## UNIT 3 : SENSORS & MACHINE VISION

# Introduction to Sensors:

Sensors are devices that are used to measure physical variables like temperature, pH, velocity, rotational rate, flow rate, pressure and many others. Today, most sensors do not indicate a reading on an analog scale (like a thermometer), but, rather, they produce a voltage or a digital signal that is indicative of the physical variable they measure. Those signals are often imported into computer programs, stored in files, plotted on computers and analyzed to death.

Sensors come in many kinds and shapes to measure all kinds of physical variables. However, many sensors have some sort of voltage output. There are a number of implications to that.

1. If a sensor has a voltage output, then it is a voltage source that is controlled by the physical variable it measures.
2. the sensor is a voltage source, you need to remember that no physical voltage sources are ideal, and non-ideal voltage sources are usually best described with a Thevinin Equivalent Circuit that contains the voltage source and an internal resistance.
3. If a source has an internal resistance, there is a possibility of loading the source. If a significant load is attached to the source, the terminal voltage will drop. At that point, the terminal voltage is not what you expect it to be (from calibrations, spec sheets, etc.)

# Need of Sensors:

The latest sensor equipment includes heart rate, electrical voltage, gas, light, sound, temperature, and distance sensors. Data is collected via the sensors and then transmitted to the computer. Up to date software is used to collect, display and store the experimental data. The computer software can then display this data in different formats - such as graphs, tables or meter readings, which make it easy for students to understand the process and bring science to life.

The significance of sensor technology is constantly growing. Sensors allow us to monitor our surroundings in ways we could barely imagine a few years ago. New sensor applications are being identified everyday which broadens the scope of the technology and expands its impact on everyday life.

**In Industry**

On the factory floor, networked vibration sensors warn that a bearing is beginning to fail. Mechanics schedule overnight maintenance, preventing an expensive unplanned shutdown. Inside a refrigerated grocery truck, temperature and humidity sensors monitor individual containers, reducing spoilage in fragile fish or produce.

**In the Environment**

Networks of wireless humidity sensors monitor fire danger in remote forests. Nitrate sensors detect industrial and agricultural runoff in rivers, streams and wells, while distributed seismic monitors provide an early warning system for earthquakes. Meanwhile built-in stress sensors report on the structural integrity of bridges, buildings and roadways, and other man-made structures.

**For Safety and Security**

Fire fighters scatter wireless sensors throughout a burning building to map hot spots and flare-ups. Simultaneously, the sensors provide an emergency communications network.
Miniature chemical and biological sensors in hospitals, post offices, and transportation centers raise an alarm at the first sign of anthrax, smallpox or other terror agents.

## Requirements of a Sensor :

1. **Range:** It indicates the limits of the input in which it can vary. In case of temperature measurement, a thermocouple can have a range of 25 – 250 0C.
2. **Accuracy:** It is the degree of exactness between actual measurement and true value. Accuracy is expressed as percentage of full range output.
3. **Sensitivity:** Sensitivity is a relationship between input physical signal and output electrical signal. It is the ratio of change in output of the sensor to unit change in input value that causes change in output.
4. **Stability:** It is the ability of the sensor to produce the same output for constant input over a period of time.
5. **Repeatability:** It is the ability of the sensor to produce same output for different applications with same input value.
6. **Response Time:** It is the speed of change in output on a stepwise change in input.
7. **Linearity:** It is specified in terms of percentage of nonlinearity. Nonlinearity is an indication of deviation of curve of actual measurement from the curve of ideal measurement.
8. **Ruggedness:** It is a measure of the durability when the sensor is used under extreme operating conditions.

## SENSORS USED IN ROBOTICS

The use of sensors in robots has taken them into the next level of creativity. Most importantly, the sensors have increased the performance of robots to a large extent. It also allows the robots to perform several functions like a human being. The robots are even made intelligent with the help of Visual Sensors (generally called as machine vision or computer vision), which helps them to respond according to the situation. The Machine Vision system is classified into six sub-divisions such as Pre-processing, Sensing, Recognition, Description, Interpretation, and Segmentation

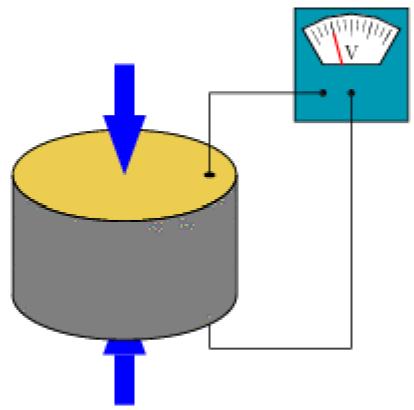
## Different types of sensors:

### 1. Position Sensors:

A variety of devices which are classed as Input Devices and are therefore called "Sensors" and in particular those sensors which are Positional in nature. As their name implies, Position Sensors detect the position of something which means that they are referenced either to or from some fixed point or position. These types of sensors provide a "positional" feedback.

One method of determining a position, is to use either "distance", which could be the distance between two points such as the distance travelled or moved away from some fixed point, or by "rotation" (angular movement). For example, the rotation of a robots wheel to determine its distance travelled along the ground. Either way, Position Sensors can detect the movement of an object in a straight line using Linear Sensors or by its angular movement using Rotational Sensors.

### 2. Piezoelectric sensor :




A **piezoelectric sensor** is a device that uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge.

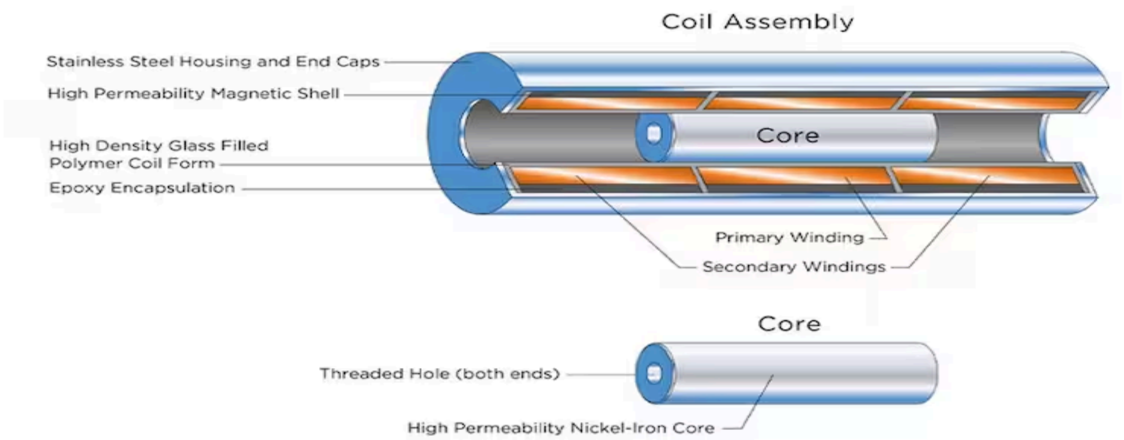
A piezoelectric sensor has very high output impedance and can be modeled as a proportional voltage source and filter network. The voltage *V* at the source is directly proportional to the applied force, pressure, or strain.[10] The output signal is related to this mechanical force as if it had passed through the equivalent circuit..

Piezoelectric technology can measure various physical quantities, most commonly pressure and acceleration. For pressure sensors, a thin membrane and a massive base is used, ensuring that an applied pressure specifically loads the elements in one direction. For accelerometers, a seismic mass is attached to the crystal elements. When the accelerometer experiences a motion, the invariant seismic mass loads the elements according to Newton's second law of motion F=ma

The main difference in working principle between these two cases is the way they apply forces to the sensing elements. In a pressure sensor, a thin membrane transfers the force to the elements, while in accelerometers an attached seismic mass applies the forces. Sensors often tend to be sensitive to more than one physical quantity. Pressure sensors show false signal when they are exposed to vibrations. Sophisticated pressure sensors therefore use acceleration compensation elements in addition to the pressure sensing elements. By carefully matching those elements, the acceleration signal (released from the compensation element) is subtracted from the combined signal of pressure and acceleration to derive the true pressure information.

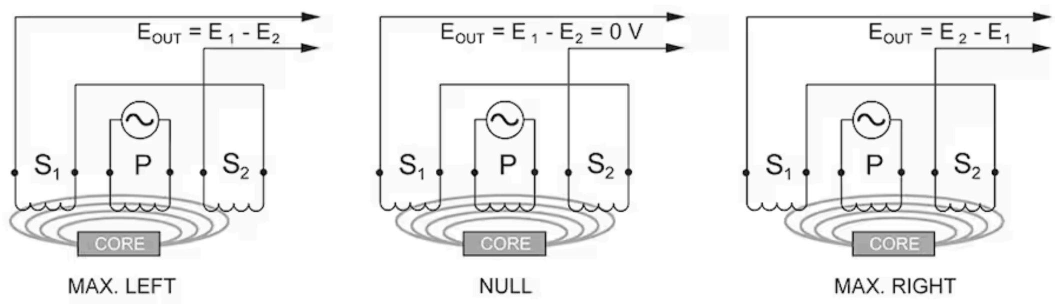
## 3. LVDT:

## (LINEAR VARIABLE DIFFERENTIAL TRANSFORMER)




**Linear Variable Differential Transformer.** It is a common type of electromechanical transducer that can convert the rectilinear motion of an object to which it is coupled mechanically into a corresponding electrical signal. internal structure consists of a primary winding centered between a pair of identically wound secondary windings, symmetrically spaced about the primary. The coils are wound on a one-piece hollow form of thermally stable glass reinforced polymer, encapsulated against moisture, wrapped in a high permeability magnetic shield, and then secured in a cylindrical stainless steel housing. This coil assembly is usually the stationary element of the position sensor. The moving element of an LVDT is a separate tubular armature of magnetically permeable material. This is called the core, which is free to move axially within the coil's hollow bore, and mechanically coupled to the object whose position is being measured. This bore is typically large enough to provide substantial radial clearance between the core and bore, with no physical contact between it and the coil. In operation, the LVDT's primary winding is energized by alternating current of appropriate amplitude and frequency, known as the primary excitation. The LVDT's electrical output signal is the differential AC voltage between the two secondary windings, which varies with the axial position of the core within the LVDT coil. Usually this AC output voltage is converted by suitable electronic circuitry to high level DC voltage or current that is more convenient to use.

Working principle:




The LVDT's primary winding, P, is energized by a constant amplitude AC source. The magnetic flux thus developed is coupled by the core to the adjacent secondary windings, S1 and S2. If the core is located midway between S1 and S2, equal flux is coupled to each secondary so the voltages, E1 and E2, induced in windings S1 and S2 respectively, are equal. At this reference midway core position, known as the null point, the differential voltage output, (E1 - E2), is essentially zero. As shown in Figure 2, if the core is moved closer to S1 than to S2, more flux is coupled to S1 and less to S2, so the induced voltage E1 is increased while E2 is decreased, resulting in the differential voltage (E1 - E2). Conversely, if the core is moved closer to S2, more flux is coupled to S2 and less to S1, so E2 is increased as E1 is decreased, resulting in the differential voltage (E2 - E1).

## 4. **Resolvers**:

A resolver is another type of analog device whose output is proportional to the angle of a rotating element with respect to a fixed element. In its simplest form, a resolver has a single winding on its rotor and a pair of windings on its stator. The stator windings are 90 apart. If the rotor is excited with a signal of the type A sin(oor) the voltage across the two pairs of stator terminals will be

$V_{s1}$(t) = A sin(ωt) sinθ and

$V_{s2}$(t) = A sin(ωt) sinθ

where θ is the angle of the rotor with respect to the stator. This signal may be used directly, or it may be converted into a digital representation using a device known as a 'resolver-to-digital' converter. Since a resolver is essentially a rotating transformer, it is important to remember that an ac signal must be used for excitation. If a dc signal were used there would be no output signal

## 5. Optical Encoders:

As microprocessors have become cheaper and with a move towards digital electronics, the encoder is virtually used everywhere for position measurement Almost all industrial robots, NC machines, etc., use encoders to measure the position and velocity of motion. Encoders are available as two basic types: incremental and absolute. There are various categories of encoding devices, but we will limit our discussion to those that are most commonly used in robots, i.e., optical encoders A simple incremental encoder is illustrated in Fig. 3.13.

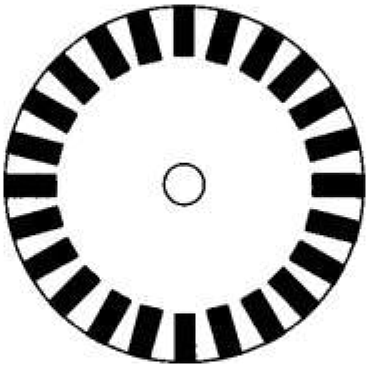
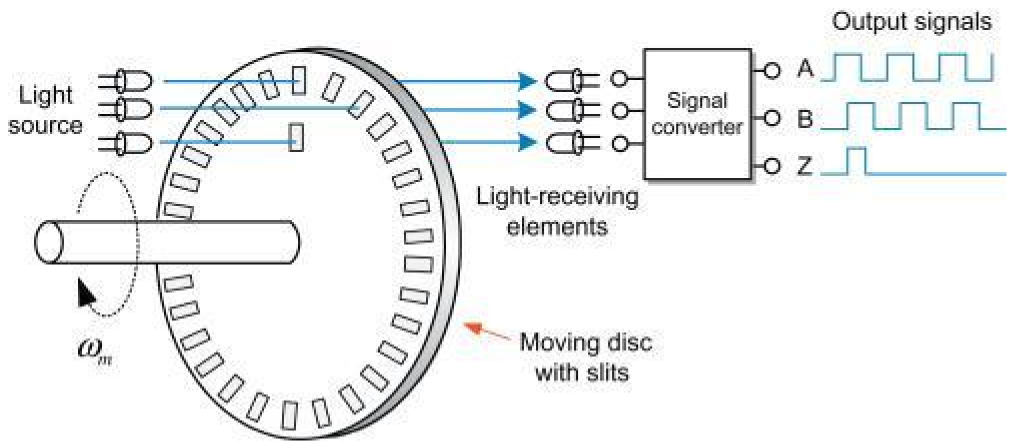


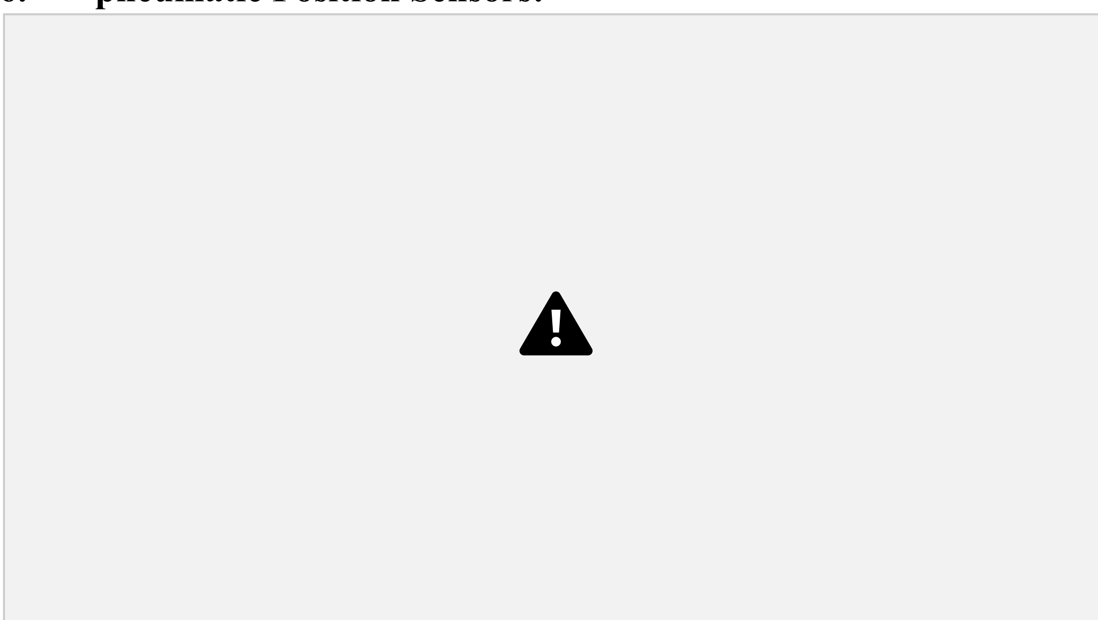
Fig: Incrementalencoder

An incremental encoder consists of a disk marked with alternating transparent and opaque stripes aligned radially. A phototransmitter (a light source) is located on one side of the disk and a photo receiver is on the other Fig. 3.14. As the disk rotates, the light beam is alternately completed and broken. The output from the photoreceiver is a pulse train whose frequency is proportional to the speed of rotation of the disk. In a typical encoder, there are two sets of phototransmitters and receivers aligned 90° out of phase. This phasing provides direction information, that is, if signal A leads to signal B by 90° the encoder disk is rotating in one direction, if B leads A then it is going in the other direction. By counting the pulses and by adding or subtracting based on the sign, it is possible to use the encoder to provide position information with respect to a known starting location. Normally, two incremental encoders are used in parallel so that the resolution of measurement is increased. These two signals are passed through an XOR gate. It can be seen that the resolution of the resulting




signal is now increased two times, as we now have two pulses in place of only one pulse from each encoder Most modern position control systems have two or more encoders in parallel to increase the resolution of the systems. The rate at which the pulses are generated by the encoder can also be counted to get an estimate of the velocity of the rotating shaft. Hence, an encoder can also be used as a velocity sensor. In some cases, it is desirable to know the, position of an object in absolute terms, that is, not with respect to a starting position. For this an absolute encoder could be used. Absolute encoders employ the same basic construction as incremental encoders except that there are more tracks of stripes and a corresponding number of receivers and transmitters. Usually the stripes are arranged to provide a binary number proportional to the shaft angle. The first track might have two stripes, the second four, the third eight and so on. In this way the angle can be read directly from the encoder without any counting being necessary

## 6. pneumatic Position Sensors:



Pneumatic cylinders often have magnets attached to their pistons, which allows for the use of magnetic proximity sensors to detect their position. The

sensor can be mounted in different places to detect the cylinder's extension, retraction, or other positions. Multiple sensors can be attached to a single cylinder to provide feedback on multiple positions.
Here are some types of pneumatic position sensors:

**Magnetic proximity sensors:**

These sensors can detect the magnet attached to the piston through the cylinder wall. For example, when the cylinder extends, the sensor detects the magnet, and when it retracts, the sensor turns on.

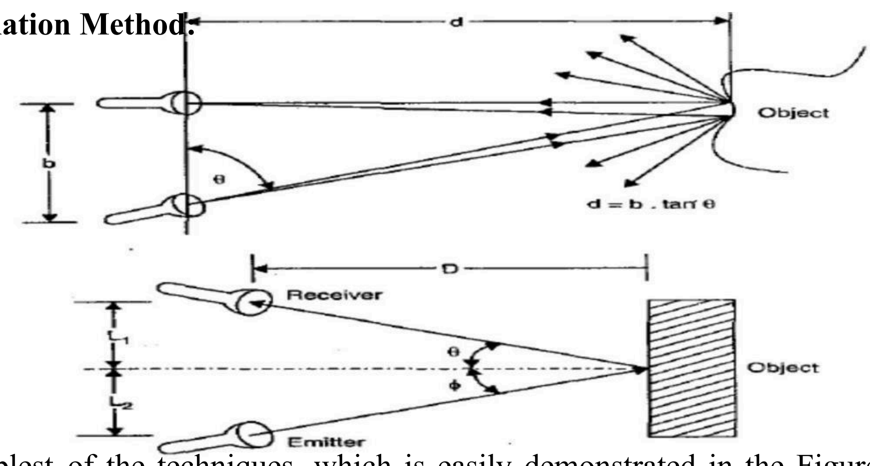
**Potentiometric sensors:**

These sensors use a resistance pot embedded in the cylinder's rear end cap, and an electrically conductive wiper that contacts a plastic probe. As the wiper moves, the resistance changes, which can be used to determine the position of the cylinder rod. These sensors are rugged, but can wear out if used frequently

## 7. Range sensors :

The distance between the object and the robot hand is measured using the range sensors Within it is range of operation. The calculation of the distance is by visual processing. Range sensors find use in robot navigation and avoidance of the obstacles in the path. The - location and the general shape characteristics of the part in the work envelope of the robot S done by special applications for the range sensors. There are several approaches like, triangulation method, structured lighting approach and time-of flight range finders etc. In these cases the source of illumination can be light-source, laser beam or based on ultrasonic.

## 8. Triangulation Method:




This is the simplest of the techniques, which is easily demonstrated in the Figure. The object is swept over by a narrow beam of sharp light. The sensor focused on a small spot of the object surface detects the reflected beam of light. If ‘Θ’ is the angle made by the illuminating source and ‘b’ is the distance between source and the sensor, the distance‘d’ of the sensor on the robot is given as

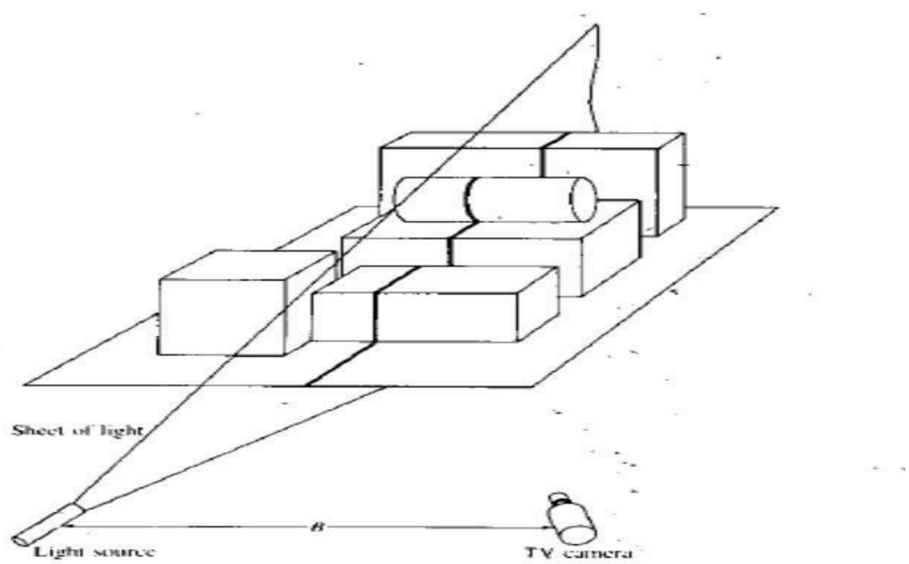
$$d = b \cdot \tan \theta$$

The distance ‘d’ can be easily transformed into 3D-co-ordinates

## 9. Structured Lighting Approach:

This approach consists of projecting a light pattern the distortion of the pattern to calculate the range. A pattern in use today is a sheet of light generated narrow slit.

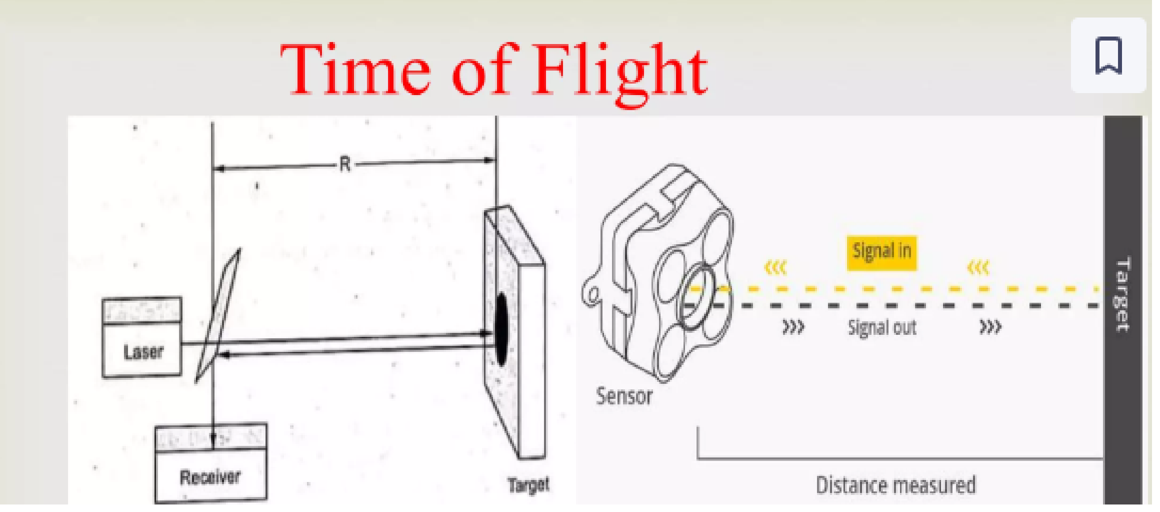
As illustrated in. Figure, the intersection of the sheet with objects in the‘ work space yields a light stripe which is viewed through a television camera displaced a distance B from the light source. The stripe pattern is easily analyzed by a computer to obtain range information. For example, an inflection indicates a change of surface, and a break corresponds to a gap between surfaces.




**Range measurement by structured lighting approach.**

Specific range values are computed by first calibrating the system. One of the simplest arrangements is shown in Figure, which represents a top view of Figure. In this, arrangement, the light source and camera are placed at the same height, and the sheet of light is perpendicular to the line joining the origin of the light sheet and the center of the camera lens. We call the vertical plane containing this line the reference plane. Clearly, the reference plane is perpendicular to the sheet of light, and any vertical flat surface that intersects the sheet Will produce a vertical stripe of light in which every point will have the same perpendicular distance to the reference plane. - The objective of. the arrangement shown in Figure. is to position the camera so that every such vertical stripe also appears vertical in the image plane. In this way, every point, the same column in the _image will be known to have the same distance to the reference plane.

## 10. Time of Flight:




The Time-of-Flight principle (ToF) is a method for measuring the distance between a sensor and an object, based on the time difference between the emission of a signal and its return to the sensor, after being reflected by an object. Various types of signals (also called carriers) can be used with the Time-of-Flight principle, the most common being sound and light. Tera Ranger sensors use light as their carrier because it is uniquely able to combine higher speed, longer range, lower weight, and eye- safety. By using infrared light we can ensure less signal disturbance and easier distinction from natural ambient light, resulting in the highest performing distance sensors for their given size and weight.

**Advantages:**

1.Mass resolution
2.Greater sensitivity
3.Rapid acquisition
4.Simple and Compact
5.Fast Distance algorithm

**Disadvantages:**

1.Background light or multiple reflection.
2.Low dynamic application.

11. **Range Finders:**

A rangefinder (also rangefinding telemeter, depending on the context) is a device used to measure distances to remote objects. Originally optical devices used in surveying, they soon found applications in other fields, such as photography, the military, and space travel. They were especially useful for finding the range of a target, such as in naval gunnery and anti-aircraft artillery.

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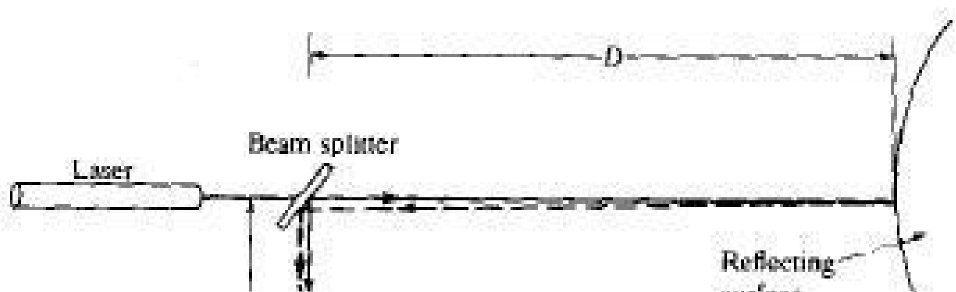
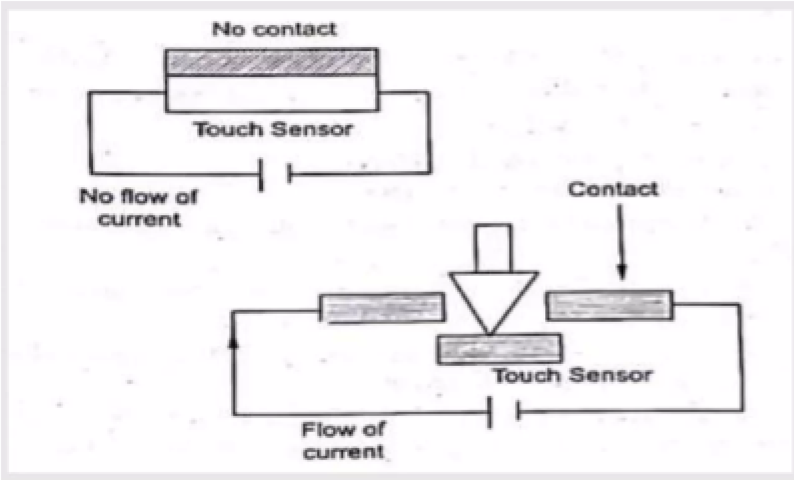
## 12. Laser range meters:

A pulsed-laser system described by larvis [produces a two-dimensional array with values proportional to distance. The two-dimensional scan is accom plished by deflecting the laser light via a rotating mirror. The 66 working range of this device is on the order of I to 4 m, with an accuracy of ± 0.25 cm. Figure shows a collection of three-dimensional objects, and Figure is the corresponding sensed array displayed as art image in which the intensity at each point is proportional to the distance between the sensor and the reflecting surface at that point (darker is closer). The bright areas around the object boundaries represent discontinuity in range determined by post processing in a computer An alternative to pulsed light is to use a continuous-beam laser and measure the delay (i.e., phase shift) between the outgoing and returning beams



**13. Touch Sensor** :




A touch sensor is a type of equipment that captures and records physical touch or embrace on a device and object. It enables a device or object to detect touch, typically by a human user or operator.

Example: Digital Sensor

**Working Principle:**

It is working of a sensor is similar to that of a simple switch. Surface of the touch sensor the circuit is closed inside the sensor and there is flow of current. When contact is released the circuit is opened and no currant flows. Some of the commonly used simple devices micro switches, limit switches. These sensors are mostly use robot obstacles. It can be reversed, turned, switched ON and stopped.

**Advantages:**

1.Durable
2.Esaily readable.
3.Simple construction
4.Good dynamic range.

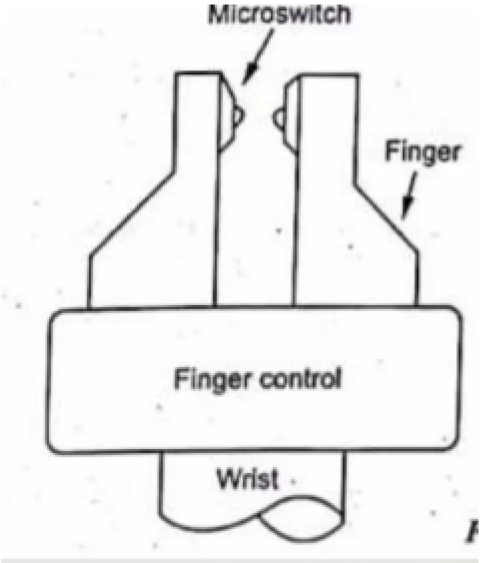
**Disadvantages:**

Hystersis
Non Linearity
Low sensitivity

**Applcations:**

Smart phones
Tablet computer.

## 14. BINARY SENSOR :




Binary sensors gather information about the state of devices which have a "digital" return value (either 1 or 0). These can be switches, contacts, pins, etc. These sensors only have two states: 0/off/low/closed/false and 1/on/high /open/true. Knowing that there are only two states allows Home Assistant to represent these sensors in a better way in the frontend according to their functionality. Binary sensor only have two states ON (or) OFF "0" (or) low (or) closed (or) false and "1" (or) ON (or)High (or) Open (or)True. Binary sensor which have either the state ON or OFF

**Working Principle:**
Sensor are contact switch which is placed on the inner side of the each finger. Object making contact with its surface. Provide more tactile information. Control signal for directing the hand over the work piece. They binary sensor detects whether the robot or object has crossed it. Information will be utilized in identifying the presence of object.

**Advantages:**

1.Reliable
2.Low cost
3.Simple to operate
4. Error is low.

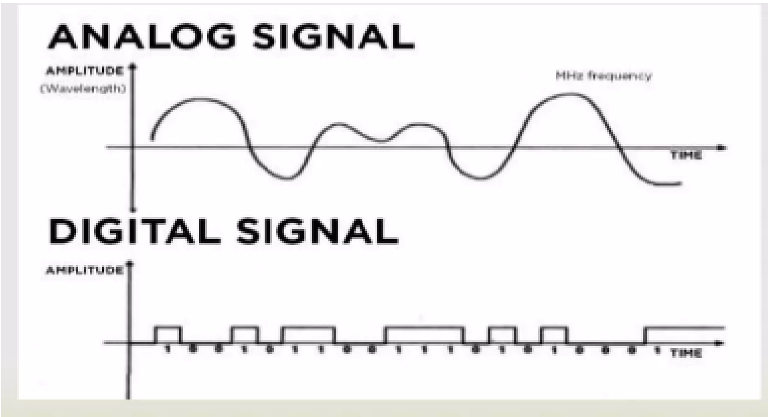
**Disadvantages:**

1.No failure recovery model.
2.No consideration for energy efficiency

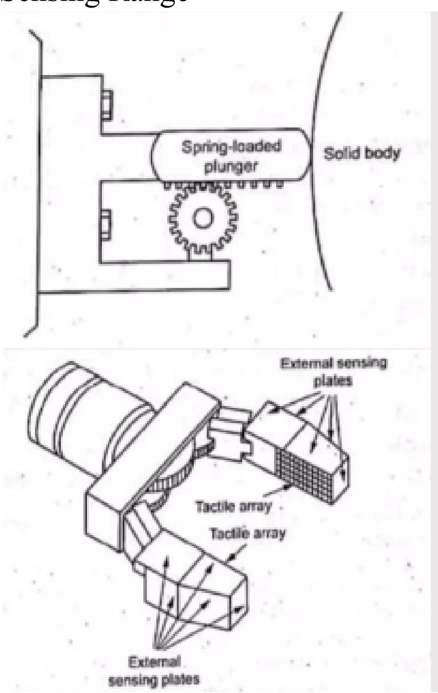
**Application:**

1.Transportation
2.Communication

## 15. Analog Sensors:




Analog Sensors produce a continuous output signal or voltage which is generally proportional to the quantity being measured. Physical quantities such as Temperature, Speed, Pressure, Displacement, Strain etc are all analog quantities as they tend to be continuous in nature. Trigger ON or OFF signals as the target moves IN or OUT of Sensing Range



Device whose output is proportional to a local force. Spring Loaded rod linked to rotating shaft. Potentiometer or digitally using a code wheel. External sensing plates are typically binary devices. Inner surface fingers has Been Covered with tactile Sensing array. The letter easily transformed into electrical signal, Whose amplitude is proportional to force.

**Advantages:**

1.Low cost
2.Less error

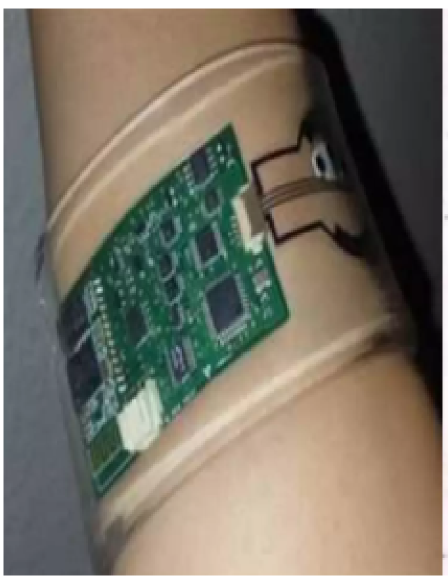
3.Less bandwidth
4.Easy construction
5.More Precise

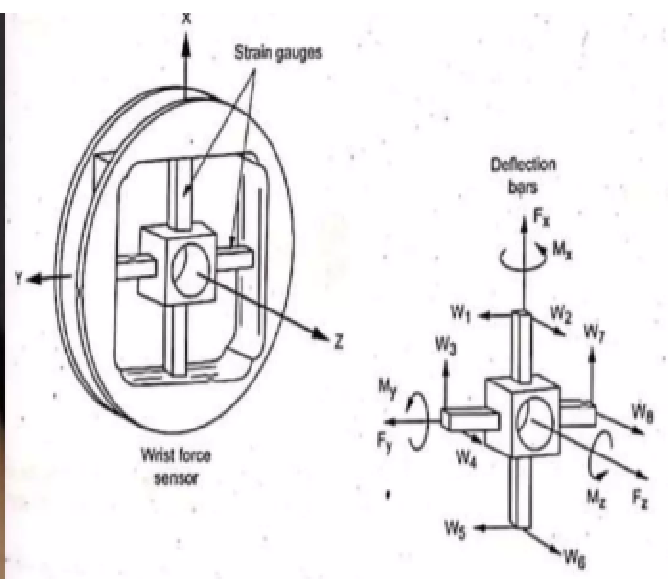
**Disadvantages:**

1.Degradation occur
2.Noisy Operation

**Uses:**
Used to measure the amount of pressure applied sensor

## 16. WRIST SENSOR:






Wrist sensors is designed to worn on the wrist and provide accurate capture of pressures exerted on the wrist. Wrist force sensor can detect and measures these forces.

Components of Wrist force sensor:

1.Metallic frame

2.Bracket for tool monitoring and strain gauge.

It is a small sensitive light weight, 10cm total diameter 3cm thickness, dynamic range up to 200lb
Eight pairs of strain gauge are used Normally X,Y and Z axes of the force co ordinate frame.
3 components of force F
3 components of moment M
Determined force by properly adding and subtracting the output voltages respectively.
Sensor reading by sensor calibration matrix.
Measure the component of force and torque acting on the base.
Base is firmly mounted on a solid surface and no provisions are made for pedestal sensing.
Pedestal sensing is similar to used wrist sensing.
Specialized pressure sensor known as stain gauge.
Converts wrist force into Electrical signals.
Robot arm joints the end effector. The point is called wrist. One or more joints that moves in various ways.
Orientation are right & Left, in & out, Up & Down.
Rotation along all three axes.
Must detect Translate also.

**Advantages:**

1.High Performance.
2.Better frequency.
3.Good Accuracy.

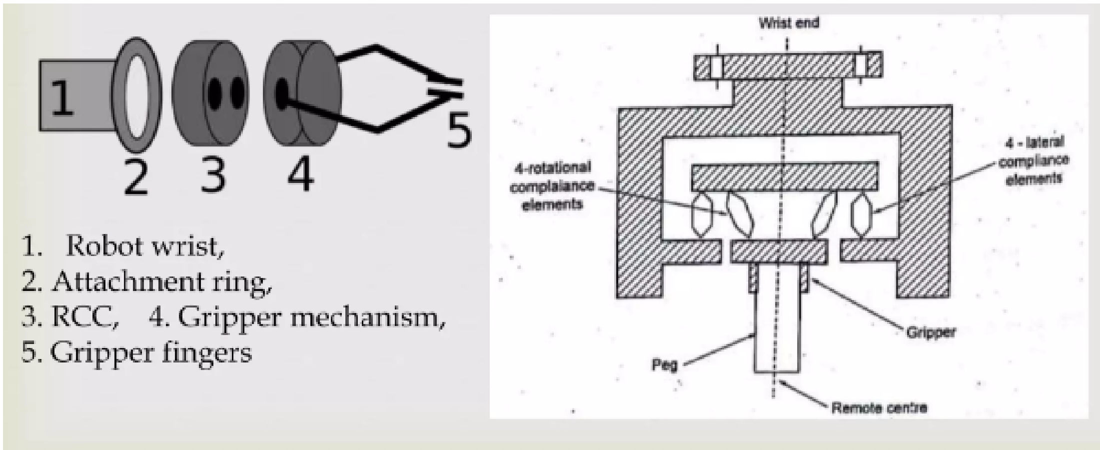
**Disadvantages:**

1.Expensive
2.Less linearity.
3.Sensitive to temperature change.

**Specification:**

1.High Stiffness 2.Compact Design 3.Linearity
4.Low hysteresis and internal friction

## 17. Remote Center Compliance Sensors(R.C.C)




It is a mechanical device that facilities automated by preventing peg like objects from jamming into a hole with tight clearance.
Robot might pick up a hook with its gripper.

RCC has Three types of compliance.
1.Lateral 2.Rotational 3.Axial.
Four Lateral and four rotational with RCC Elements.
Eight elements together provide the axial compliance.

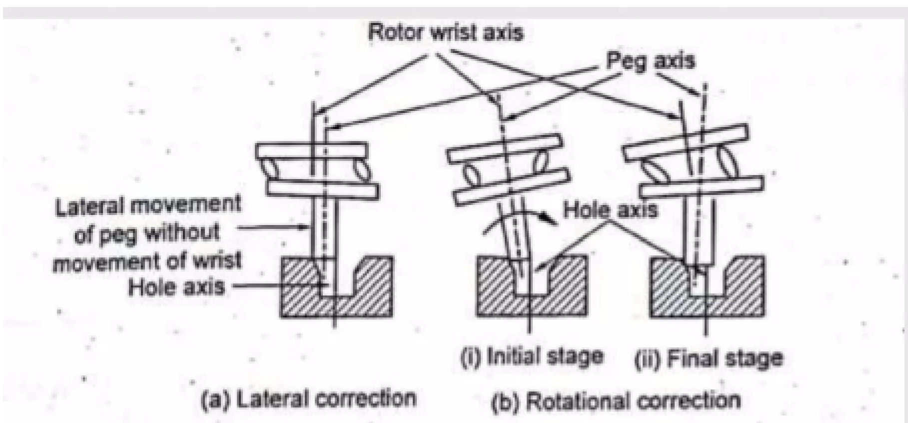



*Fig. 4.63. The working of RCC device*

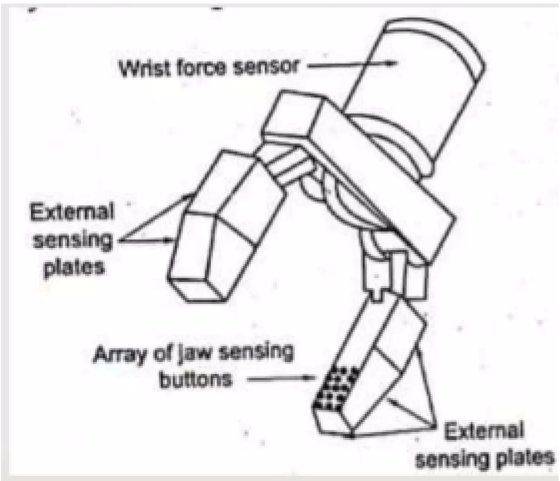
**Advantages:**

Reducing contact force
Preventing galling and jamming.
Lateral and rotational misalignment.
RCC reduce damage to material during the assembly process.

**Benefits:**

Automotive Assembly
Impossible assemblies possible

## 18. Slip Sensors:




Is the measurement and detection of the movement of an object relative to the sensor.
Interpretation the data from touch sensor or tactile array.
It is provided the robotic manipulator if the object is carried by the end effectors is slipping.

**Working Principle:**

Slip sensor is based on sensing plates.
The slip during job handling causes the molecular disturbance.
End Effecter to increase the pressure of holding.

**Features of slip sensor:**

1. The slip sensor can be measured quantitatively.
2. Measurement has good accuracy.
3. Measured the velocity of arm.

**Advantages:**

1.Lower cost
2.Simple structure
3.High reliability 4.High flexibility

**Disadvantages:**

Complex output change occur.

**Application:**

1.Smart robots.
2.Medical surgery
3.Implantable medical devices.

4.Slip control under manipulation.

## Camera:

A machine vision camera is a type of camera that can capture and process images and videos to help machines and computers make decisions. They are also known as "smart cameras" because they can understand images in a similar way to humans.
Here are some types of cameras used in machine vision:

**Line scan cameras**

Use long, thin sensors to capture images one pixel line at a time. The camera or object moves past the sensor, which scans the object row by row and then stitches the lines together.

**Area scan cameras**

Use rectangular sensors to capture images in a single frame. The digital image produced is based on the number of pixels in the sensor.

**Vision cameras**

Can recognize color and contrast, and provide information such as position and color quality.

## Frame Grabber:

A frame grabber is a device that captures individual still images from a video stream and is a key component of machine vision systems. Frame grabbers are used in machine vision, medical imaging, and scientific research because they can capture high-resolution images in a variety of settings.
Here are some things to know about frame grabbers:
Frame grabbers capture individual frames from an analog or digital video stream and save them as still images. The images can then be displayed, stored, transmitted, or analyzed. Frame grabbers can connect to a PC system directly through interfaces like USB or Ethernet.

**Capabilities**

Newer frame grabbers can capture multiple inputs at once, transform images, and perform real-time compression.

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## SENSING AND DIGITIZING IMAGE DATA:

Image sensing requires some type of image formation device such as a camera and a digitizer which stores a video frame in the computer memory. We divide the sensing and digitizing functions into several steps.

The initial step involves capturing the image of the scene with the vision camera. The image consists of relative light intensities corresponding to the various portions of the scene. These light intensities are continuous analog values which must be sampled and converted into a digital form.

The second step, digitizing, is achieved by an analog-to-digital (A/D) converter. The A/D converter is either a part of a digital video camera or the front end of a frame grabber. The choice is dependent on the type of hardware in the system.

The frame grabber, representing the third step, is an image storage and computation device which stores a given pixel array. The frame grabber can vary in capability from one which simply stores an image to significant computation capability. In the more powerful frame grabbers, thresholding, windowing, and histogram modification calculations can be carried out under computer control. The stored image is then subsequently processed and analyzed by the combination of the frame grabber and the vision controller.

**Analog-to-Digital Signal Conversion**

For a camera utilizing, the vidicon tube technology it is necessary to convert the analog signal for each pixel into a digital form. The analog-to-digital (A/D) conversion process involves taking an analog input voltage signal and producing an output that represents the voltage, signal in the digital memory of a computer.
A/D conversion consists of three phases: sampling, quantization, and encoding.

2.1.Sampling A given analog signal is sampled periodically to obtain a series of discrete time analog signals. This process is illustrated in Fig. By setting a specified sampling rate, the analog signal can be approximated by the sampled digital outputs. How well we approximate the analog signal is determined by the sampling rate of the A/D converter. The sampling rate should be at least twice the highest frequency in the video signal if we wish to reconstruct that signal exactly."

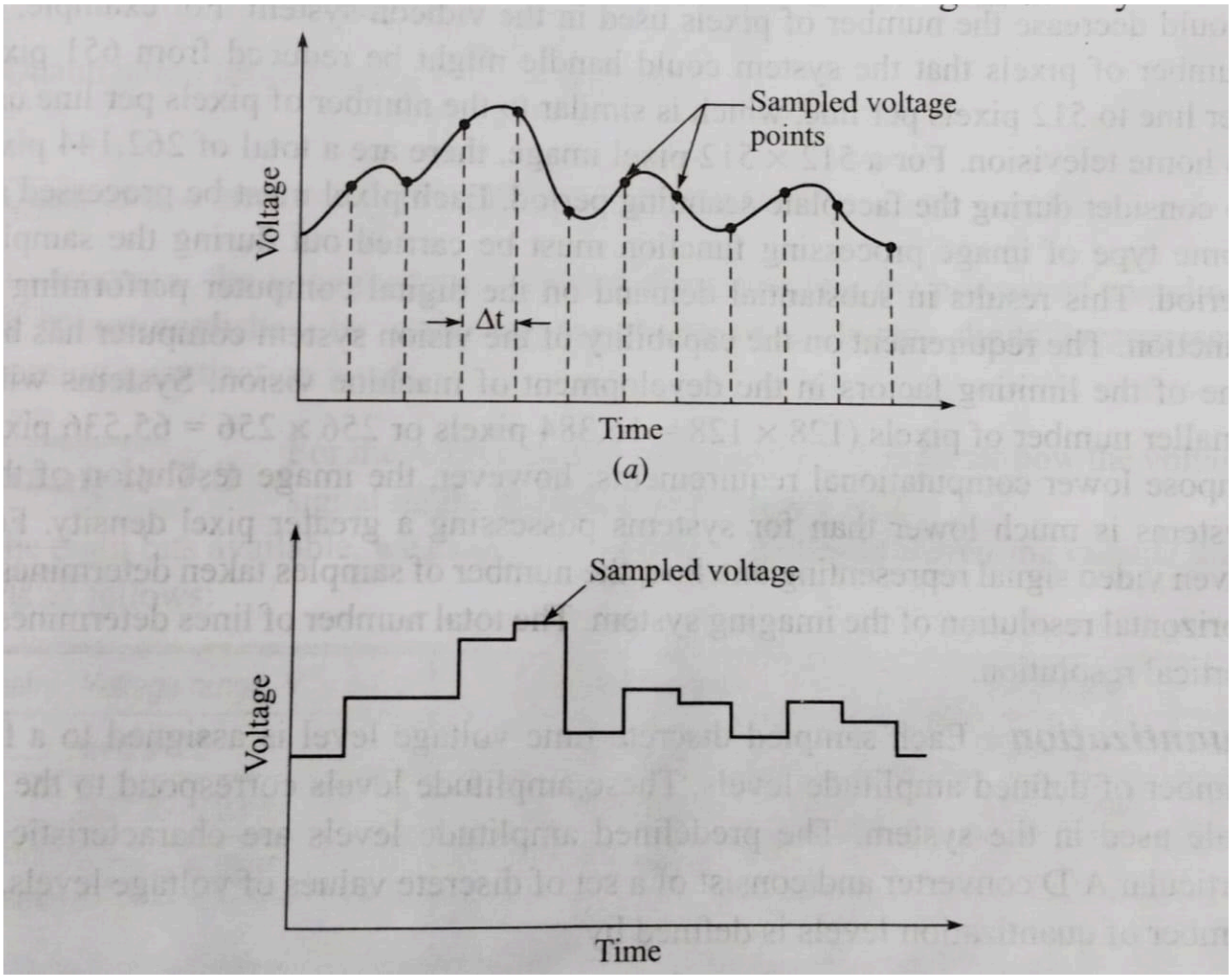

Fig. Sampling and digitizing an analog waveform: (a) Analog waveform indicating sampling interval, t, and sampled voltage points, (b) Digital approximation to analog signal

For a 512x 512 pixel image, there are a total of 262,144 pixels to consider during the faceplate scanning period. Each pixel must be processed and some type of image processing function must be carried out during the sampling period. This results in substantial demand on the digital computer performing the function. The requirement on the capability of the vision system computer has been one of the limiting factors in the development of machine vision. Systems with a smaller number of pixels (128 x 128 16,384 pixels or 256 x 256 65,536 pixels) impose lower computational requirements: however, the image resolution of these systems is much lower than for systems possessing a greater pixel density. For a given video signal representing one line, the number of samples taken determines the horizontal resolution of the imaging system. The total number of lines determines the vertical resolution.

2.2.Quantization Each sampled discrete time voltage level is assigned to a finite number of defined amplitude levels. These amplitude levels correspond to the gray scale used in the system. The predefined amplitude levels are characteristic to a particular A/D converter and consist of a set of discrete values of voltage levels. The number of quantization levels is defined by

Number of quantization levels = 2" where n is the number of bits of the A/D converter. A large number of bits enables

a signal to be represented more precisely. For example, an 8 bit converter would

allow us to quantize at 2-256 different values whereas 4 bits would allow only

2-16 different quantization levels.

2.3.Encoding the amplitude levels that are quantized must be changed into digital code. this process, termed encoding, involves representing an amplitude level by a binary digit sequence. the ability of the encoding process to distinguish between various amplitude levels is a function of the spacing of each quantization level. given the full-scale range of an analog video signal, the spacing of each level would

be defined by

quantization level spacing = full-scale range / 2n

the quantization error resulting from the quantization process can be defined as

quantization error =$\pm \frac{1}{2}$ (quantization level spacing)

## Image Storage:

**Central database**
Store images and data in a central database.
**Image formats**
Depending on your system, you may need to convert images into different file formats. For example, RGB is a popular format, but there are others available.
**Image compression**
Compressing images can help minimize storage space. JPEG XL is one compression format that can be used to compress images to a Butteraugli distance of 2 from the original image.
**Image storage options**
There are several ways to store computer vision data, including file systems, object storage, and ReductStore. Each option has its own advantages and disadvantages.

**Image color modes**

Some common image color modes include RGB, RGBA, CMYK, Indexed, and HSV. HSV is often used in computer vision because it separates color information from brightness.

**Lighting Techniques**

An essential ingredient in the application of machine vision is proper lighting. Good illumination of the scene is important because of its effect on the level of complexity of image-processing algorithms required. Poor lighting makes the task of interpreting the scene more difficult. Proper lighting techniques should provide high contrast and minimize specular reflections and shadows unless specifically designed into the system. The basic types of lighting devices used in machine vision may be grouped into

the following categories:

**1. Diffuse surface** devices Examples of diffuse surface illuminators are the typical fluorescent lamps and light tables.

**2. Condenser projectors** A condenser projector transforms an expanding light source into a condensing light source. This is useful in imaging optics.

3. **Flood or spot projectors** Flood lights and spot lights are used to illuminate surface areas.

4. **Collimators** Collimators are used to provide a parallel beam of light on the subject

5. **Imagers** Imagers such as slide projectors and optical enlargers form an image of the target at the object plane.

There are two basic illumination techniques used in machine vision: front lighting and back lighting.

**3.1.Front lighting** simply means that the light source is on the same side of the scene as the camera. Accordingly, reflected light is used to create the image viewed by the camera. In back lighting, the light source is directed at the camera and is located behind the objects of interest. The image seen by the camera is a silhouette of the object under study.

**3.2.Back lighting** is suitable for applications in which a silhouette of the object is sufficient for recognition or where there is a need to obtain relevant measurements. The table also lists other miscellaneous techniques that may be used to provide illumination.

## IMAGE PROCESSING AND ANALYSIS:

For use of the stored image in industrial applications, the computer must be programmed to operate on the digitally stored image. This is a substantial task considering the large amount of data that must be analyzed. Consider an industrial vision system having a pixel density of 350 pixels per line and 280 lines (a total of 98,000 picture elements), and a 6-bit register for each picture element to represent various gray levels; this would require a total of 98,000 x 6588,000 bits of data for each $\frac{1}{30}$ s. This is a formidable amount of data to be processed in a short period of time and has led to various techniques to reduce the magnitude of the imageprocessing problem. These techniques include:

1. Image data reduction

2. Segmentation

3. Feature extraction

4. Object recognition

**4.1.Image Data Reduction**

In image data reduction, the objective is to reduce the volume of data. As a preliminary step in the data analysis, the following two schemes have found common usage for data reduction:

1. Digital conversion 2. Windowing

The function of both schemes is to eliminate the bottleneck that can occur from the large volume of data in image processing.

**4.1.1.Digital conversion** reduces the number of gray levels used by the machine vision system. For example, an 8-bit register used for each pixel would have 25-256 gray levels. Depending on the requirements of the application, digital conversion can be used to reduce the number of gray levels by using fewer bits to represent the pixel light intensity. Four bits would reduce the number of gray levels to 16. This kind of conversion would significantly reduce the magnitude of the image-processing problem

**4.1.2.Windowing** involves using only a portion of the total image stored in the frame buffer for image processing and analysis. This portion is called the window. For example, for inspection of printed circuit boards, one may wish to inspect and analyze only one component on the board. A rectangular window is selected to surround the component of interest and only pixels within the window are analyzed. The rationale for windowing is that proper recognition of an object requires only certain portions of the total scene.

**4.2.Segmentation**

Segmentation is a general term which applies to various methods of data reduction. In segmentation, the objective is to group areas of an image having similar characteristics or features into distinct entities representing parts of the image. For example, boundaries (edges) or regions (areas) represent two natural segments of an image. There are many ways to segment an image.

Three important techniques are:

1. Thresholding

2. Region growing

3. Edge detection

**4.2.1.Thresholding** is a binary conversion technique in which each pixel is converted into a binary value, either black or white. This is accomplished by utilizing a frequency histogram of the image and establishing what intensity

(gray level) is to be the border between black and white.

threshold is only one of a large number of ways to threshold an image. It is however the method used by many of the commercially available robot vision systems today. Such a method is said to use a global threshold for the entire image. In some cases, this is not possible and a local thresholding method as described below may be employed.

When it is not possible to find a single threshold for an entire image (for example, if many different objects occupy the same scene, each having different levels of intensity), one approach is to partition the total image into smaller rectangular areas and determine the threshold for each window being analyzed.

Thresholding is the most widely used technique for segmentation in industrial vision applications. The reasons are that it is fast and easily implemented and that the lighting is usually controllable in an industrial setting.

Once thresholding is established for a particular image, the next step is to identify particular areas associated with objects within the image. Such regions usually possess uniform pixel properties computed over the area. The pixel properties may be multidimensional, that is, there may be more than a single attribute that can be used to characterize the pixel (eg, color and light intensity). We will avoid this complication and confine our discussion to single pixel attributes (light intensity) of a region.

**4.2.2.Region growing** is a collection of segmentation techniques in which pixels are -grouped in regions called grid elements based on attribute similarities. Defined regions can then be examined as to whether they are independent or can be merged to other regions by means of an analysis of the difference in their average properties and spatial connectiveness. For instance, consider an image as depicted in Fig. 7.7(a). To differentiate between the objects and the background, assign 1 for any grid element occupied by an object and 0 for background elements. It is common practice to use a square sampling grid with pixels spaced equally along each side of the grid. For the two-dimensional image of a key as shown, this would give the pattern indicated in Fig. 7.7(b). This technique of creating 'runs' of Is and Os is often used as a first-pass analysis to partition the image into identifiable segments or 'blobs. Note that this simple procedure did not identify the hole in the key of Fig. 7.7(a). This could be resolved by decreasing the distance between grid points and increasing the accuracy with which the original image is represented.

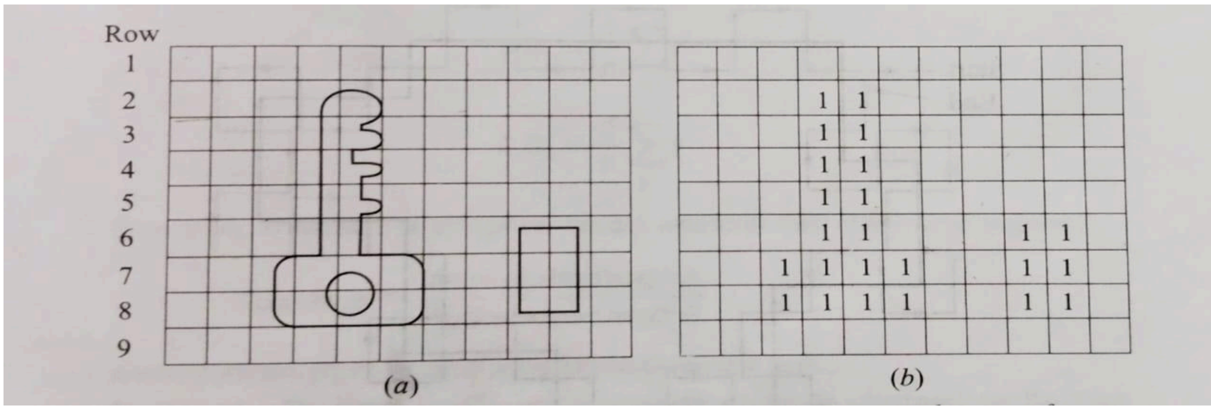


Fig. Image segmentation: (a) Image pattern with grid. (b) Segmented image after runs test.

For a simple image such as a dark blob on a light background, a runs technique can provide useful information. For more complex images, this technique may not provide an adequate partition of an image into a set of meaningful regions. Such regions might contain pixels that are connected to each other and have similar attributes, for example, gray level. A typical region-growing technique for complex images could have the following procedure:

1. Select a pixel that meets a criterion for inclusion in a region. In the simplest case, this could mean select white pixel and assign a value of 1.

Compare the pixel selected with all adjacent pixels. Assign an equivalent value to adjacent pixels if an attribute match occurs.
Go to an equivalent adjacent pixel and repeat process until no equivalent pixels can be added to the region.
This simple procedure of growing regions around a pixel would be repeated until no new regions can be added for the image. The region growing segmentation technique described here is applicable when images are not distinguishable from each other by straight thresholding or edge detection techniques. This sometimes occurs when lighting of the scene cannot be adequately controlled. In industrial robot vision systems, it is common practice to consider only edge detection or simple thresholding. This is due to the fact that light- ing can be a controllable factor in an industrial setting and hardware/computational implementation is simpler.

**4.2.3.Edge detection** considers the intensity change that occurs in the pixels at the boundary or edges of a part. Given that a region of similar attributes has been found but the boundary shape is unknown, the boundary can be determined by a simple edge following procedure. This can be illustrated by the schematic of a binary image as shown in Fig. 7.8. For the binary image, the procedure is to scan the image until a pixel within the region is encountered. For a pixel within the region, turn left and step, otherwise, turn right and step. The procedure is stopped when the boundary is traversed and the path has returned to the starting pixel. The contour-following procedure described can be extended to gray level images.

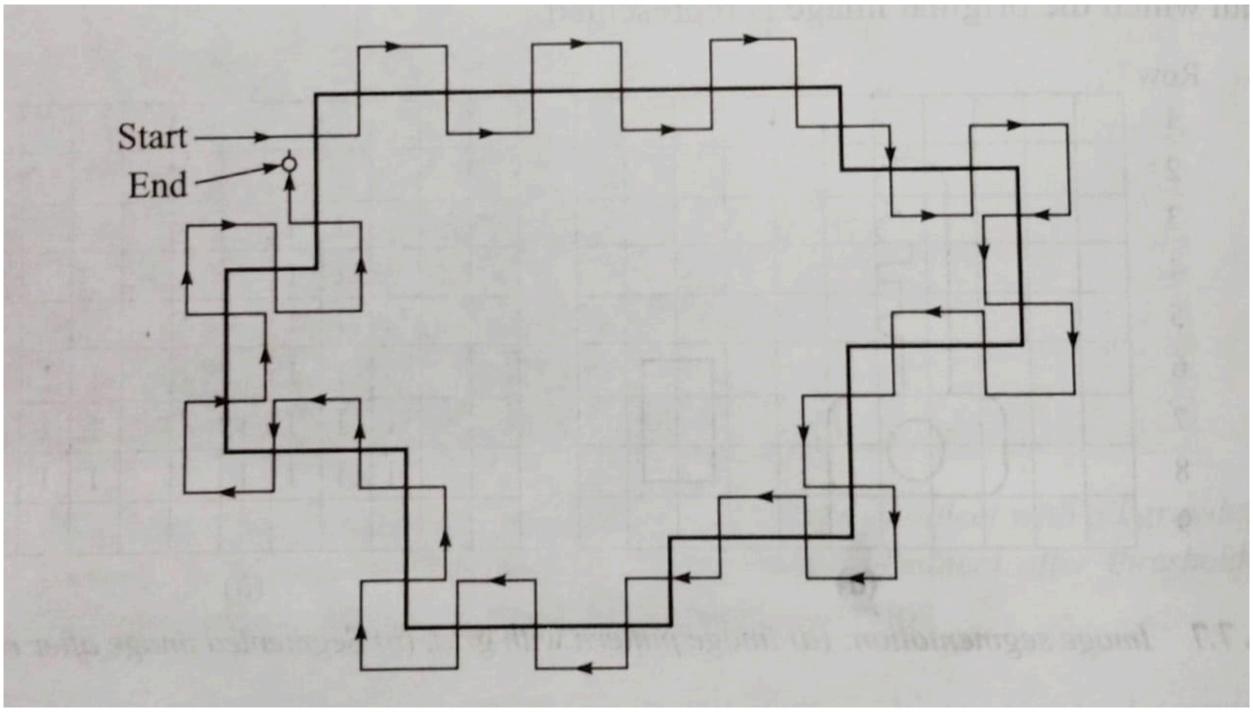


Fig. Edge following procedure to detect the edge of a binary image.

### 4.3.Feature Extraction

In machine vision applications, it is often necessary to distinguish one object from another. This is usually accomplished by means of features that uniquely characterize the object. Some features of objects that can be used in machine vision include area, diameter, and perimeter. A feature, in the context of vision systems, is a single parameter that permits ease of comparison and identification. A list of some of the features commonly used in vision applications is given in Table 7.2. The techniques available to extract feature values for two-dimensional cases can be roughly categorized as those that deal with boundary features and those that deal with area features. The various features can be used to identify the object or part and determine the part location and/or orientation.

The region-growing procedures described before can be used to determine the area of an object's image. The perimeter or boundary that encloses a specific area can be determined by noting the difference in pixel intensity at the boundary and simply counting all the pixels in the segmented region that are adjacent to pixels not in the region, that is, on the other side of the boundary. An important objective in selecting these features is that the features should not depend on position or orientation. The vision system should not be dependent on the object being presented in a known and fixed relationship to the camera.

**Table 7.2 Basic features and measures for object identification for two-dimensional objects:**

| |
|---|
| Gray level (maximum, average, or minimum) |
| Area |
| Perimeter length |
| Diameter |
| Minimum enclosing rectangle |
| Center of gravity |
| Eccentricity |
| Aspect ratio The length-to-width ratio of a boundary rectangle which encloses the object. One objective is to find the rectangle which gives the minimum aspect ratio. |

### 4.4.Object Recognition

The next step in image data processing is to identify the object the image represents. This identification problem is accomplished using the extracted feature information described in the previous subsection. The recognition algorithm must be powerful enough to uniquely identify the object. Object recognition techniques used in industry today may be classified into two major categories:

1. Template-matching techniques 2. Structural techniques

**4.4.1.Template-matching techniques** are a subset of the more general statistical pattern. Recognition techniques that serve to classify objects in an image into predetermined categories. The basic problem in template matching is to match the object with a stored pattern feature set defined as a model template. The model template is obtained during the training procedure in which the vision system is programmed for known prototype objects. These techniques are applicable if there is not a requirement for a large number of model templates. The procedure is based on the use of a sufficient number of features to minimize the frequency of errors in the classification process. The features of the object in the image (e.g., its area, diameter, aspect ratio, etc.) are compared to the corresponding stored values. These values constitute the stored template. When a match is found, allowing for certain statistical variations in the comparison process, then the object has been properly classified. Structural techniques of pattern recognition consider relationships between features or edges of an object. For example, it the image of an object can be subdivided into four straight lines (the lines are called primitives) connected, their end points, and the connected lines are at right angles, then the object is rectangle. This kind of technique, known as syntactic pattern recognition, is the widely used structural technique.

**4.4.2.Structural techniques** differ from decision theor techniques in that the latter deals with a pattern on a quantitative basis and for the most part interrelationships among object primitives. A detailed discus of pattern recognition techniques is the subject of complete books and is beyond scope of this text.

It can be computationally time consuming for complete pattern recogniti Accordingly, it is often more appropriate to search for simpler regions or within an image. These simpler regions can then be used to extract the required features. The majority of commercial robot vision systems make use of this appross to the recognition of two-dimensional objects. The recognition algorithms are us to identify each segmented object in an image and assign it to a classification (eg nut, bolt, flange, etc.)

## 5.ROBOTIC APPLICATIONS

Many of the current applications of machine vision are inspection tasks that do not involve the use of an industrial robot. A typical application is where the machi vision system is installed on a high-speed production line to accept or reject parts made on the line. Unacceptable parts are ejected from the line by some mechanical device that is communicating with the vision system.

Machine vision applications can be considered to have three levels of difficulty These levels depend on whether the object to be viewed is controlled in position and or appearance. Controlling the position of an object in a manufacturing environment usually requires precise fixturing. Controlling the appearance of an object is accomplished by lighting techniques. Also, appearance is influenced by the object's surface texture or coloration. The three levels of difficulty used to categorize machine vision applications in an industrial setting are:

1. The object can be controlled in both position and appearance.

2. Either position or appearance of the object can be controlled but not both.

3. Neither position nor appearance of the object can be controlled.

The third level of difficulty requires advanced vision capabilities. The objective in engineering the vision application is to lower the level of difficulty involved. thereby reducing the level of sophistication of the vision system required in the application. For example, one problem that occurs in object recognition is that the recognition process is facilitated if the object is in a known position and orientation. Parts in a factory are typically not positioned and oriented in this manner. This problem can be reduced from a third level to a first level of difficulty by fixturing the parts and using techniques such as structured lighting to control the appearance.

In this section, the use of machine vision in robotic applications will be emphasized. Robotic applications of machine vision fall into the three broad categories listed below:

Inspection

2. Identification

3. Visual serving and navigation

**5.1 Inspection** process. This is carried out by the machine vision system, and the robot is used in a secondary to support the application. The objectives of machine vision inspection include checking for gross surface defects, discovery of flaws in labeling (during final inspection of the product package), verification of the presence of components in assembly, measuring for dimensional accuracy, and checking for the presence of holes and other features in a part. When these kinds of inspection operations are performed manually, there is a tendency for human error. Also, the time required in most manual inspection operations requires that the procedures be accomplished on a sampling basis. With machine vision, these procedures are carried out automatically, using 100 percent inspection, and usually in much less time. In Chap. 15, we will return to robotic inspection in which many of the applications of robots make use of machine vision.

**5.2 Identification,** is concerned with applications in which the purpose of the machine vision system is to recognize and classify an object rather than to inspect it. Inspection implies that the part must be either accepted or rejected. Identification involves a recognition process in which the 'part itself, or its position and/or orientation, is determined. This is usually followed by a subsequent decision and action taken by the robot. Identification applications of machine vision include part sorting, palletizing and depalletizing, and picking parts that are randomly oriented from a conveyor or bin.

**5.3 Visual serving and navigational control**, the purpose of the vision system is to direct the actions of the robot (and other devices in the robot cell) based on its visual input. The generic example of robot visual serving is where the machine vision system is used to control the trajectory of the robot's end effector toward an object in the workspace. Industrial examples of this application include part positioning, retrieving parts moving along a conveyor, retrieving and reorienting parts moving along a conveyor, assembly, bin picking, and seam tracking in continuous arc welding.