FATIMA MICHAEL COLLEGE OF ENGINEERING & TECHNOLOGY
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An ISO 9001:2008 Certified Institution

ME6010 - ROBOTICS

UNITS 1 - 5

UNIT I Fundamentals of Robots

ROBOT (AU-Nov/Dec-2010)

RIA defines a robot as a ―programmable, multifunction manipulator designed to Move materials, parts, tools or special devices through variable programmed motions for the performance of the variety of tasks‖.

TYPES OF ROTARY JOINT NOTATIONS (AU-Nov/Dec-2008)

- Rotational joint (type R)
- Twisting joint (type T)
- Revolving joint (type V)

WORK SPACE (AU-Nov/Dec-2010)

The space in which the end point of the robot arm is capable of operating is called as workspace in other words reach ability of robot arm is known as workspace.

Accuracy of robot

The robot‘s ability to reach a reference point within the robot‘s full work volume is known as accuracy of robot.

Benefits of industrial robots

- Increased Productivity
- Significant Savings
- Improved Quality
- Better Safety
- Competitive Edge

Repeatability of robot

Repeatability refers to robot‘s ability to return to the programmed point when it is commanded to do so.

Pitch, Yaw And Roll (AU-Nov/Dec-2008)

Pitch is rotation around the X axis, yaw is around the Y axis, and roll is around the Z axis. Yaw is side to side swinging around an axis. Pitch is up and down movement about an axis and roll is rotatory motion about an axis.

WORK VOLUME (AU-Nov/Dec-2008)

The volume of the space swept by the robot arm is called work volume.

QUALITY OF ROBOT

A Robot is said to be high quality when the precision and accuracy is more.

ROBOT ANATOMY (AU-Nov/Dec-2009)

Study of structure of robot is called robot anatomy. Manipulator is constructed of a series of joints and links. A joint provides relative motion between the input link and the output link.

THREE DEGREES OF FREEDOM ASSOCIATED WITH THE ARM AND BODY MOTION

(AU-Nov/Dec-2009)

- Right (or) left movement (X-axis motion)
- In and out movement (Y-axis motion)
- Vertical movement (Z-axis motion)

INDUSTRIAL ROBOT. (AU-NOV/DEC-2010)

An industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes. A programmable mechanical device that is used in place of a person to perform dangerous or repetitive tasks with a high degree of accuracy.

PAYLOAD CAPACITY OF ROBOT (AU-NOV/DEC-2010)

The maximum load which can be carried by the manipulator at low or normal speed.

Base And Tool Coordinate System. (AU-Nov/Dec-2012)

A tool coordinates definition system capable of easily obtaining a transformation matrix for defining a tool coordinates system of a robot. The tool coordinates system at the 0° position of the robot is rotated around each axis so that the tool coordinates system becomes parallel to a base coordinates system.

Important Specifications Of An Industrial Robot. (AU-Nov/Dec-2012)

- Accuracy
- Repeatability
- Degree of Freedom
- Resolution
- Envelope

FOUR BASIC ROBOT CONFIGURATIONS AVAILABLE COMMERCIALLY (AU-Apr/May-2010)

- Cartesian coordinate system
- Cylindrical coordinate system
- Polar or spherical coordinate system
- Revolute coordinate system

Work Envelop (AU-Apr/May-2010)

The work envelop is described by the surface of the work space.

different types of robots. (AU-Nov/Dec-2008)

Industrial robots

Industrial robots are robots used in an industrial manufacturing environment. Usually these are articulated arms specifically developed for such applications as welding, material handling, painting and others. If we judge purely by application this type could also include some automated guided vehicles and other robots.

Domestic or household robots

Robots used at home. This type of robots includes many quite different devices such as robotic vacuum cleaners, robotic pool cleaners, sweepers, gutter cleaners and other robots that can do different chores. Also, some surveillance and telepresence robots could be regarded as household robots if used in that environment.

Medical robots

Robots used in medicine and medical institutions. First and foremost - surgery robots. Also, some automated guided vehicles and maybe lifting aides.

Service robots

Robots that dont fall into other types by usage. These could be different data gathering robots, robots made to show off technologies, robots used for research, etc.

Military robots

Robots used in military. This type of robots includes bomb disposal robots, different transportation robots, reconnaissance drones. Often robots initially created for military purposes can be used in law enforcement, search and rescue and other related fields.

Entertainment robots

These are robots used for entertainment. This is a very broad category. It starts with toy robots such as robosapien or the running alarm clock and ends with real heavyweights such as articulated robot arms used as motion simulators.

Space robots

This type would include robots used on the International Space Station, Canadarm that was used in Shuttles, as well as Mars rovers and other robots used in space.

Hobby and competition robots

Most of the hobbyist robots are mobile and made to operate by rolling around on wheels propelled by electric motors controlled by an on board microprocessor.

Explorer robots

The majority of these robots are completely self-reliant due to their sensory systems, however they may also be controlled by humans giving orders through computer commands. The other types of explorer robots are underground mine exploring robots, seeing and walking undersea robots, and even bomb defusing robots used by police.

Laboratory robots

Laboratory robotics is the act of using robots in biology or chemistry labs. For example, pharmaceutical companies employ robots to move biological or chemical samples around to synthesize novel chemical entities or to test pharmaceutical value of existing chemical matter.

Sequence robots

A manipulator which progresses successively through the various stages of an operation according to the predetermined sequence.

Playback robots

The playback robots are capable of performing a task by teaching the position. These positions are stored in the memory, and done frequently by the robot. Generally, these playback robots are employed with a complicated control system. It can be divided into two important types, namely:

Point to Point control robots

Continuous Path control robots

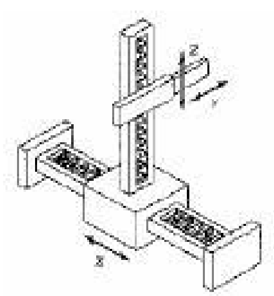
the four basic robot configurations classified according to the coordinate system. (AU-Nov/Dec-2009; 2010)

Classification Based on Physical Configuration (or) Co-ordinate Systems:

- Cartesian configuration
- Cylindrical configuration
- Polar configuration
- Joint-arm configuration

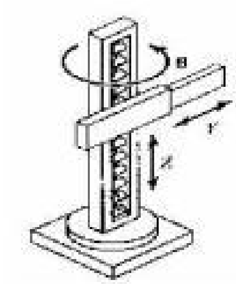
Cartesian Configuration:

Robots with Cartesian configurations consist of links connected by linear joints (L). Gantry robots are Cartesian robots (LLL).



Cylindrical Configuration:

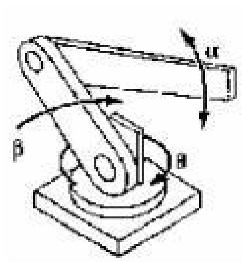
Robots with cylindrical configuration have one rotary (R) joint at the base and linear (L) joints succeeded to connect the links.



The designation of the arm for this configuration can be TRL or TRR. Robots with the designation TRL are also called spherical robots. Those with the designation TRR are also called articulated robots. An articulated robot more closely resembles the human arm.

Joint-arm Configuration:

The jointed-arm is a combination of cylindrical and articulated configurations. The arm of the robot is connected to the base with a twisting joint. The links in the arm are connected by rotary joints. Many commercially available robots have this configuration.



Simple Comparison

Configuration	Advantages	Disadvantages
Cartesian coordinates	3 linear axes, easy to visualize, rigid structure, easy to program	Can only reach front of itself, requires large floor space, axes hard to seal
Cylindrical coordinates	2 linear axes +1 rotating, can reach all around itself, reach and height axes rigid, rotational axis easy to seal	Can't reach above itself, base rotation axis as less rigid, linear axes is hard to seal, won't reach around obstacles
SCARA coordinates	1 linear + 2 rotating axes, height axis is rigid, large work area for floor space	2 ways to reach point, difficult to program off-line, highly complex arm
Spherical coordinates	1 linear + 2 rotating axes, long horizontal reach	Can't reach around obstacles, short vertical reach
Revolute coordinates	3 rotating axes can reach above or below obstacles, largest work area for least floor space	Difficult to program off-line, 2 or 4 ways to reach a point, most complex manipulator

Joint Notation Scheme.

(AU-Nov/Dec-2009)

A robot joint is a mechanism that permits relative movement between parts of a robot arm. The joints of a robot are designed to enable the robot to move its end-effector along a path from one position to another as desired.

The basic movements required for a desired motion of most industrial robots are:

1. Rotational movement: This enables the robot to place its arm in any direction on a horizontal plane.

2. Radial movement: This enables the robot to move its end-effector radially to reach distant points.

3. Vertical movement: This enables the robot to take its end-effector to different heights.

These degrees of freedom, independently or in combination with others, define the complete motion of the end-effector. These motions are accomplished by movements of individual joints of the robot arm. The joint movements are basically the same as relative motion of adjoining links. Depending on the nature of this relative motion, the joints are classified as prismatic or revolute.

Prismatic joints are also known as sliding as well as linear joints. They are called prismatic because the cross section of the joint is considered as a generalized prism. They permit links to move in a linear relationship.

Revolute joints permit only angular motion between links. Their variations include:

- Rotational joint (R)
- Twisting joint (T)
- Revolving joint (V)

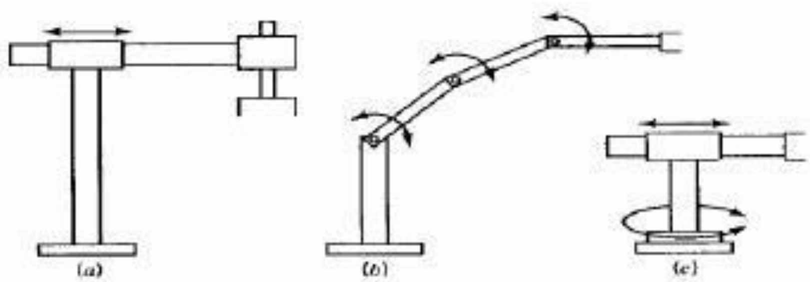
In a prismatic joint, also known as a sliding or linear joint (L), the links are generally parallel to one another. In some cases, adjoining links are perpendicular but one link slides at the end of the other link. The joint motion is defined by sliding or translational movements of the links. The orientation of the links remains the same after the joint movement, but the lengths of the links are altered.

A rotational joint (R) is identified by its motion, rotation about an axis perpendicular to the adjoining links. Here, the lengths of adjoining links do not change but the relative position of the links with respect to one another changes as the rotation takes place.

A twisting joint (T) is also a rotational joint, where the rotation takes place about an axis that is parallel to both adjoining links.

A revolving joint (V) is another rotational joint, where the rotation takes place about an axis that is parallel to one of the adjoining links. Usually, the links are aligned perpendicular to one another at this kind of joint. The rotation involves revolution of one link about another.

The Joint Notation:



Robot configurations: (a) LL Robot, (b) RRR robot, (c) TL robot technical specification in Robotics. (AU-Nov/Dec-2008; 2009)

Accuracy:

How close does the robot get to the desired point? When the robot's program instruct the robot to move to a specified point, it does not actually perform as per specified. The accuracy measure such variance. That is, the distance between the specified position that a robot is trying to achieve (programming point), and the actual X, Y and Z resultant position of the robot end effector.

Repeatability:

The ability of a robot to return repeatedly to a given position. It is the ability of a robotic system or mechanism to repeat the same motion or achieve the same position. Repeatability is is a measure of the error or variability when repeatedly reaching for a single position. Repeatability is often smaller than accuracy.

Degree of Freedom (DOF):

Each joint or axis on the robot introduces a degree of freedom. Each DOF can be a slider, rotary, or other type of actuator. The number of DOF that a manipulator possesses thus is the number of independent ways in which a robot arm can move. Industrial robots typically have 5 or 6 degrees of freedom. 3 of the degrees of freedom allow positioning in 3D space (X, Y, Z), while the other 2 or 3 are used for orientation of the end effector (yaw, pitch and roll). 6 degrees of freedom are enough to allow the robot to reach all positions and orientations in 3D space. 5 DOF requires a restriction to 2D space, or else it limits orientations. 5 DOF robots are commonly used for handling tools such as arc welders.

Resolution:

The smallest increment of motion or distance that can be detected or controlled by the robotic control system. It is a function of encoder pulses per revolution and drive (e.g. reduction gear) ratio. And it is dependent on the distance between the tool center point and the joint axis.

Envelope:

A three-dimensional shape that defines the boundaries that the robot manipulator can reach; also Known as reach envelope.

Reach:

The maximum horizontal distance from the center of the robot base to the end of its wrist.

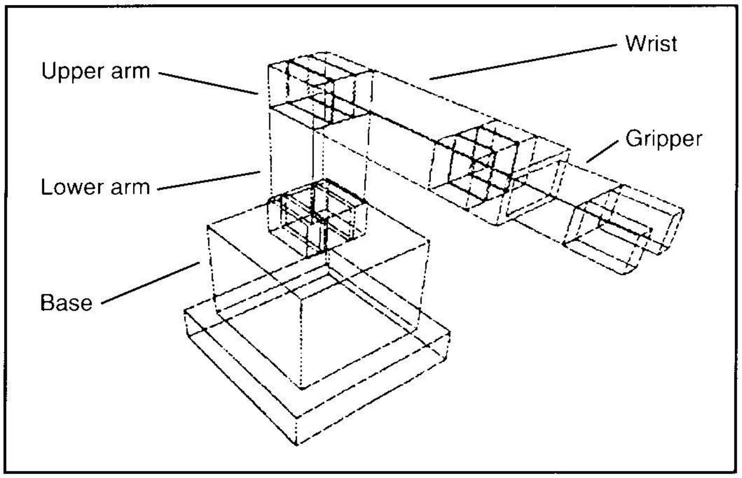
Maximum Speed:

A robot moving at full extension with all joints moving simultaneously in complimentary directions at full speed. The maximum speed is the theoretical values which does not consider under loading condition.

Payload:

The maximum payload is the amount of weight carried by the robot manipulator at reduced speed while maintaining rated precision. Nominal payload is measured at maximum speed while maintaining rated precision. These ratings are highly dependent on the size and shape of the payload due to variation in inertia.

various parts of a robot with neat sketch. (AU-Nov/Dec-2008)



Controller:

Every robot is connected to a computer, which keeps the pieces of the arm working together. This computer is known as the controller. The controller functions as the "brain" of the robot. The controller also allows the robot to be networked to other systems, so that it may work together with other machines, processes, or robots.

Robots today have controllers that are run by programs - sets of instructions written in code. Almost all robots of today are entirely pre-programmed by people; they can do only what they are programmed to do at the time, and nothing else. In the future, controllers with artificial intelligence, or AI could allow robots to think on their own, even program themselves. This could make robots more self-reliant and independent.

Arm:

Robot arms come in all shapes and sizes. The arm is the part of the robot that positions the end-affector and sensors to do their pre-programmed business.

Many (but not all) resemble human arms, and have shoulders, elbows, wrists, even fingers. This gives the robot a lot of ways to position itself in its environment. Each joint is said to give the robot 1 degree of freedom. So, a simple robot arm with 3 degrees of freedom could move in 3 ways: up and down, left and right, forward and backward.

Drive:

The drive is the "engine" that drives the links (the sections between the joints into their desired position. Without a drive, a robot would just sit there, which is not often helpful. Most drives are powered by air, water pressure, or electricity.

End-Effector:

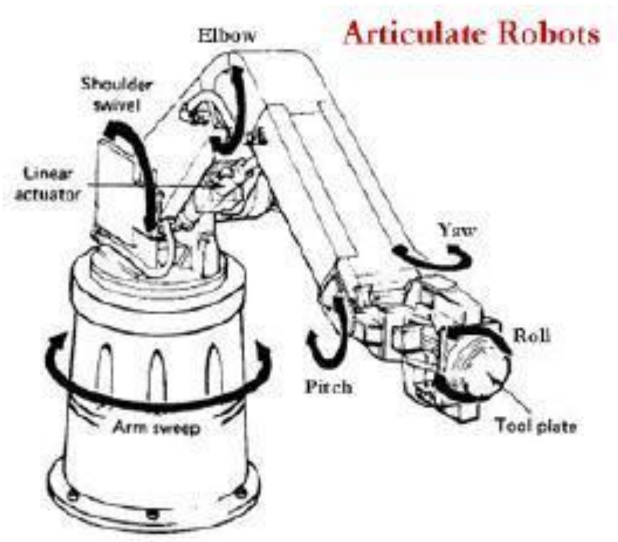
The end-effector is the "hand" connected to the robot's arm. It is often different from a human hand - it could be a tool such as a gripper, a vacuum pump, tweezers, scalpel, blowtorch - just about anything that helps it do its job. Some robots can change end-effectors, and be reprogrammed for a different set of tasks.

Sensor:

Most robots of today are nearly deaf and blind. Sensors can provide some limited feedback to the robot so it can do its job. Compared to the senses and abilities of even the simplest living things, robots have a very long way to go.

The sensor sends information, in the form of electronic signals back to the controller. Sensors also give the robot controller information about its surroundings and lets it know the exact position of the arm, or the state of the world around it.

Robot anatomy with neat sketch.



Robot anatomy is concerned with the physical construction and characteristics of the body, arm, and wrist, which are the component of the robot manipulator.

- **Base.-**fixed are mobile
- **The manipulator**- arm which several degrees of freedom (DOF).
- **The end-effector or gripper**- holding a part or tool
- **Drives or actuators** – Causing the manipulator arm or end effector to move in a space.
- **Controller** – with hardware & software support for giving commands to the drives
- **Sensors** - To feed back the information for subsequent action of the arm or grippers as well as to interact with the environment in which the robot is working.
- **Interface** – Connecting the robot subsystem to the external world.

Which consist of a number of component that allowed be oriented in a verity of position movements between the various components of the body, arm, and wrist are provided by a series of joints. These joint movements usually involve either rotation or sliding motions.

types of joints used in robots.

The Robot Joints is the important element in a robot which helps the links to travel in different kind of movements. There are five major types of joints such as:

- Rotational joint
- Linear joint
- Twisting joint
- Orthogonal joint
- Revolving joint

Rotational Joint:

Rotational joint can also be represented as R – Joint. This type will allow the joints to move in a rotary motion along the axis, which is vertical to the arm axes.

Linear Joint:

Linear joint can be indicated by the letter L – Joint. This type of joints can perform both translational and sliding movements. These motions will be attained by several ways such as telescoping mechanism and piston. The two links should be in parallel axes for achieving the linear movement.

Twisting Joint:

Twisting joint will be referred as V – Joint. This joint makes *twisting motion* among the output and input link. During this process, the output link axis will be vertical to the rotational axis. The output link rotates in relation to the input link.

Orthogonal Joint:

The O – joint is a symbol that is denoted for the orthogonal joint. This joint is somewhat similar to the linear joint. The only difference is that the output and input links will be moving at the right angles.

Revolving Joint:

Revolving joint is generally known as V – Joint. Here, the output link axis is perpendicular to the rotational axis, and the input link is parallel to the rotational axes. As like twisting joint, the output link spins about the input link.

the four types of robot controls. (AU-Apr/May-2010)

1. Point-to-point (PTP) control robot
2. Continuous-path (CP) control robot
3. Controlled-path robot
4. Stop-to-Stop

Point to Point Control Robot (PTP):

The PTP robot is capable of moving from one point to another point. The locations are recorded in the control memory. PTP robots do not control the path to get from one point to the next point. Common applications include:

- Component insertion
- Spot welding
- hole drilling
- Machine loading and unloading
- Assembly operations

Continuous-Path Control Robot (CP):

The CP robot is capable of performing movements along the controlled path. With CP from one control, the robot can stop at any specified point along the controlled path. All the points along the path must be stored explicitly in the robot's control memory. Applications Straight-line motion is the simplest example for this type of robot. Some continuous-path controlled robots also have the capability to follow a smooth curve path that has been defined by the programmer. In such cases the programmer manually moves the robot arm through the desired path and the controller unit stores a large number of individual point locations along the path in memory (teach-in).

Typical applications include:

- spray painting
- finishing
- gluing
- Arc welding operations

Controlled-Path Robot:

In controlled-path robots, the control equipment can generate paths of different geometry such as straight lines, circles, and interpolated curves with a high degree of accuracy. Good accuracy can be obtained at any point along the specified path.

Only the start and finish points and the path definition function must be stored in the robot's control memory. It is important to mention that all controlled-path robots have a servo capability to correct their path.

Stop-to-Stop:

- It is open loop system
- Position and velocity unknown to controller
- On/off commands stored as valve states
- End travel set by mechanical stops

UNIT II Robots Drive Systems and End Effectors

End effector.

End effector is a device that is attached to the end of the wrist arm to perform specific task.

Examples of Robot End Effector.

- Gripper
- Tools
- Welding equipments
- End of arm Tooling (EOAT)

Gripper

Gripper is the End effector which can hold or grasp the object.

THE DIFFERENCE BETWEEN INTERNAL GRIPPERS AND EXTERNAL GRIPPERS

(AU-Nov/Dec-2008)

In internal grippers, the finger pads are mounted on the inside of the fingers. This mounting allows the pads to fit into the inside diameter of the part it must lift. The pads are pressed against the inside wall of the part.

An external gripper is designed so that the finger pads press against the outside of the component. Grips the exterior surface of the objects with closed fingers.

TYPES OF MECHANICAL GRIPPERS (AU-Apr/May-2010)

- Linkage actuation gripper
- Gear and rack actuation gripper
- Cam actuated gripper
- Screw actuated gripper

TWO LIMITATIONS OF MAGNETIC GRIPPERS

- Residual magnetism
- Side slippage
- More than one sheet will be lifted by the magnet from a stack

FOUR IMPORTANT FACTORS TO BE CONSIDERED IN THE SELECTION AND DESIGN OF GRIPPERS.

- The gripper must have the ability to reach the surface of a work part. (AU-Apr/May-2011)
- The change in work part size must be accounted for providing accurate positioning.
- During machining operations, there will be a change in the work part size. As a result, the gripper must be designed to hold a work part even when the size is varied.
- The gripper must not create any sort of distort and scratch in the fragile work parts.

EXAMPLES OF TOOL AS ROBOT END EFFECTOR.

- Spot Welding Tools
- Arc welding Torch
- Spray painting nozzle
- Water jet cutting tool

FEEDBACK DEVICES USED IN ROBOTICS.

- Potentiometer
- Resolver
- Encoder

TYPES OF ENCODERS

(a) Linear encoder

(b). Rotary encoder

(i) Absolute encoder (ii) Incremental encoder

TYPES OF DRIVE SYSTEMS USED IN ROBOTS.

- Electric motors like: Servomotors, Stepper motors
- Hydraulic actuators
- Pneumatic actuators

CHARACTERISTICS OF ACTUATING SYSTEMS.

- Weight
- Power-to-weight ratio
- Operating Pressure
- Stiffness Vs. Compliance

FEATURES OF A STEPPER MOTOR.

- Moves in known angle of rotation.
- Position feedback is not necessary.
- Rotation of the shaft by rotation of the magnetic field.

RCC device

In robotics, a Remote Center Compliance, Remote Center of Compliance or RCC is a mechanical device that facilitates automated assembly by preventing peg-like objects from jamming when they are inserted into a hole with tight clearance. In a naive design without an RCC, a robot might pick up a peg with its gripper, center the peg over the hole and then push the peg along the axis of the hole.

Mechanical drives system.

When the various driving methods like hydraulic, pneumatic, electrical servo motors and stepping motors are used in robots, it is necessary to get the motion in linear or rotary fashion. When motors are used, rotary motion is converted to linear motion through rack and pinion gearing, lead screws, worm gearing or bail screws.

Rack and Pinion Movement:

The pinion is in mesh with rack (gear of infinite radius). If the rack is fixed, the pinion will rotate. The rotary motion of the pinion will be converted to linear motion of the carriage.

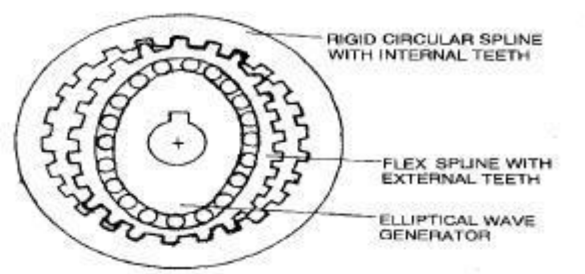
Ball Screws:

Sometimes lead screws rotate to drive the nut along a track. But simple lead screws cause friction and wear, causing positional inaccuracy. Therefore ball bearing screws are used in robots as they have low friction. The balls roll between the nut and the screw. A cage is provided for recirculation of the balls. The rolling friction of the ball enhances transmission efficiency to about 90%.

Gear Trains:

Gear trains use spur, helical and worm gearing. A reduction of speed, change of torque and angular velocity are possible. Positional errors are caused due to backlash in the gears.

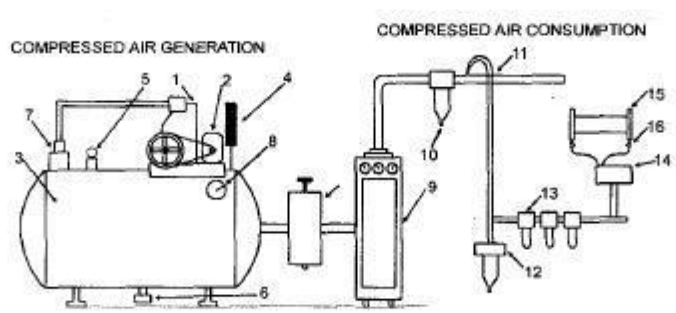
Harmonic Drive:



For speed reduction, standard gear transmission gives sliding friction and backlash. Moreover, it takes more space. Harmonic drive due to its natural preloading eliminates backlash and greatly reduces tooth wear. Harmonic drives are suitable for robot drives due to their smooth and efficient action. The harmonic drive as shown in figure is made up of three major elements: the circular spline, the wave generator and the flex spline. The circular spline is a rigid ring with gear teeth machined on the inside diameter. The flex spline is a flexible ring with the teeth cut on its outside diameter. The flex spline has fewer teeth (say 2 teeth less) than the circular spline. The wave generator is elliptical and is given input motion. The wave generator is assembled into the flex spline the entire assembly of. Wave generator and flex spline is placed into the circular spline such that the outer tooth of flex spline is in mesh with the internal teeth of circular spline

If the circular spline has 100 teeth and the flex spline has 98 teeth, and if the wave generator makes one complete revolution, the flex spline will engage 98 teeth of the circular spline. Since circular spline has 100 teeth and only 98 teeth have been in engagement for one complete rotation, the circular saline's position has been shifted by 2 teeth. Thus after 50 revolutions of the wave generator, the circular spline will have made one full rotation. The ratio of harmonic drive is 2: 100 or 1: 50. The gear ratio is influenced by the number of teeth cut into the circular spline and the flex spline. The harmonic drive has high torque capacity.

Pneumatic actuators system with neat sketch.



Pneumatic systems use pressurized air to make things move. Basic pneumatic system consists of an air generating unit and an air-consuming unit. Air compressed in compressor is not ready for use as such, air has to be filtered, moisture present in air has to be dried, and for different applications in plant pressure of air has to be varied. Several other treatments are given to the air before it reaches finally to the Actuators. The figure gives an overview of a pneumatic system. Practically some accessories are added for economical and efficient operation of system.

Compressor:

A device, which converts mechanical force and motion into pneumatic fluid power, is called compressor. Every compressed-air system begins with a compressor, as it is the source of airflow for all the downstream equipment and processes Electric Motor Electric motor is used to drive the compressor.

Air Receiver:

It is a container in which air is stored under pressure. Pressure Switch. Pressure Switch is used to maintain the required pressure in the receiver; it adjusts the High Pressure Limit and Low Pressure Limit in the receiver. The compressor is automatically turned off when the pressure is about to exceed the high limit and it is also automatically turned on when the pressure is about to fall below the low limit.

Safety Valve:

The function of the safety valve is to release extra pressure if the pressure inside the receiver tends to exceed the safe pressure limit of the receiver.

Check Valve:

The valve enables flow in one direction and blocks flow in a counter direction is called Check Valve. Once compressed air enters the receiver via check valve, it is not allowed to go back even when the compressor is stopped.

Direction Control Valve:

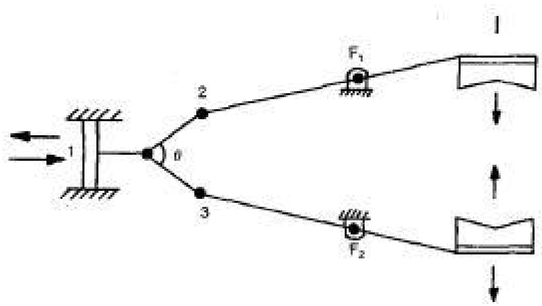
Directional-control valve are devices used to change the flow direction of fluid within a Pneumatic/Hydraulic circuit. They control compressed-air flow to cylinders, rotary actuators, grippers, and other mechanisms in packaging, handling, assembly, and countless other applications. These valves can be actuated either manually or electrically.

Pneumatic Actuator:

A device in which power is transferred from one pressurized medium to another without intensification. Pneumatic actuators are normally used to control processes requiring quick and accurate response, as they do not require a large amount of motive force. They may be reciprocating cylinders, rotating motors or may be a robot end effectors.

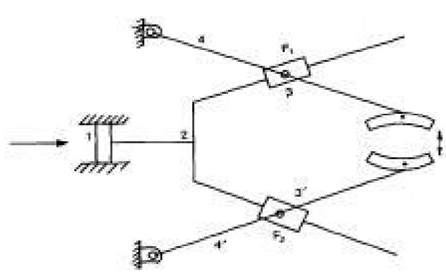
various types of Gripper mechanisms. (AU-Nov/Dec-2010)

Pivoting or Swinging Gripper Mechanisms:

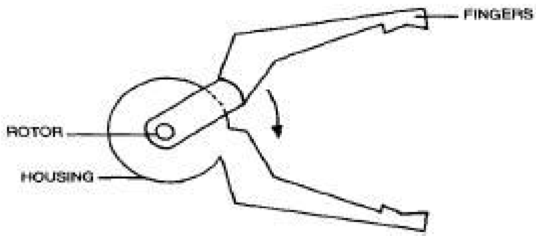


This is the most popular mechanical gripper for industrial robots. It can be designed for limited shapes of an object, especially cylindrical work piece. If actuators that produce linear movement are used, like pneumatic piston- cylinders, the device contains a pair of slider-crank mechanisms.

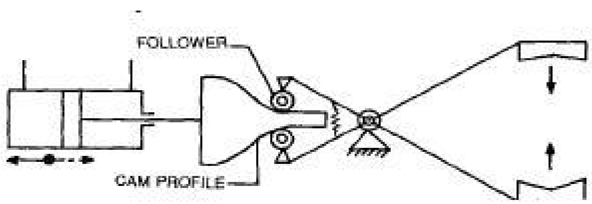
When the piston 1 is pushed by pneumatic pressure to the right, the elements in the cranks 2 and 3, rotate counter clockwise with the fulcrum F and clockwise with the fulcrum F respectively, when B < 1800. These rotations make the grasping action at the extended end of the crank elements 2 and 3. The releasing action can be obtained by moving the piston to the left. An angle B ranging from 160° to is commonly used.



This is the swing block mechanism. The sliding rod 1, actuated by the pneumatic piston transmits motion by way of the two symmetrically arranged swing-block linkages 1--2--3--4 and 1—2—3'—4' to grasp or release the object by means of the subsequent swinging motions of links 4 and 4' at their Pivots F.

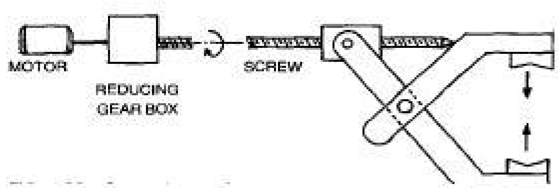


A gripper using a rotary actuator in which the actuator is placed at the cross point of the two fingers. Each finger is connected to the rotor and the housing of the actuator, respectively. The actuator movement directly produces grasping and releasing actions.



The cam actuated gripper includes a variety of possible designs, one of which is shown.

A cam and follower arrangement, often using a spring-loaded follower, can provide the opening and closing action of the gripper. The advantage of this arrangement is that the spring action would accommodate different sized objects.

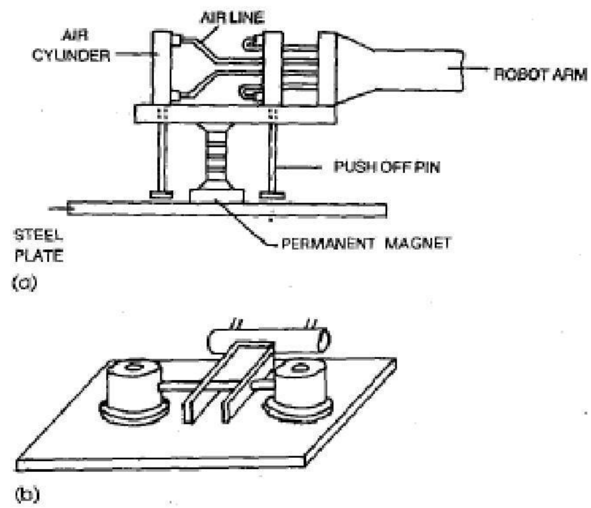


The screw is turned by a motor, usually accompanied by a speed reduction mechanism. Due to the rotation of the screw, the threaded block moves, causing the opening and dosing of the fingers depending on the direction of rotation of the screw.

Gripper selection and design (AU-Apr/May-2011)

Factor	Consideration
Part to be handled	Weight and size Shape Changes in shape during processing Tolerances on the part size Surface condition, protection of delicate surfaces
Actuation method	Mechanical grasping Vacuum cup Magnet Other methods (adhesives, scoops, etc.)
Power and signal transmission	Pneumatic Electrical Hydraulic Mechanical
Gripper force (mechanical gripper)	Weight of the object Method of holding (physical constriction or friction) Coefficient of friction between fingers and object Speed and acceleration during motion cycle
Positioning problems	Length of fingers Inherent accuracy and repeatability of robot Tolerances on the part size
Service conditions	Number of actuations during lifetime of gripper Replaceability of wear components (fingers) Maintenance and serviceability
Operating environment	Heat and temperature Humidity, moisture, dirt, chemicals
Temperature protection	Heat shields Long fingers Forced cooling (compressed air, water cooling, etc.) Use of heat-resistant materials
Fabrication materials	Strength, rigidity, durability Fatigue strength Cost and ease of fabrication Friction properties for finger surfaces Compatibility with operating environment
Other considerations	Use of interchangeable fingers Design standards Mounting connections and interfacing with robot Risk of product design changes and their effect on the gripper design Lead time for design and fabrication Spare parts, maintenance, and service Tryout of the gripper in production

Magnetic Grippers.



Magnetic grippers (a) Permanent magnet type (to Electro magnet type

Magnetic grippers are used extensively on ferrous materials. In general, magnetic grippers offer the following advantages in robotic handling operations

- Variations in part size can be tolerated
- Pickup times are very fast
- They have ability to handle metal parts with holes
- Only one surface is required for gripping

The residual magnetism remaining in the work piece may cause problems. Mother potential disadvantage is the problem of picking up one sheet at a time from a stack. The magnetic attraction tends to penetrate beyond the top sheet in the stack, resulting in the possibility that more than a single sheet will be lifted by the magnet.

Magnetic grippers can use either electromagnets or permanent magnets. Electromagnetic grippers are easier to control, but require a source of dc power and an appropriate controller. When the part is to be released, the control unit reverses the polarity at a reduced power level before switching off the electromagnet. This procedure acts to cancel the residual magnetism in the work plece ensuring a positive release of the part. The attractive force, P of an electromagnet is found from Maxwell's equation given by

$$P = \frac{(IN)^2}{25A_c(R_a + R_m)}$$

where IN = Number of amp-turns of coil
A_c = Area of contact of an object with magnet
R_a, R_m = Reluctances of magnetic paths through air and metal respectively

$$P \geq (a + g)m \times FS$$

where a = gripper acceleration
g = gravitational constant
m = mass and FS = Factor of safety

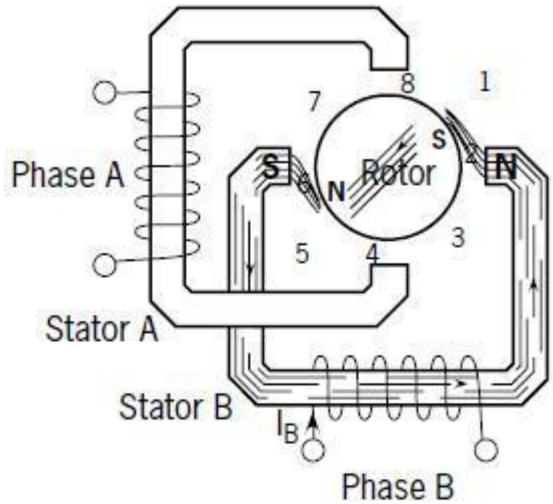
Permanent magnets do not require an external power and hence they can be used in hazardous and explosive environments, because there is no danger of sparks which might cause ignition in such environments. When the part is to be released at the end of the handling cycle, in case of permanent magnet grippers, some means of separating the part from the magnet must be provided. One such stripping device is shown in figure.

VARIOUS DRIVE SYSTEM USED WITH AN INDUSTRIAL ROBOT AND COMPARE THEIR FEATURES,

MERITS AND DEMERITS. (AU-Nov/Dec-2010)

Sl. No.	Comparing Features	Hydraulic Drive	Electric Drive	Pneumatic Drive
1.	Power to weight-ratio—	• Highest	• Moderate	• Lowest
2.	Payload carried by the robot—	• Heavy	• Medium	• Low
3.	Controlling devices—	• Needs a hydraulic power pack	• Control system is needed	• Pneumatic power control devices needed
4.	Size and stiffness—	• Very high.	• Low stiffness	• Very low
5.	Compliance of the system—	• Low	• Better	• Good
6.	Leakage and cleanliness—	• Worst	• Nil	• Better
7.	Reliability of the components—	• Low	• High	• Higher
8.	Accuracy and response—	• Good	• Higher	• Bad
9.	Need for maintainance—	• Needed more	• Low	• Less
10.	Pressure, Torque and inertia on the actuator—	• High	• Medium to high	• Low to medium
11.	Range of operational speeds—	• Wide	• Comparatively less	• Very little
12.	Striking or generation of spark—	• Not there	• Possible	• No sparks
13.	Path generation application—	• Continuous path	• Both continuous pick and place	• Only in pick and place types

working of a stepper motor. (AU-Nov/Dec-2010)



A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

This mean that a digital signal is used to drive the motor and every time it receives a digital pulse it rotates a specific number of degrees in rotation.

- Each step of rotation is the response of the motor to an input pulse (or digital command).
- Step-wise rotation of the rotor can be synchronized with pulses in a command-pulse train, assuming that no steps are missed, thereby making the motor respond faithfully to the pulse signal in an open-loop manner.
- Stepper motors have emerged as cost-effective alternatives for DC servomotors in high-speed, motion-control applications (except the high torque-speed range) with the improvements in permanent magnets and the incorporation of solid-state circuitry and logic devices in their drive systems.
- Today stepper motors can be found in computer peripherals, machine tools, medical equipment, automotive devices, and small business machines, to name a few applications.

Advantages Of Stepper Motors:

- Position error is noncumulative. A high accuracy of motion is possible, even under open-loop control.
- Large savings in sensor (measurement system) and controller costs are possible when the open-loop mode is used.

- Because of the incremental nature of command and motion, stepper motors are easily adaptable to digital control applications.
- No serious stability problems exist, even under open-loop control.
- Torque capacity and power requirements can be optimized and the response can be controlled by electronic switching.
- Brushless construction has obvious advantages.

UNIT III Sensors and Machine vision

COMMON IMAGING DEVICE USED FOR ROBOT VISION SYSTEMS

Black and white videocon camera, charge coupled devices, solid-state camera, charge injection devices.

SEGMENTATION (AU-Nov/Dec-2009)

Segmentation is the method to group areas of an image having similar characteristics or features into distinct entities representing part of the image.

THRESHOLDING

Thresholding is a binary conversion technique in which each pixel is converted into a binary value either black or white.

FUNCTIONS OF MACHINE VISION SYSTEM

- Sensing and digitizing image data
- Image Processing and analysis
- Application

SENSORS AND TRANSDUCER

Sensor is a transducer that is used to make a measurement of a physical variable of interest.

Transducer is a device that converts the one form of information into another form without changing the information content.

BASIC CLASSIFICATIONS OF SENSORS

- Tactile Sensors,
- Proximity Sensors,
- Range sensors,
- Voice sensors etc.,

TACTILE SENSOR (AU-Apr/May-2011)

Tactile sensor is device that indicates the contact between themselves and some other solid objects.

REGION GROWING

Region growing is a collection of segmentation techniques in which pixels are grouped in regions called grid elements based on attribute similarities.

FEATURE EXTRACTION

In vision applications distinguishing one object from another is accomplished by means of features that uniquely characterize the object. A feature (area, diameter, perimeter) is a single parameter that permits ease of comparison and identification.

VARIOUS TECHNIQUES IN IMAGE PROCESSING AND ANALYSIS

- Image data reduction
- Segmentation
- Feature extraction
- Object recognition

APPLICATION EXAMPLE OF A PROXIMITY SENSOR

- Ground proximity warning system for aviation safety
- Vibration measurements of rotating shafts in machinery
- Sheet break sensing in paper machine.
- Roller coasters
- Conveyor systems

WORKING OF INDUCTIVE TYPE PROXIMITY SENSOR (AU-Nov/Dec-2009)

Inductive proximity sensors operate under the electrical principle of inductance.

Inductance is the phenomenon where fluctuating current, which by definition has a magnetic component induces an electromotive force (emf) is a target object.

To amplify a devices inductance effect, a sensor manufacturer twists wire into a tight coil and runs a current through it.

FEEDBACK DEVICES USED IN ROBOTICS.

- Position Sensors
- Velocity Sensors

TYPES OF ENCODERS

- Incremental encoders
- Absolute encoders

FRAME GRABBER

It is a hardware device used to capture and store the digital image.

TYPES OF POSITION SENSORS (AU-NOV/DEC-2009)

- Incremental encoders
- Absolute encoders
- Resistive position sensors
- Linear variable differential transformer.
- Encoders
- Potentiometer
- Resolver.

TACTILE ARRAY SENSOR

Tactile array sensor is a special type of force senor composed of a matrix of force sensing elements.

characteristics of Sensors.

Resolution:

It is the minimum step size within the range of measurement of a sensor.in a wire-wound potentiometer, it will be equal to resistance of one turn of wire. In digital devices with ‗n‘ bits, resolution is ‗Full range/2n‘.

Sensitivity:

- It is defined as the change in output response divided by the change in input response.
- Highly sensitive sensors show larger fluctuations in output as a result of fluctuations in input.

Linearity:

- It represents the relationship between input variations and output variations.
- In a sensor with linear ouput, any change in input at any level within the range will produce the same change in output.

Range:

It is the difference between the smallest and the largest outputs that a sensor can provide, or the difference between the smallest and largest inputs with which it can operate properly.

Response time:

- It is the time that a sensor‘s ouput requires to reach a certain percentage of total change.
- It is also defined as the time required to observe the changein output as a result of change in input for example, ordinary mercury thermometer responsetime and digital thermometer response time.

Frequency response:

- The frequency response is the range in which the system‘s ability to resonate to the input remains relatively high.
- The larger the range of frequency response, the better the ability of the system to respond to varying input.

Reliability:

- It is the ratio between the number of times a system operates properly and the number of times it is tried.
- For continuous satisfactory operation, it is necessary to choose reliable sensors that last long while considering the cost as well as other requirements.

Accuracy:

- It shows how close the output of the sensor is to the expected value.
- For a given input, certain expected output value is related to how close the sensor‘s output value is to this value.

Repeatability:

- For the same input if the output response is different each time, then repeatability is poor. Also, a specific range is desirable for operational performance as the performanve of robots depends on sensors.

- Repeatability is a random phenomenon and hence there is no compensation.

Interfacing:

- Direct interfacing of the sensor to the microcontroller/microprocessor is desirable while some add-on circuit may be necessary in certain special sensors.
- The type of the sensor output is equally important. An ADC is required for analogue output sensors for example, potentiometer ouput to microcontroller.

Size,weight and volume:

- Size is a critical consideration for joint displacement sensors.
- When robots are used as dynamic machines, weight of the sensor is important.
- Volume or spaces also critical to micro robots and mobile robots used for surveillance.
- Cost is important expecially when quantity involved is large in the end application.

working principle of position sensors with neat sketch.

Position sensors are used to monitor the position of joints. Information about the position is fed back to the control systems that are used to determine the accuracy of positioning.

In most cases in robots, a primary interest is to control the position of the arm. There is a large variety of devices available for sensing position. However, the most popular angular-position sensors are the following devices:

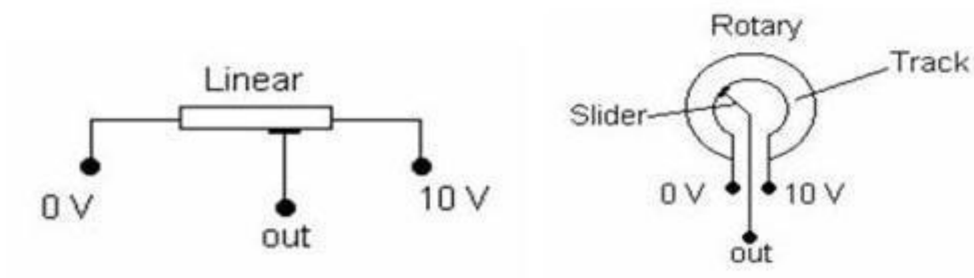
- Encoders
- Synchros
- Resolvers
- Potentiometers

Types of Position Sensor:

Position sensors use different sensing principles to sense the displacement of a body. Depending upon the different sensing principles used for position sensors, they can be classified as follows:

1. Resistance-based or Potentiometric Position sensors
2. Capacitive position sensors
3. Linear Voltage Differential Transformers
4. Magnetostrictive Linear Position Sensor
5. Eddy Current based position Sensor
6. Hall Effect based Magnetic Position Sensors
7. Fiber-Optic Position Sensor
8. Optical Position Sensors

Potentiometric Position Sensors:



Potentiometric position sensor use resistive effect as the sensing principle. The sensing element is simply a resistive (or conductive) track. A wiper is attached to the body or part of the body whose displacement is to be measured. The wiper is in contact with the track. As the wiper (with the body or its part) moves, the resistance between one end of the track and the wiper changes. Thus, the resistance becomes a function of the wiper position. The change in resistance per unit change in wiper position is linear.

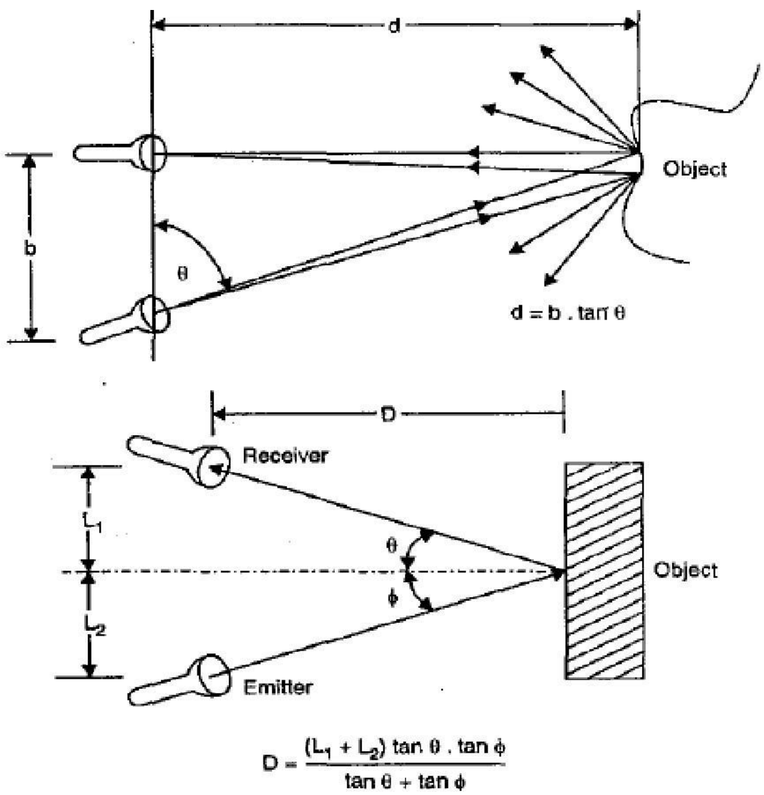
Resistance, proportional to wiper position, is measured using voltage divider arrangement. A constant voltage is applied across the ends of the track and the voltage across the resistance between the wiper and one end of the track is measured. Thus, voltage output across the wiper and one end of the track is proportional to the wiper position.

The conductive track can be made linear or angular depending upon the requirements. The tracks are made from carbon , resistance wire or piezo resistive material.

Working principle of Range sensors with neat sketch.

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.

Triangulation Method:



Triangulation Method of Range Sensing.

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 focussed on a small spot of the object surface detects the reflected beam of light. If _8' is the angle made by the illuminating source and _b'is the distance between source and the sensor, the distance _c of the sensor on the robot is given as

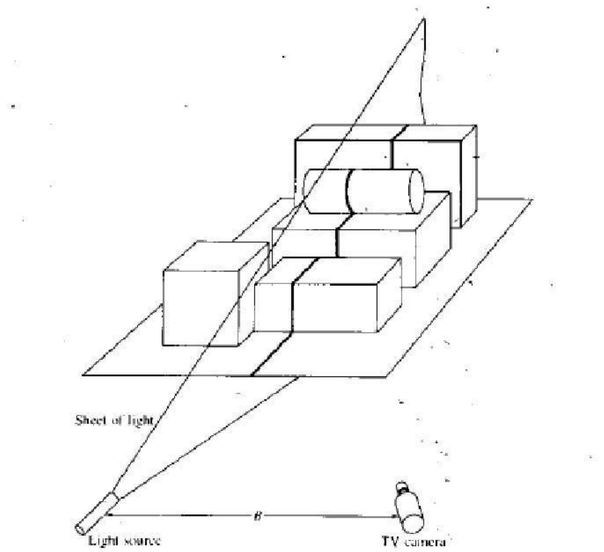
$$d = b \cdot \tan \theta$$

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

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.

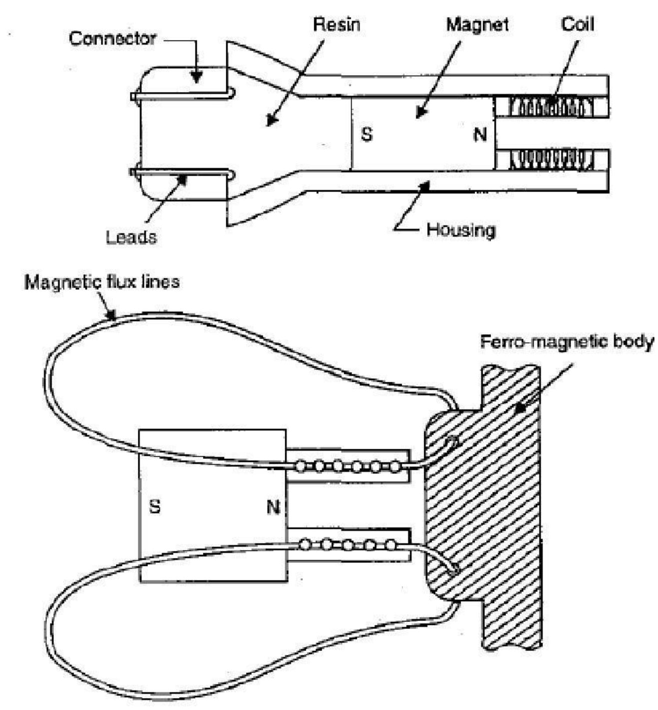
WORKING PRINCIPLE OF PROXIMITY SENSORS

Proximity Sensors:

The output of the proximity sensors gives an indication of the presence of an object with in the vicinity job operation. In robotics these sensors are used to generate information of object grasping and obstacle avoidance. This section deals with some of the important proximity sensors used in robotics.

Proximity sensor is a sensor, which senses the presence or absence of the object without having physical contact between the objects.

Inductive Proximity Sensors:



Inductive Sensor.

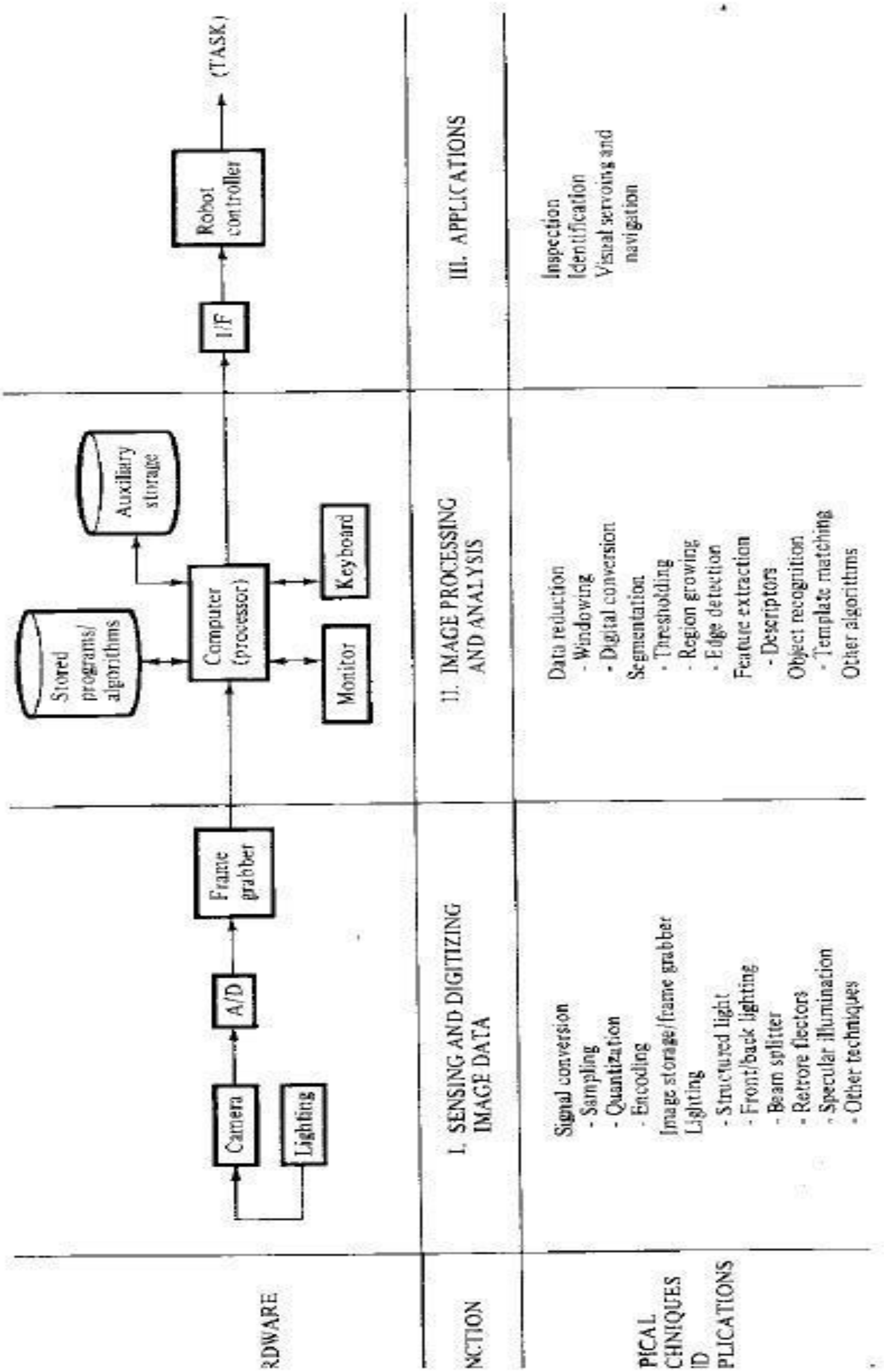
The ferromagnetic material brought close to this type of sensor results in change in position of the flux lines of the permanent magnet leading to change in inductance of the coil. The induced current pulse in the coil with change in amplitude and shape is proportional to rate of change of flux line in magnet.

Construction:

The proximity inductive sensor basically consists of a wound coil located in front of a permanent magnet encased inside a rugged housing. The lead from the coil, embedded in resin is connected to the display through a connector.

The effect of bringing the sensor in close proximity to a ferromagnetic material causes a change in the position of the flux lines of the permanent magnet.

Machine vision systems of Robot (AU-Nov/Dec-2009)



ure 7-1 Functions of a machine vision system.

- Machine vision system consists of: Lighting, camera, A/D convertor, frame grabber, computer processor, robot controller and robot manipulator.
- The hardware and software for perfomring the function of sensing and processing the image and utilising the results obtained to command the robot.
- The sensing and digitizing functions involve the input of vision data by means of a camera focused on the scene of interest. Special lighting techniques are frequently used to obtain an image of sufficient contrast for later processing.
- The image viewed by the camera is typically digitized and stored in computer memory. The digital image is called a frame of vision data, and is frequently captured by a hardware device called a frame grabber.
- These devices are capable of digitizing images at the rate of 30 frames per second. The frames consist of a matrix of data representing projections of the scene sensed by the camera.
- The elements of the matrix are called picture elements, or pixels. The number of pixels are determined by a sampling process per formed on each image frame.
- A single pixel is the projection of a small portion of the scene which reduces that portion to a single value. The value is a measure of the light intensity for that element of the scene.
- Each pixel intensity is converted into a digital value. (We are ignoring the additional complexities involved in the operation of a color video camera.)
- The digitized image matrix for each frame is stored and then subjected to image processing and analysis functions for data reduction and interpretation of the image.
- These steps are required in order to permit the real-time application of vision analysis required in robotic applications.
- Typically an image frame will be thresholded to produce a binary image, and then various feature measurements will further reduce the data representation of the image.
- This data reduction can change the representation of a frame from several.

various techniques in Image Processing and Analysis

In the industrial applications the algorithms and programs are developed to process the images captured, digitized and stored in the computer memory.

The size of data to be processed is huge, of the order of 106 which is to be substantially executed in seconds.

The difficult and time consuming task of processing is handled effectively by the following techniques.

(1) Image data reduction

(2) Segmentation

(3) Feature extraction

(4) Object recognition.

Image Data Reduction:

The purpose of image data reduction is to reduce the volume of data either by ellimination of some or part processing, leading to the following sub-techniques.

(a) Digital conversion

Digital conversion is characterized by reduction in number of gray levels. For a 8-bit register each pixel would have 28=256 gray levels. When fewer bits are used to represent pixel intensity the digital conversion is reduced, to suit the requirements.

The data reduction is effected in the following manner generalized as

Total number of bits on the face plate,

$$T_1 = N_r . N_c (2)^n$$

where N_r = number of lines or rows

N_c = number of points per line

2^n = total gray levels.

Binary bit conversion for totally black and white intensities,

$$T_2 = N_c . N_r . (2)$$

Reduction in data volume $= (T_1 - T_2)$

$= 2N_c N_r (2^{n-1} - 1)$

* *Windowing* is processing a portion of the stored digital image. The portion of focus extracted for image processing is the window. A rectangular window is selected as to highlight the component of interest on the screen. The pixels of the faceplate within the window are processed and analized by the computer.

Segmentation:

An image can be broken into regions that can then be used for later calculations. In effect this method looks for different self contained regions, and uses region numbers instead of pixel intensities.

1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	2	2	2	1	1	1	1	1	1	1
1	1	2	2	2	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	3	3	3	1
1	1	1	1	1	1	1	3	3	4	3	1
1	1	1	1	1	1	1	1	3	3	3	1
1	1	1	1	1	1	1	1	1	1	1	1

Segmented

A simple segmentation algorithm might be,

1. Threshold image to have values of 1 and 0.
2. Create a segmented image and fill it with zeros (set segment number variable to one).
3. Scanning the old image left to right, top to bottom.
4. If a pixel value of 1 is found, and the pixel is 0 in the segmented image, do a flood fill for the pixel onto the new image using segment number variable.
5. Increment segment # and go back to step 3.
6. Scan the segmented image left to right, top to bottom.
7. If a pixel is found to be fully contained in any segment, flood fill it with a new segment as in steps 4 and 5.

FEATURE EXTRACTION

The images formed on the screen can have multiple objects which are to be distinguished from one another for processing and anylysis. The features that characterize uniquely, the objects provide means to extract the identification and comparison. This is accomplished by the features like area, diameter and perimeter, also minimum enclosing rectangle, and gray levels are considered in the feature extraction.

The area of the object is described by the region growing procedure as explained before. The area is given by

$$\text{Area} = \frac{(\text{perimeter})^2}{\text{thickness}},$$

where thickness = compactness of the object.

Diameter = (Thickness × Area).

The enclosing boundary that covers the specific area can be established by the pixel intensity difference, at the boundary.

The diameter of an object image is the maximum distance obtainable on two different points on the perimeter of an object.

An important observation is that the selected feature does not depend upon position and orientation of the boundary.

Object Recognition:

Form Fitting

It can sometimes help to relate a shape to some other geometric primitive using compactness, perimeter, area, etc.

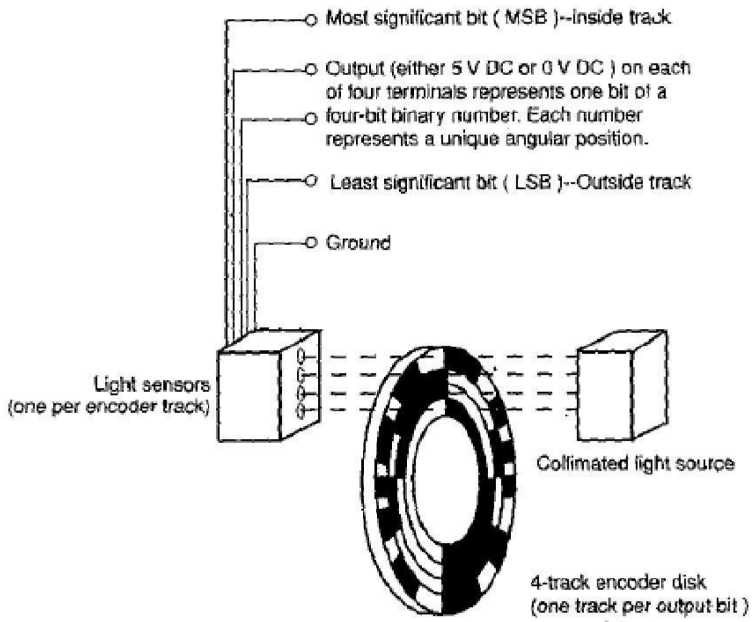
- ellipse
- square
- circle
- rectangle

(AU-Nov/Dec-2010)

(i)Optical encoders (ii) Laser range meters (iii) Capacitive type touch sensors

(iv)Ultrasonic proximity sensors

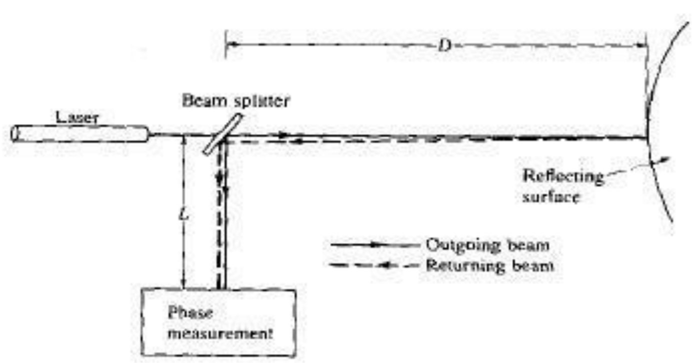
(i) Optical encoders:



Absolute optical encoder

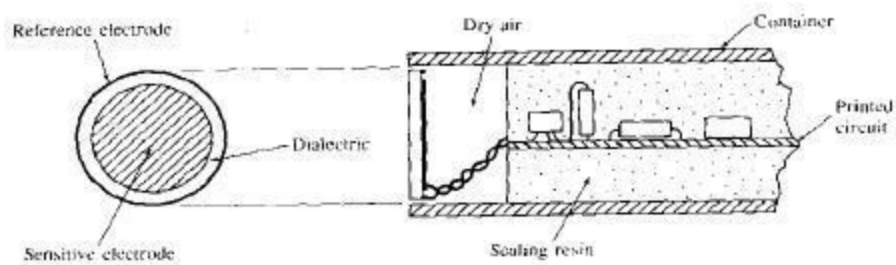
The absolute optical encoder employs the same basic construction as incremental optical encoders except that there are more tracks of stripes and a corresponding number of receivers and transmitters. Usually, the stripes are arranged to provide a binary number proportional to the shaft angle. The first 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 necessary counting. Figure illustrates an absolute optical encoder.

(ii) 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.

(iii) Capacitive type touch sensors:



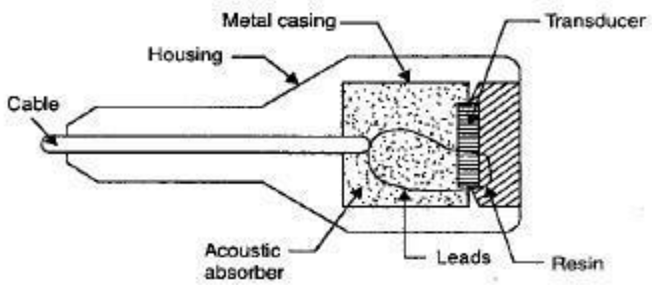
Unlike inductive and Hall-effect sensors which detect only ferromagnetic materials, capacitive sensors are potentially capable (with various degrees of sensitivity) of detecting all solid and liquid materials. As their name implies, these sensors are based on detecting a change in capacitance induced by a surface that is brought near the sensing element.

The basic components of a capacitive sensor are shown in Figure. The sensing element is a capacitor composed of a sensitive electrode and a reference electrode. These can be, for example, a metallic disk and ring separated by a dielectric material. A cavity of dry air is usually placed behind the capacitive element to provide isolation. The rest of the sensor consists of electronic circuitry which can be included as an integral part of the unit, in which case it is normally embedded in a resin to provide sealing and mechanical support.

There are a number of electronic approaches for detecting proximity based on a change in capacitance. One of the simplest includes the capacitor as part of anOscillator circuit designed so that the oscillation starts only when the capacitance of the sensor exceeds a predefined threshold value. The start of oscillation is then translated into an output voltage which indicates the presence of an object. This method provides a binary output whose triggering sensitivity depends on the threshold value.

A more complicated approach utilizes the capacitive element as part of a circuit which is continuously driven by a reference sinusoidal waveform. A change in capacitance produces a phase shift between the reference signal and a signal derived from the capacitive element. The phase shift is proportional to the change in capacitance and can thus be used as a basic mechanism for proximity detection.

(iv)Ultrasonic proximity sensors:



The previously discussed proximity sensors are useful for detection of ferro-magnetic matter only. If the robot has to handle other type of materials ultrasonic sensors find the application.

Construction:

The main part in this type of sensor is the transducer which can act both as transmitter and receiver. The sensor is covered by a resin block which protects from dust and humidity. For the acoustic damping, absorber material is provide as shown in Figure. Finally a metallic housing gives general protection.

UNIT IV Robot kinematics and Robot Programming

METHODS OF ROBOT PROGRAMMING

- Lead through methods
- Textual robot languages
- Mechanical Programming

WAYS OF ACCOMPLISHING LEAD THROUGH PROGRAMMING

- Powered Lead through
- Manual Lead through

TEACH PENDANT

The teach pendant is usually a small handheld control box with combinations of toggle switches, dials and buttons to regulate the robot‘s physical movements and program capabilities.

METHODS OF TEACHING

- Joint movements
- X-Y-Z coordinates motions
- Tool coordinate motions

robot kinematics

FORWARD KINEMATICS

It is a scheme to determine joint angles of a robot by knowing its position in the world coordinate system.

REVERSE KINEMATICS

It is a scheme to determine the position of the robot in the world coordinate system by knowing the joint angles and the link parameters of the robot.

TRAJECTORY PLANNING

It is defined as planning of the desired movements of the manipulator.

DEGREES OF FREEDOM.

The number of independent ways by which a dynamic system can move without violating any constraint imposed on it, is called degree of freedom. In other words, the degree of freedom can be defined as the minimum number of independent coordinates which can specify the position of the system completely.

JOINT MODE OF TEACHING ROBOTS.

The teach pendant has a set of toggle switches (or similar controlled devices) operate each joint either of it to directions until the endeffector has been positioned to the desired point.

REASONS FOR DEFINING POINTS IN A PROGRAM.

- To define a working position for the endeffector
- To avoid obstacles

POSITION REPRESENTATION

The position of the end of the arm may be represented by the two joint angles q1 and q2.this is known as position representation.

$$Pj = (q1,q2)$$

SERVO CONTROLLED ROBOTS

Servo controlled robots, which are programmed by lead through an textual language methods tend to actuate all axes simultaneously.

CIRCULAR INTERPOLATION

Circular Interpolation requires the programmer to define a circle in the robot‘s workspace which is done by specifying three points that lie along the circle.

IRREGULAR SMOOTH MOTIONS

The segments in manual lead though programming are sometimes approximately straight sometimes curved and sometimes back and forth motions. These motions are called irregular smooth motions.

MANUAL LEAD THROUGH PROGRAMMING

In manual lead through programming the programmer moves the manipulated wrist to teach spray-painting or arc welding. The movements consist of combination of smooth motion segments.

FORWARD AND REVERSE TRANSFORMATION OF 2-DEGREE OF FREEDOM AND 3-DEGREE OF FREEDOM ARM.

Forward Transformation of a 2-Degree of Freedom Arm

We can determine the position of the end of the arm in world space by defining a vector for link 1 and another for link 2.

$$\mathbf{r}_1 = [L_1 \cos \theta_1, L_1 \sin \theta_1] \tag{4-1}$$

$$\mathbf{r}_2 = [L_2 \cos(\theta_1 + \theta_2), L_2 \sin(\theta_1 + \theta_2)] \tag{4-2}$$

Vector addition of (4-1) and (4-2) yields the coordinates x and y of the end of the arm (point P_w) in world space

$$x = L_1 \cos \theta_1 + L_2 \cos(\theta_1 + \theta_2) \tag{4-3}$$

$$y = L_1 \sin \theta_1 + L_2 \sin(\theta_1 + \theta_2) \tag{4-4}$$

Reverse Transformation of the 2-Degree of Freedom Arm

In many cases it is more important to be able to derive the joint angles given the end-of-arm position in world space. The typical situation is where the robot's controller must compute the joint angles required to move its end-of-arm to a point in space defined by the point's coordinates. For the two-link manipulator we have developed, there are two possible configurations for reaching the point (x, y), as shown in Fig. 4-3. Some strategy must be developed to select the appropriate configuration. One approach is that employed in the control system of the Unimate PUMA robot. In the PUMA's control language, VAL, there is a set of commands called ABOVE and BELOW that determines whether the elbow is to make an angle θ_2 that is greater than or less than zero, as illustrated in Fig. 4-3. For our example, let us assume the θ_2 is positive as shown in Fig. 4-2. Using the trigonometric identities,

$$\cos(A + B) = \cos A \cos B - \sin A \sin B$$

$$\sin(A + B) = \sin A \cos B + \sin B \cos A$$

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Adding Orientation: A 3-Degree of Freedom Arm in (2D) Two Dimensions

The arm we have been modeling is very simple; a two-jointed robot arm has little practical value except for very simple tasks. Let us add to the manipulator a modest capability for orienting as well as positioning a part or tool. Accordingly, we will incorporate a third degree of freedom into the previous configuration to develop the RR:R manipulator shown in Fig. 4-5. This third degree of freedomwillrepresent a wrist joint. The world space coordinates for the wrist end would

$$\left.\begin{aligned} x &= L_1 \cos\theta_1 + L_2\cos(\theta_1+\theta_2) + L_3\cos(\theta_1+\theta_2+\theta_3) \\ y &= L_1 \sin\theta_1 + L_2\sin(\theta_1+\theta_2) + L_3\sin(\theta_1+\theta_2+\theta_3) \\ \psi &= (\theta_1+\theta_2+\theta_3) \end{aligned}\right\} \qquad (4\text{-}8)$$

We can use the results that we have already obtained for the 2-degree of freedom manipulator to do the reverse transformation for the 3-degree of freedom arm. When defining the position of the end of the arm we will use x, y, and ψ. The angle ψ is the orientation angle for the wrist. Given these three values, we can solve for the joint angles (θ_1, θ_2, and θ_3) using

$$x_3 = x - L_3\cos\psi$$

$$y_3 = y - L_3\sin\psi$$

Having determined the position of joint 3, the problem of determining θ_1 and

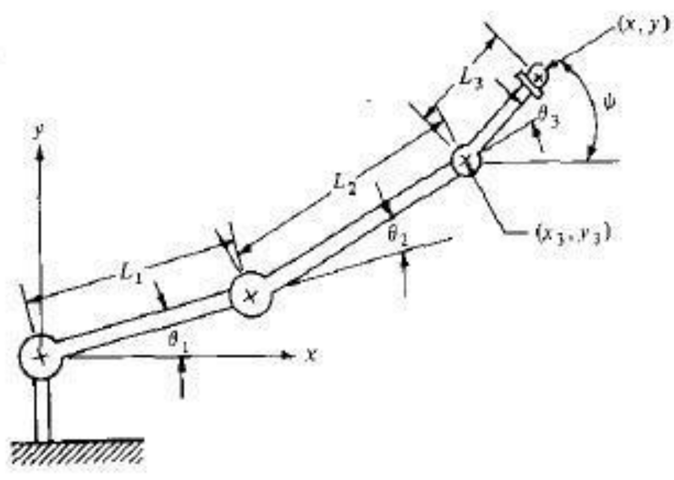


Figure 4-5 The two-dimensional 3 degree-of-freedom manipulator with orientation (type RR:R).

be.

θ_2 reduces to the case of the 2-degree of freedom manipulator previously analyzed.

Robot Programming Languages

- Robot languages have been developed for ease of control of motions of robots having different structures and geometrical capabilities.
- Some of the robot languages have been developed by modifying the existing general-purpose computer languages and some of them are written in a completely new style.
- Programming languages have been developed by the pioneer efforts of various researchers at Stanford Artificial Intelligence Laboratory; research laboratories of IBM Corporation, under U.S. Air Force sponsorship, General Electric Co., Unimation and many other robot manufacturers.

WAVE and AL:

- WAVE, developed at Stanford, demonstrated a robot hand—eye coordination while it was implemented in a machine vision system.
- Later a powerful language AL was developed to control robot arms. WAVE incorporated many important features.
- Trajectory calculations through coordination of joint movements, end-effector positions and touch sensing were some of the new features of WAVE. But the algorithm was too complex and not userfriendly.
- They could not be run in real-time and on-line. On the other hand, trajectory calculations are possible at compile time and they can be modified during run time.

AML:

- A manufacturing language, AML was developed by IBM. AML is very useful for assembly operations as different user—robot programming interfaces are possible.
- The programming language AML is also used in other automated manufacturing systems.
- The advantage of using AML is that integers, real numbers and strings can be specified in the same aggregate which is said to be an ordered set of constants or variables.

MCL:

- US Air force ICAM project led to the development of another manufacturing control language known as MCL by McDonnel—Douglas.
- This is a modification of the popular APT (Automatically Programmed Tooling) language used in CNC machine tools as many similar commands are used to control machine tools in CAM applications.

RAIL:

- RAIL was developed by Automatic for robotic assembly, inspection, arc welding and machine vision. A variety of data types as used in PASCAL can be used.
- An interpreter is used to convert the language into machine language commands. It uses Motorola 68000 type microcomputer system; It supports many commands and control of the vision system.

HELP:

- HELP was developed by General Electric Company. It acts more or less like RAIL.
- It has the capability to control two robot arms at the same time. The structure of the language is like PASCAL.

JARS:

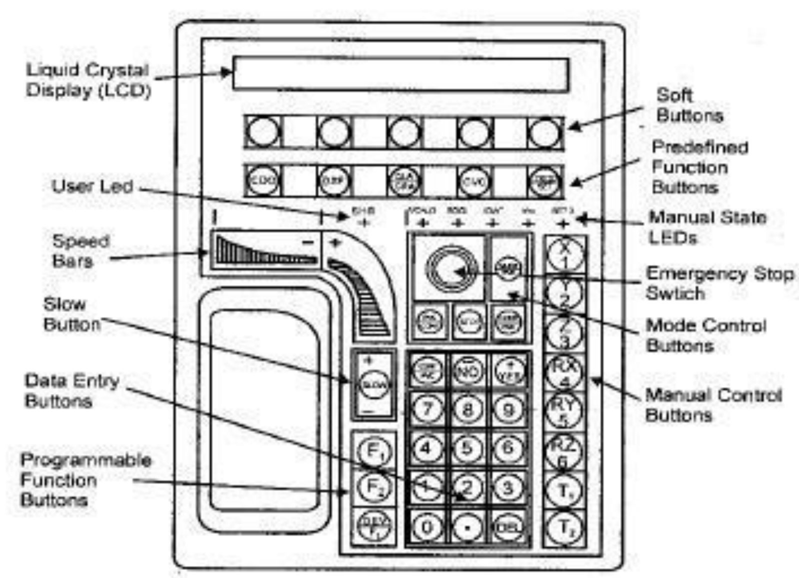
- JARS was developed by NASA JPL. The base of the language is PASCAL. JARS can be interfaced with PUMA 6000 robot for running robotic programs.

RPL:

- RPL was developed at SRI International. A compiler is used to convert a program into the codes that can be interpreted by an interpreter. Unimation PUMA 500 can be controlled with the help of RPL. The basic ideas of LISP (an AI language) have been organized into a FORTRAN-like syntax in RPL. It is modular and flexible.
- Besides these, there are some other languages like PAL, ADA etc. PAL has been written by Richard Paul by modifying WAVE and incorporating features of PASCAL. But the representations of syntaxes used in the program are difficult to handle. ADA developed by the Department of Defense (DOD) in USA is a real-time system that can be run on several microcomputers like Zilog, VAX, Motorola 68000, etc. ADA is convenient for controlling the robots used in a manufacturing cell.
- Different textual robot languages have different attributes. Far example, VAL, HELP and MC though powerful for many simple tasks, do not have the same structured modular programming capability like AL, AML, JARS and ADA or VAL II. In a manufacturing cell, multiple robots or robotic equipment work in unison. Control of two or more operations done by the robots in a coordinated manner is complex.
- Synchronizing the motions of the robots requires necessary software commands. AL, ADA, AML, MCL have the capability of controlling multiple arms. The programming language must be capable of expressing various geometric features like joint angles, coordinate transformations such as rotation, translation, and vector quantities. Homogeneous matrices are used to specify the rotation. Rotation can also be specified by Euler angles. AML, RAIL and VAL use Euler angles while AL manipulates homogeneous matrix for control. AL is very suitable for assembly tasks wherein many sensors are employed, though other languages like AML and HELP are flexible enough to run various subroutines. Slewing and straight-line motions control are available with most of the languages.

. TEACH PENDANT FOR ROBOT SYSTEM (AU-NOV/DEC-2010)

- The teach pendant has the following primary functions:
- Serve as the primary point of control for initiating and monitoring operations.
- Guide the robot or motion device, while teaching locations.
- Support application programs.
- The Teach Pendant is used with a robot or motion device primarily to teach.
- Robot locations for use: in application programs. The Teach Pendant is also used with custom. Applications that employ —teach routine's that pause execution at specified points and allow an Operator to teach * re-teach the robot locations used by the program. There are two styles of Teach Pendants: the programmer's pendant, which is designed for use while an application is being written and debugged, and the operator's pendant, which is designed for use during normal system operation.
- The operator's pendant has a palm-activated switch, which is connected to the remote emergency stop circuitry of the controller. Whenever this switch is released, arm power is removed from the motion device. To operate the Teach Pendant left hand is put through the opening on the left-hand side of the pendant and the left thumb is used to operate the pendant speed bars. The right hand is used for all the other function buttons.



The major areas of the Teach Pendant are:

1. Data Entry Buttons:

The data entry buttons are used to input data, normally in response to prompts that appear on the pendant display The data entry buttons include YES/NO, DEL, the numeric buttons, the decimal point and the REC/DONE button, which behaves like the Return or Enter key on a normal keyboard. In many cases, application programs have users press the REC/DONE button to signal that they have completed a task.

2. Emergency Stop Switch:

The emergency stop switch on the Teach Pendant immediately halts program execution and turns off arm power.

3. User LED:

The pendant is in background mode when the user LED is in not lit and none of the predefined functions are being used. The user LED is lit whenever an application program is making use of the Teach Pendant.

4. Mode Control Buttons:

The mode control buttons change the state being used to move the robot, switch control between the Teach Pendant and the application programs and enable arm power when necessary.

5. Manual Control Buttons:

When the Teach Pendant is in manual mode, these buttons select which robot joint will move, or the coordinate axis along which the robot will move.

6. Manual State LEDs:

The manual state LEDs indicates the type of manual motion that has been selected.

7. Speed Bars:

The speed bars are used to control the robot‘s speed and direction. Pressing the speed bar near the outer ends will move the robot faster, while pressing the speed bar near the center will move the robot slower.

8. Slow Button:

The slow button selects between the two different speed ranges of the speed bars.

9. Predefined Function Buttons:

The predefined function buttons have specific, system- wide functions assigned to them, like display of coordinates, clear error, etc.

10. Programmable Function Buttons:

The programmable function buttons are used in custom application programs, and their functions will vary depending upon the program being run.

11. Soft Buttons:

The ―soft‖ buttons have different functions depending on the application program being run, or the selection made from the predefined function buttons.

. CAPABILITIES AND LIMITATIONS OF LEAD THROUGH METHODS. (AU-Nov/Dec-2009)

During this programming method, the traveling of robots is based on the desired movements, and it is stored in the external controller memory. There are two modes of a control system in this method such as a run mode and teach mode. The program is taught in the teach mode, and it is executed in the run mode. The leadthrough programming method can be done by two methods namely:

- Powered Leadthrough Method
- Manual Leadthrough Method

Powered Leadthrough Method:

The powered leadthrough is the common programming method in the industries. A teach pendant is incorporated in this method for controlling the motors available in the joints. It is also used to operate the robot wrist and arm through a sequence of points. The playback of an operation is done by recording these points. The control of complex geometric moves is difficultto perform in the teach pendant. As a result, this method is good for point to point movements. Some of the key applications are spot welding, machine loading & unloading, and part transfer process.

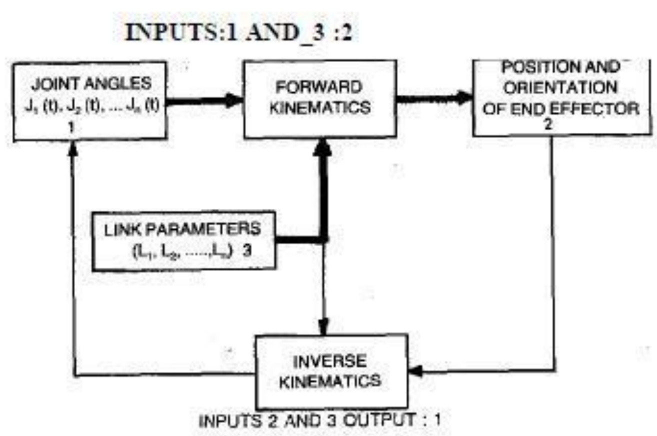
Manual Leadthrough Method:

In this method, the robot's end effector is moved physically by the programmer at the desired movements. Sometimes, it may be difficult to move large robot arm manually. To get rid of it ateach button is implemented in the wrist for special programming. The manual leadthrough method is also known as Walk Through method. It is mainly used to perform continuous path movements. This method is best for spray painting and arc welding operations.

Limitation:

- Lead through programming is not readily compatible with modern computer based technology.
- Robot cannot be used in production, while it is being programmed.

FORWARD AND INVERSE KINEMATICS (AU-Nov/Dec-2009)

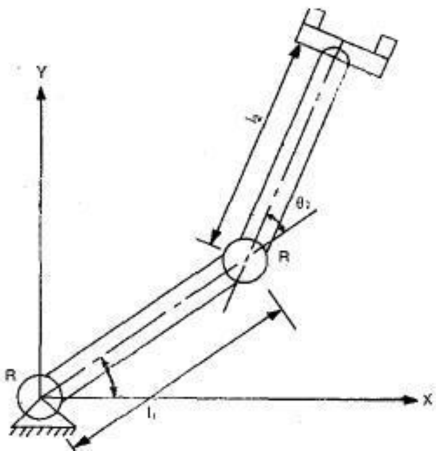


Forward kinematics:

The transformation of coordinates of the end-effector point from the joint space to the world space is known as forward kinematic transformation.

Reverse kinematics:

The transformation of coordinates from world space to joint space is known as backward or reverse kinematic transformation.



Robot Kinematics:

Robot arm kinematics deals with the analytic study of the motion of a robot arm with respect to a fixed reference coordinate system as a function of time. The mechanical manipulator can be modelled as an open loop articulated chain with several rigid links connected in series by either ‗revolute' or ‗prismatic' joints driven by the actuators.

For a manipulator, (the position and orientation of the end-effector are derived from the given joint angles and link parameters, the scheme is called the forward kinematics problem If, on the other hand, the joint angles and the different configuration of the manipulator are derived from the position and orientation of the endeffector, the scheme is called the reverse kinematics problem. F 2.1 illustrates the scheme of forward and reverse kinematics.

Representing the Position

Considering the revolute type of joint only, the position of the end-effector can be represented by the joint

angles, 0 02,...,. 0,, as,

$$P_{JOINT} = (\theta_1, \theta_2, \theta_3, \ldots \theta_n)$$

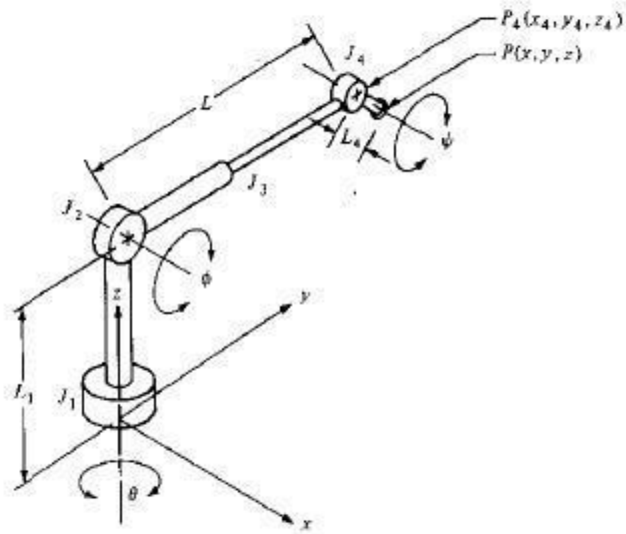
The position of the end-effector can also be defined in world space as,

$$P_{WORLD} = (x, y, z)$$

DIRECT AND INVERSE KINEMATICS OF 4 DEGREES OF FREEDOM ROBOT MANIPULATOR.

A 4-Degree of Freedom Manipulator in (3D) Three Dimensions:

The configuration of a manipulator in three dimensions. The manipulator has 4 degrees -of freedom: joint I (type T joint) allows rotation about the z axis; joint 2 (type R) allows rotation about an axis that is perpendicular to the z axis; joint 3 is a linear joint which is capable of sliding over a certain range; and joint 4 is a type R joint which allows rotation about an axis that is parallel to the joint 2 axis. Thus, we have a TRL: R manipulator.



Let us define the angle of rotation of joint I to be the base rotation 0; the angle of rotation of joint 2 will be called the elevation angle 4.; the length of linear joint 3 will be called the extension L (L represents a combination of links 2 and 3); and the angle that joint 4 makes with the x — y plane will be called the pitch angle 4. These features are shown in Fig. 4-6.

The position of the end of the wrist, P, defined in the world coordinate system for the robot, is given by

$$x = \cos\theta(L\cos\phi + L_4\cos\psi)$$
$$y = \sin\theta(L\cos\phi + L_4\cos\psi)$$
$$z = L_1 + L\sin\phi + L_4\sin\psi$$

Given the specification of point $P(x, y, z)$ and pitch angle ψ, we can find any of the joint positions relative to the world coordinate system. Using $P_4(x_4, y_4, z_4)$, which is the position of joint 4, as an example,

$$x_4 = x - \cos\theta(L_4\cos\psi) \quad (4\text{-}12)$$
$$y_4 = y - \sin\theta(L_4\cos\psi) \quad (4\text{-}13)$$
$$z_4 = z - L_4\sin\psi \quad (4\text{-}14)$$

The values of L, ϕ, and θ can next be computed:

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COMMANDS USED IN VAL II PROGRAMMING AND ITS FUNCTIONS.(AU-NOV/DEC-2009)

Definition	*Command Statement*	*Explanation*
1. Motion control	APPRO P1, Z1	Command to approach the point P1 in the z-direction by Z1 distance above the object.
	MOVE P1	Command to move the arm from the present position to point P1.
	MOVE P1 VIA P2	Asks the robot to move to point P1 through point P2.
	DMOVE (J1, ΔX)	Moves the joint J1 by an increment of ΔX (linear)
	DMOVE (J1, J2, J3) ($d\alpha$, $d\beta$, $d\theta$)	Command to move joints J1, J2 and J3 by incremental angles of $d\alpha$, $d\beta$, $d\theta$ respectively.
2. Speed control	SPEED V IPS	The speed of the end effector is to be V inch per second at the time of program execution.
	SPEED R	Command to operate the arm end effector at R percent of the normal speed at the time of program execution.
3. Position control	HERE P1	Defining the name of a point as P1.
	DEFINE P1 = POINT (x, y, z, w_α, w_β, w_θ)	The command defines the point P1 with x, y, z co-ordinates and w_α, w_β, w_θ the wrist rotation angles.
	Path control : DEFINE PATH 1 = PATH (P1, P2, P3)	The path of the end effector is defined by the connection between points P1, P2 and P3 in series.
	MOVE PATH 1	Movement of the end effector along path 1.
	Frame definition: DEFINE FRAME 1 = FRAME (P1, P2, P3)	— Assings variable name to FRAME 1 defined by points P1, P2 and P3. P1-origin, P2-point along x-axis and P3-point along xy plane.
	MOVE ROUTE: FRAME 1.	— Defines the movement in the path for frame 1.
4. End effector operation	OPEN	— Opens the gripper fingers.
	CLOSE 50 MM	— In forms gripper to close keeping 50 mm width between the fingers.

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UNIT V Implementation and Robots Economics

DIFFERENT TYPES OF MATERIAL HANDLING OPERATION

- Manually operated devices—hand trucks, powered trucks, cranes, monorails and hoists.
- Automated systems—conveyors, AGV's.
- Miscellaneous systems—industrial robots, transfer mechanisms, elevators, pipelines, containers, dial indexing tables, etc.

Gantry Robot

Cartesian coordinate robots with the horizontal member supported at both ends are sometimes called Gantry robots.

APPLICATIONS OF AGV

- Driverless train operations
- Storage distribution system
- Assembly line operation
- FMS

TYPES OF AGV VEHICLES

- Towing vehicles
- Unit load vehicles
- Pallet trucks
- Fork trucks
- Light load Vehicles
- Assembly line vehicles.

PALLETIZING AND DEPALLETIZING.

A palletizer or palletiser is a machine which provides automatic means for stacking cases of goods or products on to a pallet.

A depalletizer machine is any machine that can break down a pallet. Usually, a robot is used for this task, although there are some other forms of depalletizersthat can also break down pallets and move products from one place to another using simple push bars and conveyor belts.

THE STEPS TO BE FOLLOWED BY THE COMPANY IN ORDER TO IMPLEMENT ROBOT PROGRAMS IN ITS OPERATIONS

- Initial familiarization with the technology
- Plant survey to identify potential applications
- Selection of the application
- Selection of the robot
- Detailed economic analysis and capital authorization
- Planning and engineering the installation
- Installation

TYPICAL TECHNICAL FEATURES REQUIRED FOR MATERIAL TRANSFER

Number of axes: 3to 5

Control system: limited sequence or point-to-point playback

Drive system: pneumatic or hydraulic

Programming: manual, powered lead through

DIFFERENT METHODS OF ECONOMIC ANALYSIS

1) Payback method
2) Equivalent uniform annual cost (EUAC) method
3) Return on investment (ROI) method

ROI method

The return on investment method determines the rate of return for the proposed project based on the estimated cost and revenues.

EUAC method

Equivalent uniform annual cost (EUAC) method converts all of the present and future investments and cash flows into their equivalent uniform cash flows over the anticipated life of the project.

deadman switch

A dead man switch is a useful control feature during lead through programming. It is a trigger or toggle switch device generally located on the teach pendant which requires active pressure to be applied tom the devices in order to drive the manipulator.

the general characteristics that make potential robot application technically practical and economically feasible

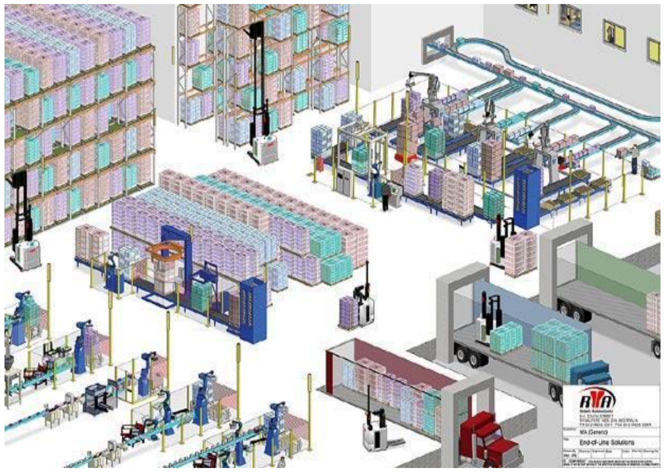
1) Hazardous or uncomfortable working conditions
2) Repetitive operations
3) Difficult handling jobs
4) Multicast operation

payback period

IT is the length of time required for the net accumulated cash flow to equal the initial investment in the project.

AGV & RGV types of robots (AU-Nov/Dec-2010)

Automated Guided Vehicles:



An AGV is a computer controlled, driverless vehicle used for transporting materials from point-to-point in a manufacturing setting. They represent a major category of automated materials handling devices. They are guided along defined pathways in the floor. The vehicles are powered by means of on-board batteries that allow operation for several hours between recharging. The definition of the pathways is generally accomplished using wire embedded in the floor or reflective paint on the floor surface. Guidance is achieved by sensors on the vehicles that can follow the guide wires or paint. When it arrives at the proper destination, the material is off loaded onto another conveyor or the workstation. The vehicle is then dispatched to the next location or to home to await further orders. A computer controls its motion.

The key terms in AGV are

Guide path — The term guide path refers to the actual path the AGV follows in making its rounds through manufacturing plant. The guide path may be of the embedded wire type or optical devices.

Routing — It is the ability of the AGV to make decisions that allow it to select the appropriate route as it moves across the shop floor.

Towing vehicles — These are the most widely used type of AG V's and are called the work horse. They are most commonly used for transporting large amounts of bulky and heavy materials from the warehouse to various locations in the manufacturing plant, e.g. driverless train

Unit load vehicles —

They are used in settings with short guide paths, high volume, and need for independent movement and versatility. Warehouses and distribution centres are the most likely settings for these vehicles. They can operate in an en vironinent where there is not much room and movement is restricted.

Rail Guided Vehicles:

Motorised vehicles that are guided by a fixed rail system constitute a third category of material transport systems. If the system uses just one rail it is called a monorail system; whereas it can also consist of a two-rail system. Monorails typically operate from a suspended position overhead, while two-rail systems are generally found on the plant floor. Vehicles operate asynchronously and are driven by an on-board electric motor, with power being supplied by an electrified rail. This removes the necessity of stoppages owing to battery-power wear-out, as with AGVs, but it presents a new safety hazard in the form of the electrified rail.

Routing variations are possible in rail systems through a combination of turntables, switches, and other specialised track sections. This allows different loads to travel different routes, in a similar manner to an AGVS. Rail-guided systems are generally considered to be more versatile than conveyor systems, but less versatile than AGVS. Considerable use is made of the system in the automotive industry where overhead monorails move large components and subassemblies in its manufacturing operations.

Sorting Transfer Vehicle (STV) is a fast, flexible and easily installed material transport system. STVs can be used to move loads of all sizes in a warehouse. For example, a STV may be used as a sorting tool for goods coming out of storage and heading to shipping. STV features sorting and collecting capabilities for multiple AS/RS aisle conveyor stations. It enables picking by order line and sorting by destination to one.

Separate input/output stations enable the STV to perform multiple tasks at one time. STVs are compact and move agilely over a track system, enabling higher throughput than conveyors. The STV track can be arranged in a loop or straight line to accommodate a variety of applications, such as mixed SKU pallet picking, cycle counting, quality inspection, load sorting and truck loading. Advantages of STVs include: fewer motors, no single point of failure, high-speed, high-throughput and expansion flexibility to handle future growth.

the economic analysis of Robots in detail (AU-Nov/Dec-2008)

In addition to the technological considerations involved in applications engineering for a robotics project, there is also the economic issue. Will the robot justify itself economically? The economic analysis for any proposed engineering project is of considerable importance in most companies because management usually decides whether to install the project on the basis of this analysis. In the present chapter, we consider the economic analysis of a robot project. We discuss the various costs and potential benefits associated with the robot installation, and we describe several methods for analyzing these factors to determine the economic merits of the project.

To perform the economic analysis of a proposed robot project, certain basic information is needed about the project. This information includes the type of project being considered, the cost of the robot installation, the production cycle time, and the savings and benefits resulting from the project.

Type of Robot Installation:

There are two basic categories of robot installations that are commonly encountered. The first involves a new application. This is where there is no existing facility. Instead, there is a need for a new facility, and a robot installation represents one of the possible approaches that might be used to satisfy that need. In this case, the various alternatives are compared and the best alternative is selected, assuming it meets the company‘s investment criteria. The second situation is the robot installation to replace a current method of operation. The present method typically involves a production operation that is performed manually, and the robot would be used somehow to substitute for the human labor. In this situation, the economic justification of the robot installation often depends on how inefficient and costly the manual method is, rather than the absolute merits of the robot method.

In either of these situations, certain basic cost information is needed in order to perform the economic analysis. The following subsection discusses the kinds of cost and operating data that are used to analyze the alternative investment projects.

Cost Data Required for the Analysis

The cost data required to perform the economic analysis of a robot project divide into two types: investment costs and operating costs.

Investment costs:

1. Robot purchase cost—The basic price of the robot equipped from the manufacturer with the proper options (excluding end effector) to perform the application.
2. Engineering costs— The costs of planning and design by the user company‘s engineering staff to install the robot.
3. Installation costs— This includes the labor and materials needed to prepare the installation site (provision for utilities, floor preparation, etc.).
4. Special tooling— This includes the cost of the end eflector, parts position and other fixtures and tools required to operate the work cell,

5. Miscellaneous costs—This covers the additional investment costs not included by any of the above categories (e.g., other equipment needed for the cell).

Operating costs and savings:

6. Direct labor cost—The direct labor cost associated with the operation of the robot cell. Fringe benefits are usually included in the calculation of direct labor rate, but other overhead costs are excluded.
7. Indirect labor cost—The indirect labor costs that can be directly allocated to thc operation of the robot cell. These costs include supervision, setup, programming, and other personnel costs not included in category 6 above
8. Maintenance—This covers the anticipated costs of maintenance and repair for the robot cell. These costs are included under this separate heading rather than in category 7 because the maintenance costs involve not only indirect labor (the maintenance crew) but also materials (replacement parts) and service calls by the robot manufacturer. A reasonable ‗rule of thumb‖ in the absence of better data is that the annual maintenance cost for she robot will be approximately 10 percent of the purchase price (category l).
9. Utilities—this includes the cost of utilities to operate the robot cell (e.g., electricity, air pressure, gas). These are usually minor costs compared to the above items.
10. Training—Training might be considered to be an investment cost because much of the training required for the installation will occur as a first cost of the installation. However, training should he a continuing activity, and so it is included as an operating cost.

Costs include the purchase cost of the robot and the engineering costs associated with its installation in the work cell. In many robot application projects. the engineering costs can equal or exceed the purchase cost of the robot. The operating costs include the cost of any labor needed to operate the cell, maintenance costs, and other expenses associated with the robot cell operation. lhe table lists most of the major operating costs for a robot application project. In the case of the operating costs, it is often convenient to identify the cost savings that will result from the use of a robot as compared to an existing method, rather than to separately identity the operating costs of the alternative methods. Material savings, scrap reductions. and advantages resulting from more consistent quality arc examples of these savings. Items 6 through should he interpreted to allow for this possible method of declaring cost savings between the alternatives.

The Safety sensors and safety monitoring of Robots (AU-Nov/Dec-2008)

Safety Sensors and Safety Monitoring

In addition to these various approaches for designing safety into the robotic workcell, other safety provisions can be made as well. We will describe some of the possible safety monitoring schemes that can be utilized in robot workcells in this subsection, and other measures, including emergency stop buttons and "deadman switches."

Safety monitoring, as previously defined in Chap. Eleven, involves the use of sensors to indicate conditions or events that are unsafe or potentially unsafe. The objectives of safety monitoring include not only the protection of humans who happen to be in the cell, but also the protection of the equipment in the cell. The sensors used in safety monitoring range from simple limit switches to make sure that certain steps in the sequence control have been carried out, to sophisticated vision systems that are able to scan the workplace for intruders and other deviations from normal operating conditions. We have discussed some of the possible sensors that are used in robotic workcells in Chaps. Six and Seven. An important point that should be made in the context of this discussion on safety monitoring is that the workcell controller is limited in its monitoring capability to irregularities that have been foreseen by the designer of the cell control system. If the designer has not anticipated a particular hazard, and consequently has not provided the robot with the sensing capacity to monitor that hazard, the workcell controller will not be able to respond to the event. Great care must be taken in workcell design to anticipate all of the possible mishaps that might occur during the operation of the cell, and to design safeguards to prevent or limit the damage resulting from these mishaps.

The National Bureau of Standards defines three levels of safety sensor systems in robotics[4]:

Level 1—Perimeter penetration detection
Level 2—Intruder detection inside the workcell
Level 3—Intruder detection in the immediate vicinity of the robot

The first level systems are intended to detect that an intruder has crossed the perimeter boundary of the workcell without regard to the location of the intruder. In effect this would operate much the same as the fence surrounding the cell. Level 2 systems are designed to detect the presence of an intruder in the region between the workcell boundary and the limit of the robot work volume. The exact definition of this region would depend on the cell layout and the strategy used to ensure the safety of the intruder. Level 3 systems provide intruder detection Inside the work VOluinC I,f thl: robot. ThC!>1: ~~fbllr 5ysh;ms ar" intended to protect wor~efs who must bl! in clos~ prlJl<imily to ihc robot during oper~uion of the robot (e.g .. during programmlng 0r Ihi: robot). This third cDtegolY must be capable Qf I.!et~cling an imminent eollision between the workC:f ~nd the robot, find of I:xl:cuting H strategy for Hvoldinl; the eolUsion, Figure 17·2 illustrates the three sensor levels.

Two common means of inlpl(HftCfliiflg a robot sa.fety IIIcHsin!; S~h'!m are pressure sensitive floor mats and light curtaifl!:. rr¢s~ytc sensitive mats 3fc area pads placed on the floor around the workcell which sense the weight nf SOmeone standing on the mill, Light curtains consist Ur "ght beams and photosensitive devices placed aroulld the workcell th;!,l sefiSC the rresence I,r an intruder by an interruption of the light beam. Pressure sensitive nC)or pads C3n be USed fOr either level i or level 2 !lensing systems, The use of fig" t curtains WQytd be more ~pprljpr!3te as level ! sySh:f!'IS. Proximhy Seo)',o!':- located on the robot arm could be utilized as l\lvel .l sensors,

The safety monitoring litrategies that might be followed by the workecll eontroller would include ihl: following IIchemcs. Some of the }iuatcgh:fi wuuld be mot~ npproprtare for certain levels of semor detection systems thun for others.

Complete shutdown of the robot upon detection of un intruder
Activation of warning 3!armf.
Reduction in the speed of thc robot to a "safc" level
Directing the rOoot to move its arm away [rom the intruder to IIVt1idcollision.
Th!!! !s so!'!lel!rnes fe'ferred 10 as "()bloludt; ilvuiYilma:,';
Dircctin~ the robot to perform tasks if! another region of the wQrkcel1 away from the intruder,

A more sophisticated system used in safety monitoring i5 called a "fail-Stile hilUlrd dctccwr",7 The concept of this deteCtor is bnSGd on the recog-

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