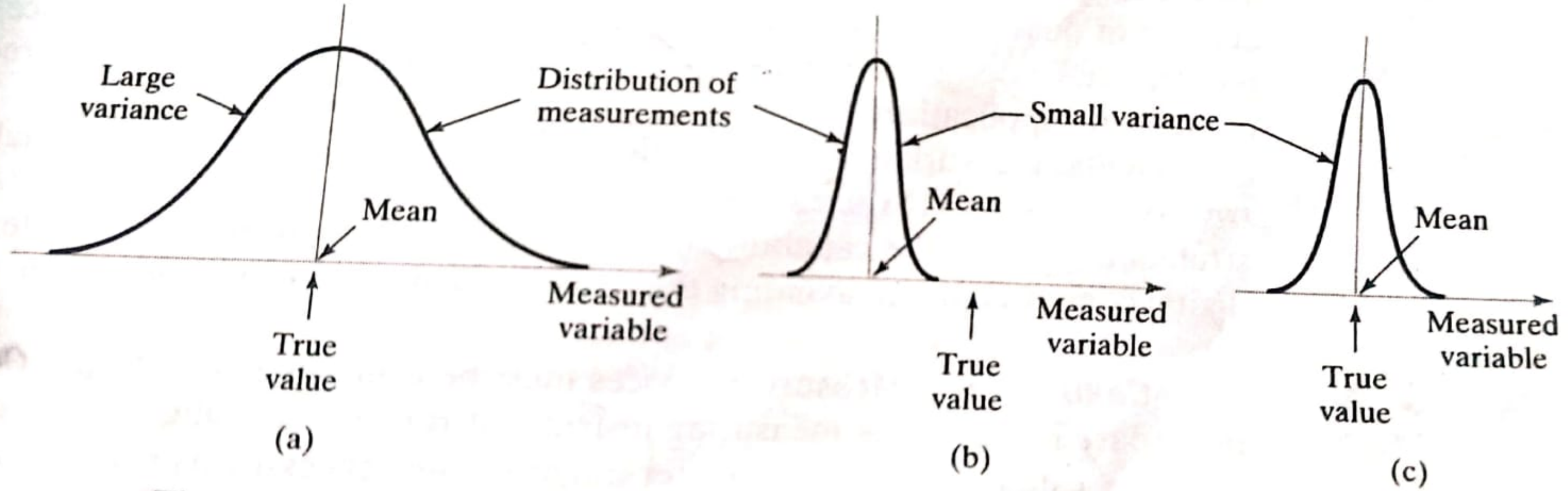

Figure 23.1 Accuracy versus precision in measurement: (a) high accuracy but low precision, (b) low accuracy but high precision, and (c) high accuracy and high precision.

b) Measurement Standards and Systems

... is going metric and adopting the SI. ... has stubbornly clung to its U.S.C.S. Gradually, the

TABLE 23.1 Standard Units for Basic Physical Quantities (System Internationale)

Quantity	*Standard Unit*	*Symbol*	*Standard Unit Defined*
Length	**Meter**	m	The distance traveled by light in a vacuum in 1/299,792,458 of a second.
Mass	**Kilogram**	kg	A cylinder of platinum-iridium alloy that is kept by the International Bureau of Weights and Measures in Paris. A "duplicate" is retained by the National Institute of Standards and Technology (NIST) near Washington, DC.
Time	**Second**	s	Duration of 9,192,631,770 cycles of the radiation associated with a change in energy level of the cesium atom.
Electric current	**Ampere**	A	Magnitude of current which, when flowing through each of two long parallel wires a distance of 1 m apart in free space, results in a magnetic force between the wires of $2 \times 10^{-7} N$ for each meter of length.
Thermodynamic temperature	**Kelvin**	K	The kelvin temperature scale has its zero point at absolute zero and has a fixed point of 273.15 K at the triple point of water, which is the temperature and pressure at which ice, liquid water, and water vapor are in equilibrium. The Celsius temperature scale is derived from the kelvin as $C = K - 273.15$.
Light intensity	**Candela**	cd	Defined as the luminous intensity of 1/600,000 of a square meter of a radiating cavity at the melting temperature of platinum (1769°C).
Matter	**Mole**	mol	Defined as the number of atoms in 0.012 kg mass of carbon 12.

2) Contact Vs Noncontact Inspection Techniques

- Contact inspection involves the use of mechanical probe or other device that makes contact with the object being inspected. The purpose of the probe is to measure or gage the object in some way.

The principal contact inspection technologies are:

(i) Conventional measuring and gaging instruments, manual and automated

(ii) Coordinate measuring machines (CMMs) and related techniques

(iii) Stylus type surface texture measuring machines.

Diagram

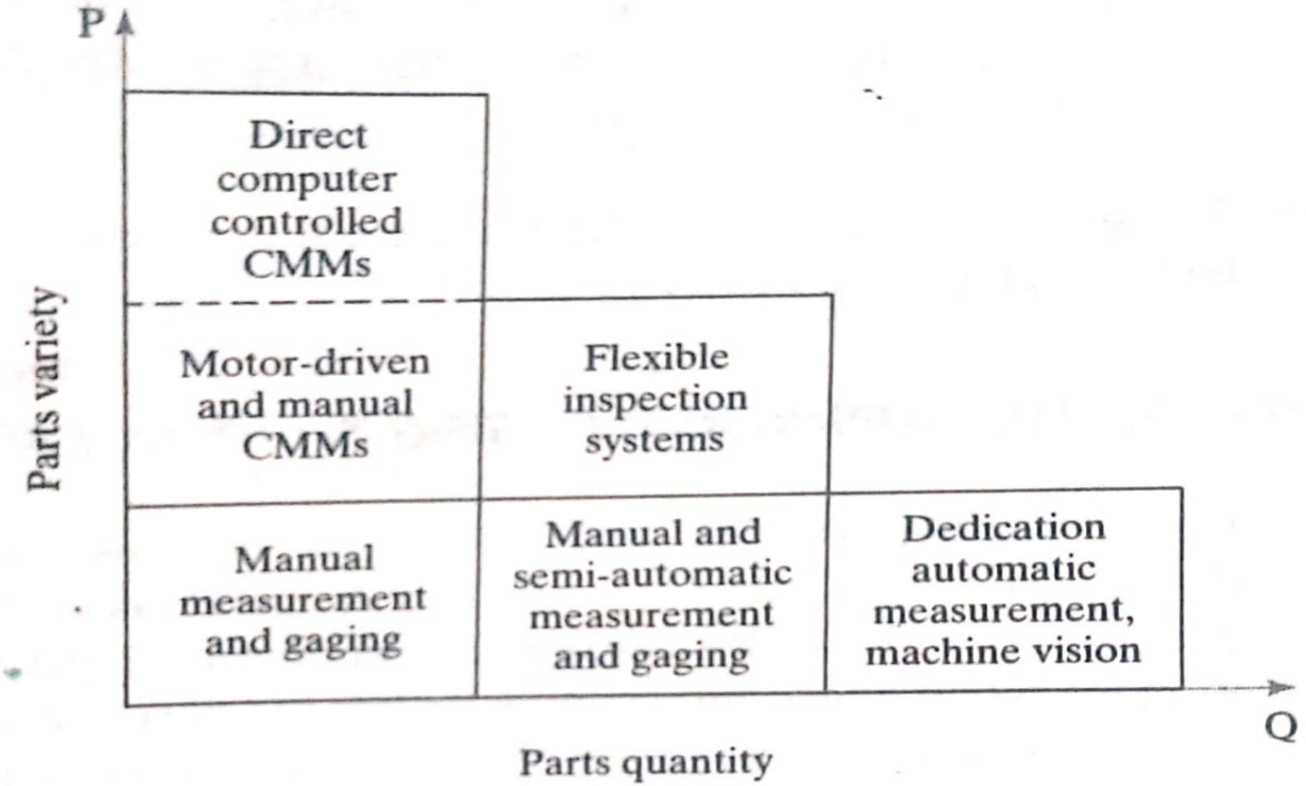

Figure 23.2 PQ chart indicating most appropriate measurement equipment as a function of parts variety and quantity (adapted from [2]).

Contd.

Reasons why these contact inspection methods are technologically and commercially important include the following:

(i) They are the most widely used inspection technologies today

(ii) They are accurate and reliable

(iii) In many cases, they represent the only methods available to accomplish the inspection

b) Noncontact Inspection Technologies

They are classified into two categories (i) Optical (ii) nonoptical.

- Optical inspection technologies make use of light to accomplish the measurement or gaging cycle.
- Nonoptical inspection technologies utilize energy forms other than light to perform the inspection; these other energies include various electrical fields, radiation (other than light), and ultrasonics.
- Noncontact inspection offers certain advantages over contact inspection techniques. The advantages include:

(i) Avoidance of damage to the surface that might result from contact inspection

(ii) Inherently faster inspection cycle times. The reason is that contact inspection procedures require the contacting probe to be positioned against the part, which takes time.

(iii) Noncontact methods can often be accomplished on the production line without the need for any additional handling of the parts, whereas special handling and positioning of the parts is usually required in contact inspection

(iv) Increased opportunity for 100% automated inspection. Faster inspection cycle times and reduced need for special handling means that 100% inspection is more feasible with noncontact methods.

3) Conventional Measuring and Gaging Techniques

TABLE 23.2 Comparison of Resolution and Relative Speed of Several Inspection Technologies

Inspection Technology	*Typical Resolution*	*Relative Speed of Application*
Conventional instruments:		
Steel rule	0.25 mm (0.01 in)	Medium speed (medium cycle time)
Vernier caliper	0.025 mm (0.001 in)	Slow speed (high cycle time)
Micrometer	0.0025 mm (0.0001 in)	Slow speed (high cycle time)
Coordinate measuring machine	0.0005 mm (0.00002 in)*	Slow cycle time for single measurement. High speed for multiple measurements on same object.
Machine vision	0.25 mm (0.01 in)**	High speed (very low cycle time per piece)

Also see Table 23.5 for other parameters on coordinate measuring machines.

Contd.

TABLE 23.3 Common Conventional Measuring Instruments and Gages (Adapted from [10])—Some of These Devices Can Be Incorporated into Automated Inspection Systems

Instrument and Description
Steel rule – Linear graduated measurement scale used to measure linear dimensions. Available in various lengths, typically ranging from 150 to 1000 mm, with graduations of 1 or 0.5 mm. (U.S.C.S. rules available from 6 to 36 in, with graduations of 1/32 in or 0.01 in.)
Calipers – Family of graduated and nongraduated measuring devices consisting of two legs joined by a hinge mechanism. The ends of the legs contact the surfaces of the object to provide a comparative measure. Can be used for internal (e.g., inside diameter) or external (e.g., outside diameter) measurements.
Slide caliper – Steel rule to which two jaws are added, one fixed and the other movable. Jaws are forced to contact part surfaces to be measured, and the location of the movable jaw indicates the dimension of interest. Can be used for internal or external measurements.
Vernier caliper – Refinement of the slide caliper, in which a vernier scale is used to obtain more precise measurements (as close as 0.001 in are readily possible).
Micrometer – Common device consisting of a spindle and C-shaped anvil (similar to a C-clamp). The spindle is closed relative to the fixed anvil by means of a screw thread to contact the surfaces of the object being measured. A vernier scale is used to obtain precisions of 0.01 mm in S.I. (0.0001 in in U.S.C.S.). Available as ***outside micrometers, inside micrometers***, or ***depth micrometers***. Also available as electronic gages to obtain a digital readout of the dimension of interest.
Dial indicator – Mechanical gage that converts and amplifies the linear movement of a contact pointer into rotation of a dial needle. The dial is graduated in units of 0.01 mm in S.I. (0.001 in in U.S.C.S.). Can be used to measure straightness, flatness, squareness, and roundness.
Gages – Family of gages, usually of the go/no-go type, that check whether a part dimension lies within acceptable limits defined by tolerance specified in part drawing. Includes: (1) ***snap gages*** for external dimensions such as a thickness, (2) ***ring gages*** for cylindrical diameters, (3) ***plug gages*** for hole diameters, and (4) ***thread gages***.
Protractor – Device for measuring angles. ***Simple protractor*** consists of a straight blade and a semicircular head graduated in angular units (e.g., degrees). ***Bevel protractor*** consists of two straight blades that pivot one to the other; the pivot mechanism has a protractor scale to measure the angle of the two blades.

4) Coordinate Measuring Machines

- Coordinate metrology is concerned with the measurement of the actual shape and dimensions of an object and comparing these with the desired shape and dimensions as might be specified on a part drawing.
- In this connection, coordinate metrology consists of the evaluation of the location, orientation, dimensions and geometry of the part or object.
- A coordinate measuring machine (CMM) is an electromechanical system designed to perform coordinate metrology.

Figure

.4 / Coordinate Measuring Machines

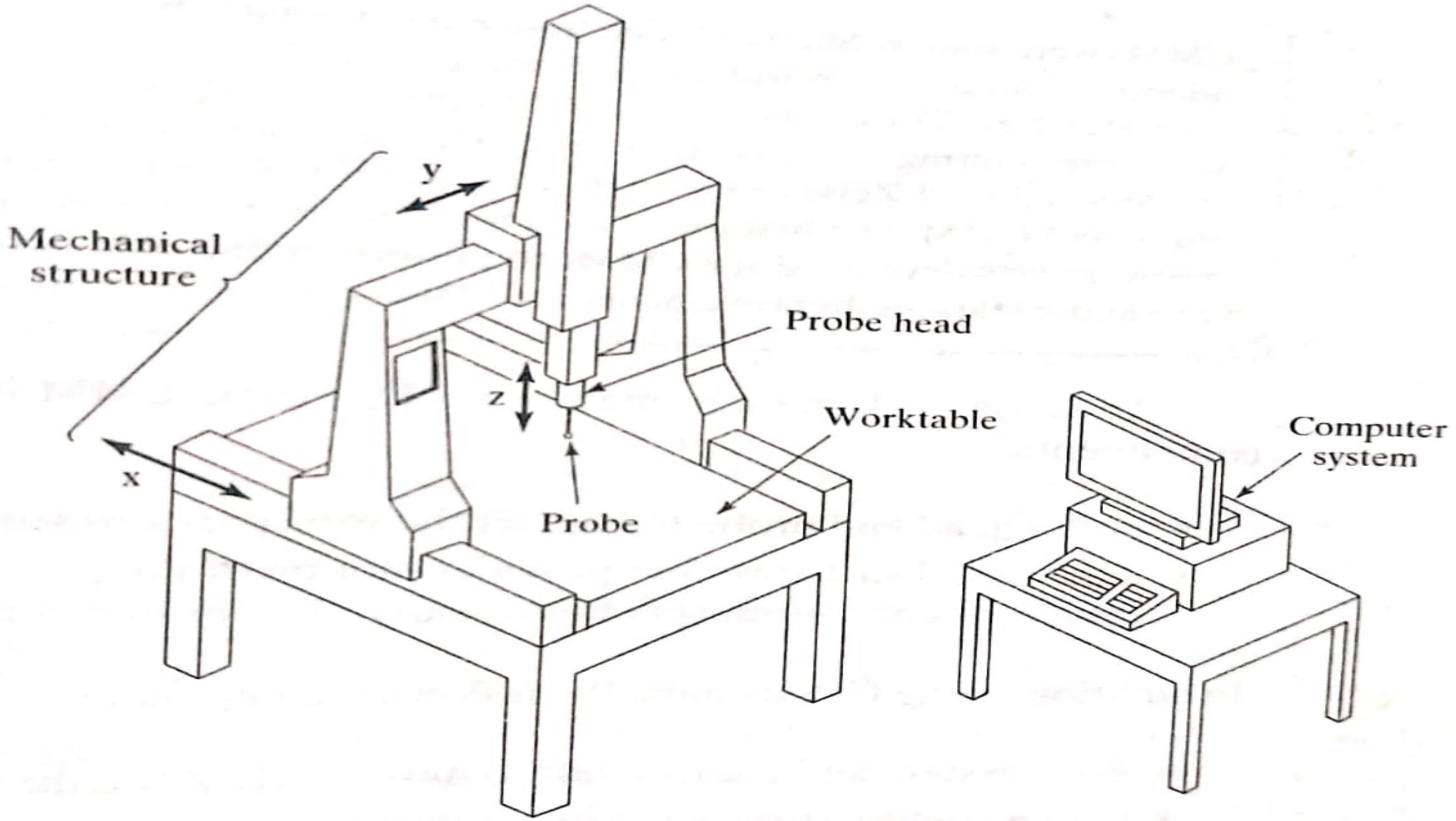

Figure 23.3 Coordinate measuring machine.

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- To accomplish measurement in 3-D a basic CMM is composed of the following components:

(i) Probe head and probe to contact the workpart surfaces

(ii) Mechanical structure that provides motion of the probe in three cartesian axes and displacement transducers to measure the coordinate values of each axis.

- In addition, many CMMs have the following components:

(i) Drive system and control unit to move each of the three axes
(ii) digital computer system with application software

a) CMM Construction

(i) Probe: Most probes today are touch-trigger probes, which actuate when the probe makes contact with the part surface. Commercially available touch-trigger probes utilize any of various triggering mechanisms, including the following:

(a) The trigger is based on a highly sensitive electrical contact switch that emits a signal when the tip of the probe is defected from its neutral position

(b) The trigger actuates when electrical contact is established between the probe and the part surface.

(c) The trigger uses a piezoelectric sensor that generates a signal based on tension or compression loading of the probe.

Figure

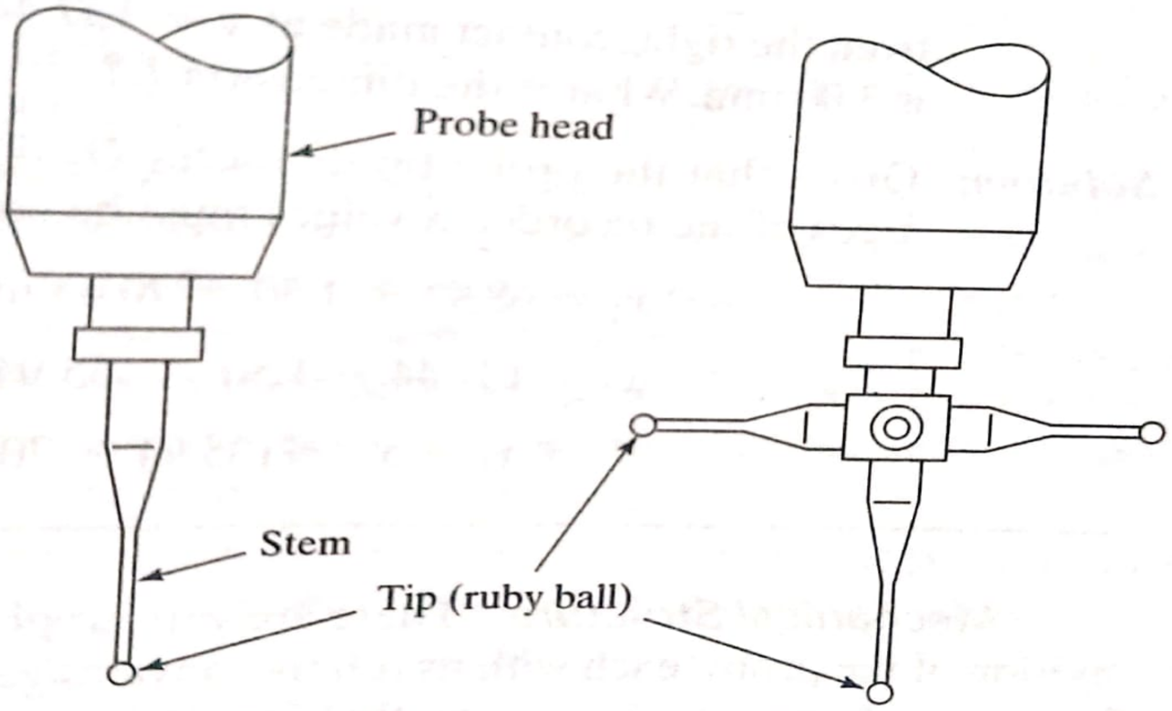

Figure 23.4 Contact probe configurations: (a) single tip and (b) multiple tips.

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(ii) Mechanical Structure

Figure 23.6:

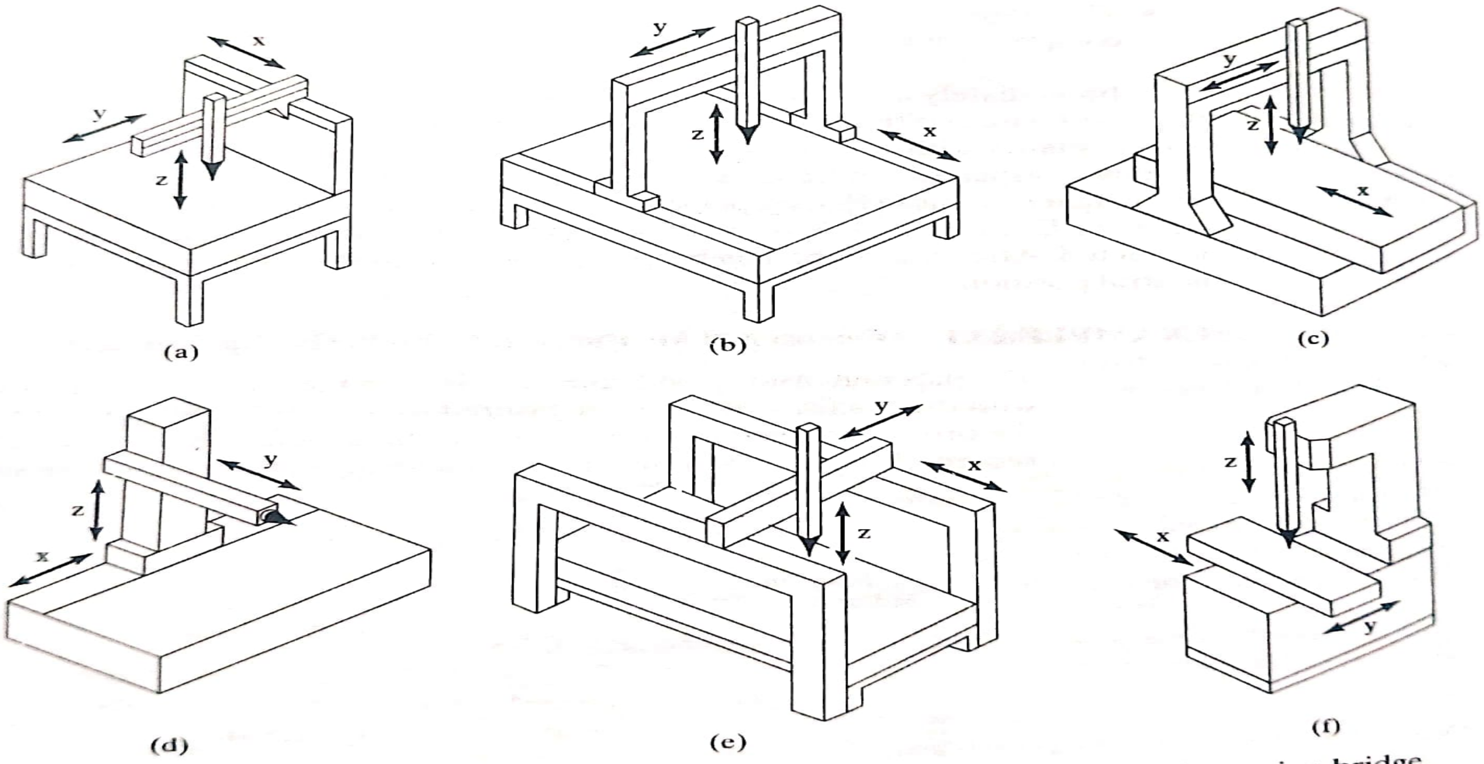

Figure 23.6 Six types of CMM construction: (a) cantilever, (b) moving bridge, (c) fixed bridge, (d) horizontal arm (moving ram type), (e) gantry, and (f) column.

b) CMM Operation and Programming

(i) Types of CMM controls

(a) Manual drive

(b) Manual drive with computer-assisted data processing

(c) Motor drive with computer-assisted data processing

(d) DCC with computer-assisted data processing.

(ii) Programming of computer-controlled CMM

C) Other CMM Software

- Core Software other than DCC Programming

(i) Probe calibration
(ii) Part coordinate system definition
(iii) Geometric feature construction
(iv) Tolerance analysis

- Post Inspection Software

(i) Statistical analysis
(ii) Graphical data representation

- Reverse Engineering and Application Specific Software

(i) Gear checking
(ii) Thread checking
(iii) Cam checking
(iv) Automobile body checking

Example

EXAMPLE 23.3 Determining the Center and Diameter of a Drilled Hole

Three point locations on the surface of a drilled hole have been measured by a CMM in the x-y axes. The three coordinates are: (34.41, 21.07), (55.19, 30.50), and (50.10, 13.18) mm. The given coordinates have been corrected for probe radius. Determine: (a) coordinates of the hole center and (b) hole diameter, as they would be computed by the CMM software.

Solution: To determine the coordinates of the hole center, we must establish three equations patterned after Eq. (23.5) in Table 23.4:

$$(34.41 - a)^2 + (21.07 - b)^2 = R^2 \quad \text{(i)}$$

$$(55.19 - a)^2 + (30.50 - b)^2 = R^2 \quad \text{(ii)}$$

$$(50.10 - a)^2 + (13.18 - b)^2 = R^2 \quad \text{(iii)}$$

Expanding each of the equations, we have:

$$1184.0481 - 68.82a + a^2 + 443.9449 - 42.14b + b^2 = R^2 \quad \text{(i)}$$

$$3045.9361 - 110.38a + a^2 + 930.25 - 61b + b^2 = R^2 \quad \text{(ii)}$$

$$2510.01 - 100.2a + a^2 + 173.7124 - 26.36b + b^2 = R^2 \quad \text{(iii)}$$

Setting Eq. (i) = Eq. (ii):

$$1184.0481 - 68.82a + a^2 + 443.9449 - 42.14b + b^2 =$$

$$3045.9361 - 110.38a + a^2 + 930.25 - 61b + b^2 \quad \text{(iv)}$$

$$1627.993 - 68.82a - 42.14b = 3976.1861 - 110.38a - 61b$$

$$-2348.1931 + 41.56a + 18.86b = 0$$

$$18.86b = 2348.1931 + 41.56a$$

$$b = 124.5065 - 2.2036a \quad \text{(iv)}$$

Now setting Eq. (ii) = Eq. (iii):

$$3045.9361 - 110.38a + a^2 + 930.25 - 61b + b^2 =$$

$$2510.01 - 100.2a + a^2 + 173.7124 - 26.36b + b^2 \quad \text{(v)}$$

$$3976.1861 - 110.38a - 61b = 2683.7224 - 100.2a - 26.36b$$

$$1292.4637 - 10.18a - 34.64b = 0$$

$$10.18a = 1292.4637 - 34.64b$$

$$a = 126.9611 - 3.4027b \quad \text{(v)}$$

Substituting Eq. (iv) for b:

$$a = 126.9611 - 3.4027(124.5065 - 2.2036a)$$

$$a = 126.9611 - 423.6645 + 7.4983a$$

$$6.4983a = 296.7034 \qquad a = 45.6586 \rightarrow 45.66$$

The value of a can now be substituted into Eq. (iv):

$$b = 124.5065 - 2.2036(45.6586) \qquad b = 23.8932 \rightarrow 23.89$$

Now using the values of a and b in Eq. (i) to find R (Eqs. (ii) and (iii) could also be used), we have:

$$R^2 = (34.41 - 45.6586)^2 + (21.07 - 23.8932)^2$$

$$= (-11.2486)^2 + (-2.8232)^2 = 126.531 + 7.970 = 134.501$$

$$R = \sqrt{134.501} = 11.60 \text{ mm} \qquad D = 23.20 \text{ mm}$$

d) CMM Applications and Benefits

1. Many inspectors performing repetitive manual inspection operations
2. Post-Process inspection
3. Measurement of geometric features requiring multiple contact points
4. Multiple inspection setups are required if parts are manually inspected
5. Complex part geometry
6. High variety of parts to be inspected
7. Repeat orders

When applied in the appropriate parts quantity-parts variety range, the advantages of using CMMs over manual inspection methods are:

1. Reduced inspection cycle time
2. Flexibility
3. Reduced operator errors
4. Greater inherent accuracy and precision
5. Avoidance of multiple setups.

e) Flexible Inspection Systems

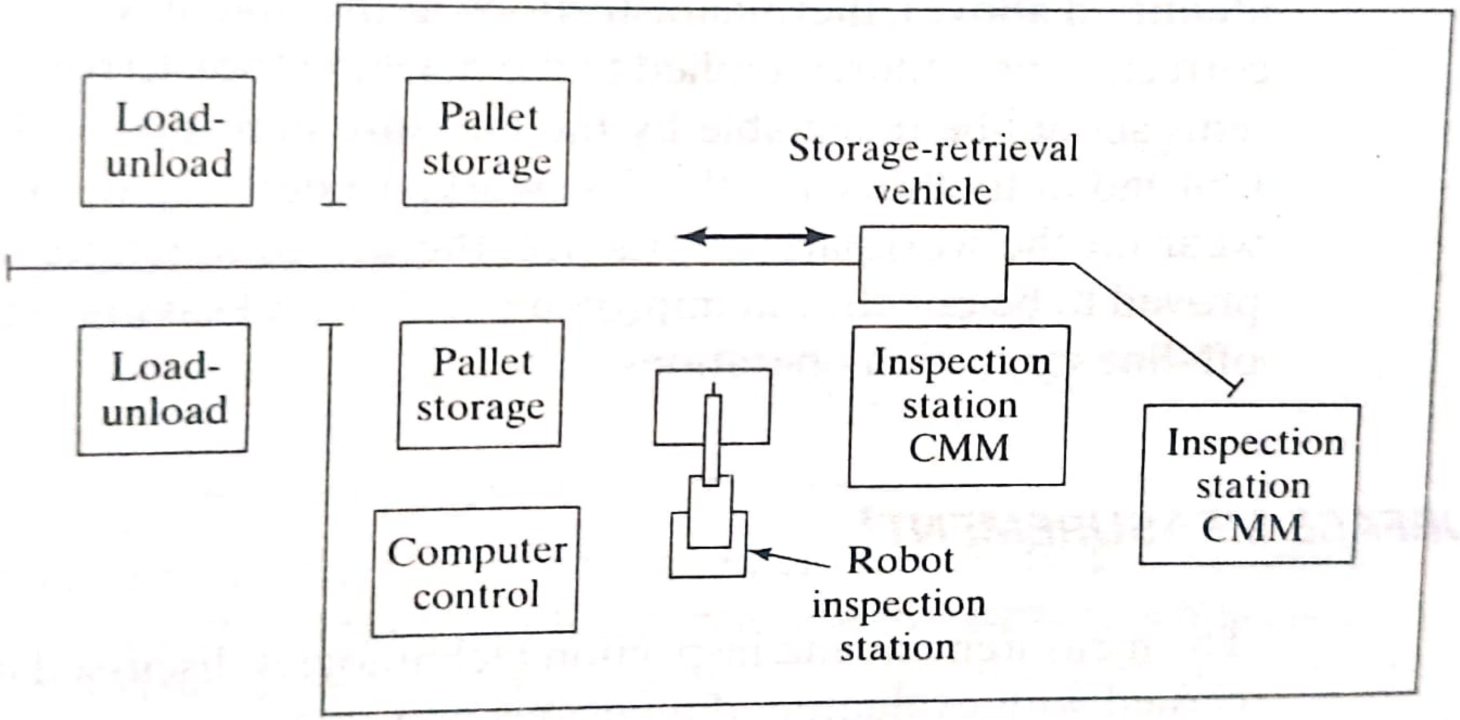

Figure 23.7 Layout plan of flexible inspection system (FIS).

f) Inspection Probes on Machine Tools

- In recent years there has been a significant growth in the use of tactile probes as on-line inspection systems in machine tool applications
- These probes are mounted in toolholders inserted into the machine tool spindle, stored in the tool drum and handled by the automatic tool changer in the same way that cutting tools are handled. When mounted in the spindle, the machine tool is controlled very much like a CMM.
- Sensors in the probe determine when contact has been made with the part surface.
- Signals from the sensor are transmitted by any of several means(e.g, direct electrical connection, induction coil, infrared data transmission) to the controller that performs the required data processing to interpret and utilize the signal.

5) Surface Measurement

a) Stylus Instruments

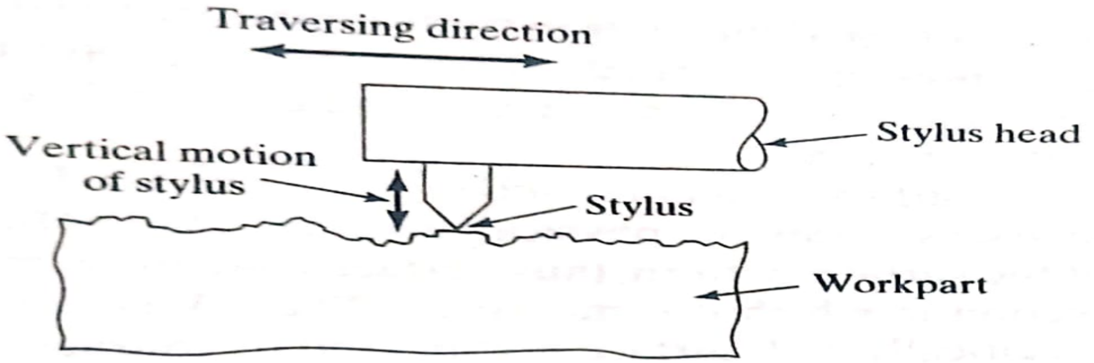

Figure 23.8 Sketch illustrating the operation of stylus-type instrument. Stylus head traverses horizontally across surface, while stylus moves vertically to follow surface profile. Vertical movement is converted into either: (1) a profile of the surface or (2) the average roughness value (source: [10]).

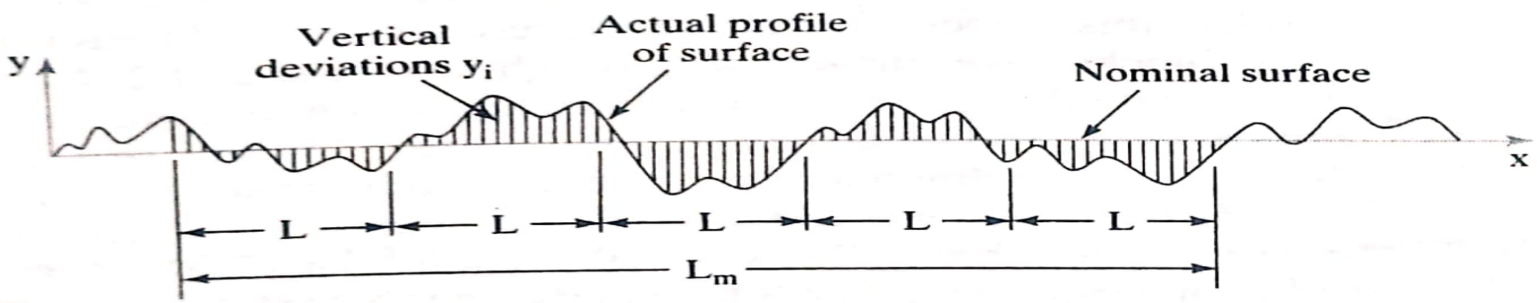

Figure 23.9 Deviations from nominal surface used in the definition of surface roughness (source: [10]).

b) Other Surface Measuring Techniques

(i) To estimate the roughness of a given test specimen, the surface is compared to the standard both visually and by using a fingernail test. In this test, the user gently scratches the surfaces of the specimen and the standard, judging which standard is closest to the specimen.

(ii) The most other surface measuring instruments employ optical techniques to assess roughness.

6) Machine Vision

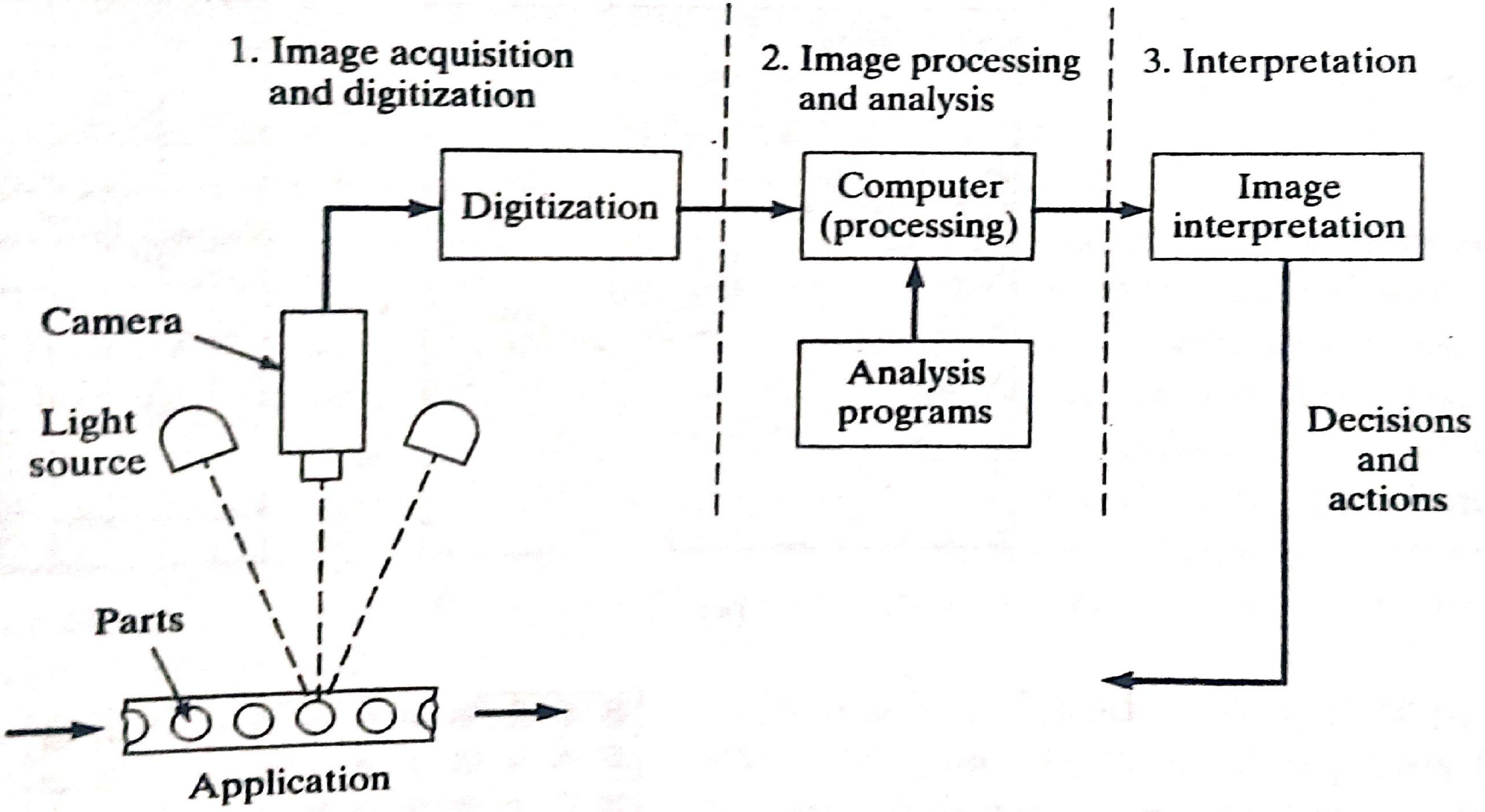

Figure 23.10 Basic functions of a machine vision system.

a) Image Acquisition and Digitization

- Image acquisition and digitization is accomplished using a video camera and a digitizing system to store the image data for subsequent analysis.

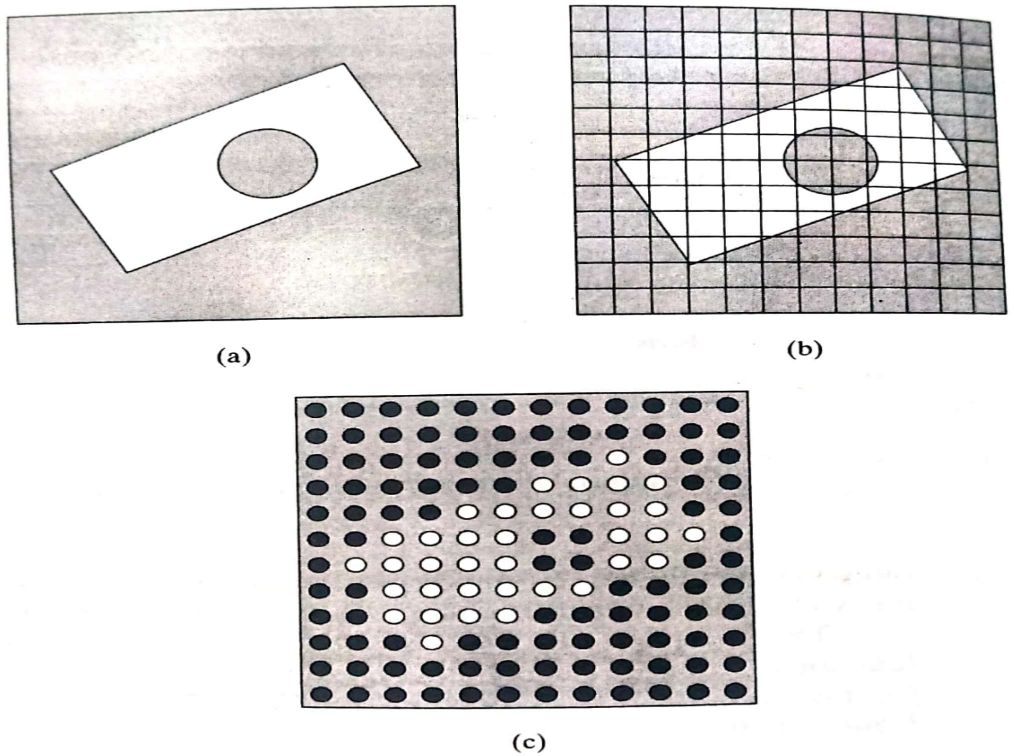

Figure 23.11 Dividing the image into a matrix of picture elements, where each element has a light intensity value corresponding to that portion of the image: (a) the scene; (b) 12 × 12 matrix superimposed on the scene; and (c) pixel intensity values, either black or white, for the scene.

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- Solid state cameras
- Illumination

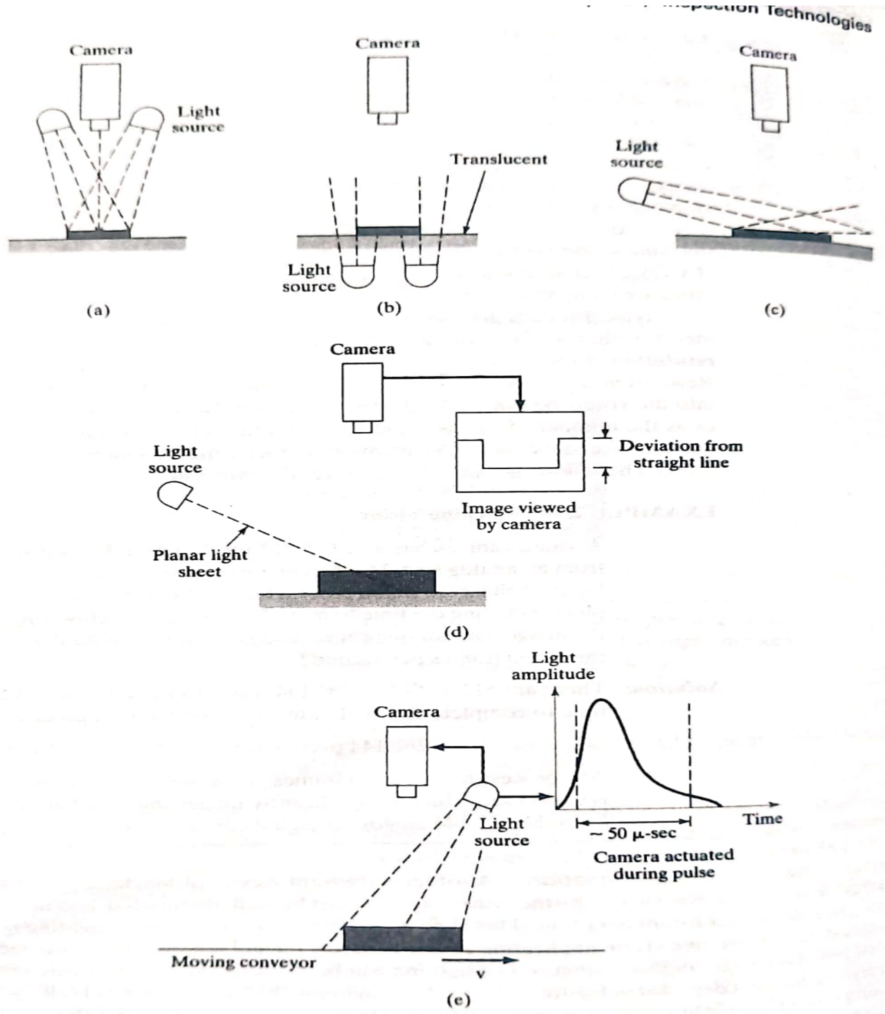

Figure 23.12 Types of illumination in machine vision: (a) front lighting, (b) back lighting, (c) side lighting, (d) structured lighting using a planar sheet of light, and (e) strobe lighting.

b) Image Processing and Analysis

(i) Segmentation: It is intended to define and separate regions of interest within the image. Two techniques are thresholding and edge detection

(ii) Thresholding involves the conversion of each pixel intensity level into a binary value, representing either white or black. This is done by comparing the intensity value of each pixel with a defined threshold value.

(iii) Edge detection is concerned with determining the location of boundaries between an object and its surroundings in an image. This is accomplished by identifying the contrast in light intensity that exists between adjacent pixels at the borders of the object.

(iv) Another set of technique is feature extraction. Some feature include object area, length, width, diameter, perimeter, center of gravity and aspect ratio.

C) Interpretation

(i) Pattern recognition. The objective in these tasks is to identify the object in the image by comparing it with predefined models or standard values.

(ii) Feature weighting: It is a technique in which several features (area, length and perimeter) are combined into a single measure by assigning a weight to each feature according to its relative importance in identifying the object.

d) Machine Vision Applications

The machine vision applications in manufacturing divide into three categories

(i) Inspection: Typical industrial inspection tasks include the following

(a) Dimensional measurement

(b) Dimensional gaging

(c) Verification of the presence of components

(d) Verification of hole location and number of holes

(e) Detection of surface flaws and defects

(f) Detection of flaws in a printed label.

(ii) Identification

(iii) Visual guidance and control

7) Other Optical Inspection Methods

(i) Scanning laser system

(ii) Linear Array Devices

(iii) Optical Traingulation Techniques

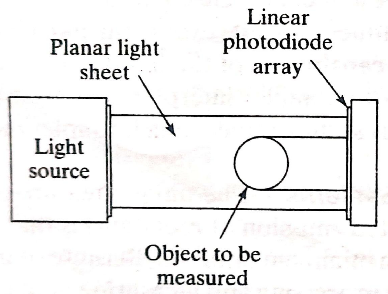

Figure 23.14 Operation of a linear array measuring device.

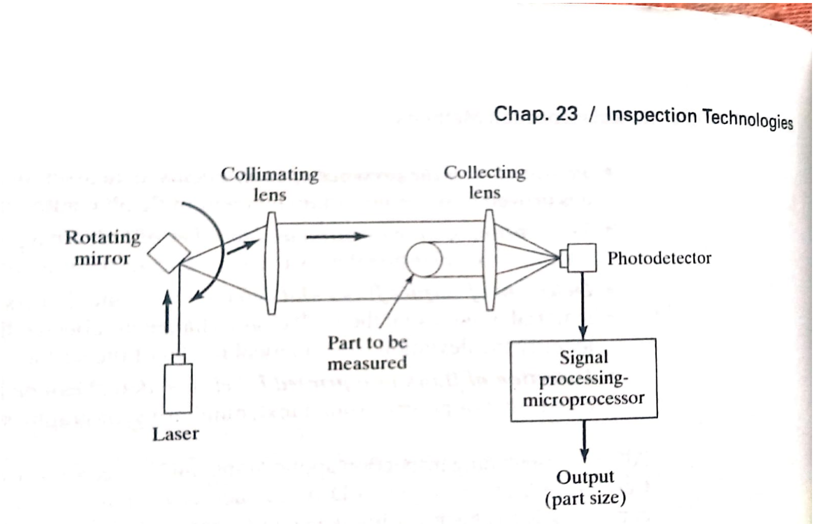

Figure 23.13 Diagram of scanning laser device.

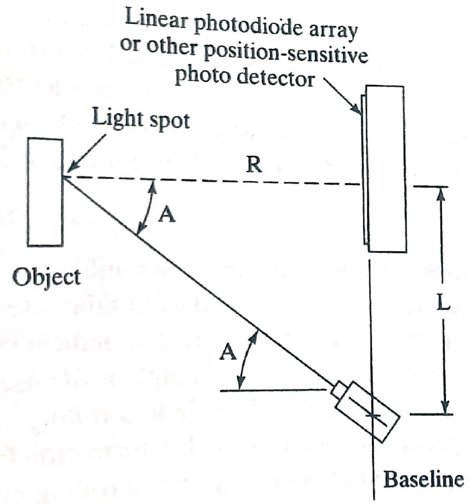

Figure 23.15 Principle of optical triangulation sensing.

8) Noncontact nonoptical Inspection Techniques

(i) Electrical Field Techniques
(ii) Radiation Techniques
(iii) Ultrasonics Inspection Methods