## 3.7 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.

### 3.7.1 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

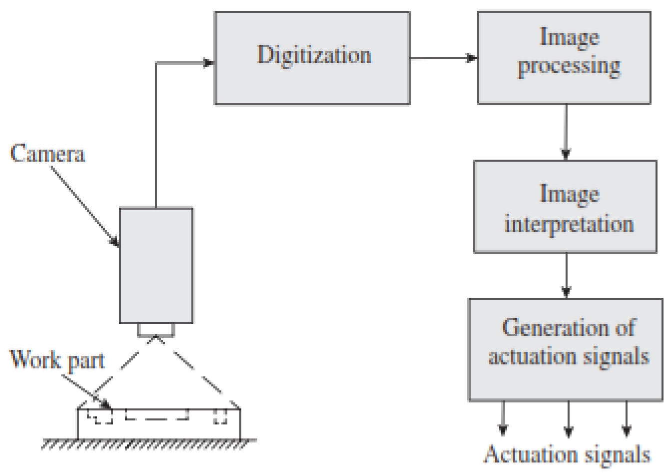


**Fig. 3.46 Stages of Machine Vision**

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-254]

### 3.7.1.1 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).

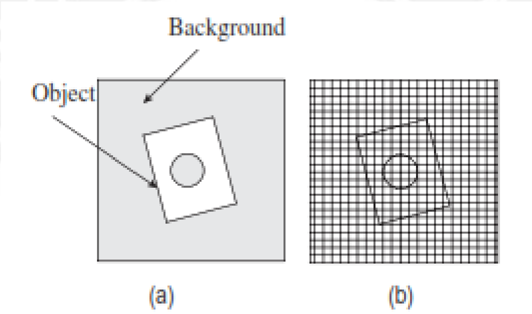


**Fig. 3.47 Vision system (a) Object and background (b) Matrix of pixels**

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-254]

This digitized frame of the image is referred to as the frame buffer. While Fig. 10.41(a) 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.

### 3.7.1.2 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.

### 3.7.1.3 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.

#### 3.7.1.4 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.

### 3.7.2 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.

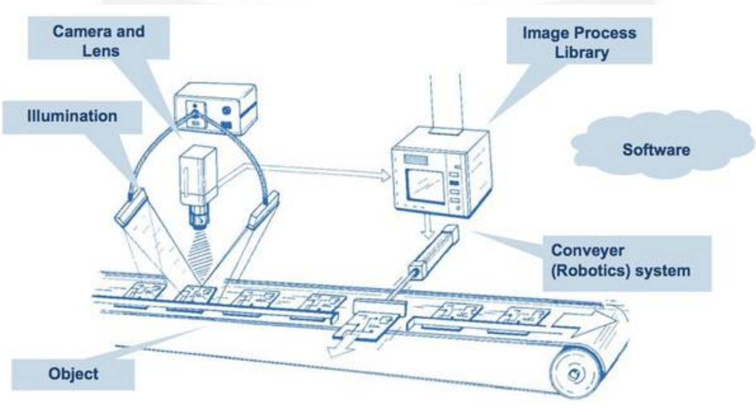


**Fig. 3.47 Machine Vision System**

[source: https://www.roboticstomorrow.com/article/2019/12/what-is-machine-vision/14548]

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.

### 3.7.3 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 analyzing the characteristic of image.
(iv) Interpretation of image and decision-making.

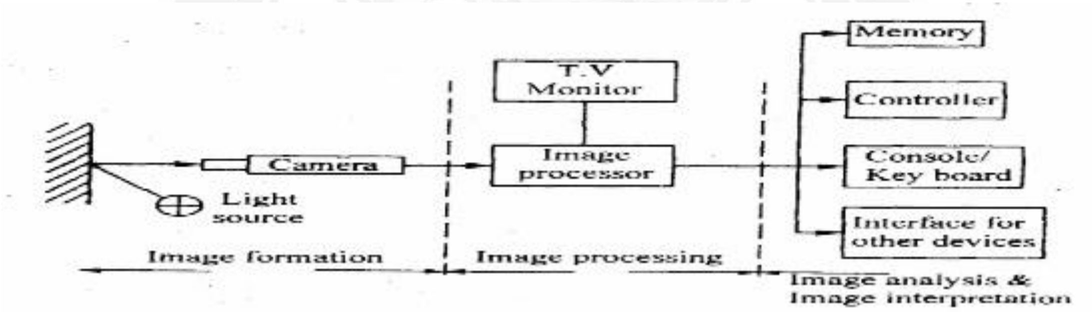


**Fig. 3.48 Principle Machine Vision System**

[source: https://what-when-how.com/metrology/principle-of-working-metrology/]

(i) **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.

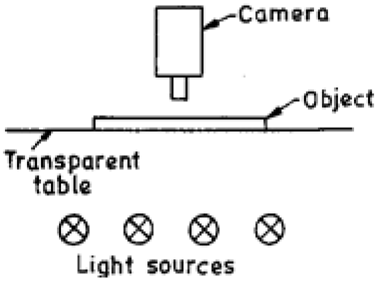


**Fig. 3.49 Back lighting.**

[source: https://what-when-how.com/metrology/principle-of-working-metrology/]

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).

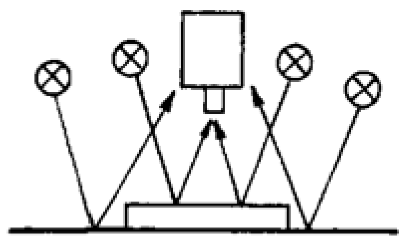

**Fig. 3.50 Diffused front lighting.**

[source: https://what-when-how.com/metrology/principle-of-working-metrology/]

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).

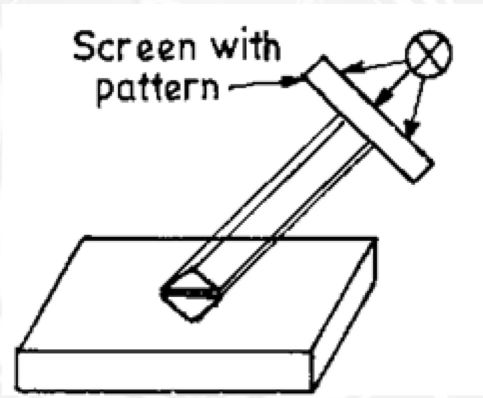


**Fig. 3.51** Structured light.

[source: https://what-when-how.com/metrology/principle-of-working-metrology/]

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.

### 3.7.4 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

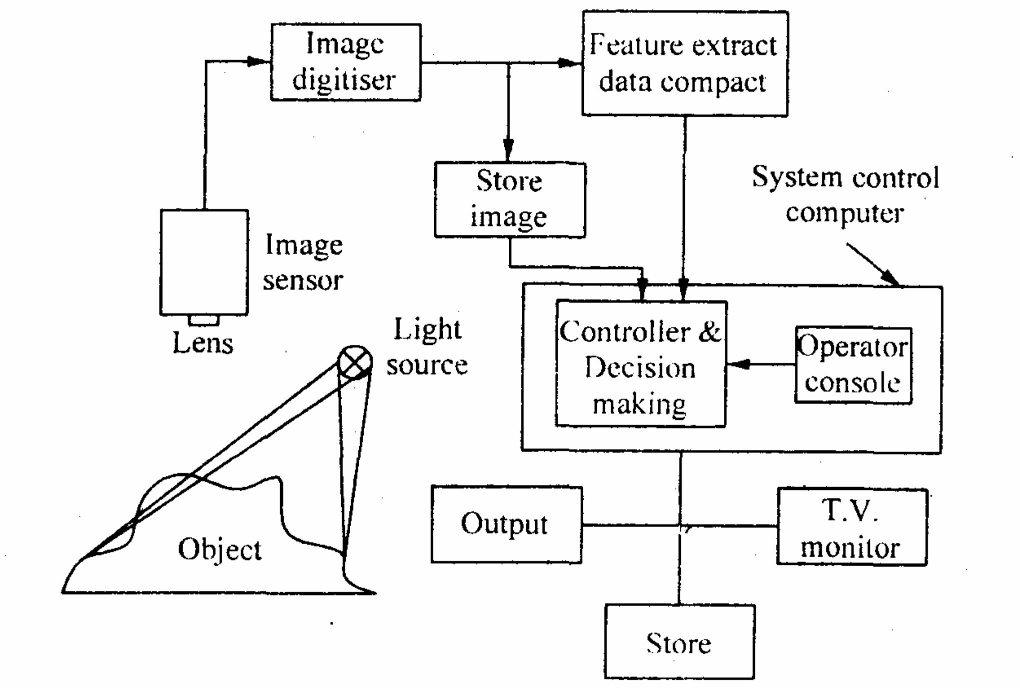


**Fig. 3.52 Block Diagram of Machine Vision Function**

[source: https://what-when-how.com/metrology/how-machine-vision-system-functions-metrology/]

### 3.7.5 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.