3. With the use of extension bars the test radius can be selected to reflect the size of the machine and the sensitivity to particular issues (e.g. large radius circles are better at highlighting machine geometry errors, smaller circles are more sensitive to servo mismatch or lag).
4. Data capture is shown live on screen, so any errors or problems can be detected as the test progresses and the test stopped without wasting additional time (important if you are carrying out a large radius test with a slow feed rate).

5.6.1.3 Data analysis and diagnosis

1. The user has a choice of several report formats according to international standards (e.g., ISO, ASME) and the comprehensive Renishaw diagnostics (including volumetric analysis) with a number of different screens views and links to the help manual.
2. These reports give a value for a single overall indicator of machine positioning performance, e.g., circular deviation.
3. Many reports can be customised and can deliver an in-depth diagnosis of a machine's errors; all from a single test.

5.7 Computer Aided Metrology

5.7.1 Role of Computers in Metrology

1. **Computer based in Inspection**

Computer Aided Inspection (CAI) is a new technology that enables one to develop a comparison of a physical part to a 3D CAD model. This process is faster, more complete, and more accurate than using a Coordinate Measuring Machine (CMM) or other more traditional methods. An automatic inspection method and apparatus using structured light and machine vision camera is used to inspect an object in conjunction with the geometric model of the object. Camera images of the object are analyzed by computer to produce the location of points on the object's surfaces in three dimensions.

Point-cloud data is taken from a laser scanner or other 3-D scanning device. During a setup phase before object inspection, the points are analyzed with respect to the geometric model of the object. The software provides a graphical comparison of the manufactured part compared to the CAD model.

Many points are eliminated to reduce data-taking and analysis time to a minimum and prevent extraneous reflections from producing errors. When similar objects are subsequently inspected, points from each surface of interest are spatially averaged to give high accuracy measurements of object dimensions. The inspection device uses several multiplexed sensors, each composed of a camera and a structured light source, to measure all sides of the object in a single pass.

2. COMPUTER AIDED INSPECTION USING ROBOTS

Robots can be used to carry out inspection or testing operation for mechanical dimension physical characteristics and product performance.

Checking robot, programmable robot, and co-ordinate robot are some of the types given to a multi axis measuring machines. These machines automatically perform all the basic routines of a CNC coordinate measuring machine but at a faster rate than that of CMM.

They are not as accurate as p as CMM but they can check up to accuracies of 5micrometers. The co-ordinate robot can take successive readings at high speed and evaluate the results using a computer graphics based real time statistical analysis system.

5.8 CO-ORDINATE MEASUREMENT MACHINES (CMM)

The term measuring machine generally refers to a single-axis measuring instrument. Such an instrument is capable of measuring one linear dimension at a time. The term coordinate measuring machine refers to the instrument/machine that is capable of measuring in all three orthogonal axes. Such a machine is popularly abbreviated as CMM.

A CMM enables the location of point coordinates in a three-dimensional (3D) space. It simultaneously captures both dimensions and orthogonal relationships. Another remarkable feature of a CMM is its integration with a computer. The computer provides additional power to generate 3D objects as well as to carry out complex mathematical calculations. Complex objects can be dimensionally evaluated with precision and speed.

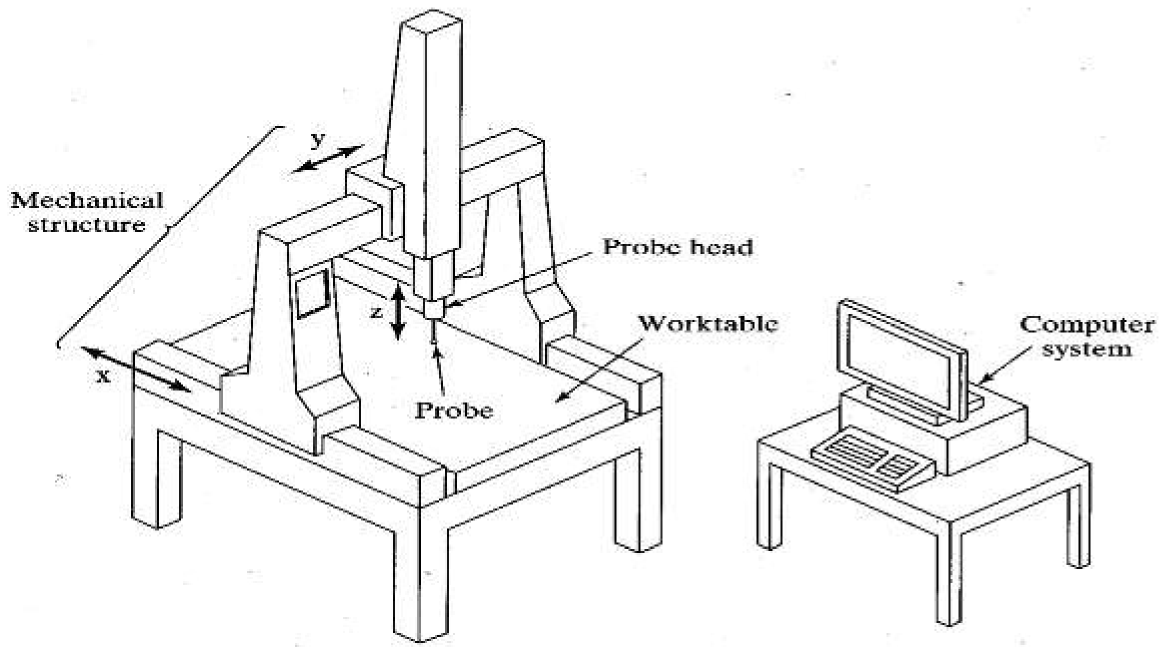


Fig. 5.31 CO-ORDINATE MEASUREMENT MACHINE

The first batch of CMM prototypes appeared in the United States in the early 1960s. However, the modern version of CMM began appearing in the 1980s, thanks to the rapid developments in computer technology. The primary application of CMM is for inspection. Since its functions are driven by an on-board computer, it can easily be integrated into a computer-integrated manufacturing (CIM) environment. Its potential as a sophisticated measuring machine can be exploited under the following conditions:

Multiple features The more the number of features (both dimensional and geometric) that are to be controlled, the greater the value of CMM.

Flexibility It offers flexibility in measurement, without the necessity to use accessories such as jigs and fixtures.

Automated inspection Whenever inspection needs to be carried out in a fully automated environment, CMM can meet the requirements quite easily.

High unit cost If rework or scrapping is costly, the reduced risk resulting from the use of a CMM becomes a significant factor.

5.8.1 Introduction

- 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.
- 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.

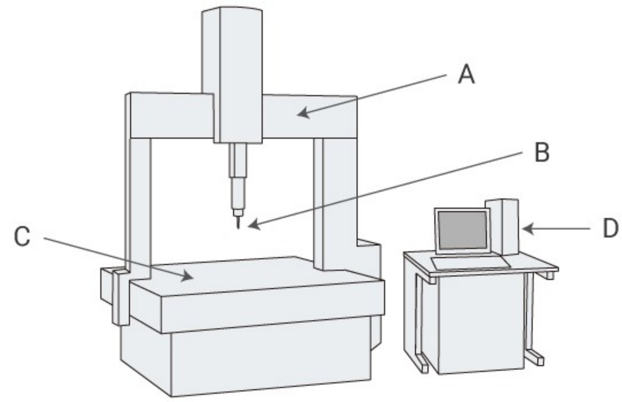
5.8.2 Types of Measuring Machines

- Length bar measuring machine.
- Newell measuring machine.
- Universal measuring machine.
- Co-ordinate measuring machine.
- Computer controlled co-ordinate measuring machine.

3.8.3 Structure

The basic version of a CMM has three axes, along three mutually perpendicular directions. Thus, the work volume is cuboidal. A carriage is provided for each axis, which is driven by a separate motor. While the straight-line motion of the second axis is guided by the first axis, the third axis in turn is guided by the second axis. Each axis is fitted with a precision measuring system, which continuously records the displacement of the carriage from a fixed reference.

The third axis carries a probe. When the probe makes contact with the workpiece, the computer captures the displacement of all the three axes. Depending on the geometry of the workpiece being measured, the user can choose any one among the five popular physical configurations. Figure illustrates the five basic configuration types: cantilever, bridge, column, horizontal arm and gantry.



A. Moving bridge B. Trigger probe

C. Stage D. Controller

Fig. 5.32 Co-Ordinate Measurement Machines (CMM)

5.8.4 TYPES OF CO-ORDINATE MEASUREMENT MACHINES (CMM)

5.8.4.1 Cantilever type CMM

The vertically positioned probe is carried by a cantilevered arm. The probe moves up and down along the Z-axis, whereas the cantilever arm moves in and out along the Y-axis (lateral movement). The longitudinal movement is provided by the X-axis, which is basically the work table. This configuration provides easy access to the workpiece and a relatively large work volume for a small floor space.

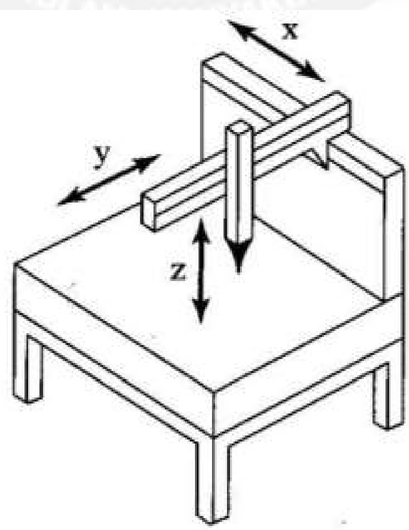


Fig. 5.33 Cantilever type CMM

5.8.4.2 Bridge type CMM

A bridge-type configuration is a good choice if better rigidity in the structure is required. The probe unit is mounted on a horizontal moving bridge, whose supports rest on the machine table.

a) Moving Bridge type CMM

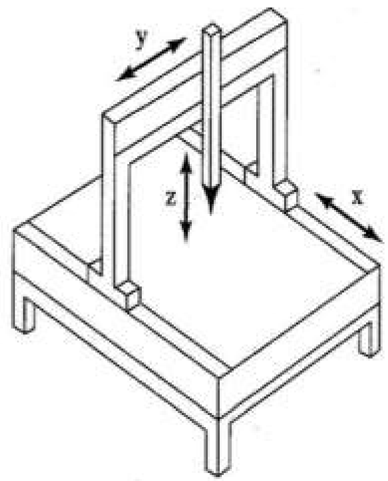


Fig. 5.33 Moving Bridge type CMM

- Most widely used
- Has stationary table to support work piece to be measured and a moving bridge
- **Disadvantage**- with this design, the phenomenon of yawing (sometimes called walking) can occur- affect the accuracy
- **Advantage**- reduce bending effect

b) Fixed Bridge type CMM

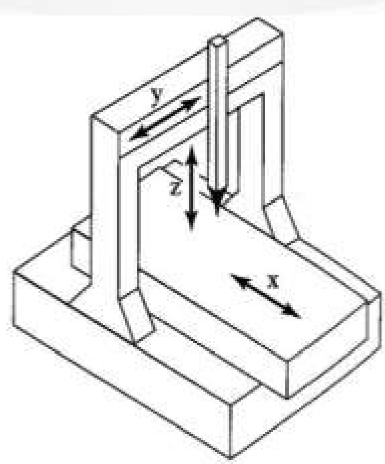


Fig. 5.34 Fixed Bridge type CMM

- In the fixed bridge configuration, the bridge is rigidly attached to the machine bed
- This design eliminates the phenomenon of walking and provides high rigidity

5.8.4.3 Column type CMM

This configuration provides exceptional rigidity and accuracy. It is quite similar in construction to a jig boring machine. Machines with such a configuration are often referred to as universal measuring machines.

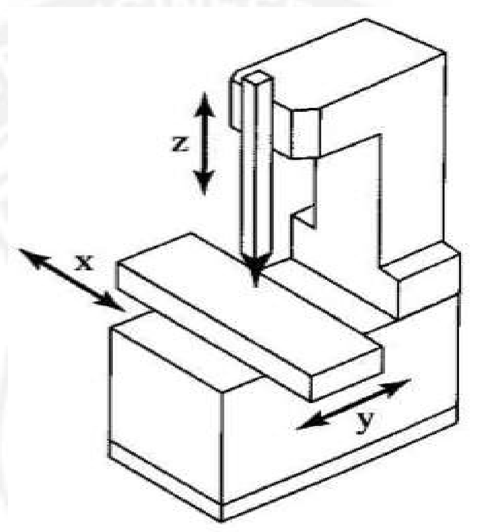


Fig. 5.35 Column type CMM

5.8.4.4 Horizontal arm type CMM

In this type of configuration, the probe is carried by the horizontal axis. The probe assembly can also move up and down along a vertical axis. It can be used for gauging larger workpieces since it has a large work volume. It is often referred to as a layout.

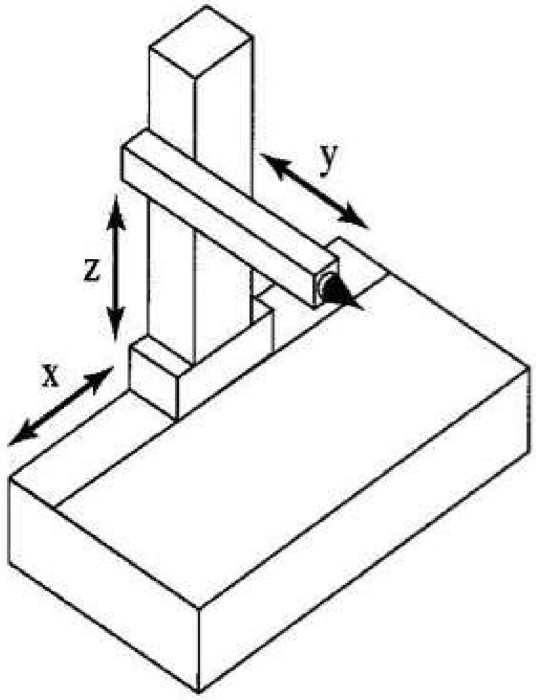


Fig. 5.36 Horizontal arm type CMM

5.8.4.5 Gantry type CMM

In this configuration, the support of the workpiece is independent of the X- and Y-axis. Both these axes are overhead and supported by four vertical columns from the floor. The operator can walk along with the probe, which is desirable for large workpieces. Some of the machines may have rotary tables or probe spindles, which will enhance the versatility of the machines. The work space that is bounded by the limits of travel in all the axes is known as the work envelop. Laser interferometers are provided for each of the axes if a very precise measurement is necessary.

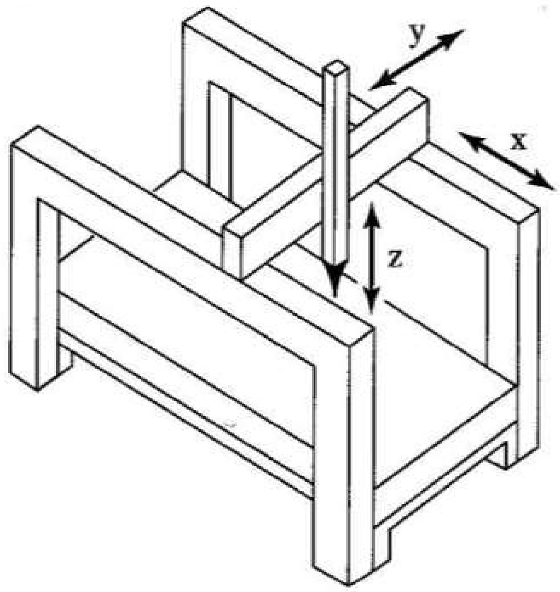


Fig. 3.37 Gantry type CMM

5.8.5 Modes of Operation

Modes of operation are quite varied in terms of type of construction and degree of automation. Accordingly, CMMs can be classified into the following three types based on their modes of operation:

1. Manual
2. Semi-automated
3. Computer controlled

The manual CMM has a free-floating probe that the operator moves along the machine's three axes to establish contact with part features. The differences in the contact positions are the measurements. A semi-automatic machine is provided with an electronic digital display for measurement. Many functions such as setting the datum, change of sign, and conversion of dimensions from one unit to another are done electronically.

A computer-controlled CMM has an on-board computer, which increases versatility, convenience, and reliability. Such machines are quite similar to CNC machines in their control and operation. Computer assistance is utilized for three major functions. Firstly, a programming software directs the probe to the data collection points. Secondly, measurement commands enable comparison of the distance traversed to the standard built into the machine for that axis. Thirdly, computational capability enables processing of the data and generation of the required results.5

5.8.6 CMM Operation and Programming

Positioning the probe relative to the part can be accomplished in several ways, ranging from manual operation to direct computer control.

Computer-controlled CMMs operate much like CNC machine tools, and these machines must be programmed.

5.8.6.1 CMM Operation

This section explains the operation or the measurement process using a CMM. Most modern CMMs invariably employ computer control. A computer offers a high degree of versatility, convenience, and reliability. A modern CMM is very similar in operation to a computer numerical control (CNC) machine, because both control and measurement cycles are under the control of the computer. A user-friendly software provides the required functional features. The software comprises the following three components:

1. Move commands, which direct the probe to the data collection points

2. Measurement commands, which result in the comparison of the distance traversed to the standard built into the machine for that axis

3. Formatting commands, which translate the data into the form desired for display or printout.

Machine Programming

Most measurement tasks can be carried out using readily available subroutines. The subroutines are designed based on the frequency with which certain measurement tasks recur in practice. An operator only needs to find the subroutine in a menu displayed by the computer. The operator then inputs the data collection points, and using simple keyboard commands the desired results can be obtained. The subroutines are stored in the memory and can be recalled whenever the need arises.

The program automatically calculates the centre point and the diameter of the best-fit circle. A cylinder is slightly more complex, requiring five points. The program determines the best-fit cylinder and calculates the diameter, a point on the axis, and a best-fit axis.

Situations concerning the relationship between planes are common. Very often, we come across planes that need to be perfectly parallel or perpendicular to each other. A situation where the perpendicularity between two planes is being inspected. Using a minimum of two points on each line, the program calculates the angle between the two lines. Perpendicularity is defined as the tangent of this angle. In order to assess the parallelism between two planes, the program calculates the angle between the two planes. Parallelism is defined as the tangent of this angle.

In addition to subroutines, a CMM needs to offer a number of utilities to the user, especially mathematical operations. Most CMMs have a measurement function library. The following are some typical library programs:

1. Conversion from SI (or metric) to British system

2. Switching of coordinate systems, from Cartesian to polar and vice versa

3. Axis scaling

4. Datum selection and resetting

5. Nominal and tolerance entry

6. Bolt-circle centre and diameter

7. Statistical tools

5.8.7 CMM Controls

The methods of operating and controlling a CMM can be classified into four main categories:

1. Manual drive,
2. Manual drive with computer-assisted data processing,
3. Motor drive with computer-assisted data processing, and
4. Direct Computer Control with computer-assisted data processing

1. In **Manual drive CMM**, the human operator physically moves the probe along the machine's axes to make contact with the part and record the measurements.

- The measurements are provided by a digital readout, which the operator can record either manually or with paper print out.
- Any calculations on the data must be made by the operator.

2. A CMM with **Manual drive and computer-assisted data processing** provides some data processing and computational capability for performing the calculations required to evaluate a give part feature.

- The types of data processing and computations range from simple conversions between units to more complicated geometry calculations, such as determining the angle between two planes.

3. A **Motor-driven CMM with computer-assisted data processing** uses electric motors to drive the probe along the machine axes under operator control.

- A joystick or similar device is used as the means of controlling the motion.
- Motor-driven CMMs are generally equipped with data processing to accomplish the geometric computations required in feature assessment.

4. A CMM with **Direct computer control** (DCC) operates like a CNC machine tool. It is motorized and the movements of the coordinate axes are controlled by a dedicated computer under program control.

- The computer also performs the various data processing and calculation functions.
- As with a CNC machine tool, the DCC CMM requires part programming.

5.8.8 DCC CMM Programming

There are two principle methods of programming a DCC measuring machine:

1. Manual lead through method.

2. Off-line programming.

1. In the **Manual Lead through method**, the operator leads the CMM probe through the various motions required in the inspection sequence, indicating the points and surfaces that are to be measured and recording these into the control memory.

- During regular operation, the CMM controller plays back the program to execute the inspection procedure.

2. **Off-line Programming** is accomplished in the manner of computer-assisted NC part programming; The program is prepared off-line based on the part drawing and then downloaded to the CMM controller for execution.

5.9 PROBES IN CMM

A **Coordinate Measuring Machine** is defined by the ability of its probe. As with CMMs, there are several types of probes available. There is the contact probe, which measures the workpieces by making contact with them. The non-contact probe that employs lasers or machine vision probes which scan with optical sensors.

Contact probes are a more accurate way of measuring. However, the laser or machine vision probes are far quicker to use, while still holding a high degree of accuracy. There are also multi-sensor probes which combine both touch and optical scanning, giving the benefit of both types in one probe.

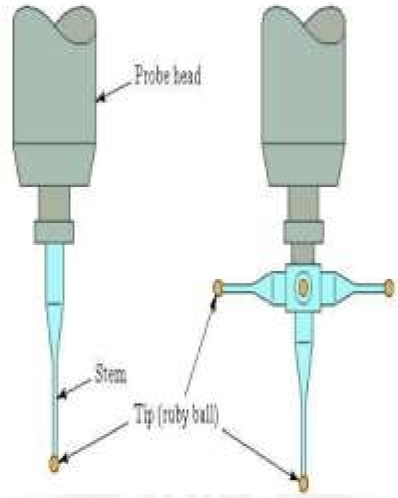


Fig. 5.38 PROBES IN CMM

The probe is the main sensing element in a CMM. Generally, the probe is of 'contact' type, that is, it is in physical contact with the workpiece when the measurements are taken. Contact probes may be either 'hard' probes or 'soft' probes. However, some CMMs also use a non-contact-type.

A probe assembly comprises the probe head, probe, and stylus. The probe is attached to the machine quill by means of the probe head and may carry one or more styli. Some of the probes are motorized and provide additional flexibility in recording coordinates.

The stylus is integral with hard probes and comes in various shapes such as pointed, conical, and ball end. As a power feed is used to move the probe along different axes, care should be exercised when contact is made with the workpiece to ensure that excessive force is not applied on the probe. Excessive contact force may distort either the probe itself or the workpiece, resulting in inaccuracy in measurement. Use of soft probes mitigates this problem to a large extent. Soft probes make use of electronic technology to ensure application of optimum contact pressure between the probe and the workpiece. Linear voltage differential transformer heads are generally used in electronic probes. However, 'touch trigger' probes, which use differences in contact resistance to indicate deflection of the probe, are also popular.

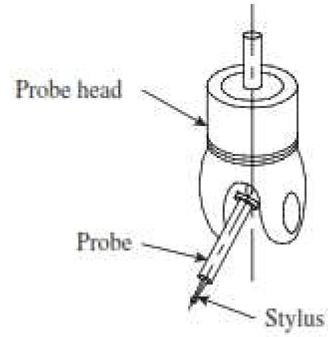


Fig. 5.39 Probe Assembly

Some measurement situations, for example, the inspection of printed circuit boards, require non-contact-type probes. Measurement of highly delicate objects such as clay or wax models may also require this type of probe. Most non-contact probes employ a light beam stylus. This stylus is used in a manner similar to a soft probe. The distance from the point of measurement is known as standoff and is normally 50 mm. The system provides 200 readings per second for surfaces with good contrast. The system has high resolution of the order of 0.00005 mm. However, illumination of the workpiece is an important aspect that must be taken into consideration to ensure accurate measurement.

5.9.1 TYPES OF PROBES

5.9.1.1 Contact Probes

The two most common contact probes are Touch Trigger Probes and Analog Scanning Probes.

a. Touch Trigger Probes:

A touch trigger probe has a stylus that is attached to a bearing plate. This is then connected to pressure sensors inside the housing of the probe. Each time the probe makes contact with the workpiece, it generates an electrical signal. The signal is sent back to the CMM to create accurate measurements.

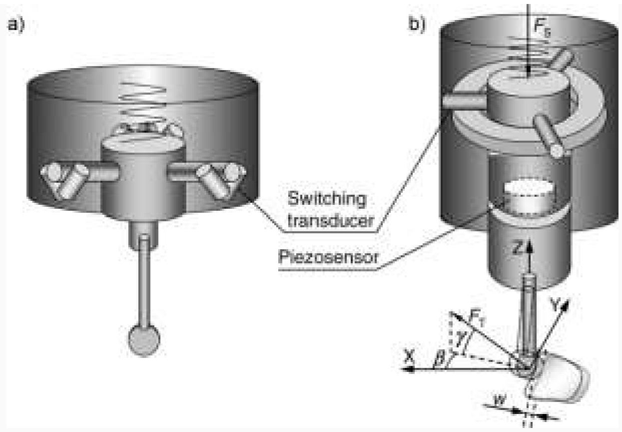


Fig.50.40 Schematic of the touch trigger probes. (a) One-stage type with an electromechanical switching transducer. (b) two-stage type based on a piezoelectric transducer.

With a touch trigger probe, the head is mounted at the end of one of the CMM's moving axes. The probe can be rotated either manually or automatically and can accommodate a variety of attachments and stylus tips.

The advantage of touch probes is that they are versatile and flexible. By incorporating the **piezo-based sensors**, the effect of stylus bending was eliminated, while the **strain gauge technology** advancements have ensured that the probes trigger with constant force regardless off the angle of contact it has with the workpiece. These two things combined eliminate directional sensitivity which has given these probes a sub-micron level of accuracy.

b. Analog Scanning Probes

Analogue scanning probes are another type of stylus-based probes that are used for measuring contoured surfaces such as sheet metal assemblies. Unlike digital probes, which touch individual points, the analogue probe keeps continual contact with the workpiece taking measurements as it is dragged across it.

Fig. 5.41 Analog Scanning Probes

The continual contact which yields analogue measurements offers dramatically increased levels of data acquisition. The structure of the continuous analogue scanning (CAS) probes is based on continuous data acquisition rather than the point to point of a digital probe.

Analogue scanning probes are extremely useful for collecting the measurement data for complex contoured shapes such as turbine engine blades, cams, automobile bodies, crankshafts and prosthetics.

There are two types of continuous analogue scanning, CAS, systems:

1. Closed-Loop Systems: This probe automatically detects changes in the surface and direction of the workpiece and adjusts itself accordingly to ensure that it maintains contact at all times. The closed-loop system is particularly useful for digitising unknown and complex shapes.

2. Open-Loop Systems: This probe gets driven along a specific path using dimensional information obtained from a data file. The open-loop system is particularly useful for high-speed data gathering on parts with geometry that has been well defined by surface points and vectors or by CAD data.

Analogue probes can acquire up to fifty times more data than touch trigger probes in the same amount of time. The more data that is collected, the more confidence in its accuracy. If there are large gaps between data points the accuracy of the data may not be so assured.

Another advantage of analogue scanning probes over digital probes is their ability to also be used as a touch trigger probe which gives its users more flexibility. An operator will be able to choose which features require a quick touch and which need more time devoted to them. A critical feature that is particularly complex would require continual contact.

5.9.1.2 Non-Contact Probes

A non-contact probe is essential for any workpiece that is likely to become deformed under the pressure of a contact probe. They are also useful for more complex, smaller and high-precision workpieces. A non-contact probe is either laser-based or vision-based.

a. Laser Probes

A laser probe works in a similar way to the touch trigger probe. Instead of using a stylus, it uses a concentrated beam of light to take readings. The beam of light acts as an optical switch. When the beam is projected onto the part, the position will then be read by triangulation through a lens inside the probe receptor.

Fig. 5.42 Analog Scanning Probe

This technique is similar to the one used by surveyors when they want to find a position or location with bearings from a known distance between two fixed points.

b. Vision-Based Probes

Microprocessors and other very small parts require the use of vision-based probes. Rather than measuring the parts themselves, a mould is electronically digitised that will generate accurate dimensions for future workpieces.

Fig. 5.43 Vision-Based Probes

The Vision-Based Probes is a high-definition camera that is capable of generating multiple measurement points in one frame. This allows the features to be measured and compared to the electronic model by counting the pixels. A vision system lens only requires calibration once which is a huge advantage as other probes require recalibration more often.

The key advantage of a non-contact probe is that it enables the user to collect data from a larger surface area in less time than is possible with contact probes. However, the downside is that the accuracy of the readings is not as great as the contact probes. If you want speed over accuracy, then a non-contact probe is ideal. If you have a particularly complex essential part, you would be better suited to using a contact probe.

5.6.2 Probe Calibration

A remarkable advantage of a CMM is its ability to achieve a high level of accuracy even with reversal in the direction of measurement. It does not have the usual problems such as backlash and hysteresis associated with measuring instruments. However, the probe may mainly pose a problem due to deflection. Therefore, it needs to be calibrated against a master standard. Figure illustrates the use of a slip gauge for calibration of the probe. Calibration is carried out by touching the probe on either side of the slip gauge surface.

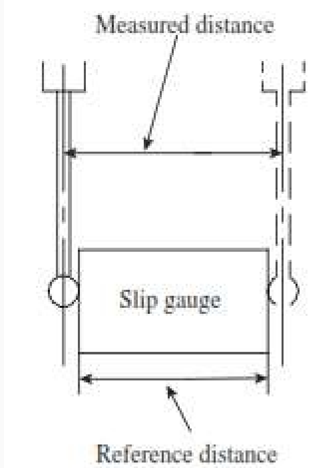


Fig. 5.44 Probe Calibration

The nominal size of the slip gauge is subtracted from the measured value. The difference is the 'effective' probe diameter. It differs from the measured probe diameter because it contains the deflection and backlash encountered during measurement. These should nearly remain constant for subsequent measurements.

5.9.3 Major Applications

The CMM is a sophisticated equipment, which offers tremendous versatility and flexibility in modern manufacturing applications. It uses the fundamental principles of metrology to an extent that is not matched by any other measurement instrument. However, its use is limited to situations where production is done in small batches but products are of high value. It is especially useful for components of varied features and complex geometry. In addition to these factors, a CMM is a good choice in the following situations:

1. A CMM can easily be integrated into an automated inspection system. The computer controls easy integration in an automated environment such as an FMS or a CIM. The major economic benefit is the reduction in downtime for machining while waiting for inspection to be completed.

2. A CMM may be interfaced with a CNC machine so that machining is corrected as the workpiece is inspected. A further extension of this principle may include computer assisted design and drafting (CADD).

3. Another major use (or abuse?) of CMMs is in reverse engineering. A complete 3D geometric model with all critical dimensions can be built where such models do not exist. Once the geometric model is built, it becomes easier to design dies or moulds for manufacturing operations. Quite often, companies create 3D models of existing critical dies or moulds of their competitors or foreign companies. Subsequently, they manufacture the dies, moulds, or components, which create a grey market for such items in the industry.

5.9.4 ADVANTAGES

- The inspection rate is increased.
- Accuracy is more.
- Operator's error can be minimized.
- Skill requirements of the operator is reduced.
- Reduced inspection fix Turing and maintenance cost.
- Reduction in calculating and recording time.
- Reduction in set up time.
- No need of separate go / no go gauges for each feature.
- Reduction of scrap and good part rejection.
- Reduction in off line analysis time.

5.9.5 DISADVANTAGES

- The table and probe may not be in perfect alignment.
- The probe may have run out.
- The probe moving in Z-axis may have some perpendicular errors.
- Probe while moving in X and Y direction may not be square to each other.
- There may be errors in digital system.

5.10 CAUSES OF ERRORS IN CMM

The table and probes are in imperfect alignment. The probes may have a degree of run out and move up and down in the Z-axis may occur perpendicularity errors. So CMM should be calibrated with master plates before using the machine.

Dimensional errors of a CMM is influenced by

- Straightness and perpendicularity of the guide ways.
- Scale division and adjustment.
- Probe length.
- Probe system calibration, repeatability, zero-point setting and reversal error.
- Error due to digitization.
- Environment
- Other errors can be controlled by the manufacture and minimized by the measuring software. The length of the probe should be minimum to reduce deflection.
- The weight of the work piece may change the geometry of the guide ways and therefore, the work piece must not exceed maximum weight.
- Variation in temperature of CMM, specimen and measuring lab influence the uncertainly of measurements.
- Translation errors occur from error in the scale division and error in straightness perpendicular to the corresponding axis direction.
- Perpendicularity error occurs if three axes are not orthogonal.

5.10.7 Comparison between conventional and coordinate measuring technology

TABLE 5.1 Comparison between conventional and coordinate measuring technology

CONVENTIONAL METROLOGY	COORDINATE METROLOGY
Manual, time consuming alignment of the test piece	Alignment of the test piece not necessary
Single purpose and multi-point measuring instruments making it hard to adapt to changing measuring task	Simple adaptation to the measuring test by software
Comparison of measurement with material measures, i.e., gauge block	Comparison of measurement with mathematical or numerical value
Separate determination of size, form, location and orientation with different machines	Determination of size, form, location and orientation in one setup using one reference system

5.6.8 Features of CMM Software

- Measurement of diameter, center distance, length.
- Measurement of plane and spatial carvers.
- Minimum CNC programmed.
- Data communications.
- Digital input and output command.
- Program me for the measurement of spur, helical, bevel' and hypoid gears.
- Interface to CAD software
- Generally, software packages contain some or all of the following capabilities:

1. Resolution selection
2. Conversion between SI and English (mm and inch)
3. Conversion of rectangular coordinates to polar coordinates

4. Axis scaling
5. Datum selection and reset
6. Circle center and diameter solution
7. Bolt-circle center and diameter
8. Save and recall previous datum
9. Nominal and tolerance entry
10. Out-of tolerance computation

5.10.1 BASIC CONCEPTS OF MACHINE VISION SYSTEM

Machine vision can be defined as a means of simulating the image recognition and analysis capabilities of the human system with electronic and electromechanical techniques.

A machine vision system enables the identification and orientation of a work part within the field of vision, and has far-reaching applications. It can not only facilitate automated inspection, but also has wide ranging applications in robotic systems. Machine vision can be defined as the acquisition of image data of an object of interest, followed by processing and interpretation of data by a computer program, for useful applications.

5.10.1 Stages of Machine Vision

The principal applications in inspection include dimensional gauging, measurement, and verification of the presence of components. The operation of a machine vision system, illustrated in Fig., involves the following four important stages:

1. Image generation and digitization
2. Image processing and analysis
3. Image interpretation
4. Generation of actuation signals

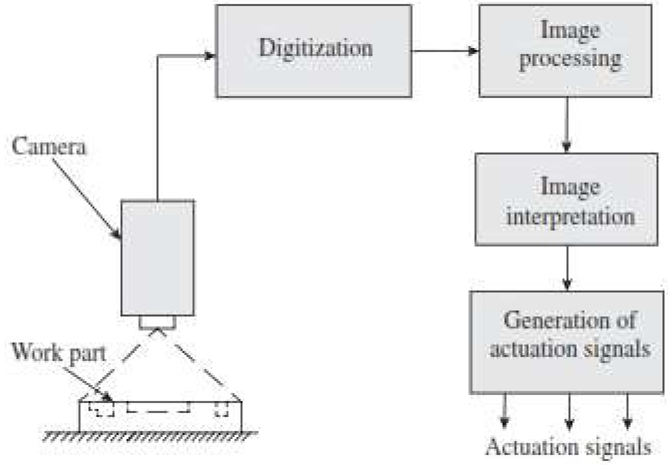


Fig. 5.46 Stages of Machine Vision

5.10.1.1 Image Generation and Digitization

The primary task in a vision system is to capture a 2D or 3D image of the work part. A 2D image captures either the top view or a side elevation of the work part, which would be adequate to carry out simple inspection tasks. While the 2D image is captured using a single camera, the 3D image requires at least two cameras positioned at different locations. The work part is placed on a flat surface and illuminated by suitable lighting, which provides good contrast between the object and the background. The camera is focused on the work part and a sharp image is obtained. The image comprises a matrix of discrete picture elements popularly referred to as pixels. Each pixel has a value that is proportional to the light intensity of that portion of the scene. The intensity value for each pixel is converted to its equivalent digital value by an analog-to-digital converter (ADC).

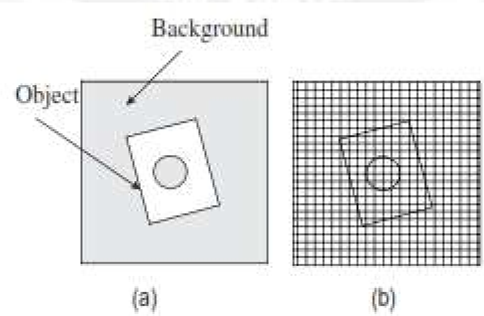


Fig. 5.47 Vision system (a) Object and background (b) Matrix of pixels

This digitized frame of the image is referred to as the frame buffer. While Fig. 10 illustrates the object kept in the scene of vision against a background, Fig. shows the division of the scene into a number of discrete spaces called pixels. The choice of camera and proper lighting of the scene are important to obtain a sharp image, having a good contrast with the background. Two types of cameras are used in machine vision applications, namely vidicon cameras and solid-state cameras. Vidicon cameras are analog cameras, quite similar to the ones used in conventional television pictures.

The image of the work part is focused onto a photoconductive surface, which is scanned at a frequency of 25–30 scans per second by an electron beam. The scanning is done in a systematic manner, covering the entire area of the screen in a single scan. Different locations on the photoconductive surface, called pixels, have different voltage levels corresponding to the light intensity striking those areas. The electron beam reads the status of each pixel and stores it in the memory. Solid-state cameras are more advanced and function in digital mode. The image is focused onto a matrix of equally spaced photosensitive elements called pixels. An electrical charge is generated in each element depending on the intensity of light striking the element. The charge is accumulated in a storage device. The status of every pixel, comprising either the grey scale or the colour code, is thus stored in the frame buffer. Solid-state cameras have become more popular because they adopt more rugged and sophisticated technology and generate much sharper images. Charge-coupled-device (CCD) cameras have become the standard accessories in modern vision systems.

5.10.1.2 Image Processing and Analysis

The frame buffer stores the status of each and every pixel. A number of techniques are available to analyse the image data. However, the information available in the frame buffer needs to be refined and processed to facilitate further analysis. The most popular technique for image processing is called segmentation. Segmentation involves two stages: thresholding and edge detection.

Thresholding converts each pixel value into either of the two values, white or black, depending on whether the intensity of light exceeds a given threshold value. This type of vision system is called a binary vision system. If necessary, it is possible to store different shades of grey in an image, popularly called the grey-scale system. If the computer has a higher main memory and a faster processor, an individual pixel can also store colour information. For the sake of simplicity, let us assume that we will be content with a binary vision system. Now the entire frame of the image will comprise a large number of pixels, each having a binary state, either 0 or 1. Typical pixel arrays are 128 × 128, 256 × 256, 512 × 512, etc.

Edge detection is performed to distinguish the image of the object from its surroundings. Computer programs are used, which identify the contrast in light intensity between pixels bordering the image of the object and resolve the boundary of the object.

In order to identify the work part, the pattern in the pixel matrix needs to be compared with the templates of known objects. Since the pixel density is quite high, one-to-one matching at the pixel level within a short time duration demands high computing power and memory. An easier solution to this problem is to resort to a technique known as feature extraction. In this technique, an object is defined by means of its features such as length, width, diameter, perimeter, and aspect ratio. The aforementioned techniques—thresholding and edge detection—enable the determination of an object's area and boundaries.

5.7.1.3 Image Interpretation

Once the features have been extracted, the task of identifying the object becomes simpler, since the computer program has to match the extracted features with the features of templates already stored in the memory. This matching task is popularly referred to as template matching. Whenever a match occurs, an object can be identified and further analysis can be carried out. This interpretation function that is used to recognize the object is known as pattern recognition. It is needless to say that in order to facilitate pattern recognition, we need to create templates or a database containing features of the known objects. Many computer algorithms have been developed for template matching and pattern recognition. In order to eliminate the possibility of wrong identification when two objects have closely resembling features, feature weighting is resorted to. In this technique, several features are combined into a single measure by assigning a weight to each feature according to its relative importance in identifying the object. This adds an additional dimension in the process of assigning scores to features and eliminates wrong identification of an object.

5.7.1.4 Generation of Actuation Signals

Once the object is identified, the vision system should direct the inspection station to carry out the necessary action. In a flexible inspection environment, the work-cell controller should generate the actuation signals to the transfer machine to transfer the work part from machining stations to the inspection station and vice versa. Clamping, declamping, gripping, etc., of the work parts are done through actuation signals generated by the work-cell controller.

5.7.2 Vision System

The schematic diagram of a typical vision system is shown. This system involves image acquisition; image processing Acquisition requires appropriate lighting. The camera and store digital image processing involve manipulating the digital image to simplify and reduce number of data points. Measurements can be carried out at any angle along the three reference axes x y and z without contacting the part. The measured values are then compared with the specified tolerance which stores in the memory of the computer.

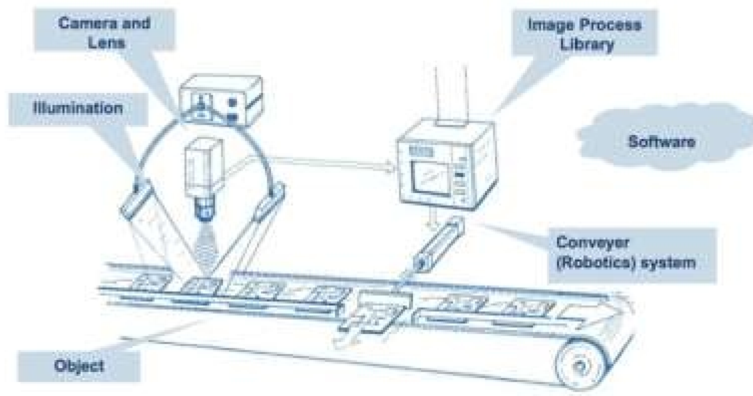


Fig. 5.47 Machine Vision System

The main advantage of vision system is reduction of tooling and fixture costs, elimination of need for precise part location for handling robots and integrated automation of dimensional verification and defect detection.

5.7.3 Principle

Four types (OR) Elements of machine vision system and the schematic arrangement is

Shown

(i) Image formation.

(ii) Processing of image in a form suitable for analysis by computer.

(iii) Defining and analysing the characteristic of image.

(iv) Interpretation of image and decision-making.

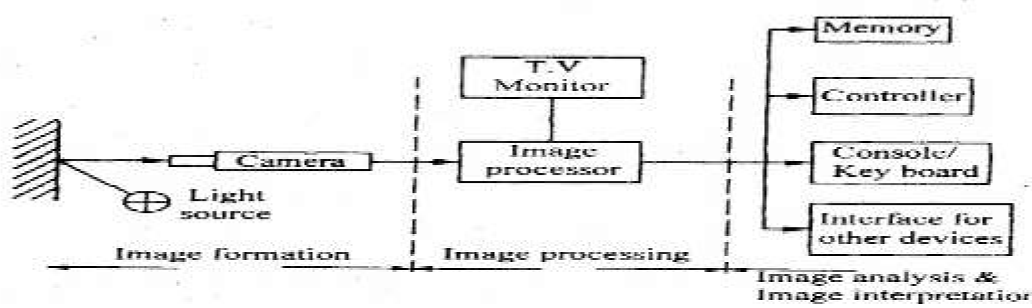


Fig. 5.48 Principle Machine Vision System

Image formation.

For formation of image suitable light source is required. It may consist of incandescent light, fluorescent tube, fiber-optic bundle, arc lamp, or strobe light. Laser beam is used for triangulation system for measuring distance. Polarised or ultraviolet light is used to reduce glare or increase contrast. It is important that light source is placed correctly since it influences the contrast of the image. Selection of proper illumination technique, (viz., back lighting, front lighting-diffused or directed bright field, or directed dark field, or polarised, structured light) is important. Back lighting is suited when a simple silhouette image is required to obtain maximum image contrast.

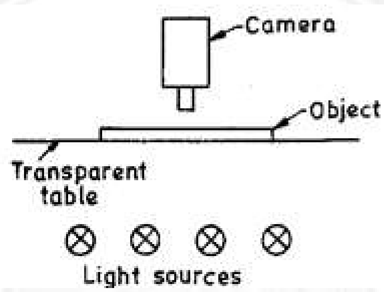


Fig. 5.49 Back lighting.

Front lighting is used when certain key features on the surface of the object are to be inspected. If a three-dimensional feature is being inspected, side lighting or structured lighting may be required. The proper orientation and fixturing of part also deserve full attention. An image sensor like vidicon camera, CCD or CID camera is used to generate the electronic signal representing the image. The image sensor collects light from the scene through a lens and using a photosensitive target, converts it into electronic signal. Most image sensors generate signals representing two-dimensional arrays (scans of the entire image).

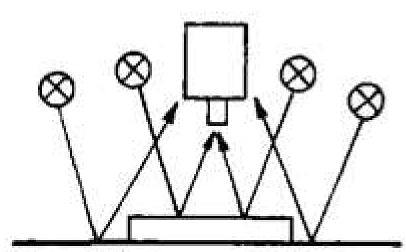
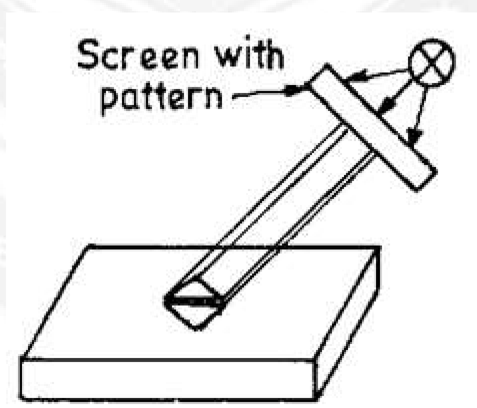


Fig. 5.50 Diffused front lighting.

Vidicon Camera used in closed-circuit television systems can be used for machine vision systems. In it, an image is formed by focussing the incoming light through a series of lenses onto the photoconductive face plate of the vidicon tube. An electron beam within the tube scans the photo conductive surface and produces an analog output voltage proportional to the variations in light intensity for each scan line of the original scene. It provides a great deal of information of a scene at very fast speeds. However, they tend to distort the image due to their construction and are subject to image burn-in on the photo conductive surface. These are also susceptible to damage by shock and vibration.

Solid State Cameras.

These are commonly used in machine vision systems. These employ charge coupled device (CCD) or charge injected device (CID) image sensors. They contain matrix or linear array of small, accurately spaced photo sensitive elements fabricated on silicon chips using integrated circuit technology. Each detector converts the light falling on it, through the camera lens, into analog electrical signal corresponding to light intensity. The entire image is thus broken down into an array of individual picture elements (pixels).



Typical matrix array solid state cameras may have 256 x 256 detector elements per array. Solid-state cameras are smaller, rugged and their sensors do not wear out with use. They exhibit less image distortion because of accurate placement of the photodetectors. CCD and CID differ primarily in how the voltages are extracted from the sensors.

(ii) Image Processing. The series of voltage levels available on detectors representing light intensities over the area of the image need processing for presentation to the microcomputer in a format suitable for analysis. A camera may typically form an image 30 times per sec i.e. at 33 m sec intervals. At each time interval the entire image has to be captured and frozen for processing by an image processor. An analog to digital converter is used to convert analog voltage of each detector into digital value.

If voltage level for each pixel is given either 0 or 1 value depending on some threshold value, it is called Binary System. On the other hand gray scale system assigns upto 256 different values depending on intensity to each pixel. Thus in addition to black and white, many different shades of gray can be distinguished. This thus permits comparison of objects on the basis of surface characteristics like texture, colour, orientation, etc., all of which produce subtle variations in light intensity distributions. Gray scale systems are used in applications requiring higher degree of image refinement. For simple inspection tasks, silhouette images are adequate and binary system may serve the purpose. It may be appreciated that gray-scale system requires huge storage processing capability because a 256 x 256 pixel image array with upto 256 different pixel values will require over 65000-8 bit storage locations for analysis, at a speed of 30 images per second. The data processing requirements can thus be visualised. It

is, therefore, essential that some means be used to reduce the amount of data to be processed. Various techniques in this direction are :

(a) Windowing. This technique is used to concentrate the processing in the desired area of interest and ignoring other non-interested part of image. An electronic mask is created around a small area of an image to be studied.

Thus only the pixels that are not blocked out will be analysed by the computer.

(b) Image Restoration. This involves preparation of an image in more suitable form during the pre-processing stage by removing the degradation suffered. The image may be degraded (blurring of lines/boundaries ; poor contrast between image regions, presence of background noise, etc.) due to motion of camera/object during image formation, poor illumination/poor placement, variation in sensor response, poor contrast on surface, etc.).

The quality may be improved, (i) by improving the contrast by constant brightness addition, (ii) by increasing the relative contrast between high and low intensity elements by making light pixels lighter and dark pixels darker (contrast stretching) or (iii) by fourier domain processing.

Other techniques to reduce processing are edge detection and run length encoding. In former technique, the edges are clearly found and defined and rather than storing the entire image, only the edges are stored. In run-length encoding, each line of the image is scanned, and transition points from black to white or vice versa are noted, along with the number of pixels between transitions. These data are then stored instead of the original image, and serve as the starting point for image analysis.

(iii) Image Analysis.

Digital image of the object formed is analysed in the central processing unit of the system to draw conclusions and make decisions. Analysis is done by describing and measuring the properties of several image features which may belong to either regions of the image or the image as a whole. Process of image interpretation starts with analysis of simple features and then more complicated features are added to define it completely. Analysis is carried for describing the position of the object, its geometric configuration, distribution of light intensity over its visible surface, etc.

Three important tasks performed by machine vision systems are measuring the distance of an object from a vision system camera, determining object orientation, and defining object position.

The distance of an object from a vision system camera can be determined by stadimetry (direct imaging technique, in which distance is judged by the apparent size of an object in the field of view of camera after accurate focussing), or by triangulation technique, or by stereo vision (binocular vision technique using the principle of parallax). The object orientation can be determined by the methods of equivalent ellipse (by calculating an ellipse of same area as the image of object in two-dimensional plane, and orientation of object being defined by the major axis of the ellipse), the connecting of three points (defining orientation by measuring the apparent relative position of three points of image), light intensity distribution (determining orientation based on relative light intensity), structured light method (in which the workpiece is illuminated by the structured light and the three dimensional shape and the orientation of the part are determined by the way in which the pattern is distorted by the part).

Image can be interpreted by analysis of the fundamental geometric properties of two-dimensional images.

Usually, parts tend to have distinct shapes that can be recognized on the basis of elementary features. For complex three-dimensional objects, additional geometric properties need to be determined, including descriptions of various image segments (process being known as feature extraction). In this method the boundary locations are determined and the image is segmented into distinct regions and their geometric properties determined. Then these image regions are organised in a structure describing their relationship.

An image can also be interpreted on the basis of difference in intensity of light in different regions. Analysis of subtle changes in shadings over the image can add a great deal of information about the three-dimensional nature of the object.

(iv) Image Interpretation.

Image interpretation involves identification of an object based on recognition of its image. Various conclusions are drawn by comparing the results of the analysis with a prestored set of standard criteria.

In a binary system, the image is segmented or windowed on the basis of clustering of white and black pixels. Then all groups of black pixels within each segment (called blocks) and groups of white pixels (called holes) are counted and total quantity is compared with expected numbers to determine how closely the real image matches the standard image.

Statistical approach can be utilised to interpret image by identification of a part on the basis of a known outline. The extent of analysis required for part recognition depends on both the complexity of the image and the goal of the analysis. The complex images can be interpreted by use of Gray-scale interpretation technique and by the use of various algorithms.

The most commonly used methods of interpreting images are feature weighing (several image features and measured to interpret an image, a simple factor weighing method being used to consider the relative contribution of each feature to be analysed) and template matching (in which a mask is electronically generated to match a standard image of an object). In actual practice, several known parts are presented to the machine for analysis. The part features are stored and updated as each part is presented, until the machine is familiar with the part. Then the actual parts are studied by comparison with this stored model of a standard part.

Similarly mathematical models of the expected images are created. For complex shapes, the machine is taught by allowing it to analyse a simple part. Standard image-processing software is available for calculating basic image features and computing with models.

5.7.4 Function of Machine Vision

Lighting and presentation of object to evaluated.

- It has great compact on repeatability, reliability and accuracy.
- I.ighting source and projection should be chosen and give sharp contrast.
- Images sensor compressor TV camera may he vidicon or solid state.
- For simple processing, analog comparator and a computer controller to convert the video information to a binary image is used.
- Data compactor employs a high speed away processor to provide high speed processing of the input image data.
- System control computer communicates with the operator and make decision about the part being inspected.
- The output and peripheral devices operate the control of the system. The output enables the vision system to either control a process or provide caution and orientation information two a robot, etc.
- These operate under the control of the system control of computer

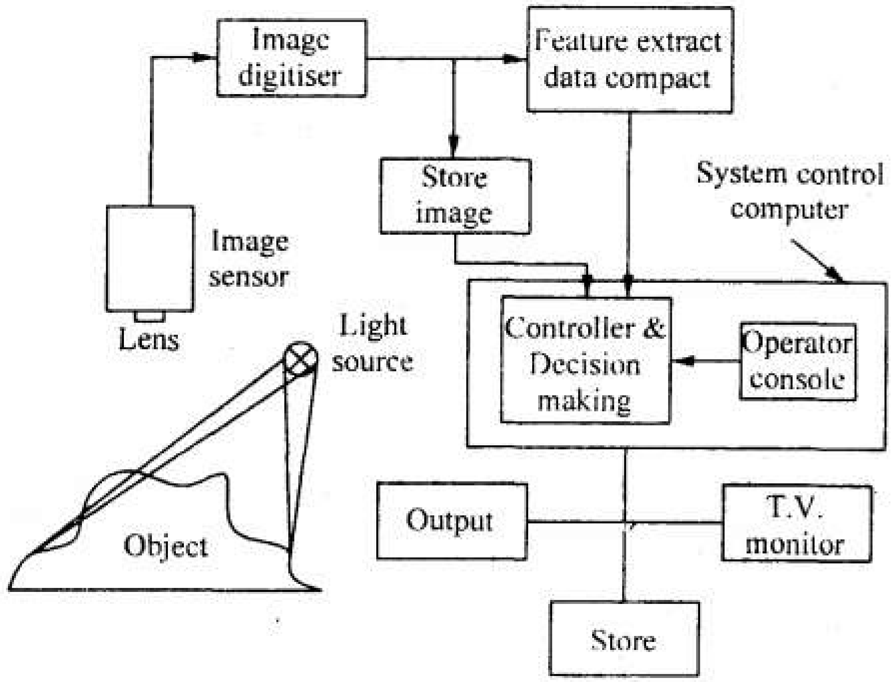


Fig. 5.52 Block Diagram of Machine Vision Function

5.7.5 Applications of Machine Vision in Inspection

Machine vision can he used to replace human vision fur welding. Machining and maintained relationship between tool and work piece and assembly of parts to analyze the parts.

- This is frequently used for printed circuit board inspection to ensure minimum conduction width and spacing between conductors. These are used for weld seam tracking, robot guideness and control, inspection of microelectronic devices and tooling, on line inspection in machining operation, assemblies monitoring high-speed packaging equipment etc.
- It gives recognition of an object from its image. These are designed to have strong geometric feature interpretation capabilities and pa handling equipment.

Machine vision systems are used for various applications such as part identification, safety monitoring, and visual guidance and navigation. However, by far, their biggest application is in automated inspection. It is best suited for mass production, where 100% inspection of components is sought. The inspection task can either be in on-line or off-line mode. The following are some of the important applications of machine vision system in inspection:

Dimensional gauging and measurement

Work parts, either stationary or moving on a conveyor system, are inspected for dimensional accuracy. A simpler task is to employ gauges that are fitted as end effectors of a transfer machine or robot, in order to carry out gauging, quite similar to a human operator. A more complicated task is the measurement of actual dimensions to ascertain the dimensional accuracy. This calls for systems with high resolution and good lighting of the scene, which provides a shadow-free image.

Identification of surface defects

Defects on the surface such as scratch marks, tool marks, pores, and blow holes can be easily identified. These defects reveal themselves as changes in reflected light and the system can be programmed to identify such defects.

Verification of holes

This involves two aspects. Firstly, the count of number of holes can be easily ascertained. Secondly, the location of holes with respect to a datum can be inspected for accuracy.

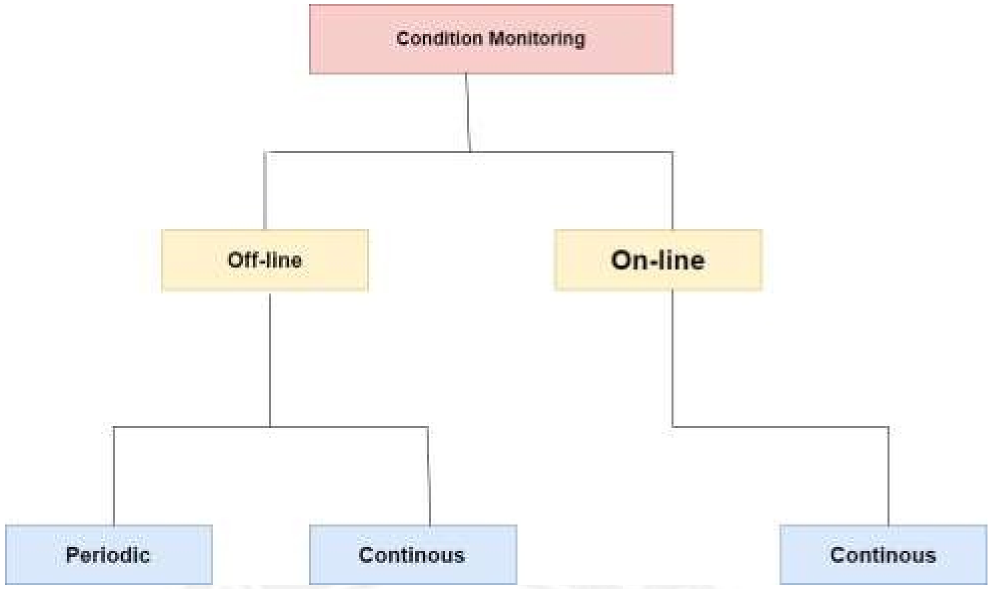
Identification of flaws in a printed label

Printed labels are used in large quantities on machines or packing materials. Defects in such labels such as text errors, numbering errors, and graphical errors can be easily spotted and corrective action taken before they are dispatched to the customer.

5.8 Combined On-Line and In-process Monitoring or Condition Based Maintenance

on-Load and Off-Load Testing

Condition monitoring can be done in two methods such as off-line or on-line condition monitoring, the machine is withdrawn from service and from supply. The machine is withdrawn from service and disconnected from its normal supply.



5.53 BLOCK DIAGRAM OF ONLINE AND OFFLINE SYSTEM

Off load monitoring is for interior or inaccessible parts which need to be stopped temporarily to check the condition. However, there may be several situations such as two-shift working or plant's temporary shut down for other reasons when this class can be conducted without productions loss.

Off-line monitoring systems can be periodic or continuous. In periodic system, monitoring equipment are connected during the time of monitoring or taking data or reading and then removed. In continuous monitoring, the monitoring equipment or instruments are connected as long as they operate.

On load monitoring means monitoring or adjusting the parameters while the machine or equipment is running. Thus, it is done for superficial, easily accessible and non-interfering parts of the equipment which can be carried out without interruption to the operation.

5.8.1 Methods and Instruments for Condition Monitoring

Various condition monitoring methods/techniques have been developed for the past 35years and they are in use. A number of strategies and techniques exist for collecting data and interpreting them for taking corrective action.

The success of condition monitoring depends on the efficiency of identifying the deteriorating trend in machine components. For this purpose, it is essential to recognize the source or cause of failure. There is variety of technologies which can be used as a part of condition monitoring program.

The extensive range of condition-based monitoring techniques are:

1. Oil Analysis

Oil analysis applies to machine oils, lubricants and fluids. It can detect wear, overheating, and contamination. High levels of iron, for example, often indicate dirt and grit. Spotted on time, this reduces gearbox failures by 50%. Avoiding contamination decreases bearing failure by 75%.

2. Vibration Analysis

Vibration analysis is one of the most well-known predictive maintenance methods. It can detect misalignments, imbalances, and wear about 3 months before they cause a breakdown. It’s also an opportunity to improve energy consumption, since misaligned water pumps, for example, spend up to 15% more energy.

3. Motor Circuit Analysis

Motor circuit analysis, also known as MCA testing, assesses the condition of electric motors. It can be used to analyse the motor’s condition (including rotors, coupling/ belt problems, power quality), electric imbalances, and insulation. More than preventing failures, MCA can be used to cut energy costs and improve equipment efficiency by 10-15%.

4. Thermography

Thermography studies the heat and radiation patterns in machines. Data analysis does the rest, spotting patterns that indicate failure or degradation. It has a wide array of applications, including detecting misalignment, imbalances, improper lubrication, wear, and stress in mechanical parts. In electrical equipment, it identifies overheating, pipe leaks, and pressure vessel weaknesses

5. Ultrasonic Monitoring

We've already mentioned ultrasonic analysis a while back (missed it? Read "vibration analysis" again), but it deserves a place of its own on this list. Ultrasonic monitoring uses high-frequency sound waves to catch leaks, parts seating, and cavitations, which can reduce inspections by 30%.

6. Radiography

Like thermography, radiography (including radiation analysis and neutron radiography) is a very thorough method of non-destructive testing. Imaging allows technicians to inspect internal defects, such as corrosion in sintered parts and flaws in welding. However, the main advantage is that it can be used in all types of materials, provided technicians protect themselves.

7. Laser interferometry

Laser interferometers measure changes to calculate displacement based on laser-generated wavelengths. They are used in condition monitoring to identify surface and subsurface defects like corrosion and cavities. Interferometry includes laser shearography, laser ultrasonics, strain mapping, electronic speckle pattern interferometry, and digital holography.

8. Electrical monitoring

A little over 53% of all accidental domestic fires in the UK are electrical fires. Likewise, electricity is one of the biggest reasons behind injuries and fatalities at work. Preventing electrical failures with close monitoring not only avoids breakdowns but also improves safety. This includes tests to assess resistance, induction, capacitance, pulse response, frequency response, and degradation.

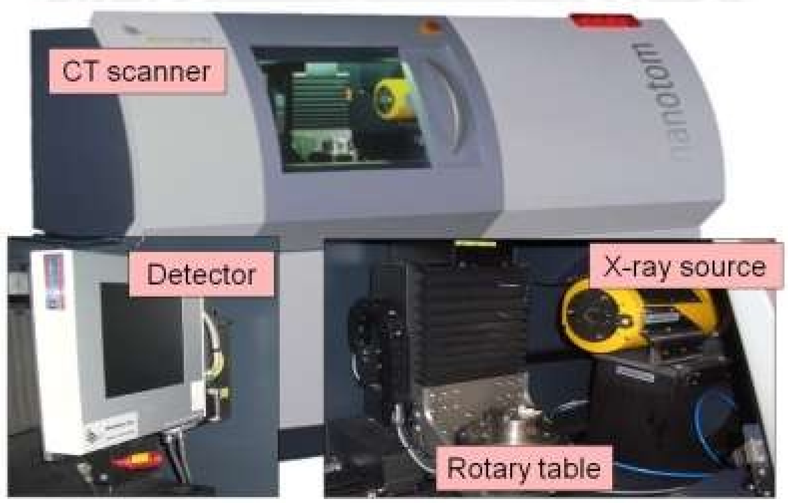
9. Electromagnetic Measurement

Electromagnetic measurement shouldn't be confused with electrical monitoring. Electromagnetic monitoring measures magnetic field distortions to spot cracks, dents, corrosion, weaknesses, and other defects (e.g., thinning).

COMPUTED TOMOGRAPHY

CT is a powerful tool capable of inspecting external and internal structures in many industrial applications as well as providing accurate geometrical information with very high accuracy

5.9 COMPUTED TOMOGRAPHY PRINCIPLE



COMPUTED TOMOGRAPHY

CT creates cross section images by projecting a beam of emitted photons through one plane of an object from defined angle positions performing one revolution. As the X-rays (emitted photons) pass through the object Â, some of them are absorbed Â, some are scattered Â, and some are transmitted. The process of X-ray intensity reduction, involving just those X-rays which are scattered or absorbed, is called attenuation. Xrays which are attenuated due to the interactions with the object do not reach the Xray detector. Photons transmitted through the object at each angle are collected on the detector and visualized by computer, creating a complete reconstruction of the scanned object.

5.9.1 CT Metrology for Comparison of Nominal and Actual Values

3D scans are frequently used for a comparison of surfaces. CT provides precise and clear models of surfaces including internal surfaces and interface for a non-destructive analysis of internal features and their connection to the external surface. Especially, it is also possible to compare a CT scan with a CAD model. Once the datasets have been aligned, the differences between the respective surfaces are naturally shown by color classes. So, this feature is used to compare the surface distances of a casting with those of the CAD model to detect changes in shape with respect to the theoretical value in terms of degree of wear over time in CT with a CAD file to identify pores close to machining surfaces which may trigger losses or leakages.

5.9.2 CT Metrology in Dimensional Survey of Internal Structures

CT is regularly used to collect data for compliance records on individual cavities of multi molds in plastic injection molding. The same procedure is also indispensable for drawing up the first article inspection report (FAIR) for a given production procedure. For plastic molding, CT allows the identification of tool wear simply by scanning pieces produced at different times.

Dimensional changes can be obtained and displayed in the similar way. Although a Coordinate Measuring Machine (CNfM) proves more appröpriate in certain circumstances, applied technical services identifies thar CT Provides Unmatched Among Product Validation Methods.

5.9.3 CT METROLOGY IN AEROSPACE INDUSTRIES

Effective quality management has always been crucial within the aerospace industry. Faulty designs and poorly manufactured parts not only lead to wasted resources and loss of profits, but also jeopardise company reputation and can compromise public safety.

The quest for quality has also helped push new innovations in aerospace. Whether that is through the greater usage of advanced materials like super alloys to increase aircraft performance and durability, or the adoption of additive manufacturing, enabling weight savings and space optimisation whilst allowing complex designs to be produced.

5.9.4 ADVANTAGES OF CT METROLOGY

- Precise, non-destructive measuring, including minute interior structures
- Non-sequential fast data acquisition with almost unlimited measurement points
- Excellent image quality for high-precision defect detection and the exact distinction between blowholes and material
- Substantial time savings via seamless defect analysis and nominal/actual comparison
- Reduced correction loops and cost
- Traceable measurement data for secure documentation
- Non-destructive testing method: parts are available for use after testing process
- Inspection and analysis costs from first article to production are significantly reduced
- Product quality is improved, reducing the risk of recalls
- Can scan different types of materials ranging in different sizes
- Can scan for the location, porosity, orientation, and web of internal fibers
- Varying wall thickness of a part can be identified and measured
- Reduces operational cost by minimizing time allocated toward quality control in preproduction when compared to traditional testing methods
- Fast and easy to retrieve results from a specialized lab.

5.10. WHITE LIGHT SCANNERS

White light scanners, also known as structured light scanners or 3D scanners, are devices used to capture the three-dimensional shape and geometry of objects or environments. These scanners project a pattern of structured light onto the surface of the object and then capture the reflected light using one or more cameras. The data from the captured light pattern is then processed to create a detailed 3D model of the scanned object.

The term "white light" in white light scanners refers to the use of visible light spectrum, typically from white light sources, such as LED projectors or flash lamps. The light projected onto the object creates a series of patterns that allow the scanner to measure the depth and shape of the object's surface.

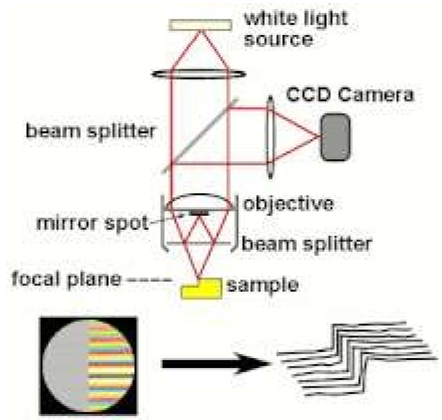
The process of 3D scanning using white light scanners involves the following steps:

1. Projection: The scanner projects a known pattern of light onto the object's surface. This pattern can be a series of stripes, grids, or dots.
2. Reflection: The patterned light reflects off the object's surface, and the scanner's cameras capture the deformed pattern based on the shape of the object's surface.
3. Data Processing: The captured images are processed by the scanner's software, which analyses the deformation of the pattern and calculates the 3D coordinates of points on the object's surface.
4. 3D Model Creation: The collected data is used to generate a high-resolution 3D model of the scanned object. This model can be saved in various formats, such as STL, OBJ, or PLY, and used for further analysis, visualization, or 3D printing.

White light scanners are used in various industries and applications, including reverse engineering, quality control, industrial design, medical imaging, archaeology, art preservation, and virtual reality, among others. These scanners are known for their accuracy, speed, and ability to capture intricate details of complex shapes and surfaces.

It's worth noting that since my knowledge has a cutoff date of September 2021, there may have been advancements or new developments in the field of 3D scanning beyond that point.

5.10.1 WORKING OF WHITE LIGHT SCANNERS



WHITE LIGHT SCANNING

White-light interferometry scanning (WLS) systems capture intensity data at a series of positions along the vertical axis, determining where the surface is located by using the shape of the white-light interferogram, the localized phase of the interferogram, or a combination of both shape and phase.

The white light interferogram actually consists of the superposition of fringes generated by multiple wavelengths, obtaining peak fringe contrast as a function of scan position, that is, the red portion of the object beam interferes with the red portion of the reference beam, the blue interferes with the blue, and so forth. In a WLS system, an imaging interferometer is vertically scanned to vary the optical path difference. During this process, a series of interference patterns are formed at each pixel in the instrument field of view. This results in an interference function, with interference varying as a function of optical path difference. The data are stored digitally and processed in a variety of ways depending on the system manufacturer, including being Fourier-transformed into frequency space, subject to cross-correlation methods, or analysis in the spatial domain.

5.10.2 APPLICATIONS

Industrial applications include in-process surface metrology, roughness measurement, 3D surface metrology in hard-to-reach spaces and in hostile environments, profilometry of surfaces with high aspect ratio features (grooves, channels, holes), and film thickness measurement (semi-conductor and optical industries, etc.)

5.10.3 ADVANTAGES

- They can provide a detailed view of the object's surface. This is because white light scanners use a broad spectrum of light, which allows them to capture more information about the object's surface. This can be helpful for applications where it is important to see fine details, such as quality control and inspection.
- They can be used to scan objects of any size or shape. This is because white light scanners do not require the object to be in a specific orientation. This makes them versatile and can be used to scan a wide variety of objects.
- They are relatively easy to use. White light scanners do not require any special expertise to operate. This makes them a good option for businesses that do not have a lot of experience with 3D scanning.

Here are some additional advantages of white light scanners:

- They are non-contact, which means that they do not damage the object being scanned.
- They can be used in a variety of environments, including those that are dusty or dirty.
- They can be used to create 3D models that can be used for a variety of purposes, such as visualization, reverse engineering, and manufacturing.

Overall, white light scanners are a versatile and powerful tool that can be used for a variety of applications. They are particularly well-suited for applications where a detailed view of the object's surface is required.