UNIT II SENSORS AND VISION SYSTEM

Sensors:

Sensors are devices that can sense and measure physical properties of the environment, e.g. temperature, luminance, resistance to touch, weight, size, etc. Transduction (engineering) is a process that converts one type of energy to another. They deliver low-level information about the environment.

Transducers and sensors:

Transducer is a device that converts one type of physical variable (eg; force, temperature, velocity, flow rate etc) into another form. Generally we convert this to electrical voltages. The reason for this is that the converted signal is more convenient to use and evaluate.

Sensor is just used to sense the signals. Any transducer or sensor requires calibration in order to be useful as a measuring device calibration is the procedure by which the relation between the measured variable and the converted output signal is established.

Types of transducers:

1.Analog Trancducers.

Provides a continuous signal such as electrical voltage or current as output .

2.Digital Trancducers:

Provides digital output signal in the form of status bits or series of pulses that can be counted. Output value represents the measured value.Digital trancducers are more easy to read the output and they offer high accuracy and more compatible with digital computer than analog based sensors.

Desirable features of Sensors:

1. Accuracy

Accuracy should be high. How close output to the true value is the accuracy of the device.

2. Precision

There should not be any variations in the sensed output over a period of time precision of the sensor should be high.

3. Operating Range

Sensor should have wide range of operation and should be accurate and precise over this entire range.

4. Speed of Response

Should be capable of responding to the changes in the sensed variable in minimum time.

5. Calibration

Sensor should be easy to calibrate time and trouble required to calibrate should be minimum. It should not require frequent recalibration.

6. Reliability

It should have high reliability. Frequent failure should not happen.

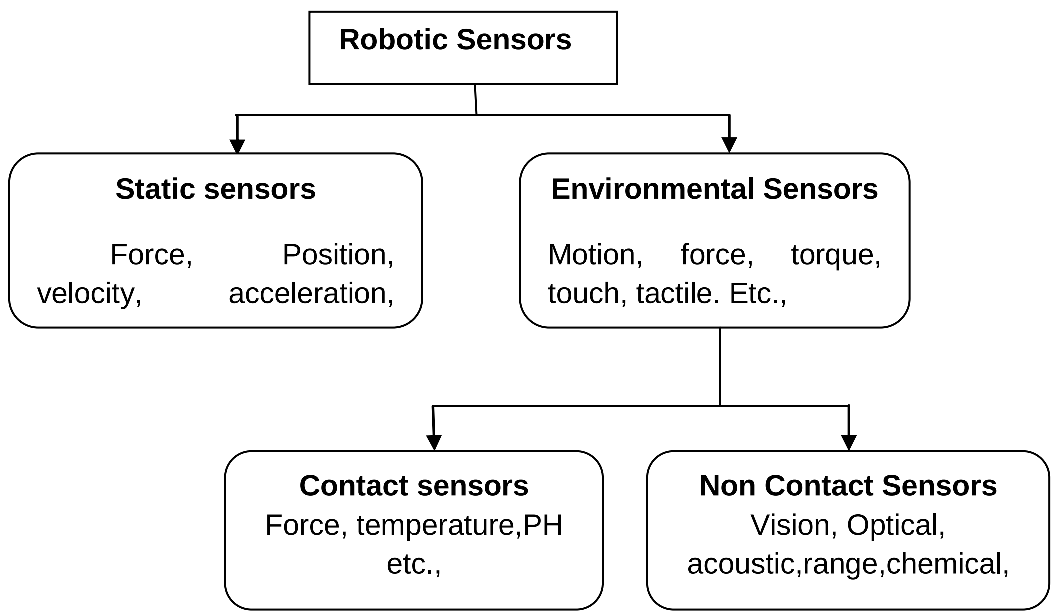
7. Cost and Ease of operation

Cost should be as low as possible, installation, operation and maintenance should be easy and should not required skilled or highly trained persons.

Examples of Sensors:

A) Potentiometers
B) Thermocouples, thermistors.
C) Strain gauge
D) Load cell
E) Infrared sensors
F) LVDT
G) Pyrometers
H) Pizeo electric devices
I) Pressure Transducers
J) Vision and voice sensors.

Robotic Sensors:



There are generally two categories of sensors used in robotics; these are for internal purposes, and those for external purposes. **Internal sensors** are used to monitor and control the various joints of the robot; they form a feedback control loop with the robot controller. Examples of internal sensors include potentiometers and optical encoders, while tachometers of various types can be deployed to control the speed of the robot arm. **External sensors** are external to the robot itself, and are used when we wish to control the operations of the robot with other pieces of equipment in the robotic work cell. External sensors can be relatively simple devices, such as limit switches that determine whether a part has been positioned properly, or whether a part is ready to be picked up from an unloading bay.

ROBOTIC SENSORS For certain robot application, the type of workstation control using interlocks is not adequate the robot must take on more human like senses and capabilities in order to perform the task in a satisfactory way these senses and capability includes vision and hand eye coordination, touch, hearing accordingly we will dived the types of sensors used in robotics into the following three categories.

A number of advanced sensor technologies may also be used; these are outlined in Table 1.

Table 1: Advanced sensor technologies for robotics

Sensor Type	Description
Tactile sensors	Used to determine whether contact is made between sensor and another object. Two types: touch sensors—which indicate when contact is made, and no more; and force sensors—which indicate the magnitude of the force with the object.
Proximity sensors	Used to determine how close an object is to the sensor. Also called a range sensor.
Optical sensors	Photocells and other photometric devices that are used to detect the presence or absence of objects. Often used in conjunction to proximity sensors.
Machine vision	Used in robotics for inspection, parts identification, guidance, and other uses.
Others	Miscellaneous category of sensors may also be used; including devices for measuring: temperature, fluid pressure, fluid flow, electrical voltage, current, and other physical properties.

Range sensor:

Ranging sensors include sensors that require no physical contact with the object being detected. They allow a robot to see an obstacle without actually having to come into contact with it. This can prevent possible entanglement, allow for better obstacle avoidance (over touch-feedback methods), and possibly allow software to distinguish between obstacles of different shapes and sizes. There are several methods used to allow a sensor to detect obstacles from a distance.

Light-based ranging sensors use multiple methods for detecting obstacles and determining range. The simplest method uses the intensity of the reflected light from an obstacle to estimate distance. However, this can be significantly affected by the color/reflectivity of the obstacle and external light sources. A more common method is to use a beam of light projected at an angle and a strip of detectors spaced away from the emitter as in the animation to the right. The pictured Sharp sensor uses this method. This method is less affected by the color/reflectivity of the object and ambient light.

LIDAR, a more advanced method of range detection, uses a laser that is swept across the sensor's field of view. The reflected laser light is usually analyzed one of two ways. Units with longer ranges sometimes actually determine distance by measuring the time it takes for the laser pulse to return to the sensor. This requires extremely fast timing circuitry. Another method uses phase shift detection to determine range by analyzing the incoming light and comparing it to a reference signal.

Tactile sensor

Tactile sensors provide the robot with the capability to respond to contact forces between itself and other objects within its work volume. Tactile sensors can be divided into two types:

1. Touch sensors
2. Stress sensors

Touch sensors are used simply to indicate whether contact has been made with an object. A simple micro switch can serve the purpose of a touch sensor. Stress sensors are used to measure the magnitude of the contact force. Strain gauge devices are typically employed in force measuring sensors. Potential use of robots with tactile sensing capabilities would be in assembly and inspection operations. In assembly, the robot could perform delicate part alignment and joining operations. In inspection, touch sensing would be used in gauging operations and dimensional measuring activities.

Proximity sensor

Proximity sensors are used to sense when one object is close to another object. On a robot, the proximity sensors would be located n or near the end effectors. This sensing capability can be engineered by means of optical proximity devices, eddy-current proximity detectors, magnetic field sensors, or other devices. In robotics, proximity sensors might be used to indicate the presence or absence of a work part or other object. They could also be helpful in preventing injury to the robots human coworkers in the factory.

Optical or Infrared Light-Based sensors

This is one of the areas that is receiving a lot of attention in robotics research computerized visions systems will be an important technology in future automated factories. Robot vision is made possible by means of video camera a sufficient light source and a computer programmed to process image data. The camera is mounted either on the robot or in a fixed position above the robot so that its field of vision includes the robots work volume. The computer software enables the vision system to sense the presence of an object and its position and orientation. Vision capability would enable the robot to carry out the following kinds of operations. Retrieve parts which are randomly oriented on a conveyor Recognize particular parts which are intermixed with other objects Perform assembly operations which require alignment.

Another very popular method uses projected light waves, usually infrared, to detect obstacles. This system projects a pulse of light and looks for the reflection. Properties of the reflected light are analyzed to determine characteristics about the object detected. Light has the advantages of traveling extremely fast, allowing for fast sensor response time, high resolution, and less error to account for. Light from this type of sensor is often formed into a narrow beam or many times a laser is used. This provides good resolution over large distances.9

Proximity sensors

The simplest light-based obstacle sensor projects a light and looks for a reflection of certain strength. If the reflection is strong enough, it can be inferred that an obstacle lies within a certain range of the sensor. Multiple light sources can be pulsed on in sequence to give some resolution to the sensor as in the figures.

Voice sensors

Another area of robotics research is voice sensing or voice programming. Voice programming can be defined as the oral communication of commands to the robot or other machine. The robot controller is equipped with a speech recognition system which analyzes the voice input and compares it with a set of stored word patterns when a match is found between the input and the stored vocabulary word the robot performs some actions which corresponds to the word. Voice sensors could be useful in robot programming to speed up the programming procedure just as it does in NC programming. It would also be beneficial in especially in hazardous working environments for performing unique operations such as maintenance and repair work. The robot could be placed in hazardous environment and remotely commanded to perform the repair chores by means of step by step instructions.

Internal sensor

Internal sensors measure the robot's internal state. They are used to measure its position, velocity and acceleration.

Position sensor

Position sensors measure the position of a joint (the degree to which the joint is extended). They include:

Encoder: a digital optical device that converts motion into a sequence of digital pulses.

Potentiometer: a variable resistance device that expresses linear or angular displacements in terms of voltage.

Linear variable differential transformer: a displacement transducer that provides high accuracy. It generates an AC signal whose magnitude is a function of the displacement of a moving core.

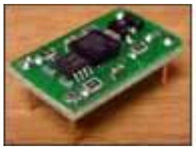
Synchronous and Resolvers

Velocity Sensor

A velocity or speed sensor measures consecutive position measurements at known intervals and computes the time rate of change in the position values.

Acceleration Sensors:

Accelerometer



An accelerometer measures acceleration (change in speed) of anything that it's mounted on. How does it work? Inside an accelerator MEMS device are tiny micro-structures that bend due to momentum and gravity. When it experiences any form of acceleration, these tiny structures bend by an equivalent amount which can be electrically detected. Today, accelerometers are easily and cheaply available, making it a very viable sensor for cheap robotics hobbyists like you and me

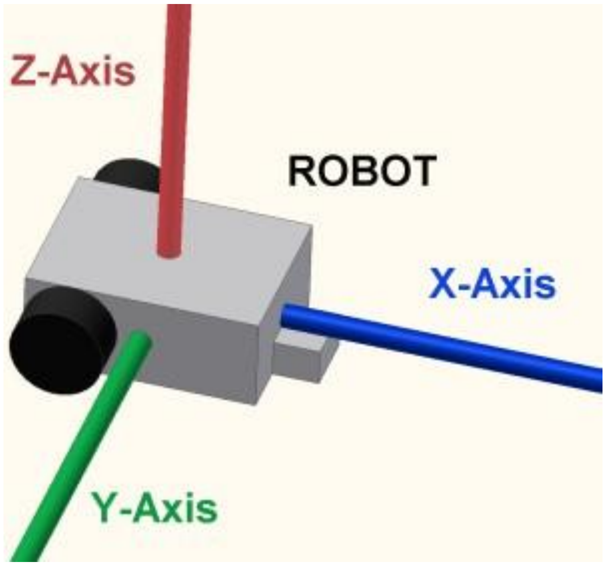
Applications for Accelerometers are very important in the sensor world because they can sense such a wide range of motion. They're used in the latest Apple Power books (and other laptops) to detect when the computer's suddenly moved or tipped, so the hard drive can be locked up during movement. They're used in cameras, to control image stabilization functions. They're used in pedometers, gait meters, and other exercise and physical therapy devices. They're used in gaming controls to generate tilt data. They're used in automobiles, to control airbag release when there's a sudden stop. There are countless other applications for them.

Possible uses for accelerometers in robotics:

- Self balancing robots
- Tilt-mode game controllers
- Model airplane auto pilot
- Alarm systems
- Collision detection
- Human motion monitoring
- Leveling sensor, inclinometer
- Vibration Detectors for Vibration Isolators
- G-Force Detectors

Axis of acceleration

The tiny micro-structures can only measure force in a single direction, or axis of acceleration. This means with a single axis measured, you can only know the force in either the X, Y, or Z directions, but not all. So if say your X-axis accelerometer endowed robot was running around and ran into a wall (in the X direction). Your robot could detect this collision. But if say another robot rammed into it from the side (the Y direction), your robot would be oblivious to it. There are many other situations where a single axis would not be enough. It is always a good idea to have at least 2 axes (more than one axis).



Gravity

Gravity is acceleration. Your accelerometer will always be subject to a -9.81 m/s^2 acceleration (negative means towards the ground). Because of this, your robot can detect what angle it is in respect to gravity. If your robot is a biped, and you want it to always remain balanced and standing up, just simply use a 2-axis accelerometer. As long as the X and Y axes detect zero acceleration, this means your robot device is perfectly level and balanced.

Accelerometers, Rated G When you buy your accelerometer, you will notice it saying something like 'rated at 2g' or '3g accelerometer.' This is the maximum g force your sensor can report. Gravity accelerates objects at 1g, or 9.81 m/s^2. For example, if your robot is moving at 1g upwards, then that means you sensor will detect 2g. For most robotics applications a 2g rating will be fine. So why not just get the highest rating possible? The lower the rating, the more sensitive it will be to changes in motion. You will always have a finer tuned sensor the lower the rating. But then again, more sensitive sensors are more affected by vibration interference.

Calculate Acceleration and Angle wrt Gravity To calculate the magnitude of acceleration for a

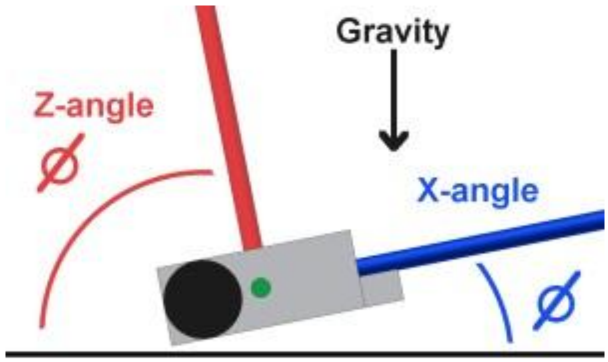
single-axis accelerometer   acceleration_max = sqrt(x^2) = x

2-axis accelerometer   acceleration_max = sqrt(x^2+y^2)

3-axis accelerometer   acceleration_max = sqrt(x^2+y^2+z^2)

To calculate the detected force on an accelerometer due to gravity:

Force_gravity = -g*cos(angle) (depends on starting axis of sensor)



Chances are you would have no need to measure the force, but if you reverse the equation you can calculate the angle by knowing the

detected force : cos(sensor_value*conversion_constant / -g)^-1 = angle

Availability and cost

The MEMS IC's are easily available and very affordable. However they all require support circuitry and come as surface mounts. I highly discourage buying an IC and doing your own wiring. However there are many already setup accelerometer packages you can buy. For example, Dimension Engineering has a great plug and play dual axis accelerometer which requires no additional support circuitry. There are several other great sensors out there, some as a 3-axis, and now some even with built in rotation sensor.

Wiring Requirements Any accelerometer package will have a power and ground line, and a single output analog pin for each axis of acceleration. Some of the sensors come with additional features/pins, read their datasheets. Additional Tips and Uses Placing an accelerometer on a mobile robot that experiences bumps can trigger the accelerometer unintentionally. Use a capacitor to smooth out output over several hundred milliseconds (testing required) to prevent this. Also, read the interpret sensor data tutorial to enhance your accelerator sensor accuracy.

Touch, Force, Torque :

A tactile sensor is a device that measures information arising from physical interaction with its environment. Tactile sensors are generally modeled after the biological sense of coetaneous touch which is capable of detecting stimuli resulting from mechanical stimulation, temperature, and pain (although pain sensing is not common in artificial tactile sensors). Tactile sensors are used in robotics, computer hardware and security systems. A common application of tactile sensors is in touchscreen devices on mobile phones and computing.

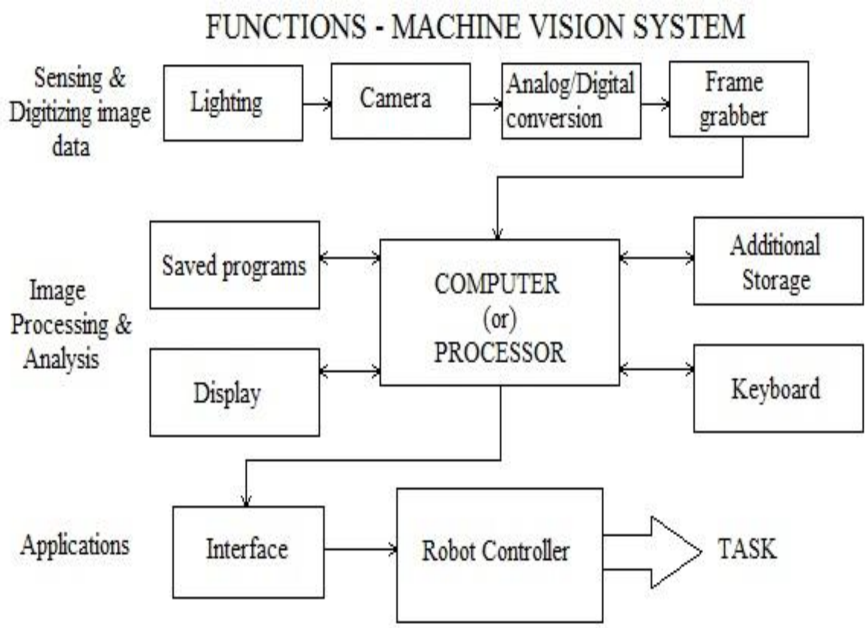
Tactile sensors may be of different types including piezoresistive, piezoelectric, capacitive and elasto-resistive sensors

Force Sensors (Force Transducers) There are many types of force sensors, usually referred to as torque cells (to measure torque) and load cells (to measure force). From this point on I will refer to them as 'force transducers.' Force transducers are devices useful in directly measuring torques and forces within your mechanical system. In order to get the most benefit from a force transducer, you must have a basic understanding of the technology, construction, and operation of this unique device.

Machine Vision System

Machine vision system is a sensor used in the robots for viewing and recognizing an object with the help of a computer. It is mostly used in the industrial robots for inspection purposes. This system is also known as artificial vision or computer vision. It has several components such as a camera, digital computer, digitizing hardware, and an interface hardware & software. The machine vision process includes three important tasks, namely:

1. Sensing & Digitizing Image Data
2. Image Processing & Analysis
3. Applications



Sensing & Digitizing Image Data:

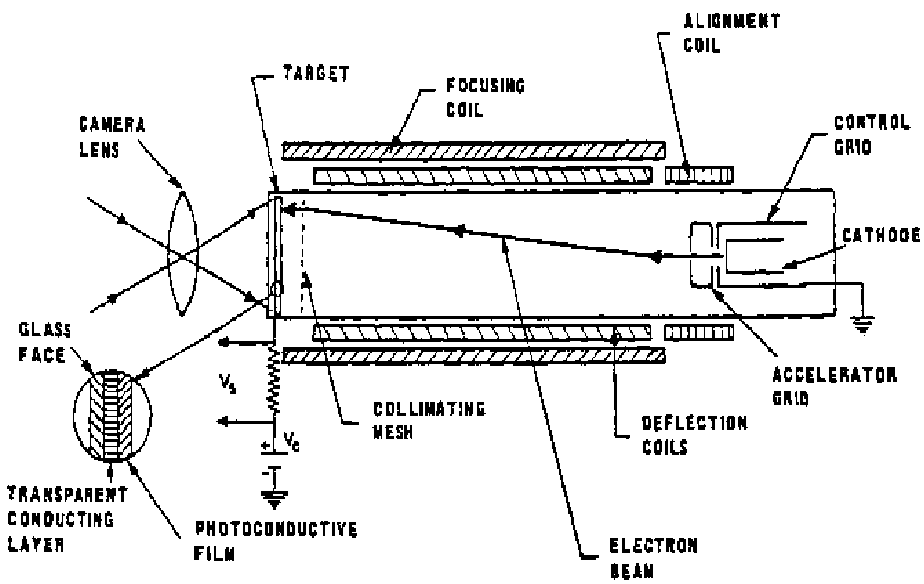
A camera is used in the sensing and digitizing tasks for viewing the images. It will make use of special lighting methods for gaining better picture contrast. These images are changed into the digital form, and it is known as the frame of the vision data. A frame grabber is incorporated for taking digitized image continuously at 30 frames per second. Instead of scene projections, every frame is divided as a matrix. By performing sampling operation on the image, the number of pixels can be identified. The pixels are generally described by the elements of the matrix. A pixel is decreased to a value for measuring the intensity of light. As a result of this process, the intensity of every pixel is changed into the digital value and stored in the computer's memory.

Imaging devices:

There are a variety of commercial imaging devices available. Camera technologies available include the older black and white and vidicon camera and the newer second generation solid state cameras. Solid state camera used for robot vision include charge coupled devices (CCD), charge injection devices (CID) and silicon bipolar sensor cameras. For our use two devices in this subsection, the vidicon camera and the charge coupled devices.

1. Vidicon camera:

A vidicon tube is a video camera tube design in which the target material is a photoconductor. The vidicon is a storage-type camera tube in which a charge-density pattern is formed by the imaged scene radiation on a photoconductive surface which is then scanned by a beam of low-velocity electrons. The fluctuating voltage coupled out to a video amplifier can be used to reproduce the scene being imaged. The electrical charge produced by an image will remain in the face plate until it is scanned or until the charge dissipates. Pyroelectric photocathodes can be used to produce a vidicon sensitive over a broad portion of the infrared spectrum



2. CHARGE-COUPLED DEVICE (CCD):

A **charge-coupled device** (**CCD**) is a device for the movement of electrical charge, usually from within the device to an area where the charge can be manipulated, for example conversion into a digital value. This is achieved by "shifting" the signals between stages within the device one at a time. CCDs move charge between capacitive *bins* in the device, with the shift allowing for the transfer of charge between bins.

The CCD is a major piece of technology in digital imaging. In a CCD image sensor, pixels are represented by p-doped MOS capacitors. These capacitors are biased above the threshold for inversion when image acquisition begins, allowing the conversion of incoming photons into electron charges at the semiconductor-oxide interface; the CCD is then used to read out these charges. Although CCDs are not the only technology to allow for light detection, CCD image sensors are widely used in professional, medical, and scientific applications where high-quality image data is required. In applications with less exacting quality demands, such as consumer and professional digital cameras, active pixel sensors (CMOS) are generally used; the large quality advantage CCDs enjoyed early on has narrowed over time.

In a CCD for capturing images, there is a photoactive region (an epitaxial layer of silicon), and a transmission region made out of a shift register (the CCD, properly speaking).

An image is projected through a lens onto the capacitor array (the photoactive region), causing each capacitor to accumulate an electric charge proportional to the light intensity at that location. A one-dimensional array, used in line-scan cameras, captures a single slice of the image, whereas a two-dimensional array, used in video and still cameras, captures a two-dimensional picture corresponding to the scene projected onto the focal plane of the sensor. Once the array has been exposed to the image, a control circuit causes each capacitor to transfer its contents to its neighbor (operating as a shift register). The last capacitor in the array dumps its charge into a charge amplifier, which converts the charge into a voltage. By repeating this process, the controlling circuit converts the entire contents of the array in the semiconductor to a sequence of voltages. In a digital device, these voltages are then sampled, digitized, and usually stored in memory; in an analog device (such as an analog video camera), they are processed into a continuous analog signal (e.g. by feeding the output of the charge amplifier into a low-pass filter), which is then processed and fed out to other circuits for transmission, recording, or other processing.

Image Processing & Analysis:

In this function, the image interpretation and data reduction processes are done. The threshold of an image frame is developed as a binary image for reducing the data. The data reduction will help in converting the frame from raw image data to the feature value data. The feature value data can be calculated via computer programming. This is performed by matching the image descriptors like size and appearance with the previously stored data on the computer.

The image processing and analysis function will be made more effective by training the machine vision system regularly. There are several data collected in the training process like length of perimeter, outer & inner diameter, area, and so on. Here, the camera will be very helpful to identify the match between the computer models and new objects of feature value data.

Applications:

Some of the important applications of the machine vision system in the robots are:

- Inspection
- Orientation
- Part Identification
- Location

There are some of the future improvements researches are going on for providing highly-developed machine vision system in the complicated areas.

Image data reduction:

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

1.Digital conversion

2.Windowing.

Digital conversion reduces the number of grey levels used by the machine vision systems. E**xample**: an 8 bit register used for each pixel could have 2^8 = 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 grey levels to 16. This kind of conversion reduces the magnitude of the image – processing problem.

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. **Example**: for inspection of printed circuit board, one may wish to inspect and analysis only one component on the board. A rectangular window is selected to surround the component of interest and only pixels only the windows are analyzed.

Segmentation:

Segmentation is a general term which is applies to the various methods of data reduction. In segmentation , the objective is to group areas of an image having similar charecterestics or features into distinct entities representing the parts of the image.

Example: Boundaries (Edges) or regions (areas) represents two natural segments of an image. There are many ways to segment an image

- Thresholding
- Region growing
- Edge detection

1. Thresholding

Thresholding is the 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 is to be border between the black and white. Thersholding is the most widely used techniques for segmentation in industrial vision application. It is the fast and easily implemented and that the lighting is usually controllable is an industrial setting.

2. Region growing

Region growing is a collection of segmentation techniques in which the pixels are grouped in regions called grid elements based on attribute similarities. To differentiate between the object and the background assign 1for any grid element occupied by an object. A typical region growing techniques for complete images could have the following procedures

- Select the pixel, In the simplest case select white pixel and assign a value of 1
- Compare the pixel, selected with all adjacent pixels
- Go to an equivalent adjacent pixel and repeat the until no equivalent pixels can be added to the region.

3.Edge detection

Edge detection is considered as the intensity change that occurs in the pixels at the boundary or edges of a part. The boundary can be determined by a simple edge following procedure is to scan a image until a pixel within the region is encountered. For a pixel within the region, turn left and step, otherwise turn right and step.

Feature Extraction

In machine vision application, it is often necessary to distinguish one object from another. This is usually accomplished by means of features that uniquely characterized the object. Some features of object that can be used in machine vision include area, diameter and perimeter. The region growing procedures described before can be used to determine the area of an object image.

Object Recognition

The next step in image data processing is to identify the object the object the image represents. The object recognition techniques used in industry today may be classified into two major categories

a) Template matching techniques
b) Structural techniques

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 into a stored pattern feature set defined as a model template. These techniques are applicable if there is no requirement for a large number of model templates. When the match is found, allowing for a 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 examples, if an image of an object can be divided into four straight lines (the lines are called primitives)connected at their endpoints and the connected lines are at right angles, then the object is rectangle . This kind of technique is known as syntactic pattern recognition is the most widely used structural techniques.

Structural techniques differ from decision theoretic techniques in that the later deals with a pattern on a quantitative basis and ignores for the most interrelationship among object primitives.

Training the vision system:

The process of vision system training is to program the vision system with known objects. The system stores these objects in the form of extracted feature values which can be subsequently compared against the corresponding features values from images of unknown objects. Physical parameters such as camera placemet, aperture setting, part position and lighting are the critical conditions that should be simulated as closely as possible during the training vision.

Robot applications:

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. The third level of difficulty requires advanced vision capabilities.
4. Large scale industrial manufacture
5. Short iron unique object manufacture.
6. Inspection of pre manufactured objects.
7. Visual stock control and management systems(counting , barcode reading , store interfaces for digital systems)
8. Control of automated guided vehicles(AGV's)
9. Quality control and refinement of food prodects.
10. Retail automation.
11. Machine vision systems are widely used in semiconductor fabrication. Inspect silicon wafers, processor chips and subcomponents such as resistors and capacitors.
12. In the automotive industry machine vision systems are used to guide industrial robots.

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.

Robot applications of machine vision fall into the three categories

a) Inspection

b) Identification

c) Visual servoing and navigation

Inspection:

The first category is one in which the primary function is the inspection process. This is carried out by the machine vision system and the robot is used in a secondary role to support the applications

The objectives of the machine vision inspection include checking for

- Gross surface defects
- Discovery of flaws in labeling verification of the presence of components in assembly
- Measuring for dimensional accuracy
- Checking for presence of holds and other feature in a part.

When these kinds of inspection operation are performed manually, there is a tendency for human error and also time required in manual inspection operation requires sampling basis. With machine vision these procedures are carried out automatically using hundred percent inspections and usually in much less time.

Identification:

The second category 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 the part must be either accepted or rejected. Identification implies that the part involves 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
- Depalletizing
- Picking parts

Visual servoing and navigation:

In the third application category, visual servoing and navigational control the purpose of the vision system is to direct the actions of the robot based on its visual input. The generic example of the robot visual servoing is where the machine vision system is used to control the trajectory of the robots end effecter toward an object in the workspace. Industrial example of this applications include part positioning, retrieving parts moving along the conveyor retrieving and reorienting parts moving along a conveyor, assembly, bin picking and tracking in continuous arc welding.

An example of navigational control would be in automatic robot path planning and collision avoidance using visual data. The bin picking application is an interesting and complex application of machine vision in robotics which involves both identification and servoing. Bin picking involves the use of a robot to grasp and retrieve randomly oriented parts will be overlapping each other.

The vision system must first recognize a target part and its orientation in the container and then it must direct the end effecter to a position to permit grasping and pickup. Solution of the bin picking problem owes much to the pioneering work in vision research at the University of Rhode Island. There are two commercially available bin picking systems one offered by object recognition systems inc called the i-bot 1 system and the other by general electric co called bin vision. Tracking in continuous arc welding is another example of the visual servoing and navigation in robotic vision systems.

Model questions

Part A

1. What are the desirable features of sensors?
2. What are the essential requirements for success in robot vision?
3. Give one example for velocity sensor.
4. Distinguish between tactile and non-tactile sensors. Give examples of each type.
5. Compare the internal state and external state sensors.

Part B

1. What are the types of fiber optic sensors? Explain in detail how they work.
2. Explain robot machine vision with suitable diagram.
3. With neat sketch explain ultrasonic proximity sensor.
4. Discuss the different sensors used in robotics.
5. What are the functions of a vision processor? What are the steps necessary in the image processing?
6. Discuss various sensors used in robots for various applications.