Robotics

Unit - I

Word robot was coined by Czech novelist Karel capek in 1920 play titled Rassum's Universal Robots (RUR). Robot in Czech is a word for worker or servent.

Definition of Robot

A Robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.

A Robot is a software - controllable mechanical device that uses sensors to guide one or more end - effectors through programmed motions in a workspace in order to manipulate physical objects

Automation & Robotics

Automation can be explained as a process to create, control and monitor the applications of technology. Automation is the process of handling the operation of equipment such as processors, machinery, stabilization of ships, aircraft, boilers and many applications with minimum human efforts.

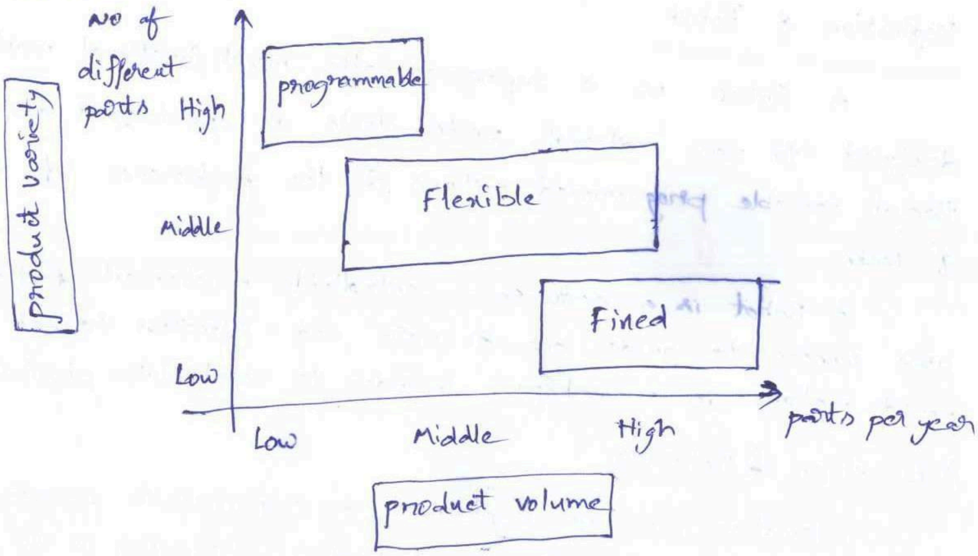
Reasons for Automation

1. To increase labour productivity
2. To reduce labor cost
3. To mitigate the effects of labor shortages.
4. To reduce or eliminate routine manual and clerical tasks
5. To improve worker safety
6. To improve product quality.
7. To reduce manufacturing lead time
8. To accomplish processes that cannot be done manually
9. To avoid the high cost of not automating.

Classification of Automation

Base on hardware and software, Three main classification

1. Fixed (hard) automation - involve hardware only
2. programmable automation - involve software only
3. Flexible automation - involve hardware and software



Fixed automation

i, High initial investment for custom - Engineered equipment.

ii, High production rates,

iii, Relatively inflexible in accommodating product changes

Programmable automation

i, High investment in general - purpose equipment

ii, Low production rates relative to fixed automation

iii, Flexibility to deal with changes in product configuration

iv, Most suitable for batch production

Flexible automation

i, High investment for a custom engineered system

ii, Continuous production of variable mixtures of products

iii, medium production rates

iv, Flexibility to deal with product design variations

Automation	When to consider	Advantages	Disadvantages
Fixed	• High demand volume • long product life cycle	• maximum efficiency • low unit cost	• large initial investment • inflexibility
programmable	• Batch production • products with different options	• Flexibility to deal with changes with in product • low unit cost for large batches	• new product requires long setup time • high unit cost relative to fixed automation
Flexible	• Low production rates • Varying demand • short product life cycles	• flexibility to deal with design variations • customized products	• large initial investment • high unit cost relative to fixed or programmable automation

CAD/CAM & Robotics

Robot work cell layout

1. Robot-centered work cell
2. In line robot work cell
3. Mobile work cell

1. Robot - centred work cell

- Center of work cell
- High utilization of robot
- Method of work part delivery
  eg: Conveyer part feeders, pallets
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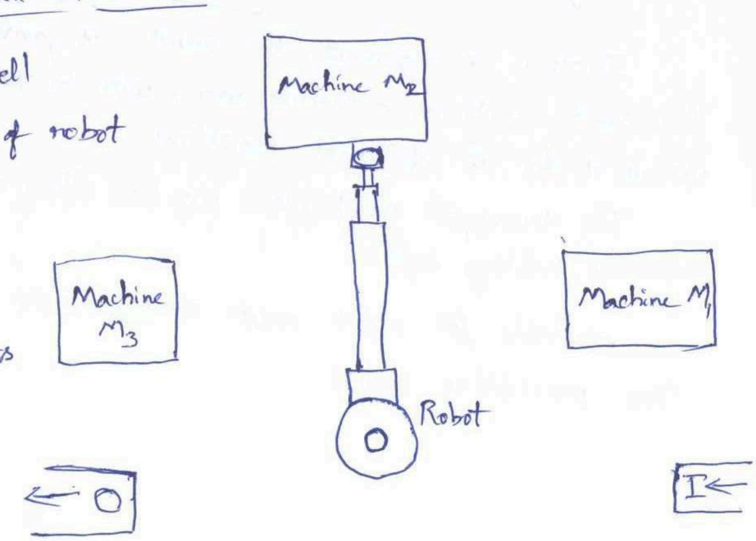
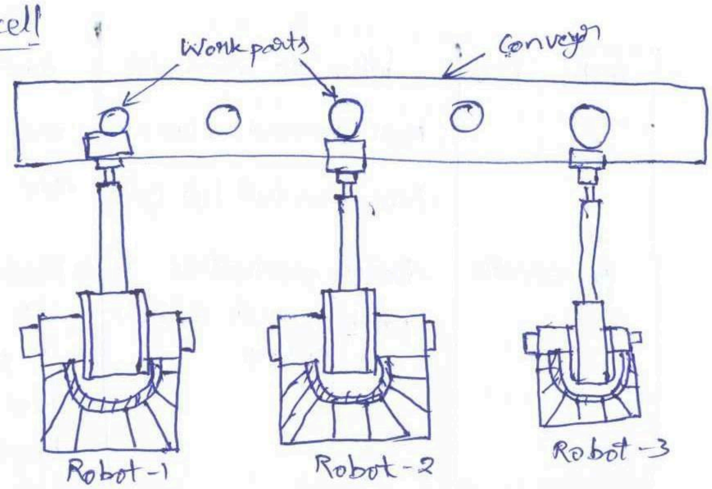


2) Inline robot work cell



- Work is organized so each robot performs assembly operation on each part
  eg: welding line

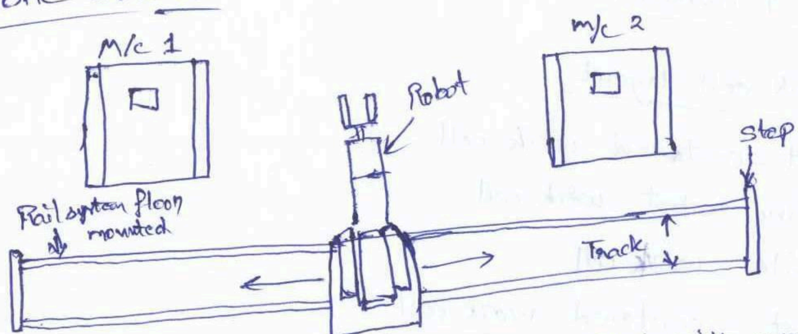
There are '3' types of work part transport systems used in Inline robot work cell

i, Intermittent transfer

ii, Continuous transfer

iii, Non synchronous transfer

3) Mobile work cell



In this arrangement, the robot is provided with a means of transport, such as a mobile base, with in the work cell to perform various tasks at different locations.

The transport mechanism may be floor mounted tracks or overhead railing system

suitable for robot must service more than one station that has long processing cycles,

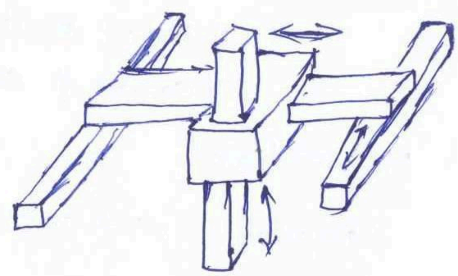
→ Future applications of robots

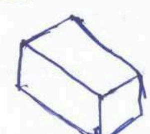
1) Transport (public & private)
2) Exploration (oceans, space, deserts etc)
3) Mining (dangerous environment)
4) Civil Defence (search & rescue, fire fighting etc)
5) Security / surveillance (patrol, observation & Intervention)
6) Domestic services (cleaning etc)
7) Entertainment (robotic toys etc)
8) Assistive technologies (support for the fragile)
9) war machines
10) scientific Instrumentation

→ Classification of Robots by coordinate system

i) Cartesian / Rectangular Gantry (3P)

These robots are made of '3' linear joints that orient the endeffector, which are usually followed by additional revolute joints





work space

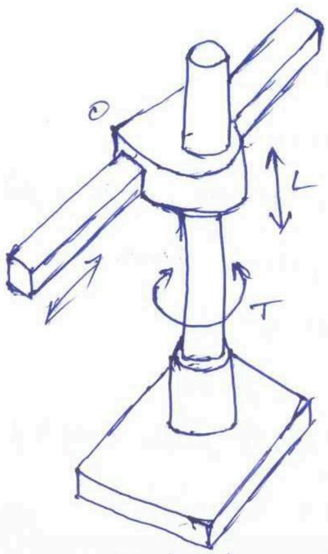
Advantages

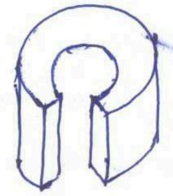
1) work envelope can be increased by travelling along x-axis
2) Linear movement and hence simpler control
3) High degree of accuracy and repeatability
4) can carry heavier loads

Disadvantages :- Movement is limited to only one direction at a time.

Applications 1) Pick and place 2) Adhesive application 3) Assembly 4) Nuclear material handling 5) Welding

Cylindrical (R2P) :- It have '2' prismatic joints and one revolute joint





work space

It uses a vertical column and a slide that can be moved up or down along the column. By rotating the column, robot is capable of achieveing a work space that approximates a cylinder

Advantages :- 1) Results in larger work volume than a rectangular robot
2) Vertical structure conserves floor space
3) capable of carrying large payloads

Disadvantages

1) Repeatability and accuracy are lower in the direction of rotary motion
2) Requires more sophisticated control system

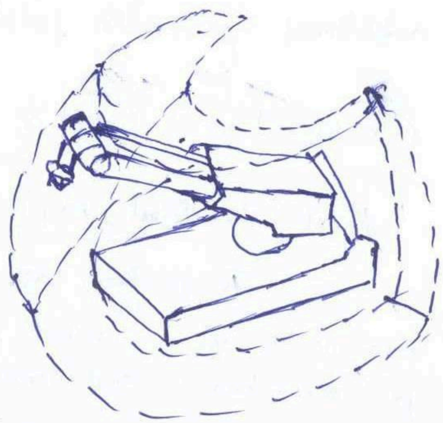
Applications

1) Assembly
2) coating applications
3) Die casting
4) Foundary and forging applications
5) Machine loading and unloading

(3) Spherical Joint (2RP) or polar configuration Robot

They follow a spherical coordinate system, which has one linear and two rotary coordinates

- The work volume of this polar configuration robot is in the form of a sphere.
- It consists the linear motion, r, corresponds to a radial in-out translation



Advantages

- Larger work envelope than the rectilinear or cylindrical configuration
- Vertical structure conserves less space.

Disadvantages

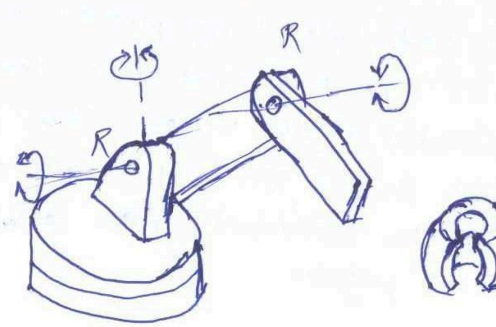
- Repeatability and accuracy are also lower in the direction of rotary motion
- Requires more sophisticated control system

Applications:- 1) Diecasting 2) Forging 3) Glass handling 4) Injection molding 5) Stacking and unstacking

(4) Articulated / anthropomorphic (3R) or Jointed arm Robot

An articulated robot's Joints are all revolute, similar to a human's arm.

A wrist is attached to an end of fore arm, thus providing several additional joints.



Cincinnati Milacron T_3 robot is commercially available

5) Selective Compliance Assembly Robot Arm (SCARA) (2R1P)

They have two revolute jonts that are parallel and allow the robot to move in horizontal plane, plus an additional prismatic joint that moves vertically.

→ Classification of Robot's based on Control systems

1. ~~Point - to - Point~~ (PTP) control robot:

To perform as per the program instructions, the joint movements of an robot must accurately be controlled. Micro-processor-based controllers are used to control the robots.

a) Limited Sequence Control

It is an elementary control type. It is used for simple motion cycles, such as pick and place operations. It is implemented by fixing limits or mechanical stops.

Feedback loops may be used to inform the controller that the action has been performed. precision is less and used in pneumatically driven robots

b) Play back with point to point control

playback control uses a controller with memory to record motion sequence in a work cycle, and then plays back the work cycle during program execution.

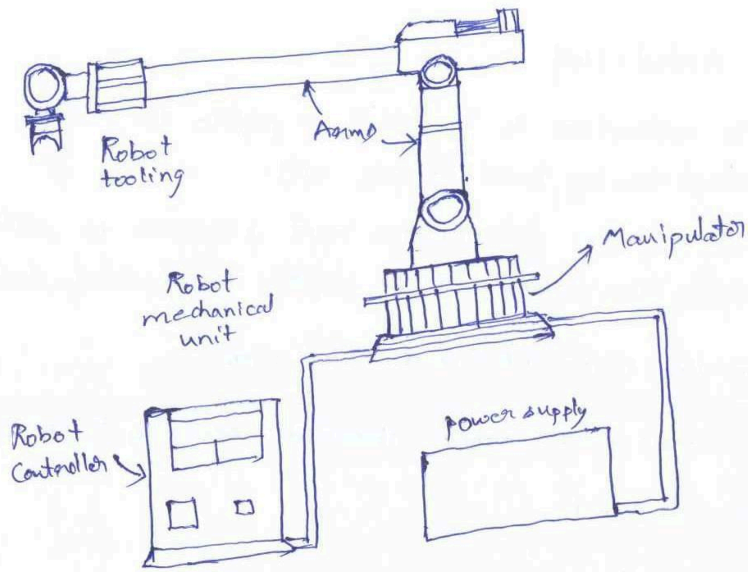
point to point means individual robot positions are recorded in the memory. These positions include both mechanical stops for each joint. Feedback control is used to confirm that the individual joints achieve the specified locations in the program.

UNIT – II

→

Components of the INDUSTRIAL ROBOTICS

Main components of robot



1. Manipulator
2. Sensor devices
3. Robot Tooling
4. Robot control unit

1. Manipulator :- It consists of base, arm and wrist similar to a human arm.
  → It also includes power source either electric, hydraulic or pneumatic
  → On receiving signals from robot controller this mechanical unit will be activated
  → The movement of manipulator can be in relation to its coordinate system.
  → Depending on the controller movement may be point to point or continuous motion.
  → The manipulator is composed of '3' divisions
    i, The major linkages
    ii, The minor linkages (wrist components)
    iii The end effector

2. Sensor devices

These elements inform the robot controller about the status of the manipulator. These sensors can be either analog or digital and combination.

These are i, visual ii, non visual.

3. Robot Tooling:-

Robot tooling is nothing but hand & gripper of the robot also called as the "endeffector". It is provided at the end of the arm. It's design ~~depends~~ depends on the nature of the work to be performed by the robot.

4. Robot - control - Unit

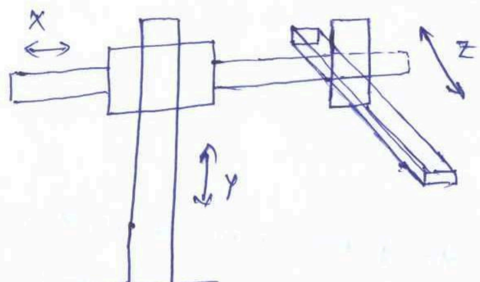
The instructions to the robot to perform the desired tasks are input through the key board of this unit.

The controller converts the input programs to suitable signals which activate the manipulator to perform the desired tasks

→ Function line representation of robot arms

The arms of the robot classified according to coordinate system.

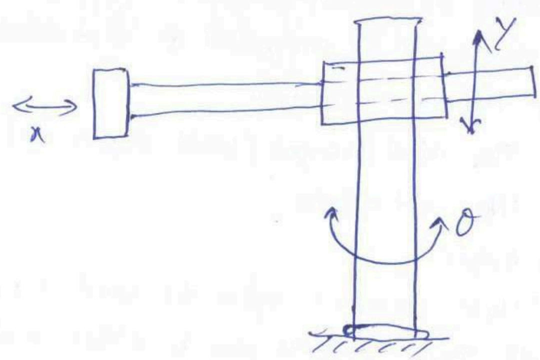
i) Cartesian Robot



It has simplest configuration with prismatic joints. The work envelope of this robot is cuboidal. It has large work volume but low density. It consists of '3' linear axes

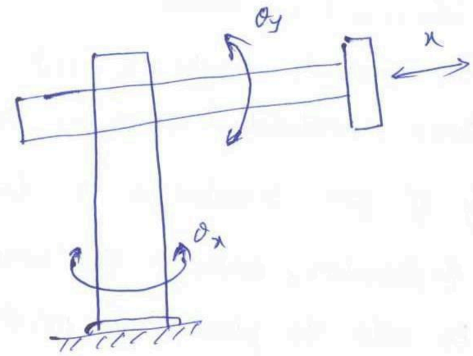
2) Cylinder Robot

It consists of two linear and one rotary axes



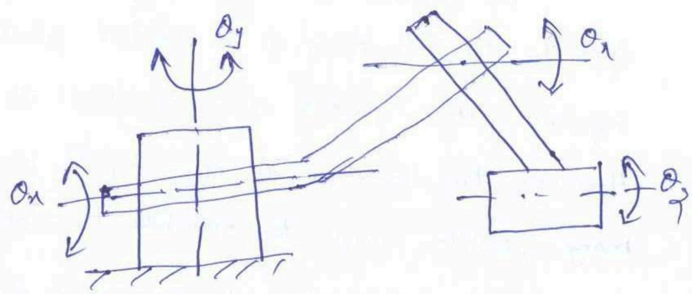
→ Polar Robot

It consists of one linear and two rotary axes

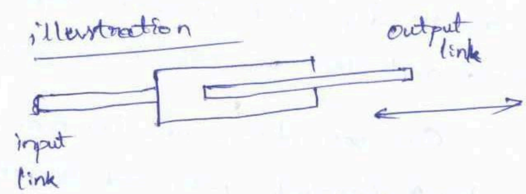
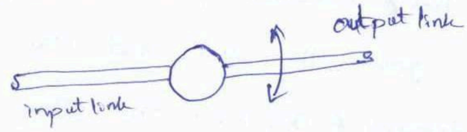
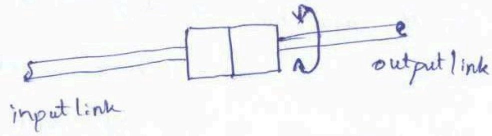
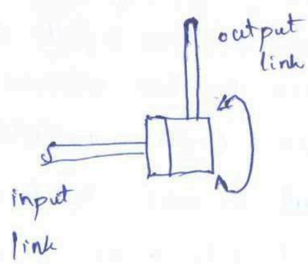


→ Joint arm Robot

It consists of '2' straight ~~link~~ links. These two links are mounted on rotary table It has all the joints are revolute joints.



→ Types of joints

Type	Name	illustration
L	Linear	
R	Rotational	
T	Twisting	
V	Revolving	

→ ## No of degrees of Freedom

In order to locate a point in space, one needs to specify three coordinates, such as the x, y, & z coordinates.

Ily if you consider a '3' dimensional device with '3' degrees of freedom, with in the workspace of the device, you should be able to place any point at any desired location.

To locate a rigid body in space, one needs to specify the location of a selected point on it, and thus it requires three pieces of information to be located as desired. However the location of the object is specified, there are infintely many possible ways to orientate the object about the selected point.

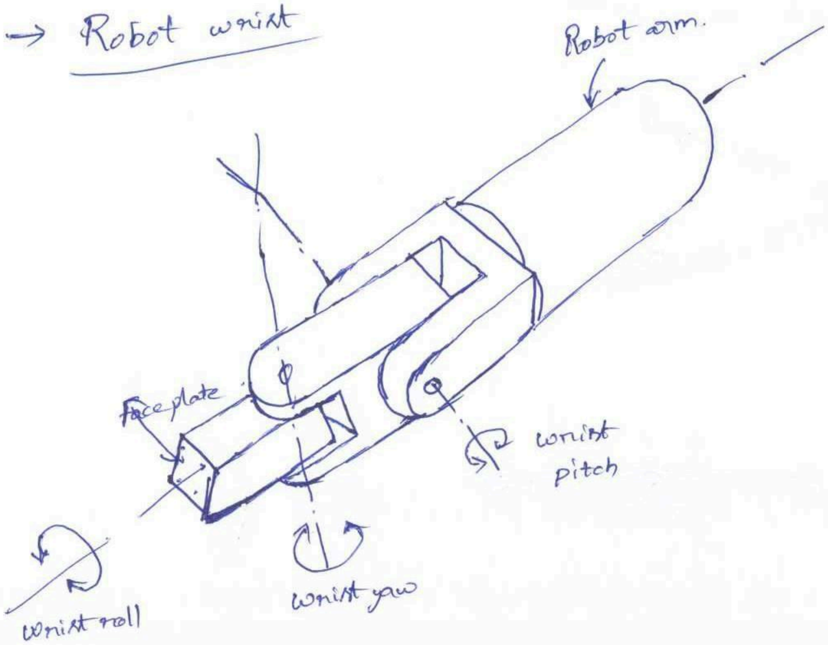
This means that there is need for a total of six pieces of information to fully specify the location and orientation. So it needs to be six degrees of freedom requires to fully place the object in space and also orientate it as desired.

Can you determine howmany degrees of freedom the human arm has? (exclude palm and fingers) but include the wrist.

You will notice that the human arm has ie shoulder has '3' degrees of freedom. The elbow has only one degree of freedom. The wrist also has '3' degrees of freedom

There are cases where a joint may have the ability to move but it's movement is not fully controlled. For example, consider a linear joint, where the arm is fully extended or fully retracted, but no control between the two extremes. This case it is assign only ½ degree of freedom. Another possibility for ½ degree of freedom is suppose that a joint is made to be only at 0, 30, 60 & 90°. ie the joint is limited to only a few possibilities.

→ Robot wrist



In robotics, an end effector is the device at the end of robotics arm. The exact nature of this device depends on the application of the robot.

Types of End effector

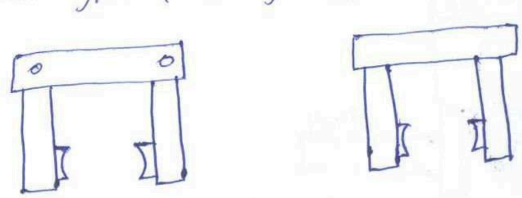
1. Grippers :- 1) used to grasp and hold objects.
   2) eg: loading and unloading, etc
2. Tools :- 1) designed to perform work on the part ~~rather~~
   2) eg spot welding, spray painting etc.

Mechanical Grippers

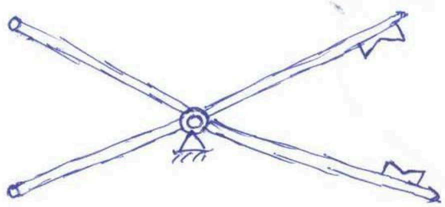
Two ways of constraining the part in the gripper

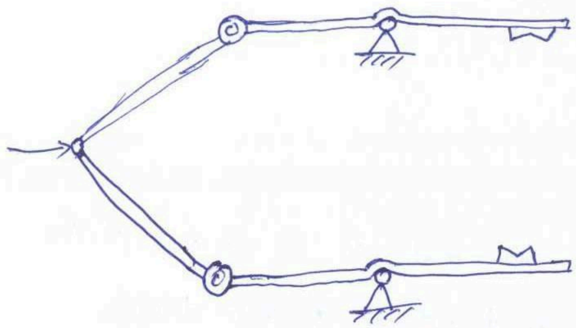
- physical construction of the part with in the fingers.
- Friction between the fingers and the work part.

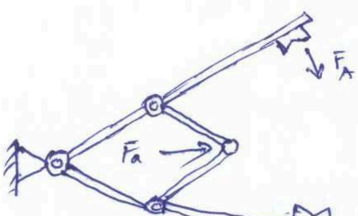
→ pivot type & sliding type

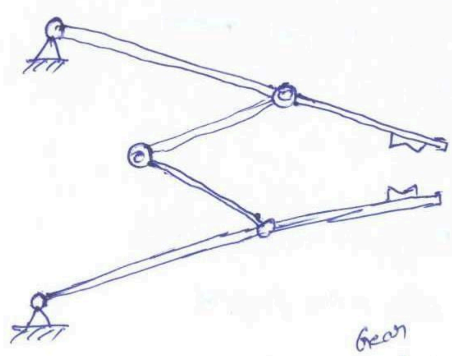


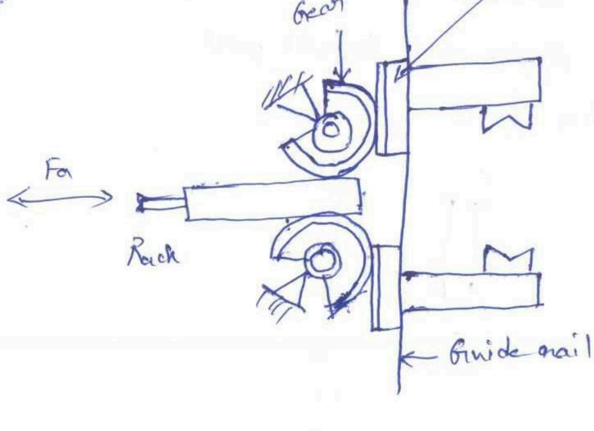
→ Some linkages for Robot Grippers



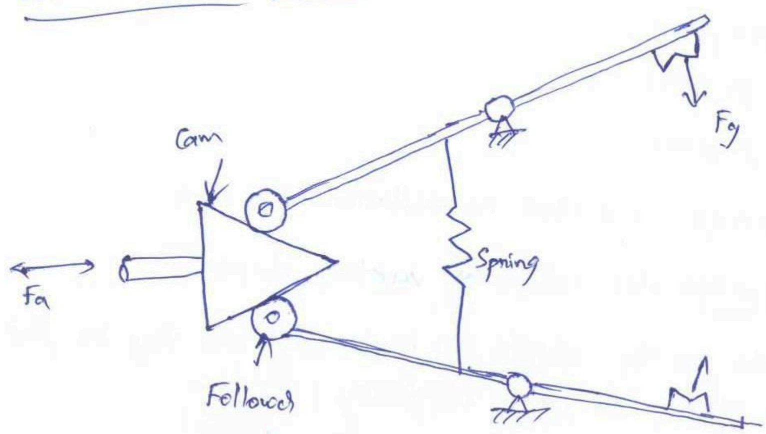




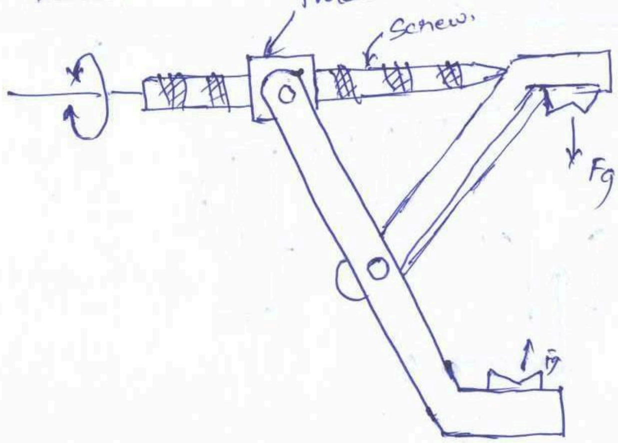




Cam actuated gripper



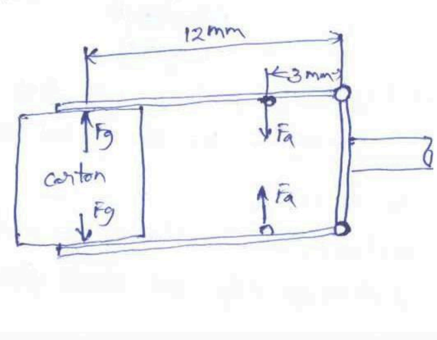
Screw type Gripper :



⇒ Gripper force analysis

Problem-I Suppose the gripper is a simple pivot type device used for holding the cardboard carton, as in fig. The gripper force $F_g = 60$ kg. The gripper is to be actuated by a piston device to apply an actuating force Fa. The corresponding lever arms for the two forces are as shown in fig

Ans Moments about the pivot arms to be summed and made equal to zero



$F_g \cdot l_g - F_a l_a = 0$

$60 \times 12 - F_a \times 3 = 0$

$F_a = \frac{720}{3} = 240$ kg

→ <u>Other types of grippers</u>

1) Vaccum grippers
2) Magnetic grippers
3) Adhesive grippers
4) Hooks, scoops and other miscellaneous devices.

<u>Vacaum grippers</u>:- also called as suction cups.

→ Requirements on the objects to be handled are they be flat, smooth and clean, to form satisfactory vacuum

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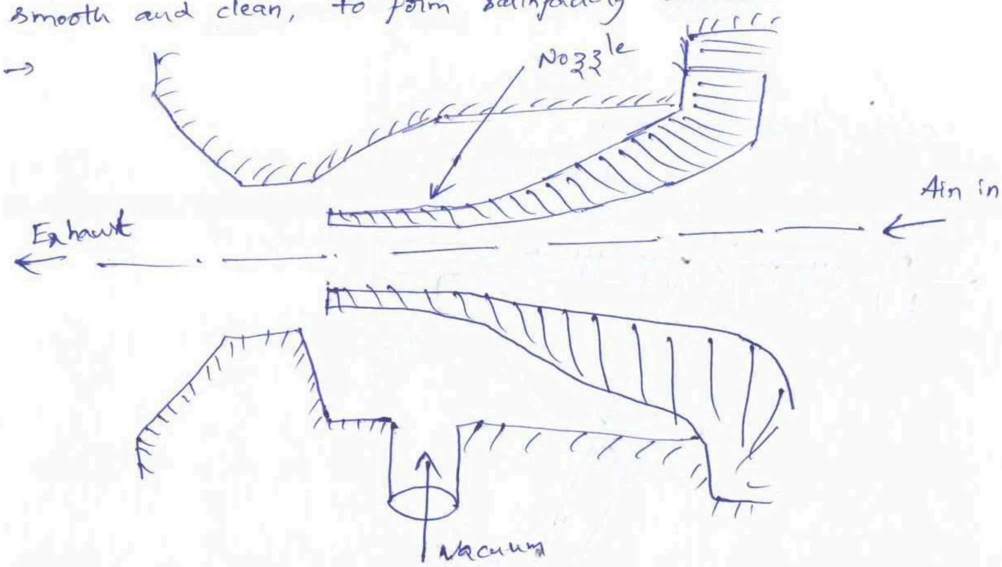
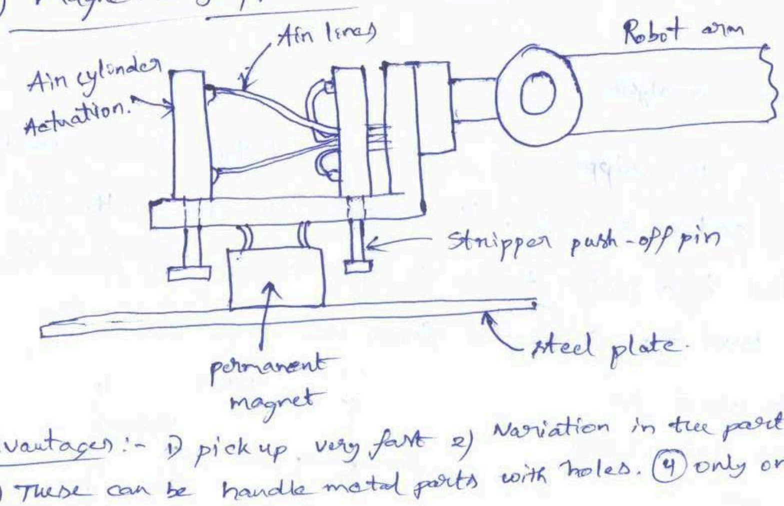


2) <u>Magnetic grippers</u>



<u>Advantages</u>:- 1) pick up very fast 2) Variation in the part size can be tolerated. 3) These can be handle metal parts with holes. (4) only one surface for gripping

<u>Disadvantages</u>

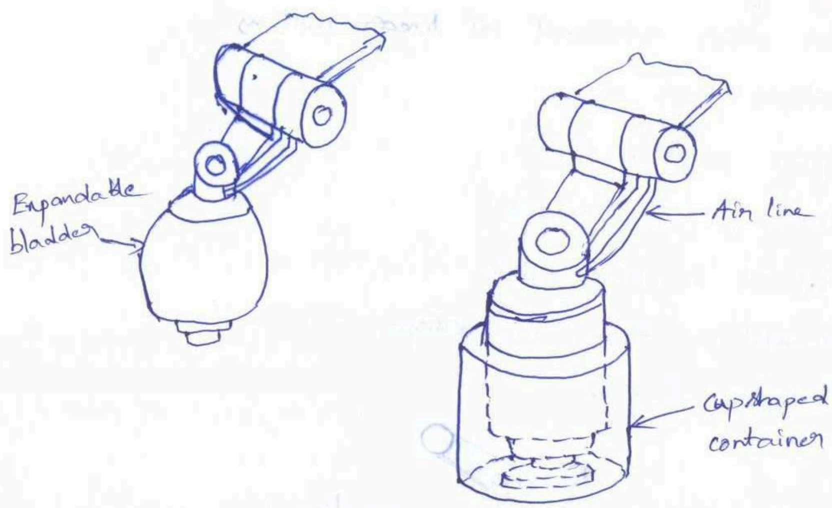
1) includes the residual magnetism remaining in the work piece.
2) picking up only one sheet from stack.

→ Adhesive grippers

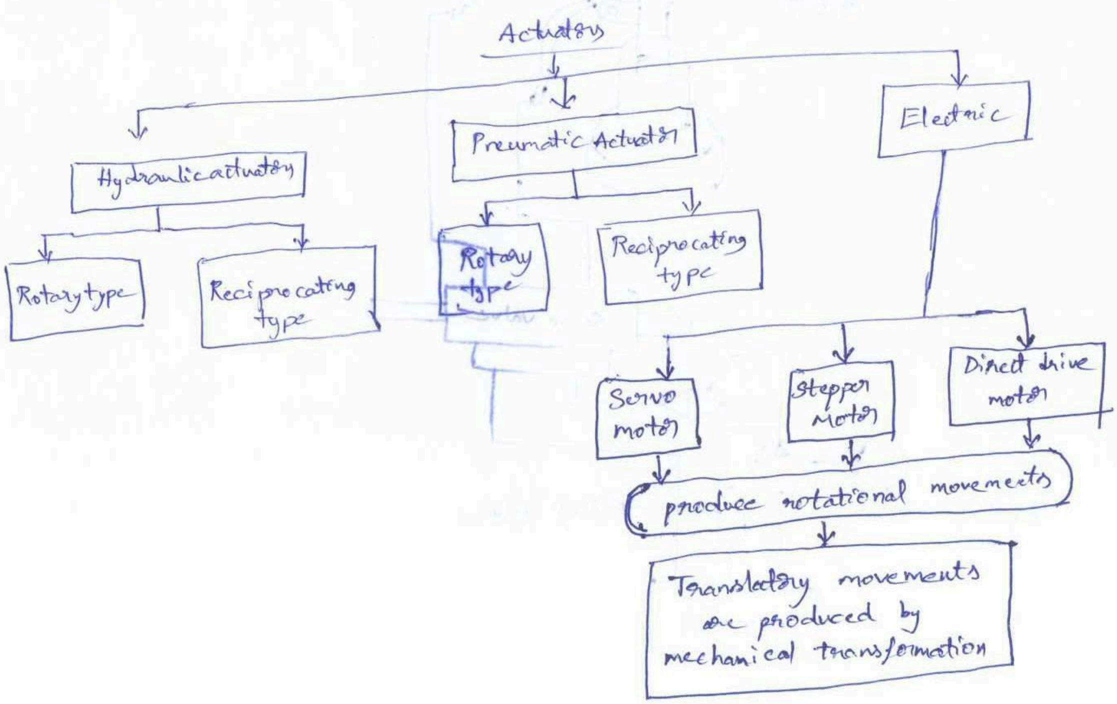
– Adhesive substance performs the grasping action

eg: Handle fabric and other light weight materials.

→ Hooks, scoops and other miscellaneous devices



→ Drive Systems



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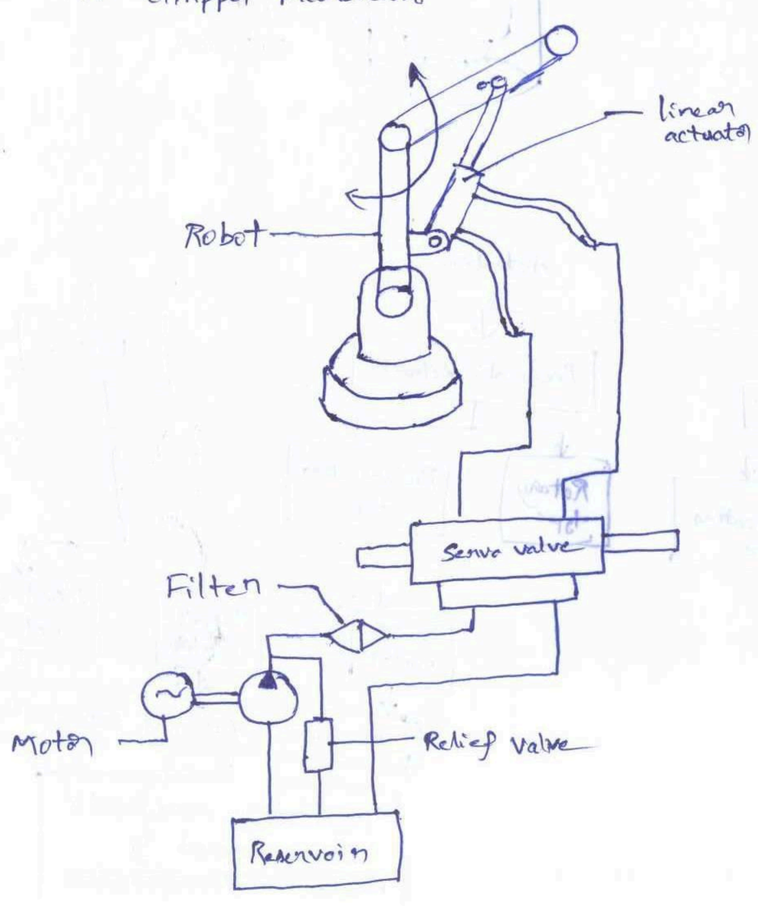
1) Hydraulic Drive

a) Associated with large robot
b) provide greater speed and strength
c) Add floor space
d) Leakage of oil
e) provide either rotational or linear motions
f) Applications such as
   i. spray painting robot
   ii. Heavy part loading robot
   iii. Material handling robot
   iv. translatory motions in cartesian robot
   v. Gripper mechanism



2. pneumatic drive

a. reserved for smaller robot

b. Limited to pick and place operations ~~of~~ with fast cycles.

c. Drift under load as air is compressible

d. provide either rotational or linear motions.

e. simple and low cost components

f. Used to open and close gripper

3. Electric drive

a. rotor, stator, brush and commutator assembly

→ Spatial Resolution

The spacial resolution of a robot is the smallest increment of movement into which the robot can divide it's work volume.

It depends on

a. the system's control resolution and

b. the robot's mechanical inaccuracies

The control resolution is determined by the robot's position control system and it's feedback measurement system. The controller divides the total range of movements for any particular joint into individual increments that can be addressed in the controller. The bit storage capacity of the control memory defines this ability to devide the total range into increments. For a particular axis, the number of separate increments is given by $= 2^n$

where n is the no of bits in the control memory.

Ex:

A robot's control memory has 8-bit storage capacity. It has two rotational joints and one linear joint. Determine the control resolution for each joint, if the linear link can vary it's length from as short as 0.2 m to as long as 1.2 m

Solu:- Control memory - 8 bit

From no of increments $= 2^8 = 256$

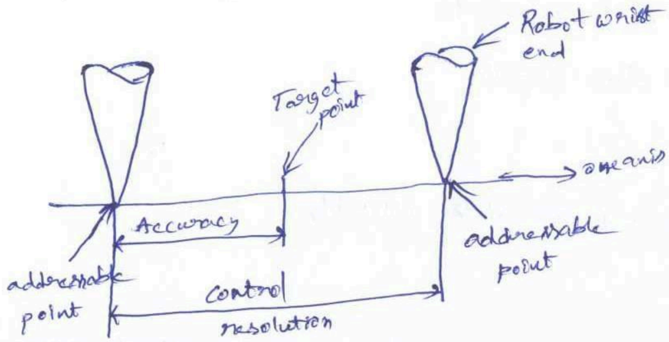
a) Total control resolution for each rotational joint $= 360/256 = 1.40625$

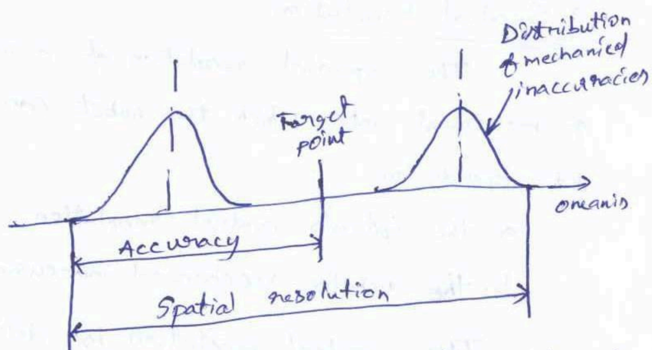
b) " " " " linear joint $= \frac{1.2 - 0.2}{256} = 1/256 = 0.003906$ m $= 3.906$ mm

→ Accuracy :

can be defined as the ability of a robot to position it's wrist end at a desired target point with in it's reach

In terms of control resolution, the accuracy can be defined as one half of the control resolution





Accuracy refers to a robot's ability to position it's wrist end at a desired target point with in the work volume.

→ Repeatability

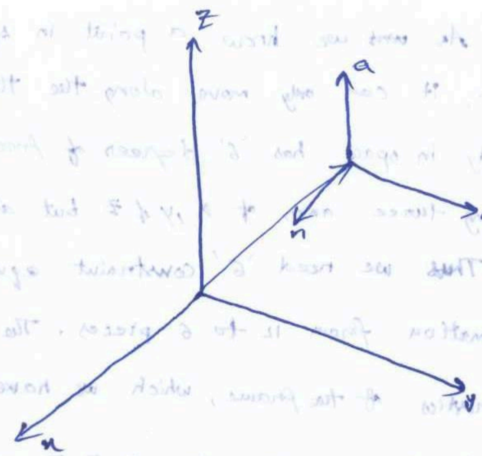
is concerned with the robot's ability to position it's wrist or an end effector attached to it's wrist at a point in space that had previously been taught to the robot. Repeatability and accuracy refer to two ~~differen~~ different aspects of the robot precision.

Unit – III

→ Representation of a frame in a fixed Reference frame

If a frame is not at the origin, then the location of the origin of the frame relative to the reference frame must also be expressed.

In order to do this, a vector will be drawn between the origin of the frame and the origin of the reference frame describing the location of the frame.



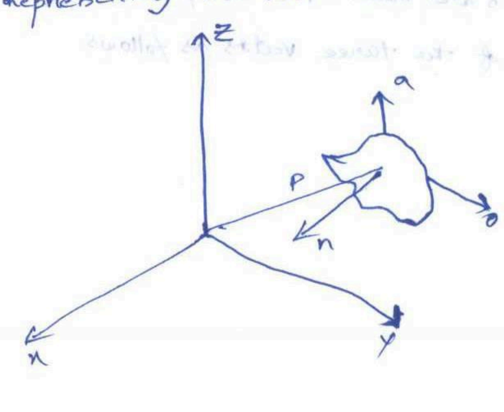
Thus the frame can be expressed by '3' vectors describing it's directional unit vectors, as well as fourth vector describing it's location as below

$$F = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

As shown in the matrix the first three vectors are directional vectors with $w=0$, representing the directions of the three unit vectors of the frame $\bar{n}, \bar{o}, \bar{a}$, while the fourth vector $w=1$ represents the location of the origin of the frame relative to the reference frame.

Representation of a Rigid Body

An object can be represented in space by attaching a frame to it and representing the frame in space.



$$F_{object} = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

As a result, so long as the frame can be described in space. The objects location and orientation relative to the fixed frame will be known. As before a frame in space can be represented by a matrix, where the origin of the frame, as well as the three vectors representing its orientation relative to the reference frame

$$F_{object} = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

As we know a point in space has only three degrees of freedom, it can only move along the three reference axes. However a rigid body in space has '6' degrees of freedom meaning that not only it can move along three axes of x, y & z but also can rotate about these three axes. Thus we need '6' constraint equations to reduce the amount of information from 12 to 6 pieces. The constraints come from the known characteristics of the frame, which we have not used yet

- the three unit vectors $\bar{n}, \bar{o}, \bar{a}$ mutually perpendicular and
- each unit vector's length must be equal to unity

1. $\bar{n} \cdot \bar{o} = 0$ (The dot product of $\bar{n}$ & $\bar{o}$ vectors must be zero)
2. $\bar{n} \cdot \bar{a} = 0$
3. $\bar{o} \cdot \bar{a} = 0$
4. $|n| = 1$ (The magnitude of the length of the vector must be 1)
5. $|o| = 1$
6. $|a| = 1$

As a result, the values representing a frame in a matrix must be such that the foregoing eqns are true. The dot product equations can be replaced by a cross product of the three vectors as follows.

$$\bar{n} \times \bar{o} = \bar{a}$$

→ Representation of Transformations

- pure translation
- pure rotation about an axis
- Combination of translations & rotations.

→ pure translation

If a frame moves in space without any change in it's orientation, the transformation is a pure translation. In this case the directional unit vectors remain in the same direction and thus do not change.

All that changes is the location of the origin of the frame relative to the reference frame.

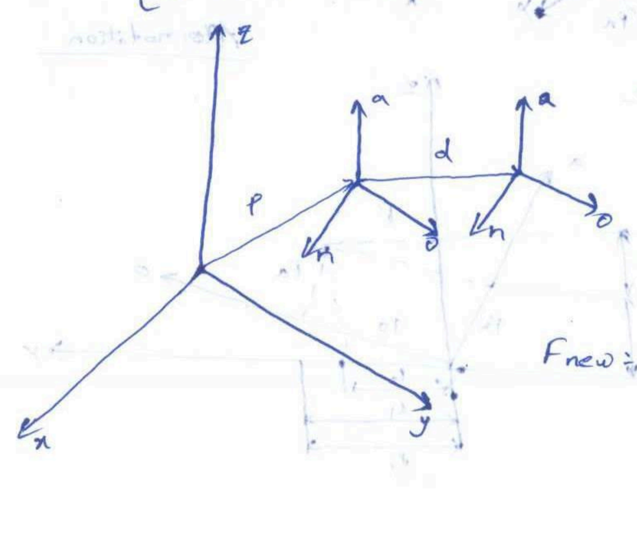
The new location of the frame relative to the fixed reference frame can be found by adding the vector representing the translation to the vector representing the original location of the origin of the frame

$$T = \begin{bmatrix} 1 & 0 & 0 & d_x \\ 0 & 1 & 0 & d_y \\ 0 & 0 & 1 & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where d_x, d_y and d_z are the three components of a pure translation vector $\vec{d}$ relative to the x, y and z axes of the reference frame.

$$F_{new} = \begin{bmatrix} 1 & 0 & 0 & d_x \\ 0 & 1 & 0 & d_y \\ 0 & 0 & 1 & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} n_x & o_x & a_x & P_x + d_x \\ n_y & o_y & a_y & P_y + d_y \\ n_z & o_z & a_z & P_z + d_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



$$F_{new} = Trans(d_x, d_y, d_z) \times F_{old}$$

→ Representation of a pure rotation about an axis

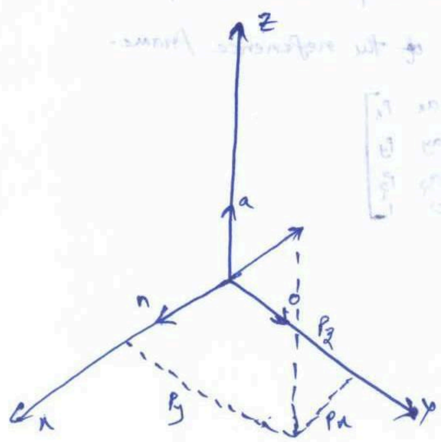
Lets assume that a frame $(\bar{n}, \bar{o}, \bar{a})$ located at the origin of the reference frame $(\bar{x}, \bar{y}, \bar{z})$ will rotate through an angle of 'θ' about the x-axis of the reference frame.

Lets also assume that attached to the rotating frame $(\bar{n}, \bar{o}, \bar{a})$ is a point P, with co-ordinates P_x, P_y & P_z relative to the reference frame and P_n, P_o, & P_a relative to the moving frame.

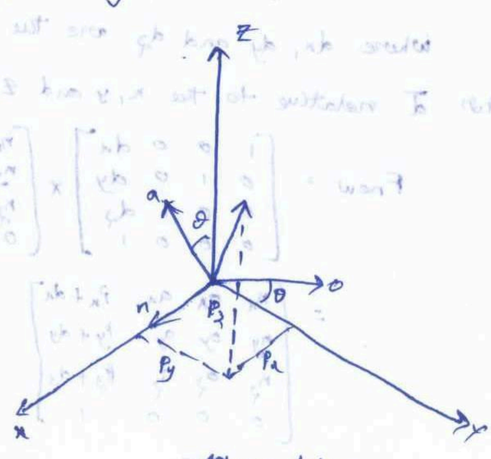
As the frame rotates about the x-axis, point P attached to the frame will also rotate with it. Before rotation, the coordinates of the point in both frames are the same.

After rotation, the P_n, P_o and P_a coordinates of the point remain the same in the rotating frame $(\bar{n}, \bar{o}, \bar{a})$ but P_x, P_y and P_z will be different in the $(\bar{x}, \bar{y}, \bar{z})$ frame.

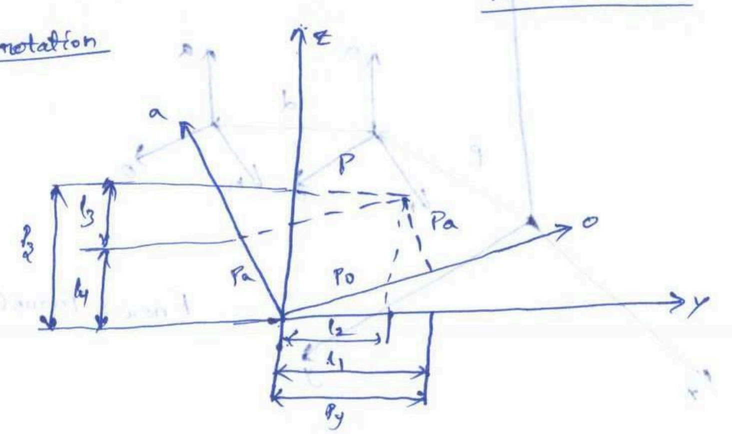
We desire to find the new coordinates of the point relative to the fixed reference frame after the moving frame has rotated.



Before rotation



After rotation



Now let's look at the same coordinates in 2-D as if we were standing on the x-axis. The coordinates of point p are shown before and after rotation. The coordinates of point p relative to the reference frame are P_x, P_y and P_z, while its coordinates relative to the rotating frame remain as P_n, P_o & P_a

The value of $P_x = P_n$

$$P_y = l_1 - l_2$$
$$= P_o \cos\theta - P_a \sin\theta$$
$$P_z = l_3 + l_4$$
$$= P_o \sin\theta + P_a \cos\theta$$

which is in matrix form

$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} P_n \\ P_o \\ P_a \end{bmatrix}$$

This means that the coordinates of the point 'P' in the rotated frame must be pre-multiplied by the rotation matrix, to get the coordinates in the reference frame. This rotation matrix is only for a pure rotation about the x-axis of the reference frame and is denoted as

$$P_{xyz} = Rot(x,\theta) \times P_{noa}.$$

To ~~simplify~~ simplify writing of these matrices $C\theta$ to denote $\cos\theta$ $S\theta$ to denote $\sin\theta$.

$$Rot(x,\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & C\theta & -S\theta \\ 0 & S\theta & C\theta \end{bmatrix}$$

You may do the same for the rotation of a frame about y- and z-axes of the reference frame.

$$Rot(y,\theta) = \begin{bmatrix} C\theta & 0 & S\theta \\ 0 & 1 & 0 \\ -S\theta & 0 & C\theta \end{bmatrix} \text{ and } Rot(z,\theta) = \begin{bmatrix} C\theta & -S\theta & 0 \\ S\theta & C\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Denoting the transformation

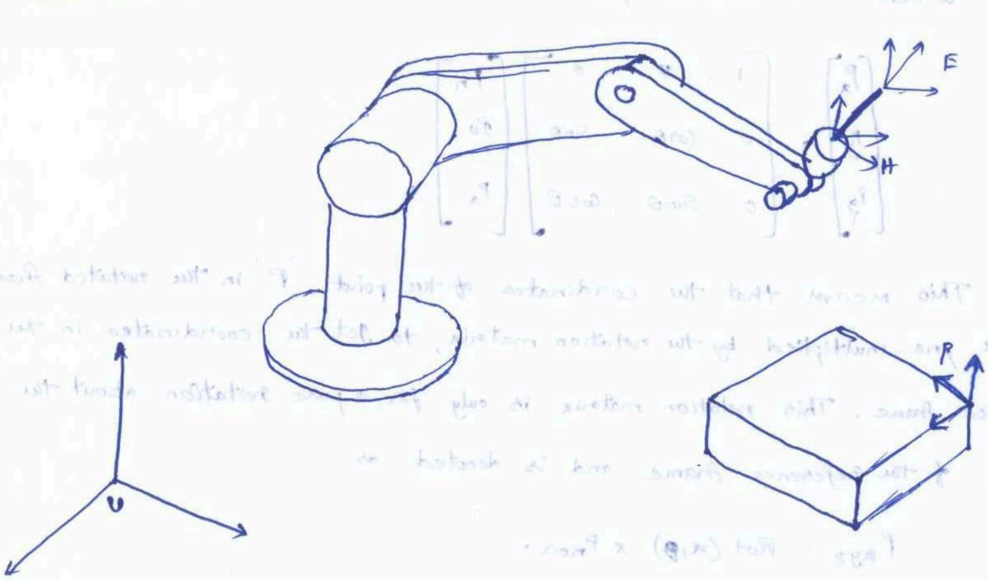
${}^{U}T_{R}$ — reading it as transformation of frame R relative to frame U

${}^{R}P$ — reading it as P relative to frame R i.e. P_{noa}

${}^{U}P$ — reading it as 'P' relative to Universal reference frame i.e. P_{xyz}

$$ {}^{U}P = {}^{U}T_{R} \times {}^{R}P $$

Inverse of Transformation Matrices



There are many situations where the inverse of a matrix will be needed in robotic analysis

Suppose that the robot in above diagram is to be moved towards part p in order to drill a hole in the part.

We can write

$$ {}^{U}T_{E} = {}^{U}T_{R}\ {}^{R}T_{H}\ {}^{H}T_{E} = {}^{U}T_{P}\ {}^{P}T_{E} $$

The only unknown transformation is ${}^{R}T_{H}$ or the transformation of the robot's hand relative to the robot's base.

We need to find out what the robot's joint variables (the angle of the revolute joints and the length of the prismatic joints of the robot) must be in order to place the end effector at the hole for drilling.

As you see, it is necessary to calculate this transformation, which will tell us what needs to be accomplished. The transformation will later be used to actually solve for joint angles and link lengths.

To calculate this matrix, unlike in an algebraic equation, we cannot simply divide the right side by the left side of the equation. We need to pre- or -postmultiply by inverse of appropriate matrices to eliminate them.

As a result we will have

$$\left({}^{U}T_{R}\right)^{-1}\left({}^{U}T_{R}\,{}^{R}T_{H}\,{}^{H}T_{E}\right)\left({}^{H}T_{E}\right)^{-1} = \left({}^{U}T_{R}\right)^{-1}\left({}^{U}T_{P}\,{}^{P}T_{E}\right)\left({}^{H}T_{E}\right)^{-1}$$

we know that

$$\left({}^{U}T_{R}\right)^{-1}\left({}^{U}T_{R}\right) = 1 \quad \text{and} \quad \left({}^{H}T_{E}\right)\left({}^{H}T_{E}\right)^{-1} = 1$$

and the left side of equation simplifies to

${}^{R}T_{H}$ and we get ${}^{R}T_{H} = {}^{U}T_{R}^{-1}\,{}^{U}T_{P}\,{}^{P}T_{E}\,{}^{H}T_{E}^{-1}$

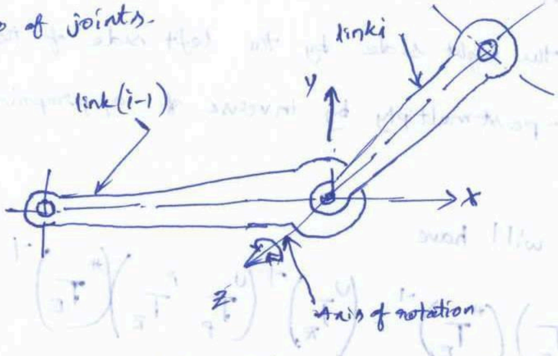
Realizing that $\left({}^{H}T_{E}\right)^{-1} = {}^{E}T_{H}$

$${}^{R}T_{H} = {}^{R}T_{U}\,{}^{U}T_{P}\,{}^{P}T_{E}\,{}^{E}T_{H}$$

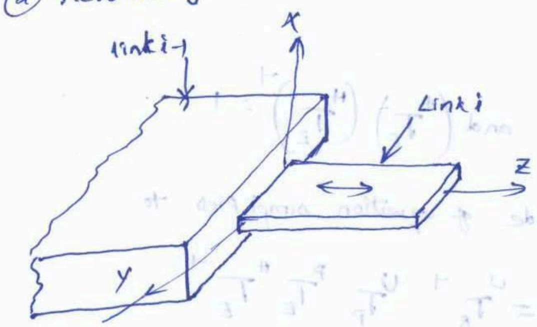
→ Mechanical structure and notations

A manipulator consists of a chain of rigid bodies called links, con-connected each other by joints.

The no of degrees of freedom a manipulator possesses is the no of independent parameters required to completly specify its position orientation in space. The degree of freedom of a manipulator are equal to no of joints.



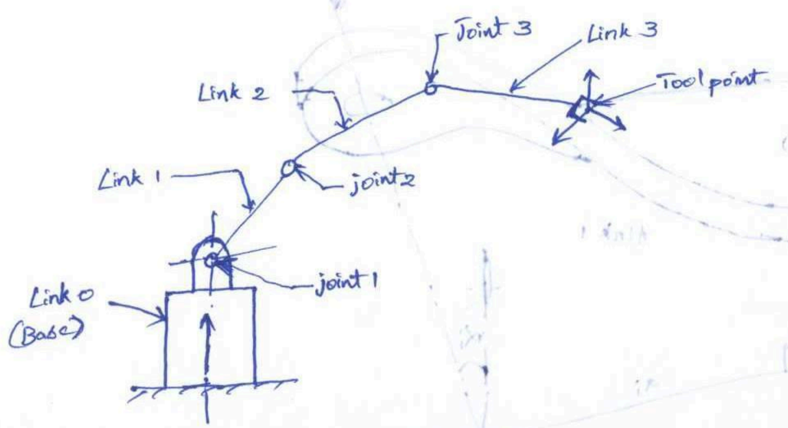
(a) revolute joint



b) prismatic (sliding) joint.

By convention, the z-axis of a coordinate frame is aligned with the joint axis

The links of a manipulator are numbered outwardly starting from the immobile base as link 0, first moving body as link 1, to the last link out to the free end as link n. Link 'n' as is the tool or end effector. The joints are numbered, similarly with joint 1 between link 0 and link 1 and so on, out to the joint 'n' between link (n-1) and link (n).



Description of Links and joints

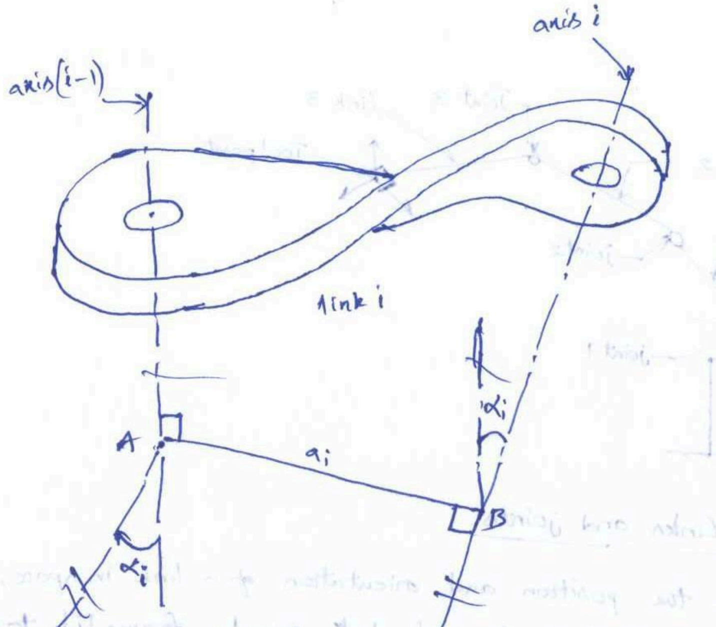
To describe the position and orientation of a link in space, a coordinate frame is attached to each link namely frame {i} to link {i}. The position and orientation of ~~a link in space~~ frame {i}, relative to previous frame {i-1}, can be described by a homogeneous transformation matrix

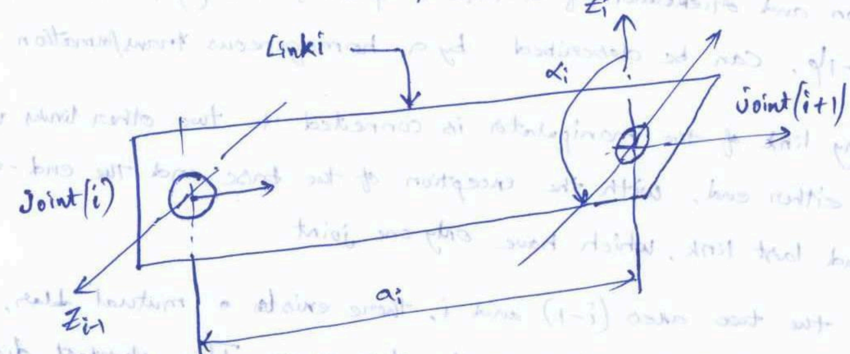
Every link of the manipulator is connected to two other links with joints at either end, with the exception of the base and the end-effector, the first and last link, which have only one joint

For the two axes (i-1) and i, there exists a mutual ~~⊥ar~~, which gives the shortest distance between the two axes. This shortest distance along the common normal is defined as the link length and is denoted as (a_i)

The angle between the projection of axis (i-1) and axis (i) on a plane perpendicular to the common normal AB, is known as the link twist and is denoted by (α_i). This link twist α_i is measured from axis (i-1) to axis i in the right hand sense about AB

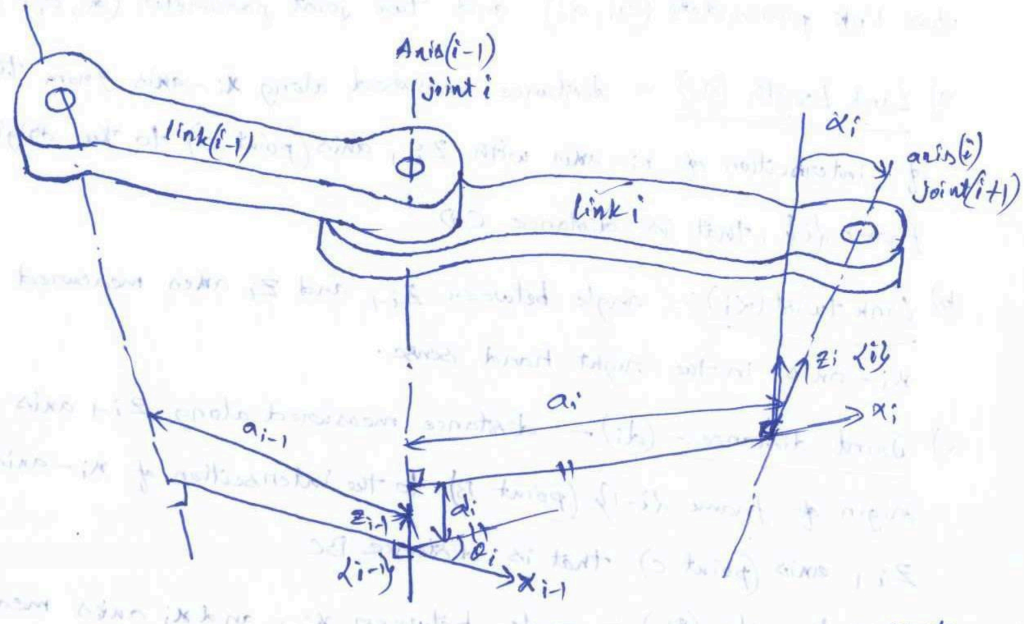
These two parameters α_i and a_i are known as link parameters and are constant for a given link.





Another common link geometry is straight link with link twist angle as multiple of $\pi/2$ radians.

Some times the link may have a bend such that the axis the axis of joint i-1 and joint i intersect and in this case the link length of link i is zero although the physical link dimension is not zero



The perpendicular distance between the two adjacent common normals $a_{(i-1)}$ and a_i measured along axis $i-1$ is (d_i)

Joint angle (θ_i) is the angle between the two adjacent common normals a_{i-1} and a_i measured in the right handed direction about the axis $i-1$

d_i and θ_i are the joint parameters.

For a revolute joint d_i is zero or constant and θ_i varies, while for a prismatic joint θ_i is zero or constant and d_i varies

Denavit – Hartenberg notation

i, The z_i-axis is aligned with axis i, its direction being arbitrary. The choice of direction defines the positive sense of joint variable θ_i.

ii, The x_i-axis is ⊥r to axis z_{i-1} and z_i and points away from axis z_{i-1} that is x_i-axis is directed along the common normal CD

iii, The origin of the ith coordinate frame, frame $\{i\}$ is located at the intersection of axis of joint $(i+1)$, that is axis i and the common normal between axes $(i-1)$ and i common normal is CD as shown in figure

iv) Finally y-axis complete the right handed orthonormal coordinate frame $\{i\}$

with respect to frame {i-1} and frame {i}, the four DH-parameters two link parameters (a_i, α_i) and two joint parameter (d_i, θ_i) are defined

a) Link Length (a_i) - distance measured along x_i-axis from the point of intersection of x_i-axis with z_{i-1} axis (point C) to the origin of frame {i}, that is distance CD

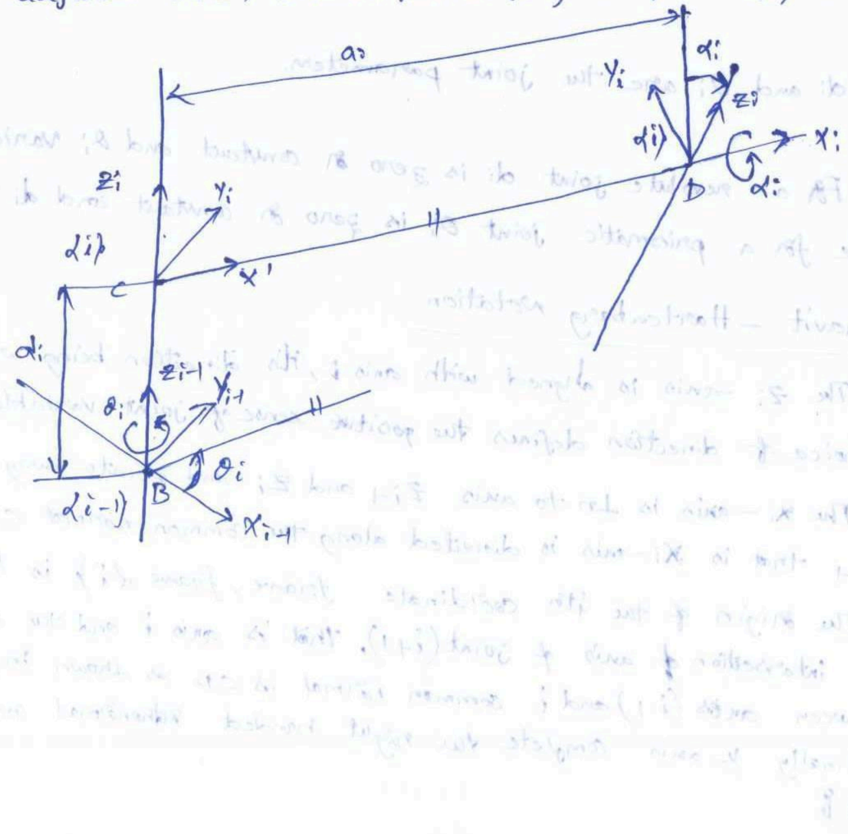
b) Link twist (α_i) :- angle between z_{i-1} and z_i axes measured about x_i-axis in the right hand sense.

c) Joint distance :- (d_i) - distance measured along z_{i-1} axis from the origin of frame {i-1} (point B) to the intersection of x_i-axis with z_{i-1} axis (point C) that is distance BC

d) Joint angle (θ_i) :- angle between x_{i-1} and x_i axes measured about the z_{i-1} axis in the right hand sense

Kinematic Relationship between adjacent Links

To find the transformation matrix relating two frames attached to the adjacent links, consider frame {i-1} and frame {i} as shown below



These two frames are associated with link $(i-1)$ and (i). The kinematic joint-link parameters involved $(\theta_i, d_i, \alpha_i, a_i)$ are shown. Points B, C, D and frame $\{i-1\}$ and $\{i\}$ are the same as in fig.

The transformation of frame $\{i-1\}$ to frame $\{i\}$ consists of four basic transformations as shown

a) A rotation about z_{i-1} - axis by an angle θ_i

b) Translation along z_{i-1} - axis by distance d_i

c) Translation by distance a_i along x_i - axis and

d) Rotation by an angle α_i about x_i - axis

Using the spatial coordinate transformations, the composite transformation matrix which describes frame $\{i\}$ with respect to frame $\{i-1\}$ is obtained

$$^{i-1}T_i = T_z(\theta_i)\, T_z(d_i)\, T_x(a_i)\, T_x(\alpha_i)$$

$$^{i-1}T_i = \begin{bmatrix} C\theta_i & -S\theta_i & 0 & 0 \\ S\theta_i & C\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\alpha_i & -S\alpha_i & 0 \\ 0 & S\alpha_i & C\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

UNIT - IV

Differential transformation

Suppose that a frame moves a differential amount relative to the reference frame. '2' cases possible

(1) motion of the frame without regard to what causes the motion

(2) Include the mechanism that causes the motion.

To understand these, suppose that you have a robot welding '2' pieces together. For best result, you will want the robot to move at a constant speed. This means that the differential motions of the hand frame must be defined to represent a constant speed in a particular direction. This relates to the differential motion of the frame

Thus we have to calculate the speeds of each and every joint at any instant such that the total motion caused by the robot will be equal to the desired speed of the frame.

The differential motions of a frame can be devided into the following

1) Differential translations

2) Differential rotations

3) Differential transformations.

1) Differential translations

is a translations of a frame at differential values. Thus it can be represented by "Trans (dx, dy, dz)". This means that the frame has moved a differential amount along the three axes

2) Differential Rotations

is a small rotation of the frame. It is represented by $Rot(k, d\theta)$, which means that the frame has rotated an angle of $d\theta$ about an axis $\hat{k}$.

differential rotations about the x, y, z - axes are defined by δx, δy & δz respectively.

but $\sin \delta x = \delta x$ (in radians) as rotations are small.

$\cos \delta x = 1$

Then the rotation matrices are

$$Rot(x, \delta x) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & -\delta x & 0 \\ 0 & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$Rot(y, \delta y) = \begin{bmatrix} 1 & 0 & \delta y & 0 \\ 0 & 1 & 0 & 0 \\ -\delta y & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$Rot(z, \delta z) = \begin{bmatrix} 1 & -\delta z & 0 & 0 \\ \delta z & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

you will notice that these matrices define the rule about the magnitudes of each vector being one unit.

As we have already seen, if the order of multiplication changes, the result will change as well. If we multiply two differential motion in different orders, we will get two different results

$$Rot(x,\delta x).\,Rot(y,\delta y) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & -\delta x & 0 \\ 0 & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & \delta y & 0 \\ 0 & 1 & 0 & 0 \\ -\delta y & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & \delta y & 0 \\ \delta x \delta y & 1 & -\delta x & 0 \\ -\delta y & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$Rot(y,\delta y)\,Rot(x,\delta x) = \begin{bmatrix} 1 & 0 & \delta y & 0 \\ 0 & 1 & 0 & 0 \\ -\delta y & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & -\delta x & 0 \\ 0 & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & \delta x \delta y & \delta y & 0 \\ 0 & 1 & -\delta x & 0 \\ -\delta y & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

if we neglect the higher order differentials such as $\delta x \delta y$, the results are exactly the same.

$$Rot(x,\delta x)\,Rot(y.\delta y) = Rot(y.\delta y)\,Rot(x,\delta x)$$

→ Differential Rotation about a general axis $\hat{k}$

We can assume that a differential motion about a general axis $\hat{k}$ is composed of '3' differential motions about the three axes, in any order. Thus a differential motion about any general axis $\hat{k}$ can be expressed as

$$Rot(k,d\theta) = Rot(x,\delta x)\,Rot(y\,\delta y)\,Rot(z,\delta z)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & -\delta x & 0 \\ 0 & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & \delta y & 0 \\ 0 & 1 & 0 & 0 \\ -\delta y & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & -\delta z & 0 & 0 \\ \delta z & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & -\delta z & \delta y & 0 \\ \delta x \delta y + \delta z & -\delta x \delta y \delta z + 1 & -\delta x & 0 \\ -\delta y + \delta x \cdot \delta z & \delta x + \delta y \delta z & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & -\delta z & \delta y & 0 \\ \delta z & 1 & -\delta x & 0 \\ -\delta y & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Example

→ Find the total differential transformation caused by small rotations about the three axes of $\delta x = 0.1$, $\delta y = 0.05$ and $\delta z = 0.02$ radians

Sol

$$Rot(k, \delta\theta) = \begin{bmatrix} 1 & -\delta z & \delta y & 0 \\ \delta z & 1 & -\delta x & 0 \\ -\delta y & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & -0.02 & 0.05 & 0 \\ 0.02 & 1 & -0.1 & 0 \\ -0.05 & 0.1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Differential transformations of a frame.

is a combination of differential translations and rotations. If we denote the original frame as T and assume that the change in the frame T as a result of a differential transformation is expressed as dT then

$$[T + dT] = [Trans(dx, dy, dz)\ Rot(k, d\theta)][T]$$

$$\text{or } [dT] = [Trans(dx, dy, dz)\ Rot(k, d\theta) - I][T] \quad -(1)$$

where 'I' is a unit matrix. [dT] expresses the change in the frame after the differential transformation. Eq (1) can be written as

$$[dT] = [\Delta][T]$$

$$[\Delta] = [Trans(dx, dy, dz) \times Rot(k, d\theta) - I]$$

'Δ' is called differential operator.

$$\Delta = Trans(dx, dy, dz) \times Rot(k, d\theta) - I$$

$$= \begin{bmatrix} 1 & 0 & 0 & dx \\ 0 & 1 & 0 & dy \\ 0 & 0 & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & -\delta z & \delta y & 0 \\ \delta z & 1 & -\delta x & 0 \\ -\delta y & \delta x & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & -\delta z & \delta y & dx \\ \delta z & 0 & -\delta x & dy \\ -\delta y & \delta x & 0 & dz \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Ex

Write the differential operator matrix for the following differential transformations, $dx = 0.5$, $dy = 0.3$, $dz = 0.1$ units, and $\delta x = 0.02$, $\delta y = 0.04$, $\delta z = 0.06$ radians.

Sol

$$\Delta = \begin{bmatrix} 0 & -0.06 & 0.04 & 0.5 \\ 0.06 & 0 & -0.02 & 0.3 \\ -0.04 & 0.02 & 0 & 0.1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Differential Motions of a robot and it's hand frame

In this section, we will relate the changes to the mechanism – in this case, the robot that accomplishes the differential motions. The frame we discussed may be any frame, including the hand frame of a robot. dT describes the changes in the components of the $\bar{n}, \bar{o}, \bar{a}, \bar{p}$ vectors.

$$\begin{bmatrix} dx \\ dy \\ dz \\ \delta x \\ \delta y \\ \delta z \end{bmatrix} = \begin{bmatrix} \\ \text{Robot} \\ \text{Jacobian} \\ \\ \end{bmatrix} \begin{bmatrix} d\theta_1 \\ d\theta_2 \\ d\theta_3 \\ d\theta_4 \\ d\theta_5 \\ d\theta_6 \end{bmatrix}$$

LAGRANGIAN MECHANICS

Lagrangian mechanics is based on the differentiation of the energy terms with respect to the systems variable and time, as shown next. For simple cases, it may take longer to use this technique than Newtonian mechanics. However as the complexity of the system increases, the Lagrangian method becomes relatively simpler to use.

$$L = K - P$$

L = Lagrangian

k = kinetic energy of the system

P = potential energy of the system.

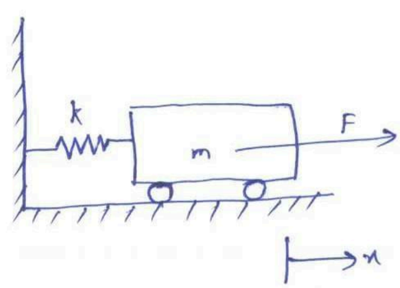
Then $$F_i = \frac{\partial}{\partial t}\left(\frac{\partial L}{\partial \dot{x}_i}\right) - \left(\frac{\partial L}{\partial x_i}\right)$$

$$T_i = \frac{\partial}{\partial t}\left(\frac{\partial L}{\partial \dot{\theta}_i}\right) - \left(\frac{\partial L}{\partial \theta_i}\right)$$

where F is the summation of all external forces for linear motion.

T is the summation of all torques in rotational motion.

→ Derive the force - acceleration relationship for the one-degree-of-freedom system shown in fig below, using both the Lagrangian mechanics as well as the Newtonian mechanics. Assume that the wheels have negligible inertia.



Sol In the above fig x-axis denotes the motion of the cart and is used as the variable in this system. As this is a 1° of freedom system, there will be only one equation describing the motion.

$$K = \frac{1}{2} m v^2 = \frac{1}{2} m \dot{x}^2$$

and $P = \frac{1}{2} k x^2$

$$L = K - P \Rightarrow \frac{1}{2} m \dot{x}^2 - \frac{1}{2} k x^2$$

The derivatives of the Lagrangian are

$$\frac{\partial L}{\partial \dot{x}} = m\dot{x}$$

$$\frac{d}{dt}(m\dot{x}) = m\ddot{x}$$

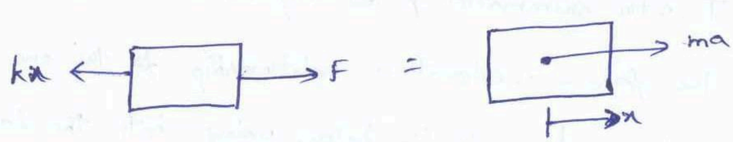
and $\frac{\partial L}{\partial x} = -kx$

The equation of motion for the cart is

$$F = m\ddot{x} + kx$$

—o—

To solve this by <u>Newtonian mechanics</u> we will draw free body diagram of the cart.

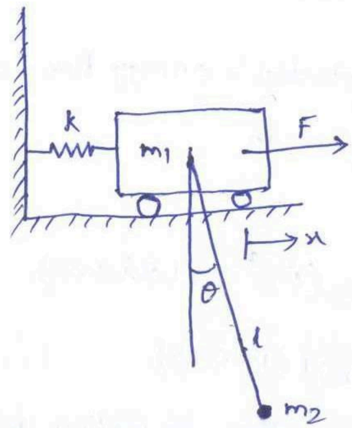


$$\Sigma F = ma$$

$$F - kx = ma$$

$$F = ma + kx$$

→ Derive the equations of motion for the 2° of freedom system shown in fig



Sol: In this problem, there are 2° of freedom, two coordinates x and θ, and there will be two equations of motion.

1. linear motion of the system
2. rotation of the pendulum

The K.E of the system is comprised of the K.E of the cart and of the pendulum. Notice that the velocity of the pendulum is the summation of the velocity of the card and of the pendulum relative to the cart or

$$\bar{V}_p = \bar{V}_c + \bar{V}_{p/c}$$

$$= \dot{x}i + l\dot{\theta}\cos\theta i + l\dot{\theta}\sin\theta j$$

$$= \left[(\dot{x} + l\dot{\theta})\cos\theta\right]i + l\dot{\theta}\sin\theta j$$

$$V_p^2 = (\dot{x} + l\dot{\theta}\cos\theta)^2 + (l\dot{\theta}\sin\theta)^2$$

Thus $k = k_{cart} + k_{pendulum}$

$$k_{cart} = \frac{1}{2} m_1 \dot{x}^2$$

$$k_{pendulum} = \frac{1}{2} m_2 (\dot{x} + l\dot{\theta}\cos\theta)^2 + \frac{1}{2} m_2 (l\dot{\theta}\sin\theta)^2$$

$$k = \frac{1}{2}(m_1 + m_2)\dot{x}^2 + \frac{1}{2} m_2 (l^2\dot{\theta}^2 + 2l\dot{\theta}\dot{x}\cos\theta).$$

Likewise, the potential energy is the summation of the P.E in the spring and in the pendulum as

$$P = \frac{1}{2} k x^2 + m_2 g l (1 - \cos\theta)$$

Notice that the zero-potential-energy line (datum) is chosen at $\theta = 0°$. The lagrangian is

$$L = K - P$$

$$= \frac{1}{2}(m_1 + m_2)\dot{x}^2 + \frac{1}{2} m_2 (l^2 \dot{\theta}^2 + 2 l \dot{\theta} \dot{x} \cos\theta)$$

$$- \frac{1}{2} k x^2 - m_2 g l (1 - \cos\theta)$$

The derivatives and the equation of motion related to the linear motion are

$$\frac{\partial L}{\partial \dot{x}} = (m_1 + m_2)\dot{x} + m_2 l \dot{\theta} \cos\theta$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) = (m_1 + m_2)\ddot{x} + m_2 l \ddot{\theta} \cos\theta - m_2 l \dot{\theta}^2 \sin\theta$$

$$\frac{\partial L}{\partial x} = -kx$$

$$F = (m_1 + m_2)\ddot{x} + m_2 l \ddot{\theta} \cos\theta - m_2 l \dot{\theta}^2 \sin\theta + kx$$

For the rotational motion, it is

$$\frac{\partial L}{\partial \dot{\theta}} = m_2 l^2 \dot{\theta} + m_2 l \dot{x} \cos\theta$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}}\right) = m_2 l^2 \ddot{\theta} + m_2 l \ddot{x} \cos\theta - m_2 l \dot{x} \dot{\theta} \sin\theta$$

$$\frac{\partial L}{\partial \theta} = -m_2 g l \sin\theta - m_2 l \dot{\theta} \dot{x} \sin\theta$$

$$T = m_2 l^2 \ddot{\theta} + m_2 l \ddot{x} \cos\theta + m_2 g l \sin\theta$$

If we write the two equations of motion in a matrix form

$$F = (m_1 + m_2)\ddot{x} + m_2 l \ddot{\theta} \cos\theta - m_2 l \dot{\theta}^2 \sin\theta + kx$$

$$T = m_2 l^2 \ddot{\theta} + m_2 l \ddot{x} \cos\theta + m_2 g l \sin\theta$$

$$\begin{bmatrix} F \\ T \end{bmatrix} = \begin{bmatrix} m_1 + m_2 & m_2 l \cos\theta \\ m_2 l \cos\theta & m_2 l^2 \end{bmatrix} \begin{bmatrix} \ddot{x} \\ \ddot{\theta} \end{bmatrix} + \begin{bmatrix} 0 & m_2 l \sin\theta \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{x}^2 \\ \dot{\theta}^2 \end{bmatrix} + \begin{bmatrix} kx \\ m_2 g l \sin\theta \end{bmatrix}$$

→ LE formulation of Dynamic Equations Algorithm

This algorithm carries out the complete dynamic formulation of an n-DOF manipulator that satisfy the condition for existence of closed form geometric solution. The various steps are

Step 1. Assign frame $\{0\}, \ldots \{n\}$ using DH notation, such that frame $\{i\}$ is oriented (aligned) with principal axis of link i

Step 2. Obtain the link transformation matrix ${}^{i-1}T_i$ for each link and from these compute product matrices ${}^0T_2$ ${}^0T_3$ and so on, which are required for computing the coefficients d_{ij} and it's derivatives using ${}^jT_k = \prod_{p=j+1}^{k} {}^{p-1}T_p$ for $j = 0, 1, 2, \ldots n-2$; $k = j+2, \ldots n$

Step 3. Define Q_i for each link using $Q_j = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ for revolute joint

(or) $Q_j = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ for prismatic joint

Step 4. For each link i determine the inertia tensor I_i with respect to the frame $\{i\}$

Step 5. Compute d_{ij} for $i, j = 1, 2, \ldots n$

$$d_{ij} = \begin{cases} {}^0T_{j-1} Q_j \, {}^{j-1}T_i & \text{for } j \le i \\ 0 & \text{for } j > i \end{cases}$$

Step 6: Compute the inertia coefficients M_{ij} for $i, j = 1, 2, \ldots n$

using $$M_{ij} = \sum_{p=\max(i,j)}^{n} Tr\left[d_{pj} \, I_p \, d_{pi}^T \right]$$

Step 7: Compute the velocity coupling coefficients h_{ijk} for

$i, j, k = 1, 2, \ldots n$ using

$$h_{ijk} = \sum_{p=\max(i,j,k)}^{n} Tr\left[\frac{\partial (d_{pk})}{\partial q_p} I_p \, d_{pi}^T \right] \quad \text{and}$$

$$\frac{\partial d_{ij}}{\partial q_k} = \begin{cases} {}^0T_{j-1} \, Q_j \, {}^{j-1}T_{k-1} \, Q_k \, {}^{k-1}T_i & \text{for } i \geq k \geq j \\ {}^0T_{k-1} \, Q_k \, {}^{k-1}T_{j-1} \, Q_j \, {}^{j-1}T_i & \text{for } i \geq j \geq k \\ 0 & \text{for } i < j \text{ or } i < k \end{cases}$$

Step 8: Compute the gravity loading terms G_i for each link $i = 1, 2, \ldots n$

using $$G_i = -\sum_{p=i}^{n} m_p \, g \, d_{pi} \, {}^p\bar{r}_p$$

Step 9: Substitute all the coefficients in

$$T_i = \sum_{j=1}^{n} M_{ij}(q) \, \ddot{q}_j + \sum_{j=1}^{n} \sum_{k=1}^{n} h_{ijk} \, \dot{q}_j \, \dot{q}_k + G_i \quad \text{for } i = 1, 2, \ldots n$$

to formulate the i^{th} equation for torque τ_i

Newton Euler famulation algorithm

This algorithm generates the joint torque eq:s for all the joint actuators of an n-DOF manipulator. The steps of algorithm are

Step 0. Define the variables

$n =$ no of degrees of freedom

$=$ no of links

$=$ no of joints.

joint variables: q_i, $\dot{q}_i$, $\ddot{q}_i$ for $i = 1, 2, \cdots n$

Link variables: F_i, f_i, N_i, n_i, T_i

Step 1: Set the initial conditions

$$ {}^0\omega_0 = {}^0\dot{\omega}_0 = {}^0v_0 = 0 $$

$$ {}^0\dot{v}_0 = g = \begin{bmatrix} g_x & g_y & g_z \end{bmatrix}^T $$

Step 2: Assign frames {0}, ---{n} using DH notation (Algorithm) such that frame {i} is oriented with principle axes of link i. Obtain rotational transformation matrices ${}^{i-1}R_i$ their products and inverses ${}^iR_{i-1}$, Centre of mass of links, inertia tensors I_i of links at centre of mass w.r.t frame {i}

Forward iteration

Step 3: Set $i = 1$

Step 4: Compute: ${}^i\omega_i$, ${}^i\dot{\omega}_i$, ${}^iv_i$ and ${}^i\dot{v}_i$ using equations in table 6.2

Step 5: If $i = n$, then goto step 6, otherwise set $i = i+1$ and goto step 4.

Backward iteration

Step 6: Set f_{n+1} = required end effector force and n_{n+1} = required end effector moment. Note that if end effector is free to move in space, it has no load and required force and moment are zero

Step 7: Compute F_i, N_i, f_i, n_i and T_i using equations in table 6.2

Step 8: if $i = 1$ then stop otherwise set $i = i-1$ and go to step 7.

UNIT - 5

Trajectory planning

Robot to move between two space points, different tasks must be solved. The best trajectory must be found, obstacles and collisions must be avoided, other limitations must be considered, high efficiency and work productivity must be achieved.

Path planning

is the planning of the whole way from point A to point B, including stopping in defined path points.

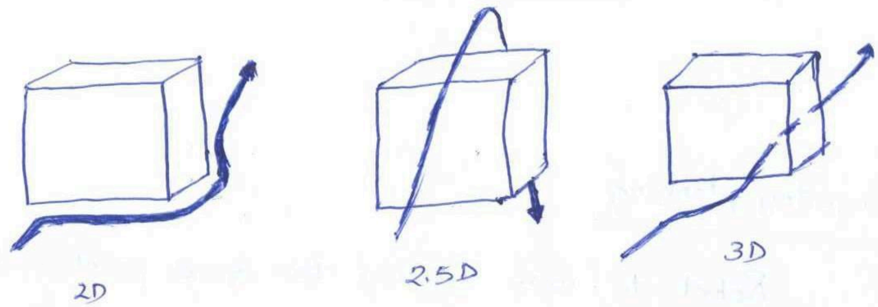
Finally the path includes several continuous motion trajectories that need the trajectory planning.

The main path planning tasks for a robot are as follows.

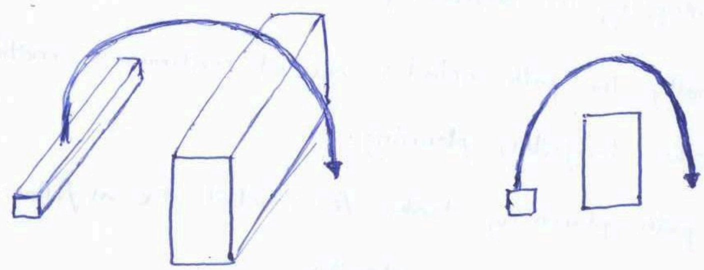
1) grasping and releasing objects
2) moving from place to place
3) Following previously specified paths
4) following moving objects.
5) working with other manipulators.
6) Exerting forces (ie pushing, pulling & holding)
7) exerting torques
8) Collecting data
9) using tools.

Obstacle and collision avoidance

Normally in the work space of a robot other machines, different constructions or devices exist. These can be considered as obstacles that have different dimensionality.

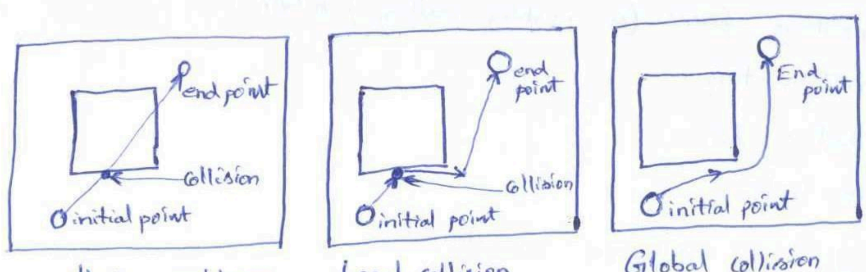


A well known problem of colision avoidance is moving high dimensional objects in rubbish environment. If the height of the obstacle is known, then the robot operates in 2.5 space. The problem of avoiding collision with obstacles can be solved in different ways



Collision detection and collision avoidance

It is the most important factor of path planning, without automatic collision avoidance, the robotic work cell must be engineered to be collision free.

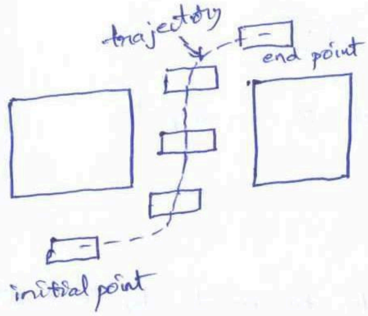


Local collision detection is important when moving through an unknown & uncertain environment. These allow for feedback to the planner for halting paths which contain collisions

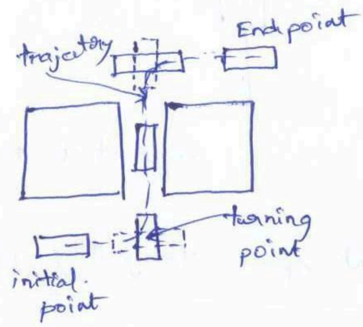
Rotation problem in obstacle avoidance

Rotations can also be a problem for some path planners. It can be difficult to rotate during motion, thus some will not rotate, some will rotate only at certain points and some will rotate along a complete path.

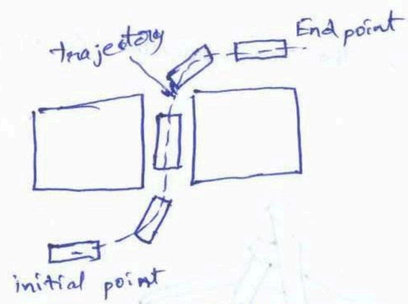
Motion occurs in the form of rotation and translation.



a) parallel motion



b) turning in definite points

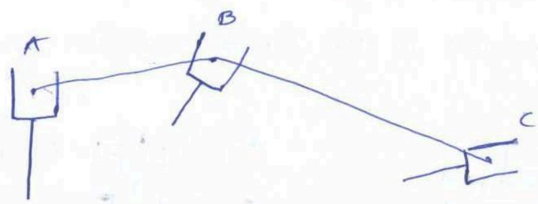


c) Continuous turning

coordination of two or more robots, which are having common working space and measures must be applied to avoid collisions between different manipulators.

→ Path :- A sequence of robot configurations in a particular order without regard to the timing of these configurations

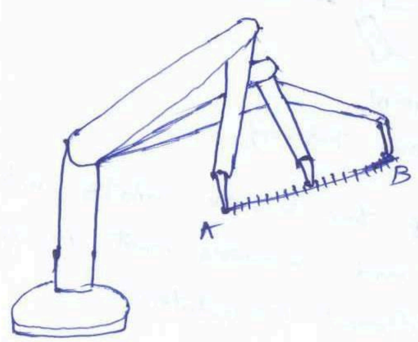
Trajectory :- It concerned about when each part of the path must be attained, thus specifying timing



Sequential robot movement in a path

→ Joint space trajectory planning

- The description of the motion to be made by the robot by it's joint values.
- The motion between the two points is unpredictable.



Sequential motions of a robot to follow a straight line

→ Cartesian space trajectory planning

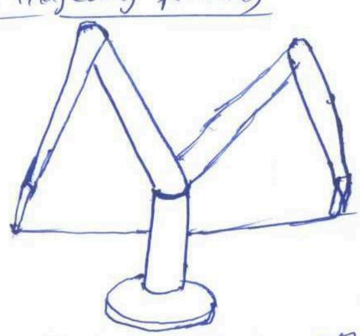


fig:- trajectory specified in cartesian coordinates may force the robot to run into it self

→ The motion between the two points is known at all times and controllable.

→ It is easy to visualize the trajectory, but is difficult to ensure that

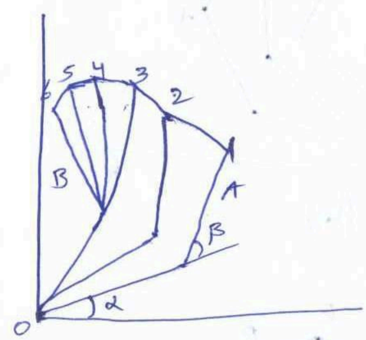
→ Basics of trajectory planning

→ Lets consider a simple 2° freedom robot.

→ we desire to move the robot from point A to point B

→ Lets assume that both joints of the robot can move at the maximum rate of 10 degree/sec

→ Lets also assume that both joints of the robot can move at the maximum rate of 10 degree/sec.

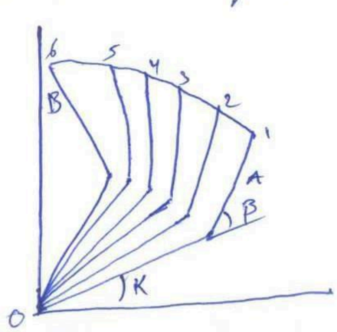


α	β
20	30
30	40
40	50
40	60
40	70
40°	80

→ Move the robot from A to B, to run both joints at their maximum angular velocities

→ After '2' sec the lower link will have finished it's motion, while the upper link continues for another '3' sec.

→ The path is irregular and the distance traveled by the robot's end are not uniform.

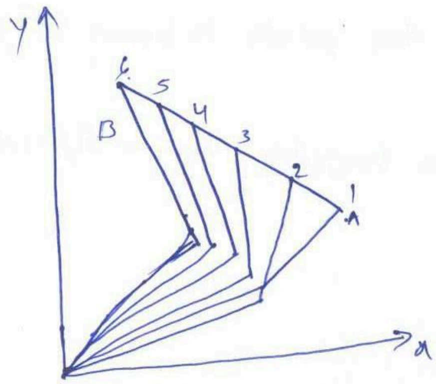


α	β
20	30
24	40
28	50
32	60
36	70
40	80

Note:-

1) Both joints move at different speeds but moves continuously together

2) The resulting trajectory will be different.



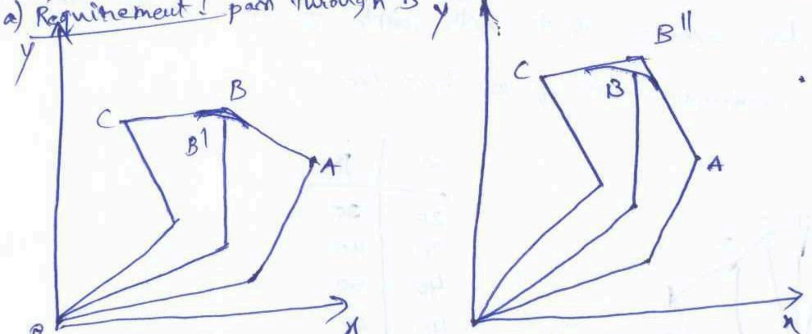
α	β
20	30
14	55
16	69
21	77
29	81
40	80

Note:- 1) Divide the line into five segments and solve for necessary angles α and β at each point

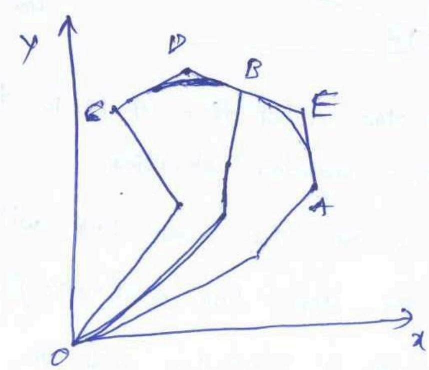
2) joint angles are not uniformly changing.

→ Blend between two portions

a) Requirement! pass through B' and smooth motion with blending



(a)



specify two via points D & E before and after point B.

→ Joint space trajectory planning

→ Third order polynomial trajectory planning

The initial location and orientation of the robot is known, and using the inverse kinematic eq's, we find the final joint angles for the desired position and orientation.

$$\theta(t) = c_0 + c_1 t + c_2 t^2 + c_3 t^3$$

$\theta_{t_i} = \theta_i \qquad \dot{\theta}(t_i) = 0$ (initial)

$\theta_{t_f} = \theta_f \qquad \dot{\theta}(t_f) = 0$ (final)

$$\dot{\theta}(t) = c_1 + 2c_2 t + 3c_3 t^2$$

substituting the initial and final conditions

$$\theta_{t_i} = c_0 = \theta_i$$

$$\theta_{t_f} = c_0 + c_1 t_f + c_2 t_f^2 + c_3 t_f^3$$

$$\dot{\theta}(t_i) = c_1 = 0$$

$$\dot{\theta}(t_f) = c_1 + 2c_2 t_f + 3c_3 t_f^2 = 0.$$

→ Fifth order polynomial trajectory planning

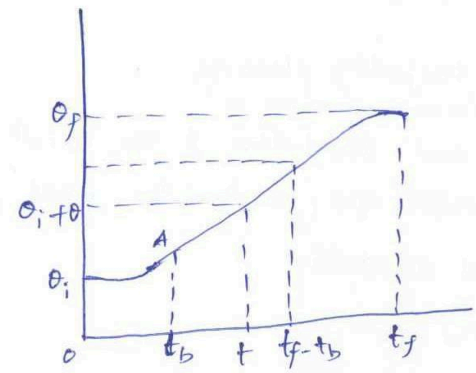
specifying the initial and final accelerations for a segment.

$$\theta(t) = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + c_4 t^4 + c_5 t^5$$

$$\dot{\theta}(t) = c_1 + 2c_2 t + 3c_3 t^2$$

$$\ddot{\theta}(t) = 2c_2 + 6c_3 t + 12c_4 t^2 + 20c_5 t^3$$

→ Linear segments with parabolic blend.



$\theta(t) = c_0 + c_1 t + \frac{1}{2} c_2 t^2$

$\dot{\theta}(t) = c_1 + c_2 t$

$\ddot{\theta}(t) = c_2$

$\theta(t=0) = \theta_i = c_0$

$\dot{\theta}(t=0) = 0 = c_1 \longrightarrow \begin{cases} c_0 = \theta_i \\ c_1 = 0 \\ c_2 = \ddot{\theta} \end{cases}$

$\ddot{\theta}(t) = c_2$

$\theta(t) = \theta_i + \frac{1}{2} c_2 t^2$

$\dot{\theta}(t) = c_2 t$

$\ddot{\theta}(t) = c_2$

$\theta_{(A)} = \theta_{(i)} + \frac{1}{2} c_2 t_b^2$

$\dot{\theta}_A = c_2 t_b = \omega$

$\theta_B = \theta_A + \omega\left((t_f - t_b) - t_b\right)$

$= \theta_A + \omega(t_f - 2t_b)$

$\dot{\theta}_B = \dot{\theta}_A = \omega$

$\theta_f = \theta_B + (\theta_A - \theta_i)$

$\theta_f' = 0$

$c_2 = \frac{\omega}{t_b}$

$\theta_f = \theta_i + c_2 t_b^2 + \omega(t_f - 2t_b)$

$\theta_f = \theta_i + \left(\frac{\omega}{t_b}\right) \cdot t_b^2 + \omega(t_f - 2t_b) \rightarrow t_b = \frac{\theta_i + \omega t_f - \theta_f}{\omega}$

$$\theta(t) = \theta_f - \frac{1}{2} c_2 (t_f - t)^2$$

where $c_2 = \frac{\omega}{t_b}$ then

$$\theta(t) = \theta_f - \frac{\omega}{2t_b} (t_f - t)^2$$

$$\dot{\theta}(t) = \frac{\omega}{t_b} (t_f - t)$$

$$\ddot{\theta}(t) = -\frac{\omega}{t_b}$$

→ Higher order polynomial

$$\theta(t) = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + \cdots + c_{n-1} t^{n-1} + c_n t^n$$

→ Manipulator path control

There are '3' common types of motion, These are slew motion, joint - interpolated motion and straight line motion.

Slew motion

It represent simplest type of motion, as the robot is commanded to travel from point A to point B, each axis of the manipulator travels as quickly as possible from its respective initial position to it's required final position. Therefore, all axes begin moving at the same time, but each axis ends its motion in an elapsed time that is proportional to the product of its distance moved and its top speed

ex Determine the time required for each joint of a 3-axis RRR-manipulator to travel the following distances using slew motion: joint 1, 30°; joint 2, 60°; and joint 3, 90°. All joints travel at a rotational velocity of 30°/s, neglecting effects of acceleration and deceleration

→ joint 1 will complete its move in 30°/30°/se = 1 se, ~~joint 2~~
joint 2 " " 60°/30°/se = 2 se
joint 3 " " 90°/30/se = 3 se.

→ Joint - interpolated motion

This required the robot controller to calculat the amount of time it will take each joint to reach its destination at commanded speed.

ex Determine the time required to complete the move and the velocity of each joint for the 3-axis RRR manipulator to travel the following distances under joint interpolated motion. joint 1 30°, joint 2 60° and joint 3 90°. The maximum velocity of any joint is 30°/s; however, no joint may travel at greater than 90 % of maximum velocity. Neglect any effect of acceleration and deceleration.

Sol joint 3 has maximum distance to travel and will therefore result in the maximum time to complete its move. The time for joint 3 to travel the 90° is

$$90^\circ / (0.9 \times 30^\circ/s) = 3.33\,s$$

the velocity for joint 2 is

$$60^\circ / 3.33\,s = 18.0^\circ/s$$

and for joint 1 the velocity is

$$30^\circ / 3.33\,s = 9.0^\circ/s.$$

→ Straight line interpolation motion

This requires the end of the manipulator to travel along a straight path defined in cartesian coordinates. This is the most demanding type of motion for the controller to execute, except for a cartesian coordinate LLL robot. For rotational joints straight line motions are unnatural and the controller must compute the sequence of incremental joint rotations required for the end-of-arm to move in a linear fashion.

St. line interpolation is very useful in applications such as arc welding, laying adhesives along a st path, inserting a peg into a hole

Robot programming

is accomplished in several ways.

1. Lead through methods
2. Textual robot programming

Lead through methods require the programmer to move the manipulator through the desired motion path and that the path be committed to memory by the robot controller. The lead through methods are sometimes referred to as "teach-by-showing" methods.

Robot programming with textual languages is accomplished some what like computer programming

Lead through programming methods

The robot is moved through the desired motion path in order to record the path into the controller memory. There are '2' ways of accomplishing lead through programming.

1. Powered lead through
2. Manual lead through.

The powered lead through method makes use of a teach pendant to control the various joint motors and to power drive the robot arm and wrist through a series of points in space. Each point is recorded into memory for subsequent playback during the work cycle.

The teach pendant is usually a small hand held control box with combinations of toggle switches, dials and buttons to regulate the robot's physical movements and programming capabilities. These include part transfer tasks, machine loading and unloading and spot welding.

The manual lead through method (also sometimes called the "walk - through" method) is more readily used for continuous - path programming, where the motion cycle involves smooth complex curvilinear movements of the robot arm.

In the manual lead-turough method, the programmer physically grasps the robot arm and manually moves it turough the desired motion cycle.

→ The textual Robot Languages

The first textual robot language was WAVE, developed in 1973 as an experimental language for research at the stanford Artificial Intelligence Laboratory.

Machine vision system was accomplished using the WAVE language. The research demonstrated the feasibility of robot hand-eye coordination.

VAL — Victor's Assembly Language — Unimation, Inc.,

AUTOPASS — } IBM ~~Corpor~~ Corporation

AML — A Manufacturing Language }

MCL — Manufacturing Control language

APT — Automatically programmed tooling

→ Generations of Robot Programming Languages

First Generation Languages :- Use a combination of command statements and teach pendant procedures for developing robot programs. These languages are sometimes referred to as motion level languages. ~~This~~ These languages features the ability to define manipulator motions, straight line interpolation, branching and elementary sensor commands involving binary signals.

Second Generation Languages

This overcomes many of the limitations of the first generation languages. These are called structured programming languages. Commonly available 2nd generation languages include AML, RAIL, MCL and VAL-II. Programming in these is very much like computer programming.

1) Motion Control. same as the first generation languages.

2) Advanced sensor capabilities :- Includes the capacity to deal with more than simple binary signals and capability to control devices by means of the sensory data.

3. Limited intelligence :- This is the ability to utilize information received about the work environment to modify system behaviour in a programmed manner.

4. Communications and data processing :- these have provisions for interacting with computers and computer data bases for the purpose of keeping records, generating reports and controlling activities in the work cell.

UNIT-6

Robot Actuation and feedback components

Actuators are the devices which provide the actual motive force for the robot joints.

Actuators are the muscles of robots. If you imagine that the links and the joints are the skeleton of the robot, the actuators act as muscles, which moves or rotate the links to change the configuration of robots

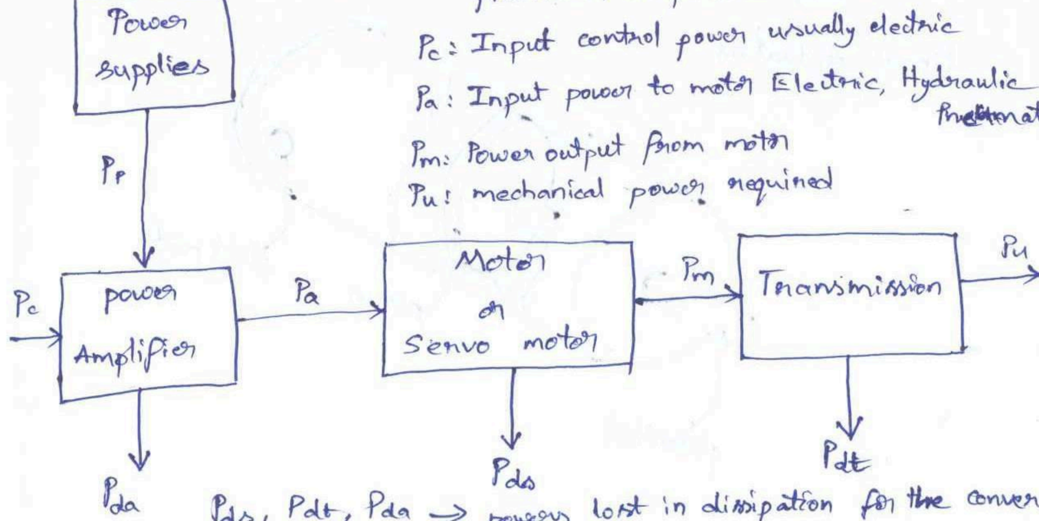
The actuators must have enough power to accelerate and decelerate the links and to carry the loads, yet be light, economical, accurate, responsive, reliable and easy to maintain.

Actuators in robotic system basically consists of

1) A power supply
2) A power amplifier
3) A servomotor
4) A transmission system.

Actuator system :-

P_p: primary source of power (Electric, Fluid pressure, Compressed air)
P_c: Input control power usually electric
P_a: Input power to motor Electric, Hydraulic or Pneumatic
P_m: Power output from motor
P_u: mechanical power required



P_{ds}, P_{dt}, P_{da} → powers lost in dissipation for the conversion performed by the Amplifier, Motor, transmission.

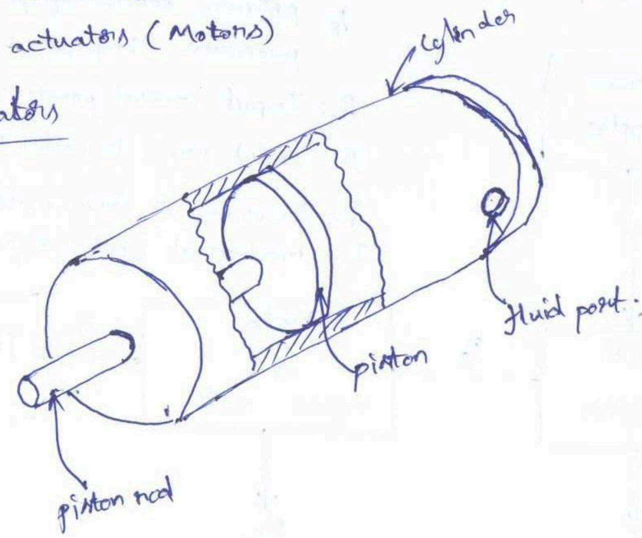
→ Issues of an Actuator

1) Load (eg: torque to overcome own inertia)
2) Speed (fast enough but not too fast)
3) Accuracy (will it move to where you want?)
4) Resolution (can you specify exactly where?)
5) Repeatability (will it do this every time?)
6) Reliability (mean time between failures)
7) power consumption (how to feed it)
8) Energy supply & its weight.

→ Pneumatic and Hydraulic Actuators

1) Both these actuators are powered by moving fluids.
2) In the first case, the fluid is compressed air and
3) In the second case, the fluid is pressurized oil.
4) Pneumatic systems typically operate at about 100 lb/in^2
5) Hydraulic systems at 1000 to 3000 lb/in^2
6) Both hydraulic and pneumatic actuators are classified as
   a) linear actuators [cylinders]
   b) Rotary actuators (Motors)

linear Actuators



→ The simplest power device could be used to actuate a linear joint by means of a moving piston.

→ There are two relationships of particular interest when discussing actuators.

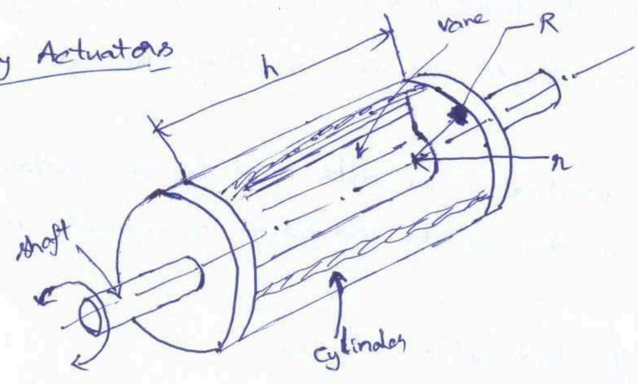
1) The velocity of the actuator w.r.t input power and
2) Force of the actuator w.r.t the input power.

$$V(t) = \frac{f(t)}{A}$$

$$F(t) = P(t) \cdot A$$

where $V(t)$ is the velocity of the piston
$f(t)$ is the fluid flow rate
$F(t)$ is the force
$P(t)$ is the pressure of the fluid and
A is the area of the piston.

Rotary Actuators



→ There is a relationship of particular interest when discussing Rotary actuator

→ The angular velocity, ω, and Torque T.

$$\omega(t) = \frac{2f(t)}{(R^2 - r^2)\,h}$$

$$T(t) = \frac{1}{2}\,P(t)\,h\,(R-r)(R+r)$$

R, outer radius of the vane
r, inner radius of
h – thickness of the vane, ω. angular velocity, T torque

→ Advantages of Pneumatic actuators

advantages

1) It is cheapest form of all actuators.

2) Compressed air can be stored and conveyed easily over long distances.

3) They have few moving parts making them inherently reliable and reducing maintenance costs

4) They have quick action and response time thus allowing for fast work cycles.

5) No mechanical transmission is usually required.

Limitations

1) Since air is compressible, precise control of speed and position is not easily obtainable unless much more complex electro mechanical devices are incorporated into system.

2) If mechanical stops are used resetting the system can be slow.

3) If moisture penetrates the units and ferrous metals have been used then damage to individual components may happen.

→ Advantages of hydraulic actuators

1) High efficiency and high power to size ratio

2) Complete and accurate control over speed position and direction of actuators are possible

3) No mechanical linkage is required ie a direct drive is obtained with mechanical simplicity.

4) They generally have greater load carrying capacity than others

5) Self lubricating non corrosive

6) Capable of with standing shock loads

Limitations of hydraulic actuators

1) Leakages can occur causing a loss in performance and general contamination of the work area
2) There is also a higher fire risk
3) The changes in temp alter the viscosity of hydraulic fluid.

→ Electric and stepper Motors

The most common types are servo & stepper motors.

→ Electric motors usually have a small rating, ranging upto a few horse power.

→ They used in all appliances

→ The principle components are magnetic poles, Armature, commutator and brushes.

→ DC Motors
→ AC Motors
→ Servo motor

Since the field strength of the motor is a function of the current through it, it can be shown that, for a DC servo motor

$$T_m = k_m \cdot I_a$$

where T_m is the the torque of the motor
I_a is the current flowing through the armature
k_m is the motor torque constant

$$e_b = k_b \omega$$

where e_b is the back emf,
k_b is the voltage constant of motor
ω is the angular velocity

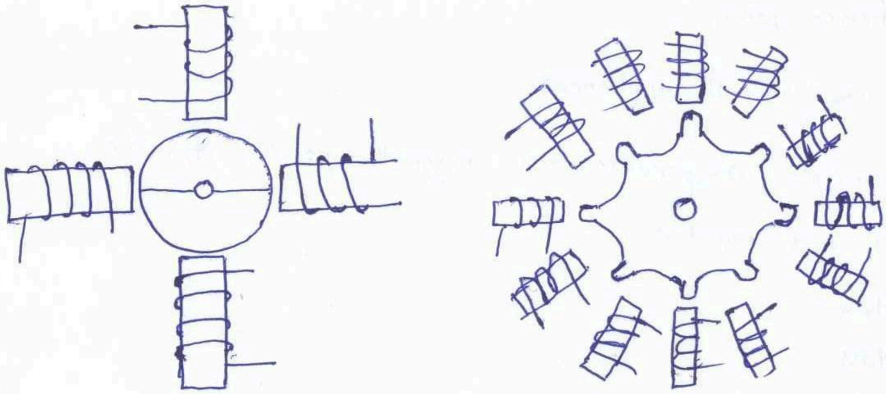
$$I_a = \frac{V_{in} - e_b}{R_a}$$

Stepper Motor

1) When incremental rotary motion is required in a robot it is possible to use stepper motors.

2) A stepper motor possesses the ability to move a specified no of revolutions

3) This is achieved by increasing the no of poles on both rotor and stator



The resolution of a stepper is determined by the no of poles in the stator and rotor

$$n = \frac{A}{360^\circ}$$

where 'n' is the resolution and A is the step angle.

Advantages of Eletric Actuators

1) Wide spread availability of power supply.
2) The basic drive element in an eletric motor is usually lighter than that for fluid power.
3) Higher power conversion efficiency
4) No pollution of work environment.
5) The accuracy and repeatability of these are better than fluid power in relation to cost
6) Easily maintained and repaired.
7) The drive system is well suited to electronic control.

Limitations

1) Electric actuators often require some mechanical transmission system this increases the unwanted movement.
2) Due to increased complexity of the transmission system additional cost is incurred for their procurement and maintenance.
3) Electric motors are not intrinsically safe. They ~~cannot~~ cannot be used in explosive atmospheres.

→ Robot feed back Components

1) position sensors
2) Velocity sensors

position sensors :-

1) potentio meter : , these are the analog devices whose output voltage is proportional to the position of the wiper.

The function of the potentiometer is as follows

$$V_0 = k_p \cdot \theta$$

and the output voltage is given by

$$V_0 = V_{ex} \frac{\theta_{act}}{\theta_{tot}}$$

and $$K_p = \frac{V_{ex}}{\theta_{tot}}$$

where V_0 = output voltage

k_p = Voltage constant

θ = position of the point in radians

V_{ex} = Excitation voltage

θ_{act} = Actual position of the wiper

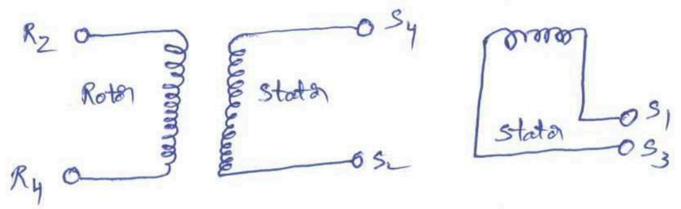
θ_{tot} = Total travel available of wiper.

Resolvers

1) It is also analog device

in resolver output is proportional to the rotating element with respect to the fixed element

2) Resolver has single winding on its rotor and a pair of windings on it's stator fixed at 90° apart as shown below



If the rotor excited with a signal of the time A ~~Sing~~ Sin ω_t, the voltage accross the two pairs of stator terminals will be

$$V_{S_1} = A \sin\omega_t \times \sin\theta$$

$$V_{S_2} = A \sin\omega_t \times \cos\theta$$

This signal may be used directly, it may be converted into a digital representation using a device known as resolver to digital converter. If AC signals must be used for excitation voltage and if DC signal used there is no output signal.

where θ = Angle of the rotor w.r.t stator

$A \sin\omega t$ = Excitation voltage to a resolver.

Encoders :-

In robotics frequently used optical encoders to findout the linear or angular displacement converted into digital or pulse signals. There are three basic components are used in encoders.

1) light source
2) Multiple channel light receiver
3) multiple track rotary disc

There are mainly '2' types of encoders. ~~receive and are~~

1) Incremental encoder
2) Absolute encoder.

Incremental encoder :-

It consists of a glass disc marked with alternating transparent and opaque strips aligned radially.

A photo transmitter is located onside of the disc and a photo receiver is another side. As the disc rotates the light beam is alternatively completed. The output from the photo receiver is pulses who's frequency is proportional to the speed of rotation of the disc. Hear the resolution is given by $-\frac{360^\circ}{2^n}$.

n – no of strips

Absolute encoder :

It consists of multiple track light source, a multiple channel light receiver and a multiple track rotary disc. The main use of absolute encoder to find out the measurement of angular displacement. The resolution of an absolute encoder is dependent on the no of tracks and is given by 2^n (Parts per resolution)

n = no of tracks or strips.

Now the angular width of each control increment is given by $= \frac{360^\circ}{2^n}$

output $= k_e \cdot \theta$

k_e - no of pulse per radians

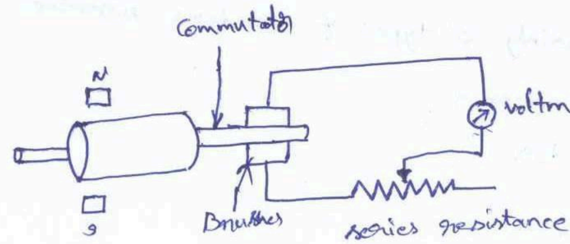
θ - shaft angle.

Tachometers

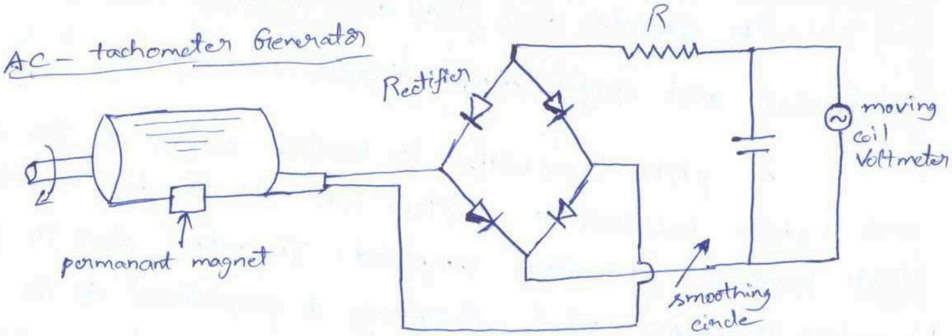
1) DC - tachometer generator

2) AC - tachometer generator

1) DC - tachometer generator



2) AC - tachometer Generator



In Ac - tachometer there is no commutator, because in Ac tachometer, the coil is wound on the stator and the magnet is allowed to rotate. The rotating magnet can be either an electro-magnet (or) permanant magnet

The output voltage is proportional to the speed of the shaft or speed of the magnet.

Applications

1) Material transfer

This is defined in which the primary object move apart from one location to another like (1) Pick and place

2) Palletizing and depalletizing

(1) In pick and place operation, the robot pickup parts at one location and moves it to another location. The part is available to the robot by machine feeding unit or belt conveyor in a known location and orientation. A simple limit switch used to stop the component to allow the part to grab by robot pickup.

(2) The storage of pallets is done by robot. Large no of containers are placed on a pallets instead of handling individual cartoons. The pallets are moved mechanically with in the manufacturing plant by fork lift, truck & conveyors.

General considerations in selecting a robot for material handling

1) Part positioning and orientation :- In application of part handling, the parts should be introduced to the robot in a specified position and orientation.

2) Gripper design :- For the pick and place operations of robot distinguished end effectors should be designed.

3. Mini distance travel :- The distance travel by the parts in the material handling operations should be minimum.

4. Robot work volume :- The amount of work carried out by the robot, should not exceed.

5. Robot weight capacity :- Robots should be specified with sufficient load carrying capacity to make sure that capacity limit does not exceed

6. Accuracy :- High accuracy is required in the pick and place operations of materials. Therefore robots must be specified with high accuracy.

7. Robot configuration, DOF & control etc : Many parts transfer applications are simple, that they can be accomplished by a robot with two, three or four.

8. Machine Utilization : It is important for the applications to effectively utilize all pieces of equipment in the cell. In a machine loading / unloading operations

• Machine loading and Unloading :- The robot is used to service a production machine by transferring parts to and from the machine

There are '3' things that fit into this application category.

1) Machine load / unload : The robot loads a raw work part into the process and unloads a finished part.

2) Machine loading :- The robot load the raw work part or material in to the machine but the part is ejected from the machine by some other means.

3. Machine unloading:- The machine produces finished parts from materials that are loaded direct into the m/c. The robot unloads the part from the machine.

Robots have been successfully applied to accomplish the loading/unloading functions in the following production operation

1) Die casting
2) plastic molding
3) Forging
4) Machining operation
5) stamping process

→ Spot Welding

Capabilities and features of robot in spot welding

1) The robot must be relatively large
2) It must be sufficiently pay load capacity
3) The work volume must be adequate for the size of the product.
4) It should have sufficient no of DOF

Benefits

1) Improved product quality.
2) operator safety.
3) Better control over the production

→ Arc Welding

Capabilities and features of robot in arc welding

1) Work volume must be large enough for the sizes of the parts to be welded
2) More DOF are required.
3) Motion control system.
4) Precision of motion
5) Input/output and control capabilities to work

Benefits

1) High productivity.
2) Improved safety and quality of work life.
3) Greater quality of product.

→ Spray painting

Advantages of robots spray paintings.

1) Consistency in operation.
2) savings in energy consumed
3) optimum use of paint material
4) Higher product quality
5) Higher productivity.

Requirements

1) Continuous path control
2) Hydraulic drive.
3) Manual lead through programming
4) Multiple program storage capability.

→ Assembly operation

1) part presentation methods
2) Assembly tasks
3) Assembly cell designs

(1) Part presentation methods:- In order for a robot to perform an assembly task, the part that is to be assembled must be presented to the robot.

a) Parts located with in specific area:- In this case the parts not positioned & oriented. The robot is required to use some form of sensors input to it to the part location and to pick up the part.

b) Parts located at a known position :-

In this case the parts not oriented. The robot would known where to go to get the part, but would have to solve the orientation problem.

c) Parts located in a known position and orientation

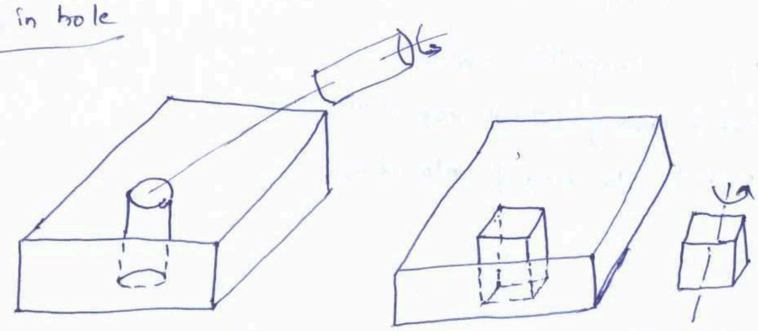
It is the most common method currently used and is infact the method used in automatic assemblies.

→ 2) Assembly task :-

Assembling operations can be devided into two basic catagories.

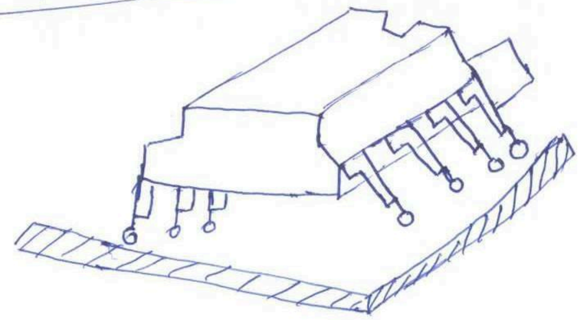
a) Parts mating :- In parts mating, two or more parts are brought into contact with each other. The parts mating operations are

i) Peg in hole



round peg in hole square peg in hole

ii) Multiple peg in hole



iii) Parts joining :- In parts joining two or more parts are mated and then additional steps are taken to ensure that the parts will maintain their relationship with each other

The joining operations are

1) Fastening screws
2) Press fits
3) snap fits
4) welding and related joining methods
5) crimping

→ Assembly cell designs

i) Single workstation assembly
ii) Series of workstation assembly
iii) parallel assembly systems

→ Inspection Applications

1) Vision inspection system
2) Robot manipulated inspection.
3) Robot loading & unloading