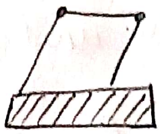
Kinematics

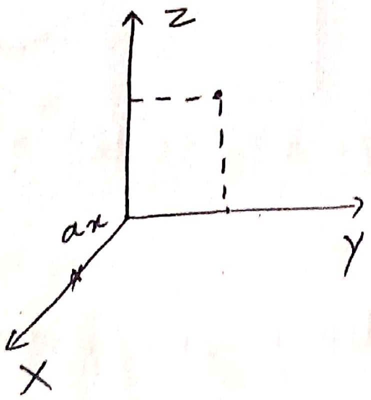
Kinematic chain

- It is a series of links connected by joints
- When each and every link in a kinematic chain is coupled to atmost 2 other links then the chain is referred to as simple kinematic chain.
- Simple kinematic chain can be closed or open.



Closed - 4 bar mechanism

How you represent a point in a space.



$$\vec{P} = a_x \hat{i} + a_y \hat{j} + a_z \hat{k}$$

Representation of a vector in space.

$\vec{P} =$

represent

$\vec{P} = 3\hat{i} + 5\hat{j} + 2\hat{k}$

represent vector in matrix form

$$P = \begin{bmatrix} 3 \\ 5 \\ 2 \end{bmatrix}$$

represent the vector in matrix form with scaling factor of 2

$$P = \begin{bmatrix} 6 \\ 10 \\ 4 \\ 2 \end{bmatrix} \rightarrow \text{scaling factor}$$

calculate the unit vector. Represent the vector in unit matrix form.

$$\hat{P} = \frac{P}{|P|} = \begin{bmatrix} 3/\sqrt{38} \\ 5/\sqrt{38} \\ 2/\sqrt{38} \end{bmatrix}$$

$=$

$\sqrt{36+100+16}$

$= \sqrt{152}$.

$\sqrt{3^2+5^2+2^2}$

$= \sqrt{9+25+4}$

$\sqrt{38}$.

• A vector v is 5 units long and is in the direction of a unit vector q ~~w~~ $= \begin{bmatrix} 0.371 \\ 0.557 \\ q_z \\ 0 \end{bmatrix}$. Express the vector in matrix form.

$$\sqrt{x^2+y^2+z^2} = 1$$

$$\sqrt{(0.371)^2 + (0.557)^2 + q_z^2} = 1$$

$(0.371)^2 + (0.559)^2 + q_z^2 = 1$

$q_z^2 = 1 - (0.371)^2 - (0.559)^2$

$= 0.55211$

$q_z = \underline{\underline{0.743}}$

8). Write the unit vector in matrix form that describes direction of cross product of $p = 5\hat{i} + 3\hat{k}$ & $q = 3\hat{i} + 4\hat{j} + 5\hat{k}$

. A vector p is 8 units long and is ⊥ to vector q and r that are described below.

Express the vector in matrix form

$$\vec{q} = \begin{bmatrix} 0.39\,q_y \\ 0.4 \\ 0 \end{bmatrix} \qquad \vec{r} = \begin{bmatrix} r_x \\ 0.5 \\ 0.4 \\ 0 \end{bmatrix}$$

$$p \times q = \begin{vmatrix} i & j & k \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

$$= \begin{vmatrix} i & j & k \\ 5 & 0 & 3 \\ 3 & 4 & 5 \end{vmatrix} = i(-12) - j(25-9) + k\,20$$

$$= -12i - 16j + 20k.$$

$$p \times q = \frac{-12i - 16j + 20k}{\sqrt{(-12)^2 + (-16)^2 + 20^2}} = \frac{-3i}{5\sqrt{2}} - \frac{4j}{5\sqrt{2}} + \frac{5k}{4\sqrt{2}}.$$

$$\vec{r} = \begin{bmatrix} -3/5\sqrt{2} \\ -4/5\sqrt{2} \\ 5/5\sqrt{2} \\ 1 \end{bmatrix}$$

$$\vec{q} = \begin{bmatrix} 0.3 \\ q_y \\ 0.4 \\ 0 \end{bmatrix} \qquad \vec{r} = \begin{bmatrix} r_x \\ 0.5 \\ 0.4 \\ 0 \end{bmatrix}$$

$$\vec{q} \times \vec{r} = \begin{vmatrix} i & j & k \\ 0.3 & q_y & 0.4 \\ r_x & 0.5 & 0.4 \end{vmatrix} = i(0.4q_y - 0.2) - j(0.12 - 0.4r_x) + k(0.15 - r_x q_y)$$

$$= \begin{bmatrix} 0.4q_y - 0.2 \\ 0.4r_x - 0.12 \\ 0.15 - r_x q_y \end{bmatrix}$$

$$= (0.4q_y - 0.2)^2 + (0.4r_x - 0.12)^2 + (0.15 - r_x q_y)^2$$

Representation of a frame at the origin of a fixed reference frame

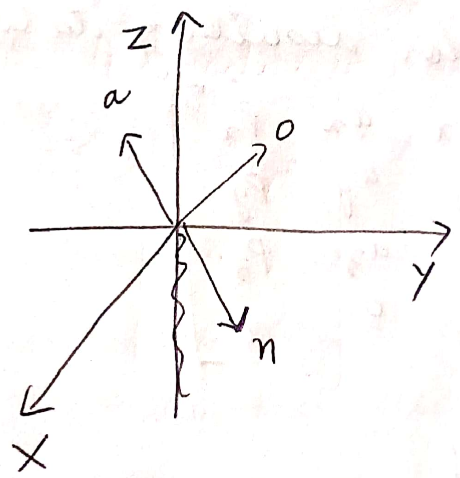
A frame is generally represented by 3 mutually orthogonal axis x, y, z. These axes x, y & z is used to represent the fixed universal reference frame $F(x, y, z)$. Suppose there is a set of axes n, o and a which represents another frame (moving) $F(n, o, a)$ relative to the reference frame.

~~Each~~ Suppose each direction of each axis of the frame $F(n,o,a)$ is located at the origin of the reference frame $F(x,y,z)$ is represented by 3 directional values

$$F(n,o,a) = \begin{bmatrix} n_x & o_x & a_x \\ n_y & o_y & a_y \\ n_z & o_z & a_z \end{bmatrix}$$

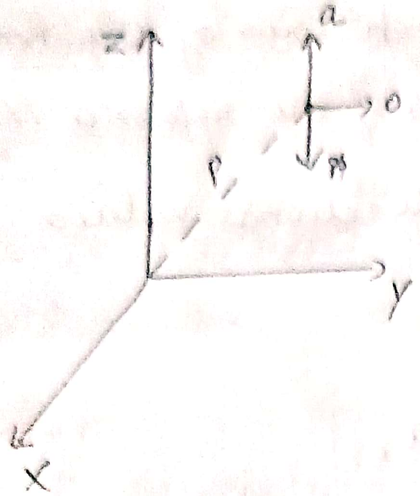
n is a unit vector

a is the unit vector for



Representation of a frame relative to fixed reference frame

In order to describe a frame relative to another frame both the location of its origin & the direction of its axis must be specified. If the frame is not at the origin of the reference frame, its location relative to the reference frame is described by the vector b/w the origin of the frame & the origin of the reference frame.



The vector is expressed by its components relative to the reference frame. Thus this frame can be expressed by 3 vectors describing its directional unit vector & the fourth vector describing its location

as $$F_{(n,o,a)} = \begin{bmatrix} n_x & a_x & a_x & P_x \\ n_y & a_y & a_y & P_y \\ n_z & a_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Representation of a rigid body

Translation

only position of the frame changes.

If a frame moves in space without any change in its orientation then the transformation is pure translation. The directional unit vector remain in the same direction and do not change. The only thing 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 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.

The matrix representation of the frame

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

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

The new frame representation can be found by pre multiplying ~~Final position~~ the frame with the matrix ~~with the~~ representing the transformation

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

Q) A frame F has been moved to 10 units along Y axis & 5 units along Z-axis of the reference frame. Find the new location of the frame.

$$F = \begin{bmatrix} 0.527 & -0.574 & 0.628 & 5 \\ 0.369 & 0.819 & 0.436 & 3 \\ -0.766 & 0 & 0.643 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$dx = 0$

$dy = 10$

$dz = 5$ $\quad F_{new} = Trans(dx, dy, dz) \times F_{old}$.

$$F_{new} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 10 \\ 0 & 0 & 1 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0.527 & -0.574 & 0.628 & 5 \\ 0.369 & 0.819 & 0.436 & 3 \\ -0.766 & 0 & 0.643 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

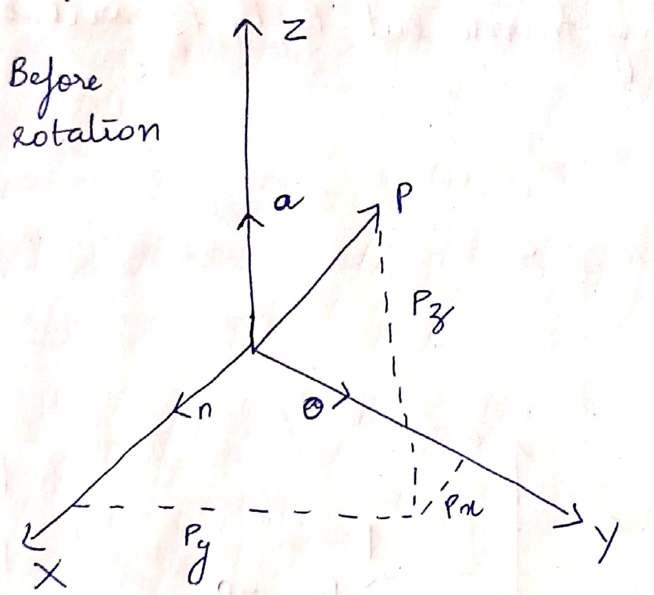
$$= \begin{bmatrix} 0.527 & -0.574 & 0.628 & 5 \\ 0.369 & 0.819 & 0.436 & 13 \\ -0.766 & 0 & 0.643 & 13 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

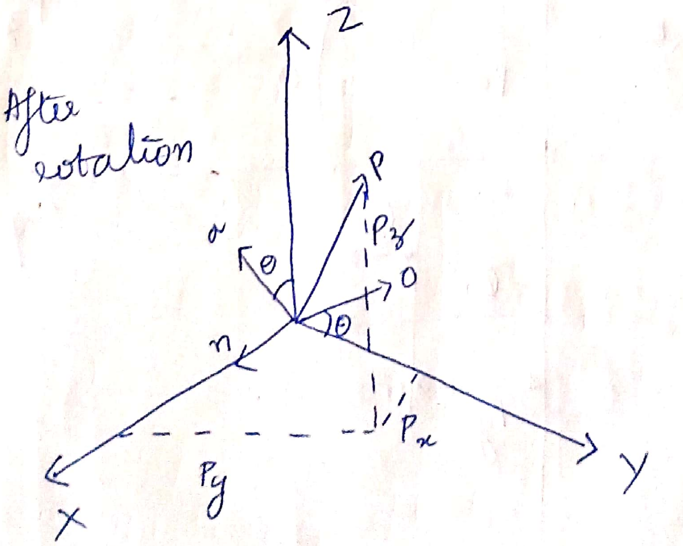
Q) The translation matrix $\{2 \quad 3 \quad 4 \quad 1\}$ find the new location of the frame $F = \begin{bmatrix} 0.707 & 0.284 & 0 & 2 \\ 0.341 & 0.523 & 1 & 4 \\ 0.586 & -0.707 & 0 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$$T_{new} = \begin{bmatrix} 1 & 0 & 0 & 2 \\ 0 & 1 & 0 & 3 \\ 0 & 0 & 1 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0.707 & 0.284 & 0 & 2 \\ 0.341 & 0.583 & 1 & 4 \\ 0.586 & 0.707 & 0 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.707 & 0.284 & 0 & 4 \\ 0.341 & 0.583 & 1 & 7 \\ 0.586 & 0.707 & 0 & 9 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

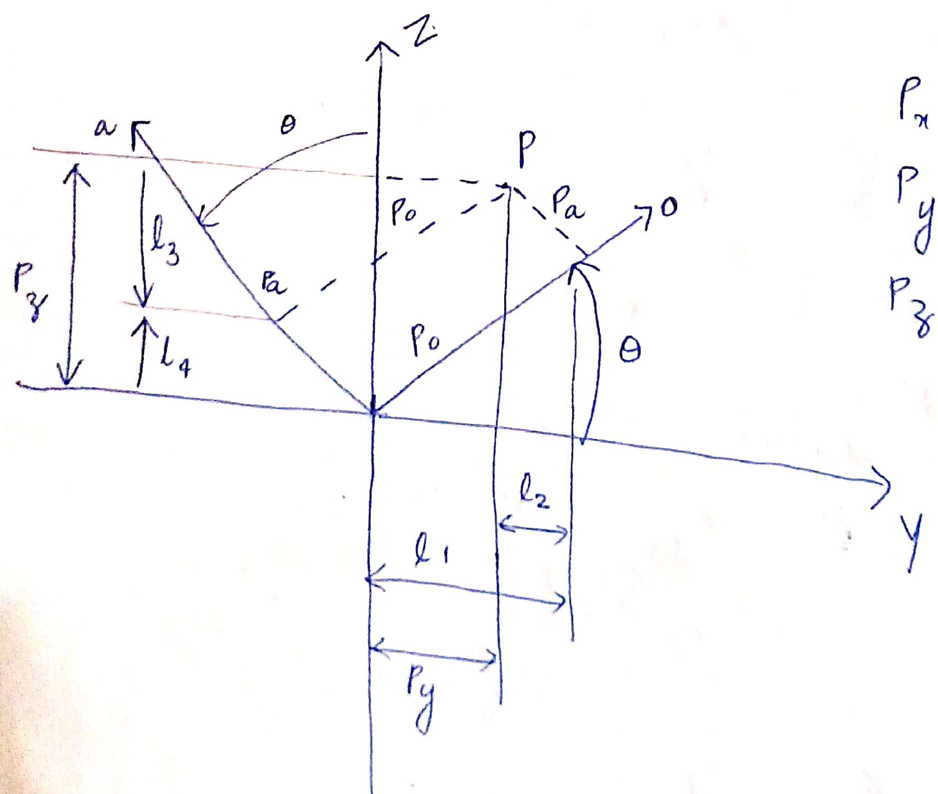
Representation of a pure rotation about an axis





Assume that the frame $F_{n,o,a}$ is located at the origin of the reference frame $F_{x,y,z}$ & rotates at an angle θ about x axis of the reference frame. Assume that there is a point p is attached to the rotating frame $F_{n,o,a}$ with coordinates P_x, P_y, P_z relating to the reference frame & P_n, P_o, P_a relative to the moving frame.

As the frame rotates about the x-axis the point p attached to the frame will also rotate with it. Before rotation the coordinates of the point in both frames are same. After rotation P_n, P_o, P_a coordinates of the points remain the same in the rotating frame but P_x, P_y, P_z will be different in F_{xyz} frame.



$P_x = P_n$

$P_y = l_1 - l_2$

$P_z = l_3 + l_4$

The values of P_x donot change as the frame rotates about X axis but the values of P_y & P_z do change

$P_x = P_n$

$P_y = l_1 - l_2$

$P_z = l_3 + l_4$

$\cos\theta = \frac{l_1}{P_o}$

$l_1 = \cos\theta P_o$

$\cos\theta = \frac{P_y + l_2}{P_o}$

$P_y = P_o \cos\theta - P_a \sin\theta$

$P_z = l_3 + l_4$

$= P_o \sin\theta + P_a \cos\theta$

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

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

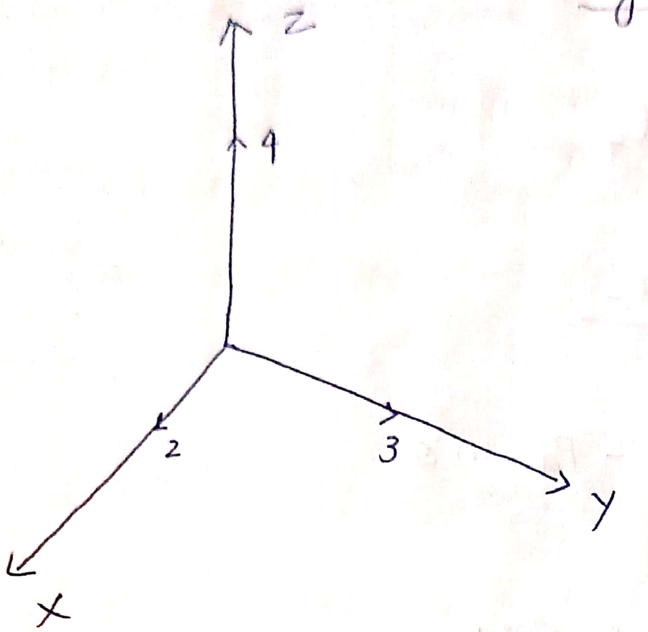
Q) A point $P(2, 3, 4)$ is attached to a rotating frame, the frame rotates 90° about the X-axis of the reference frame. Find the coordinates of the ~~frame~~ point relative to the ref frame after rotation & verify the result graphically.

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

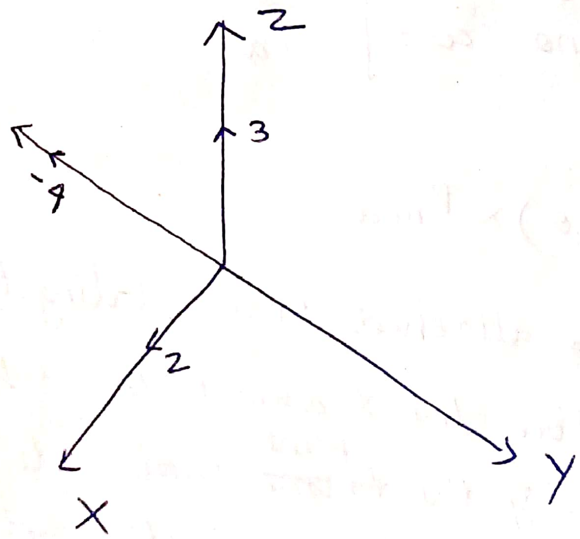
$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} 2 \\ 3 \\ 4 \end{bmatrix} = \begin{bmatrix} 2 \\ 3\cos\theta - 4\sin\theta \\ 3\sin\theta + 4\cos\theta \end{bmatrix}$$

$$= \begin{bmatrix} 2 \\ -4 \\ 3 \end{bmatrix}$$

before rotation.



After rotation.



Rotational matrix of rotation about Y-axis:

$$P_{xyz} = Rot(y, \theta) \cdot P_{noa}$$

$$Rot(y,\theta) = \begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$$

About z axis:

$$(z,\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

8) Find the coordinates of Point $P(3,5,7)$ relative to the ref frame after a rotation of 30° about z axis.

$$P_{xyz} = \begin{bmatrix} \cos 30 & -\sin 30 & 0 \\ \sin 30 & \cos 30 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 3 \\ 5 \\ 7 \end{bmatrix}$$

$$= \begin{bmatrix} 3\cos 30 - 5\sin 30 \\ 3\sin 30 + 5\cos 30 \\ 7 \end{bmatrix} = \begin{bmatrix} 3 \times \frac{\sqrt{3}}{2} - 5 \times \frac{1}{2} \\ \frac{3}{2} + 5 \cdot \frac{\sqrt{3}}{2} \\ 7 \end{bmatrix} \quad \frac{\sqrt{3}}{2} \quad \frac{1}{2}$$

$$= \begin{bmatrix} 0.098 \\ 5.83 \\ 7 \end{bmatrix}$$

9) A point $P(7,3,1)$ is attached to a frame F_{noa} and subjected to the following transformation. Find the coordinates of the point relative to the ref. frame

i) Rotation of 90° about X-axis

ii) followed by rotation of 90° about Y axis

iii) followed by translation of $(4,-3,7)$

$$P_{(x,y,z)} = Trans(4,-3,7) \times Rot(y,90) \times Rot(z,90) \times P_{(7,3,1)}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos 90 & 0 & \sin 90 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin 90 & 0 & \cos 90 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos 90 & -\sin 90 & 0 & 0 \\ \sin 90 & \cos 90 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 7 \\ 3 \\ 1 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} 5 \\ 4 \\ 10 \\ 1 \end{bmatrix}$$

Ref frame - reverse order
n, o, a → occuring order

Q) A frame B was rotated about the X axis by 90°. It was then translated about the current axis 3 inches in a axis before being rotated about the z axis by 90°. Finally it was translated about the current o axis by 5 inches. Write the eqns describing the motion. Find the location of a point P(1,5,4) attached to the frame relative to the reference frame

$$P_{(x,y,z)} = \cancel{Trans(0,5,0)} \times Rot(\cancel{z},90) \times \cancel{Rot(x,90)} \times Trans(0,0,3) \times \cancel{P(1,5,4)}$$

$$= Rot(z,90^\circ) \times Rot(x,90^\circ) \times Trans(0,0,3) \times Trans(0,5,0) \times P$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \cos 90 & -\sin 90 & 0 & 0 \\ \sin 90 & \cos 90 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 90 & -\sin 90 & 0 \\ 0 & \sin 90 & \cos 90 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 \\ 5 \\ 4 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 3 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 \\ 5 \\ 7 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cancel{4} \\ \cancel{6} \\ \cancel{8} \\ \cancel{1} \end{bmatrix} \qquad = \begin{bmatrix} 7 \\ 1 \\ 10 \\ 1 \end{bmatrix}$$

Robot Kinematics

- It uses geometry to study the movement of robot structure
- It studies the relationship b/w the position, velocity & acceleration b/w joints & links
- In order to plan & control the movement of the structure & to compute the actuator forces & torque.

Forward kinematics

In forward kinematics the joint & link parameters are given & by these values we calculate the position & orientation of the end effector.

Inverse of a transformation matrix: For finding the inverse of a homogeneous 4 x 4 transformation matrix follow the steps:

Step 1: Rotation portion of the transformation matrix is transposed.

(1,5,4)

Step 2: The position portion of the transformation matrix is the -ve of the dot product of P with (n, o, a) vectors.

Ex

$$T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

~~Transpose (T) =~~

$$T^{-1} = \begin{bmatrix} n_x & n_y & n_z & -(P \cdot n) \\ o_x & o_y & o_z & -(P \cdot o) \\ a_x & a_y & a_z & -(P \cdot a) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Q) Calculate the inverse of the transformation

$$\begin{bmatrix} 0.5 & 0 & 0.866 & 3 \\ 0.866 & 0 & -0.5 & 2 \\ 0 & 1 & 0 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T^{-1} = \begin{bmatrix} 0.5 & 0.866 & 0 & \begin{matrix} -3.232 \\ \cancel{-4.098} \end{matrix} \\ 0 & 0 & 1 & \begin{matrix} \cancel{-2}\ -5 \\ \cancel{-0.732} \end{matrix} \\ 0.866 & -0.5 & 0 & \begin{matrix} -1.59 \\ \cancel{-1.83} \end{matrix} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Q) Calculate the inverse of given transformation matrix representing Rot$(x, 40°)$ inverse.

$\cancel{0.5 \quad 0}$

$$Rot(x, 40°) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.766 & -0.643 & 0 \\ 0 & 0.643 & 0.766 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$Rot(x, 40)^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.766 & 0.643 & 0 \\ 0 & -0.643 & 0.766 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

5) calculate the inverse of the following

$$T = \begin{bmatrix} 0.527 & -0.574 & 0.628 & 2 \\ 0.369 & 0.819 & 0.439 & 5 \\ 0.766 & 0 & 0.643 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T^{-1} = \begin{bmatrix} 0.527 & 0.369 & 0.766 & \overset{6.01}{\cancel{-5.197}} \\ -0.574 & 0.819 & 0 & -2.947 \\ 0.628 & 0.439 & 0.643 & -5.38 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

8) A frame F was rotated about the Y axis by 90° followed by a rotation about the O axis by 30°. followed by a translation of 5 units along n axis & finally a translation of 4 units along the X axis. Find the total transformation matrix.

$$P_{(x,y,z)} = Trans(X) \times Rot(Y) \times Rot(O) \times \overset{Trans(n)}{\cancel{Ro}}$$

$$= (4,0,0) \times \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \sqrt{3}/2 & 0 & 1/2 & 0 \\ 0 & 1 & 0 & 0 \\ -1/2 & 0 & \sqrt{3}/2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\times (5,0,0)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \sqrt{3}/2 & 0 & 1/2 & 0 \\ 0 & 1 & 0 & 0 \\ -1/2 & 0 & \sqrt{3}/2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} -0.5 & 0 & 0.866 & 1.5 \\ 0 & 1 & 0 & 0 \\ -0.866 & 0 & -0.5 & -4.33 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Module - 4

Localisation & Mapping

Representing Robot position

There are 4 common ways to represent the robot's position:

1) Cartesian coordinate:

This representation uses 2 or 3 Dimensional coordinate system to represent position of the robot.

2) Polar coordinates:

In this method the position of the robot is described using radial method & angular direction

3) homogeneous transformation matrix

This rep uses a 4X4 matrix to represent orientation & position of the robot in a 3D space.

4) Landmark based representation:

This representation describes the position of robot relative to a known landmark in the environment.

Robot localisation

The process of determining where a ~~where the~~ mobile robot is located w.r to its environment.

Importance

The saget robot can plan possible paths with its location & map information & it can identify n-num of paths.

Challenges of localisation

- Communication
- Translational errors
- Localisation may take time
- Noise

Reactive Navigation

- It is a study of techniques for planning, working & controlling the movement of a robot towards a desired location in a collision free path

Map representation

Visualisation of a the geographical information of the environment. It involves the translation of real world data to a digital representation.

Challenges :

1) Scaling & generalisation

2) Distortion
3) data accuracy
4) Data integration & synchronisation

General control schemes for mobile robot system

- Perception
- Localisation
- cognition
- motion control

localization requires perception. The sensors in the robot & environment collect the data & the data will be processed & given to the localization module. Then the robots create the maps or uses the existing maps to do the localization.

Methods for mobile robot localization

1) Odometry
2) Map based localization
3) Autonomous ~~bus~~ map building

⇒ The localization method is called odometry if the robot uses its sensors to get the position & orientation.

~~The robot needs to know~~

The encoders attached to the robot will provide the wheel the velocity information. Then the velocity info can be used to get the position.
. the sensors will give the orientation of the

If this method is used for longer duration then the errors will be accumulated

Operation

The movement of the robot is sensed with wheel encoder or heading sensors or both. The internal sensor measure the state of the robot (wheel position or speed, battery charge etc) while the external sensor measure the state of environment (mapping, temp etc)
These info are integrated to compute the position.
The sensor measurement errors are integrated over time as a result the position error accumulates

Thus the position has to be updated from time to time by other localisation mechanisms otherwise the robot is able to maintain a meaningful position estimate in long run.

→ There are many sources of odometric errors from environment factors to resolution

1) misalignment of wheels.

2) uncertainty in wheel diameter & in particular unequal wheel diameter.

3) variation of the contact point of the wheel.

4) unequal floor contact

→ Some errors may be deterministic thus they can be eliminated by proper calculation of the system.
But there are still some non deterministic error that remain leading to uncertainties in position estimation over time.

→ From the geometric point of view, errors can be classified into 3 types:

1) Range error.

2) Turn error

3) Drift error

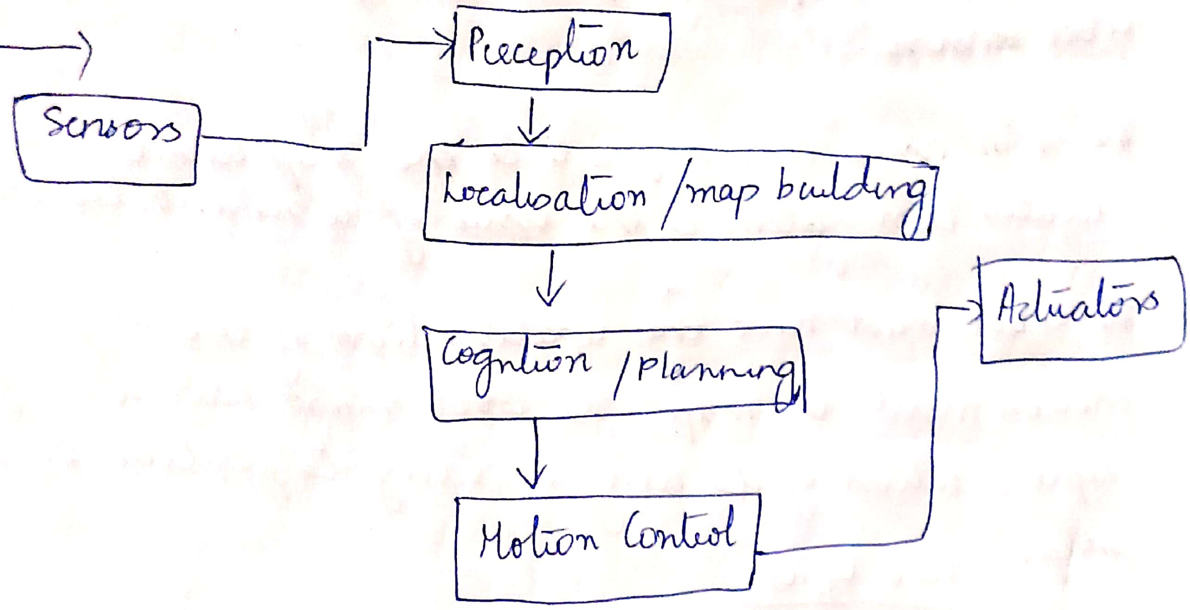
Turn & drift errors makes the position error non linear. So we need to establish an error model for odometric accuracy & see how the error propagates over time

In map based localisation the localisation is done by using the odometry info & map info we have 2 methods for that we use probabilistic localisation methods

1) Markov localisation

2) Kalman filter localisation

In probabilistic band localisation odometric measures are used but we try to minimise the odometric errors by some method



In a known location the robot will be able to move based on odometry. After certain movement the robot will get uncertain about its position then we can apply probabilistic map based localisation where the position is updated using the observation of its environment And then use that info along the map info to update robot position.

~~Acc~~ At every state the error must be reduced.

Map representation (pdf)

→ The problem of representing the environment or the problem of representing the robot possible position.

The decision made regarding the environmental representation can have impact on the choices available for robot position representation.

The precision of the map must appropriately match with the precision with which the robot needs to achieve goal.

The precision of the map & the type of features represented must match the precision & the datatype returned by the robot sensors.

The main issue that differentiate the map based localization system is the issue of representations.

The robot must have ~~the~~ a representation of the environment i.e, map. The robot must have a representation of its belief regarding its position on the map. <u>Two types</u>:

1) Continuous Representation:

It is a method for exact decomposition of the environment. Generally it uses a 2D representation. This ~~g~~ rep generally assumes that all the environment objects are specified ~~with~~ in the map. Thus the total storage needed in the map is proportional to the density of objects in the environment.

Advantages

high accuracy & expressiveness

Disadvantage

-computational cost

Decomposition strategies

A general decomposition is done & the environmental features are extracted.

1) First decomposition strategy - Exact cell decomposition:

It is a std lossless form of decomposition

It does the decomposition by selecting the boundaries b/w discrete cells based on geometric criticality.

Exact decomposition is not always appropriate.

The exact decomposition is a function of the particular environment obstacles & free space.

2) ~~Z-cell~~ fixed cell decomposition:

Robotic vision

The sensors (external sensors) are used for interaction with the environment. The camera robot uses a camera for capturing the scene. These images are processed using image processing techniques for further analysis. This is known as computer vision.

Images

The images obtained from normal cameras are 2D images. They lack depth information. Each point in the image will be represented using 2 axes. A Digital image is a rectangular array of dots or picture elements called pixels arranged in the form of a matrix with m rows & n columns. The expression m x n is called the resolution of the image. Each pixel value stores the intensity of the light coming from the object. So image is a collection of data representing the light intensities of large no. of pixels.

Stages of robotic vision

1. Sensing : The process of capturing an image. The images can be captured using analog or digital cameras. For computer vision images should be digitized. These digitized images are stored in computer memory in the binary form.

2. Preprocessing : Preprocessing is done to convert the image into a proper form that can be easily processed by the processor. It includes noise

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removal, corrections & enhancement.

3. Segmentation: The process of partitioning an image into objects of interest.

4. Description / feature extraction: Required features in an image is extracted to differentiate different objects in an image.

5. Recognition: Identifying the different objects in the images.

6. Interpretation: Assign meanings to the ~~en~~ recognized objects.

<u>Image Processing techniques</u>

1. Hys ~~Dis~~togram analysis:

Hys ~~Dis~~togram is a graphical representation of total no. of pixels of an image at each gray level. It gives a rough sense of density of the pixel value distributed in the image. Horizontal axis of the graph represent the pixel value variation by vertical axis represents the no. of pixels in that particular value.

<u>Usage</u>

1. For threshold
2. Adjusting the contrast

2. Thresholding

Process of diving the image into diff regions based on the pixel value. A particular pixel value is set as the threshold & all the other pixels are compared with the threshold. Based on the comparison the pixels are categorised. There can be more than 1 threshold depending upon the application.

Uses

- converting grey scale image to binary
- object detection
- image segmentation

3. Edge detection

Edges are the regions where a sudden change in the intensity of the pixel occur. Usually edges occur at the boundary of the 2 objects. Edge detection techniques detect the edges of the objects in the image. The result of the edge detection will be a line giving the change in the intensities.

Methods:

1. Gradient based
2. Canny edge detection
3. Robert "
4. Zero crossing

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2) Fixed cell decomposition

In Fixed cell decomposition

The continuous real environment in Fixed

is transformed into discrete approximation

Advantages

Disadvantages

- Inexact nature

- narrow passages are lost in the transformation.

3) Adaptive cell decomposition

It is the most popular map representation used in mobile robotics. ~~Any cell~~ Every cell is either filled or empty

White cells are outside the obstacles.

Black cells are inside /considered as obstacles

grey cells are part of both the regions.

Current challenges in map representation

1. Real world is dynamic.

2. Mobile Robot organisation involves the traversal of open spaces

3. existing localisation techniques generally depend on local measures such as range thereby demanding the environments that ~~has~~ are densely filled with objects that the sensors can detect & measure.

Thus wide open spaces such as parking lots, grass fields etc. cause difficulty.

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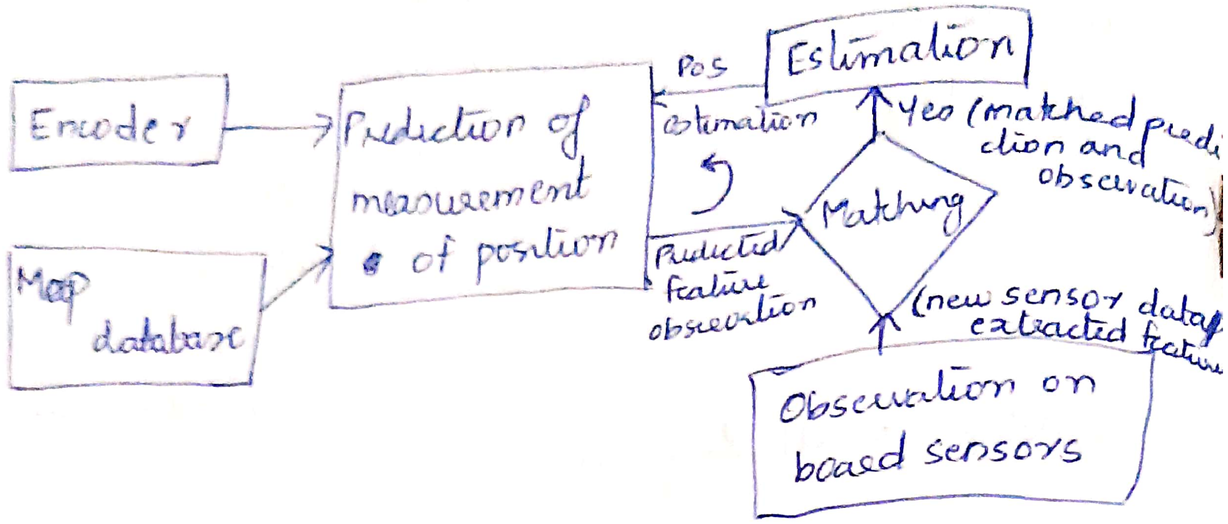
Probabilistic map based localisation



The basic Kalman filter method allows multiple measurements to be incorporated optimally into a single estimate of the state. The first assumption made is that the state does not change. The state does not change b/w the acquisition of the first & second measurement. After presenting the static case, dynamic prediction is introduced.

The perception update using a Kalman filter is a multistep process. Given a set of possible features the Kalmann filter is used to fuse the distance estimate from each feature to a matching object in the map. The first step is the action update / position prediction then the robot collects the actual sensor data & extract the appropriate features in the observation step. At the same time based on its predicted position in the map the robot generates a measurement prediction which identifies the features that the robot expects to find & the position of those features. In matching the robot identifies the best pairings b/w the features actually extracted during observation & expected features due to measurement prediction. Then the Kalman filter fuses the information provided by all these matches to update the robot belief state in estimation.

SLAM (Simultaneous localisation and mapping)

Estimate the pose of the robot & the map of the environment at the same time. SLAM problem is hard because inorder to build a map we need the position. To determine the position we need a map. SLAM has multiple parts and each part can be executed in many diff ways.

Parts : 1) Landmark detection
2) Data association
3) State estimation
4) State update.
5) Landmark update.

Landmarks are the features that can be easily be reobserved & distinguished from the environment. These are used to localise the robot.

Applications of SLAM

- SLAM is central to a range of indoor, outdoor, and & underwater application for both manned & autonomous vehicle

eg. drone, UAV, ...

Types of SLAM

1- Visual SLAM in single camera (monoculous SLAM):

- It uses a single camera to estimate the position & orientation of a device while simultaneously mapping the environment.

→ Techniques

- SFM : (Structure from Motion)

  - reconstruct a 3D structure from multiple 2D images

- Visual odometry : (VO)

  - estimates the camera's motion by analysing the changes in consecutive images providing a local map of the environment.

- Feature based tracking:

  Tracks the points of interest through successive camera frames to triangulate the 3D position.

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- Sensor fusion:
Integrating the information from other sensors to increase the accuracy & robustness

Applications

- monoculous SLAM can be used for mobile robot & Autonomous vehicles to navigate in map unknown environments.
- Augmented reality - AR application can use monoculous slam to track the user movements.
- 3D reconstruction - can be used to reconstruct 3D model of environment or objects.

2. Particle filter SLAM

- Particle filter SLAM uses Particle filter algorithm.
- It is a probabilistic method that uses a set of particles or samples to represent the robot's possible locations & environment.
- each particle carries information about the robot's pose and potentially a map of the environment.
- The particle filter uses sensor data to update the particle & refines the robot's location & the map.

Steps:

1. Prediction - Particles are moved according to the robot's motion model (odometry)

2 Observation: Then the sensor data is used to weigh the particle based on how well they match the observed environment

3 Resampling: The particles are replicated with more copies given to the particle which helps to correct & refine the search

Advantages

1. Handles non linearity
2. Robustness
3. Adaptability
~~4 R~~

Application

- mapping
- creating maps of indoor & outdoor spaces
- vehicle localisation
- determining the position of vehicle in real time
- UAV navigation.

→ Error model for odometric position estimation