Robotics & Automation

* Robot: A robot is an automatically operated machine that replaces human efforts but may not resemble humans in appearance or perform functions in a humanlike manner.

* Explain robot anatomy with examples:-

Robot anatomy refers to the structure and components that make up a robot.

The basic part of a robot includes:-

(I) Manipulator/Arm: This is robot's arms, made up with joints and links. For example an industrial robotic arm used in car manufacturing.

(II) End effector: The tool attached at the end of the robotic arm, like a gripper or welding torch.

Q. Solve (18-19)

1 (a) Define actuator. What are different types of actuators?

→ An actuator is a mechanical or electromechanical device that converts energy (typically electrical, hydraulic or pneumatic) into physical motion. In robotics and automation systems, actuators are responsible for moving or controlling mechanisms or systems. They form the core component that enables a robot to interact with its environment.

→ Types of actuators:-

① Electric actuators:

→ These actuators convert electrical energy into mechanical movement.

→ Common types: DC motors, Stepper motors, servo motors.

→ Used in precision applications like robotic arms, wheels and small mechanism.

→ Advantages: Easy control, clean operation, high accuracy.

(2) Pneumatic actuators:

→ use compressed air to produce motion.

→ Often used in factory automation and pick and place robots.

→ Advantages: Fast response time, Simple Construction.

(3) Hydraulic Actuators:

→ Use pressurized fluid to create forcefull and Smooth motion.

→ Used in heavy-duty applications like industrial robots and exoskeletons.

→ Advantages: High power to-size ratio, suitable for heavy loads.

(4) Thermal or magnetic actuators:

→ operates on the principle of thermal expansion or magnetism.

→ Used in micro robotics or MEMS ~~service~~ devices.

→ Example: Shape memory alloys (SMAs), which change shapes when heated.

(5) Piezoelectrical actuators:

→ use piezoelectric effect to produce tiny displacement.

→ very precise, used in nano-positioning applications.

1(b) why, where and how electric actuators are used in robotics?

→ Why electric actuators are used:-

→ Precision and control: Electric actuators can be precisely controlled using micro-controllers and sensors, essential for robotics.

→ clean and quiet: Unlike hydraulic or pneumatic actuators, electric actuators don't produce noise or leaks, making them ideal for medical or indoor robots.

→ Energy efficient: They consume energy only when in motion.

→ Easy of Integration: Easily interfaced with digital controll systems like aurdino, Raspberry Pi etc.

☐ **Where they are used:**

(i) Robotic arm: To control joints for pick-and-place, welding or painting tasks.

(ii) Mobile Robots: For driving wheels or steering mechanism.

(iii) Humanoid robots: To mimic muscle-like movements in limbs and fingers.

(iv) Medical robots: In surgical robots or rehabilitation devices for controlled, precise movements.

(v) Automated manufacturing systems: For tasks like material handling, packaging and inspection.

☐ **How they are used:**

(i) With sensors: electric actuators work in conjunction with encoders or potentio-meters to measure position and velocity.

(ii) Feedback loops: Used in closed-loop system for real time adjustments based on sensor data.

(iii) Controlled via software: Using programming languages like C++, Python to define motion logic.

(iv) Connected through drivers: motor drivers regulate current and voltage to safely operate the actuator.

Q 2(a): Explain the basic implementation of electric motors in robotic control.

→ Electric motors are the backbone of motion in most robotic systems. Their primary role is to convert electrical energy into mechanical motion, enabling robots to perform physical tasks.

Basic implementation:

(I) Power source: Motors receive electrical power from batteries or a regulated power supply.

(II) Motor controller: A motor driver circuit interfaces the low power control signal from the microcontroller with the high power motor.

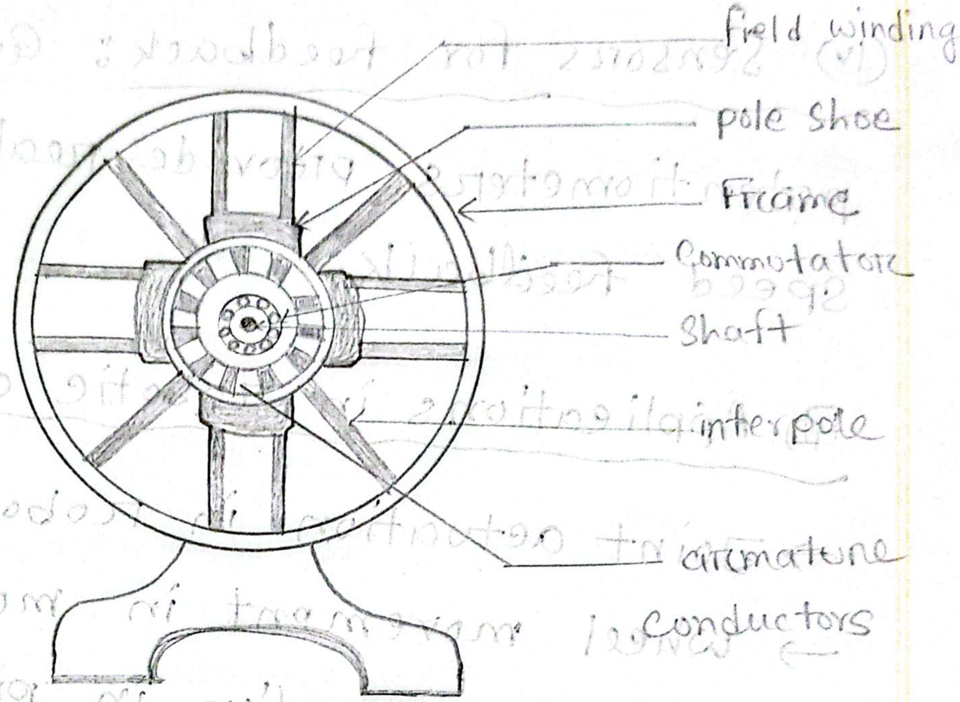
(III) Microcontroller/processor: A microcontroller (Arduino, raspberry pi) sends signals to control motor speed and direction.

(iv) Sensors for feedback: Encoders or potentiometers provide real-time position or speed feedback.

Applications in robotic control:

→ Joint actuation in robotic arms
→ wheel movement in mobile robots
→ Gripper operation in pick-and-place robots
→ Head or limb rotation in humanoid robots.

Q 2(b)



Operation of a DC motor :-

① Current flow:

→ DC voltage is applied to the motor terminals

→ Current flows through the brushes into the commutator and then into the armature windings.

② Magnetic Interaction:

→ The interaction between the magnetic

field and the current in the armature generates a force.

③ Rotation:

→ This force cause the armature to rotate.

→ The commutator reverse the direction of current in each coil as it passes through the magnetic field, ensuring continuous rotation in the same direction.

④ Principle of control:

① Speed control:

→ PWM (pulse width modulation): varies the average voltage across the motor, adjusting the speed.

→ Armature voltage control: Directly changes the voltage supplied to the motor.

(2) Direction control:

→ Using a H-Bridge circuit, the direction of current can be reversed, allowing the motor to spin forward and backword.

(3) position control:

→ Using feedback from sensors, the controller adjusts the motor to reach the desired position.

(4) Closed loop control:

→ A PID controller adjusts motor performance using feedback to minimize error in position, velocity and torque.

final (17-18)

1(a):

A robot is a programmable machine capable of carrying out complex tasks autonomously or semi-autonomously. They can:-

→ Sense their environment through their sensors like camera, lasers and microphones

→ process information using computer algorithms and software.

→ make decisions based on their programming and sensor data.

→ perform actions in the real world using motors, actuators, and other mechanisms.

☐ Robotics in present and future:-

Robotics has become an integral part of modern civilization and industrialization for several reasons:-

(1) Increased efficiency and productivity:-

Robot can work tirelessly and accurately, performing task faster and more consistently than humans.

(2) Improved safety: Roboticis can handle dangerous tasks, protecting human workers from accident and injuries.

(3) Enhanced capabilities: Robot can perform tasks beyond human limitations.

(4) New applications: Robotics is constantly evolving, opening up new possibilities in various fields like:

(i) Healthcare

(ii) manufacturing

(iii) Agriculture etc.

(5) future impact: As robots become more

sophisticated and integrated into society, they have the potential to:-

(i) Transform industries further

(ii) Create new jobs in robotics design, development and maintenance.

Q 1(b)

Evaluation of robotics research:-

(1) Ancient time: The idea of artificial helper dates back to ancient greece and china, where mechanical devices like automations were built.

(2) 20th century: The term "robot" was introduced by the czech writter karel capek in 1921. The first industrial robot, "unimate" was introduced in 1950 for assembly line work.

(3) Modern Robotics: Today's robots have evolved with advanced sensors, AI and machine learning. Modern robots are capable of autonomous navigators, object recognition and even ~~often~~ social interaction.

(4) Future Robotics: Robots are expected to become more intelligent, collaborative and integrated into daily life.

1(c)

Laws of Robotics → Discussed before.

Q(2)

Classifying robots based on implementation area:-

(1) Industrial robots:

→ Areas: manufacturing, Assembly line, welding, painting etc.

→ Features: High precision, powerful manipulators, large workplace.

→ Objectives: Increase efficiency and productivity, improve product quality, ensure worker safety.

→ Striking features: six-axis articulated arms, collaborative robots ~~for~~ safe human-robot interaction.

(2) Service robots:

→ Areas: Healthcare, household cleaning, Logistics, education, entertainment.

→ Features: sensors for perception, navigation capabilities, user interface

→ Objectives: provide assitance and support in various settings, improve quality in performing dangerous tasks.

→ Striking features: Robotic vaccum cleaners, delivery drones, humanoid robots for customer service.

(3) Mobile Robots:

→ Areas: Exploration, search & rescue, environmental monitoring, agriculture transportation.

→ Features: Autonomous navigation, obstacle avoidance, sensor fusion

→ Objectives: operate in dynamic environments, collect data, support various exploration and service missions.

(4) Aerial Robots:

→ Areas: Aerial photography, surveillance, inspection, delivery, disaster response.

→ Features: flight capabilities, equipped with cameras and sensors for data collection

→ objectives: provide aerial views and access; perform tasks in difficult-to-reach areas, offer efficient delivery solution.

→ striking features: Drones for various applications, flying taxis for future transportation.

Q-3 (i)

→ **Coordinate frames:**

If 'p' is a vector in R, and $x = \{x^1, x^2, x^3, \ldots x^n\}$ be a complete orthonormal set of R, then the coordinates of p with respect to x are denoted as $[P]^x$ and are defined as:-

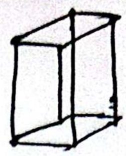
$$p = \sum_{k=1}^{n} [P]^x_k \, x^k$$

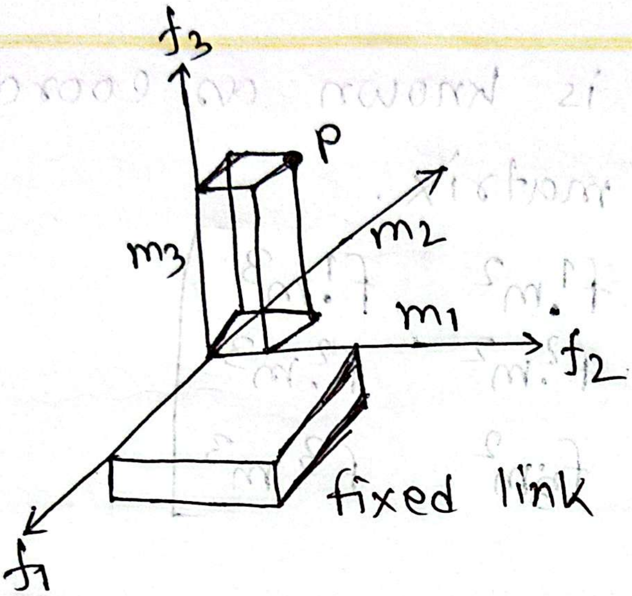
The complete orthonormal set is sometimes called an orthonormal coordinate frame.

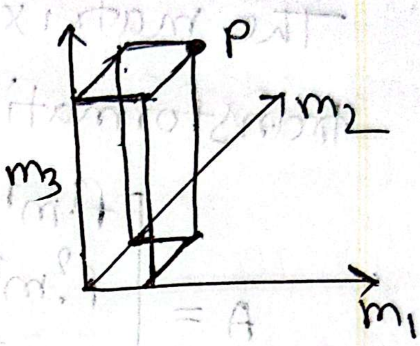
→ **Coordinates Transformation:**

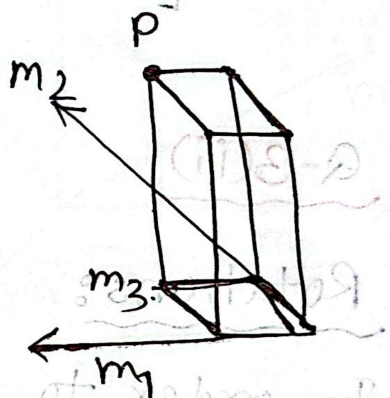
Represent position of p wrt fixed frame

$f = \{f_1, f_2, f_3\}$









The two sets of coordinates of p are given by

$$[p]^{m} = [p.m_1, p.m_2, p.m_3]$$

$$[p]^{f} = [p.f_1, p.f_2, p.f_3]$$

The coordinate transformation problem is to find the coordinates of p wrt F, given the coordinates ~~wrt A~~ of p wrt M.

The matrix A is known as coordinate transformation matrix.

$$A = \begin{bmatrix} f^1 \cdot m^1 & f^1 \cdot m^2 & f^1 \cdot m^3 \\ f^2 \cdot m^1 & f^2 \cdot m^2 & f^2 \cdot m^3 \\ f^3 \cdot m^1 & f^3 \cdot m^2 & f^3 \cdot m^3 \end{bmatrix}$$

Q-3(ii)

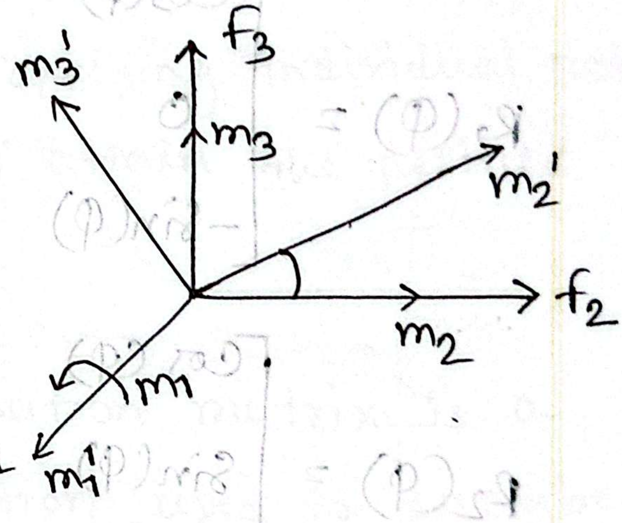
Rotations:

In order to specify the position and orientation of the mobile tool in terms of a coordinate frame attached to the fixed base, coordinate transformation involving both rotations and translations are required.

Fundamental rotations:

If the mobile coordinate frame is

obtained from the fixed coordinate frame f by rotating m about one of the unit vectors of F, then the resulting coordinate transformation matrix is called a fundamental rotation matrix



In the space R_3, there are three possibilities –

$$R_1(\phi) = \begin{bmatrix} f^1.m^{1'} & f^1.m^{2'} & f^1.m^{3'} \\ f^2.m^{1'} & f^2.m^{2'} & f^2.m^{3'} \\ f^3.m^{1'} & f^3.m^{2'} & f^3.m^{3'} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & f^2.m^{2'} & f^2.m^{3'} \\ 0 & f^3.m^{2'} & f^3.m^{3'} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix}$$

$$R_1(\phi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix}$$

$$R_2(\phi) = \begin{bmatrix} \cos(\phi) & 0 & \sin(\phi) \\ 0 & 1 & 0 \\ -\sin(\phi) & 0 & \cos(\phi) \end{bmatrix}$$

$$R_2(\phi) = \begin{bmatrix} \cos(\phi) & -\sin(\phi) & 0 \\ \sin(\phi) & \cos(\phi) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

4(a)

Composite rotation:

Composite rotation in robotics refers to combining multiple rotations to achieve a final orientation for a robot or an object.

It involves sequentially applying individual rotations around different axes to attain the desired overall rotation.

Yaw-Pitch-Roll transformation matrix is a mathematical representation used to describe the orientation or rotation of an object in three-dimensional space.

Yaw: Rotation around the vertical axes.

pitch: Rotation around the horizontal axes.

Roll: Rotation around the adjacent axes.

The matrix combines these rotations to represent the overall orientation of an object.

$$y_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_1 & -s_1 \\ 0 & s_1 & c_1 \end{bmatrix}; \quad P_y = \begin{bmatrix} c_2 & 0 & s_2 \\ 0 & 1 & 0 \\ -s_2 & 0 & c_2 \end{bmatrix}, \quad R_z = \begin{bmatrix} c_3 & -s_3 & 0 \\ s_3 & c_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$YPR = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_1 & -s_1 \\ 0 & s_1 & c_1 \end{bmatrix} \cdot \begin{bmatrix} c_2 & 0 & s_2 \\ 0 & 1 & 0 \\ -s_2 & 0 & c_2 \end{bmatrix} \begin{bmatrix} c_3 & -s_3 & 0 \\ s_3 & c_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} c_2 & 0 & s_2 \\ s_1 s_2 & c_1 & 0 \\ s_2 & s_1 & c_1 c_2 \end{bmatrix} \begin{bmatrix} c_3 & -s_3 & 0 \\ s_3 & c_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$YPR = \begin{bmatrix} c_3 & -s_3 & 0 \\ s_3 & c_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_2 & 0 & s_2 \\ 0 & 1 & 0 \\ -s_2 & 0 & c_2 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_1 & -s_1 \\ 0 & s_1 & c_1 \end{bmatrix}$$

$$= \begin{bmatrix} c_2 c_3 & -s_3 & c_3 s_2 \\ c_2 s_3 & c_3 & s_2 s_3 \\ -s_2 & 0 & c_2 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_1 & -s_1 \\ 0 & s_1 & c_1 \end{bmatrix}$$

$$= \begin{bmatrix} c_2 c_3 & -c_1 s_3 + s_1 s_2 c_3 & s_1 s_3 + c_1 c_3 s_2 \\ c_2 s_3 & c_1 c_3 & -s_1 c_3 + c_1 s_2 s_3 \\ -s_2 & s_1 c_2 & c_1 c_2 \end{bmatrix}$$

Here, $c_1 = \cos(\varphi_1)$, $s_2 = \sin(\varphi_2)$. ……

4(b)

Given that,

Yaw, $\theta_1 = \frac{\pi}{2}$

pitch, $\theta_2 = -\frac{\pi}{2}$

Roll, $\theta_3 = \frac{\pi}{2}$

$$R_1(\theta_1) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_1 & -\sin\theta_1 \\ 0 & \sin\theta_1 & \cos\theta_1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\pi/2 & -\sin\pi/2 \\ 0 & \sin\pi/2 & \cos\pi/2 \end{bmatrix}$$

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

$$R_2(\theta_2) = \begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 1 & 0 \\ -\sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix}$$

$$= \begin{bmatrix} \cos(-\pi/2) & 0 & \sin(\pi/2) \\ 0 & 1 & 0 \\ -\sin(-\pi/2) & 0 & \cos(-\pi/2) \end{bmatrix}$$

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

$$R_3(\theta_3) = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 \\ \sin\theta_3 & \cos\theta_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\pi/2 & -\sin\pi/2 & 0 \\ \sin\pi/2 & \cos\pi/2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

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

We know,

$$R_0 = R_3(\theta_3) \cdot R_2(\theta_2) \cdot R_1(\theta_1) \cdot I$$

$$= \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

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

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

4(c)

Yaw, $\theta_1 = 45^\circ$

Pitch, $\theta_2 = 60^\circ$,

Roll; $\theta_3 = 90^\circ$

$$R = \begin{bmatrix} \cos 90^\circ & -\sin 90^\circ & 0 \\ \sin 90^\circ & \cos 90^\circ & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos 60^\circ & 0 & \sin 60^\circ \\ 0 & 1 & 0 \\ -\sin 60^\circ & 0 & \cos 60^\circ \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 45^\circ & -\sin 45^\circ \\ 0 & \sin 45^\circ & \cos 45^\circ \end{bmatrix}$$

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

$$= \begin{bmatrix} 0 & -1 & 0 \\ \frac{1}{2} & 0 & \frac{\sqrt{3}}{2} \\ -\frac{\sqrt{3}}{2} & 0 & \frac{1}{2} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix}$$

$$= \begin{bmatrix} 0 & -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{\sqrt{3}}{2\sqrt{2}} & \frac{\sqrt{3}}{2\sqrt{2}} \\ -\frac{\sqrt{3}}{2} & \frac{1}{2\sqrt{2}} & -\frac{1}{2\sqrt{2}} \end{bmatrix} = \begin{bmatrix} 0 & -0.707 & 0.707 \\ 0.5 & 0.612 & 0.612 \\ -0.866 & 0.353 & 0.353 \end{bmatrix}$$

$$\therefore pF = \begin{bmatrix} 0 & -0.707 & 0.707 \\ 0.5 & 0.612 & 0.612 \\ 0.866 & 0.353 & 0.353 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0.6 \end{bmatrix}$$

$$= \begin{bmatrix} 0.4242 \\ 0.3672 \\ 0.2118 \end{bmatrix}$$

5(a)

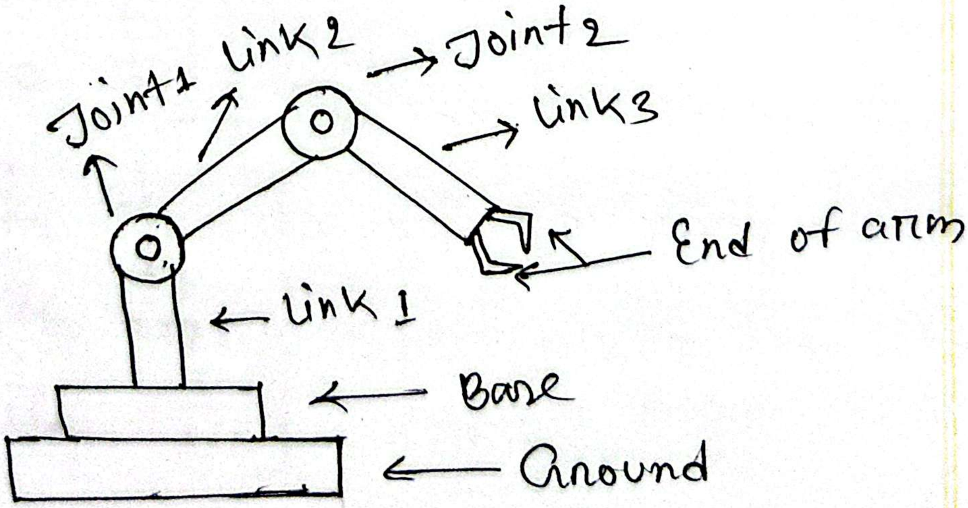
Degree of freedom:

In General degree of freedom (DOF) are the set of independent displacements that specify completely displaced or deformed ~~the~~ position of the body or system.

In robotics, degree of freedom is often used to describe the number of directions that a robot can move a Joint.

5(b)

Robot's anatomy discussed before —



Common Architecture of an industrial robot:-

① polar coordinate robot (RRP):-

(i) Two rotatory joints, one prismatic joints.

(ii) Allows positioning in a polar coordinate system.

(2) Jointed-arm body and arm assembly (RRR)

(i) Three ~~Rotatory~~ rotary joints

(ii) Offers flexibility with all three rotations, commonly used in industrial robots.

(3) Cartesian coordinate robot (PPP):

(i) Three prismatic robot

(ii) Enables motion along X, Y and Z axes for precise positioning.

(RPP)

(4) Cylindrical body and arm assembly :-

(i) One rotary joint, ~~three~~ two prismatic joints.

(ii) provides positioning and movement in cylindrical coordinates.

5(C)

(1) polar robot :

A polar robot is a type of robotic arm where the movement is defined in terms of polar coordinates.

Characteristics :

(i) Moves in polar coordinate system.

(ii) Good for reaching around objects.

(iii) Compact base, suitable for die casting and welding.

(ii) Cylindrical robot:

Cylindrical robots operate in cylindrica coordinates, combining linear and rational movements.

Characteristics:

(i) Moves in a cylindrical coordinate system.

(ii) Have three DOF, typically allowing movement in the x, y and z axes.

(iii) Can handle large force.

(iii) Cartesian robot:

They operates using cartesian coordinate (x, y, z)

characteristics:

(i) Movements is along three mutually

perpendicular axes.

(ii) High precision and accuracy

(iii) Common in CNC mechanics and 3D printers.

(iv) Angular robot:

They move in angular coordinates, emphasizing rotational movements.

(i) Highly flexible and versatile

(ii) Can perform complex movements

(iii) Used in painting, arc welding etc.

(v) SCARA robot:

A robot with two parallel rotary joints that provide compliance in a horizontal plane.

(i) Movement is similar to human arm.

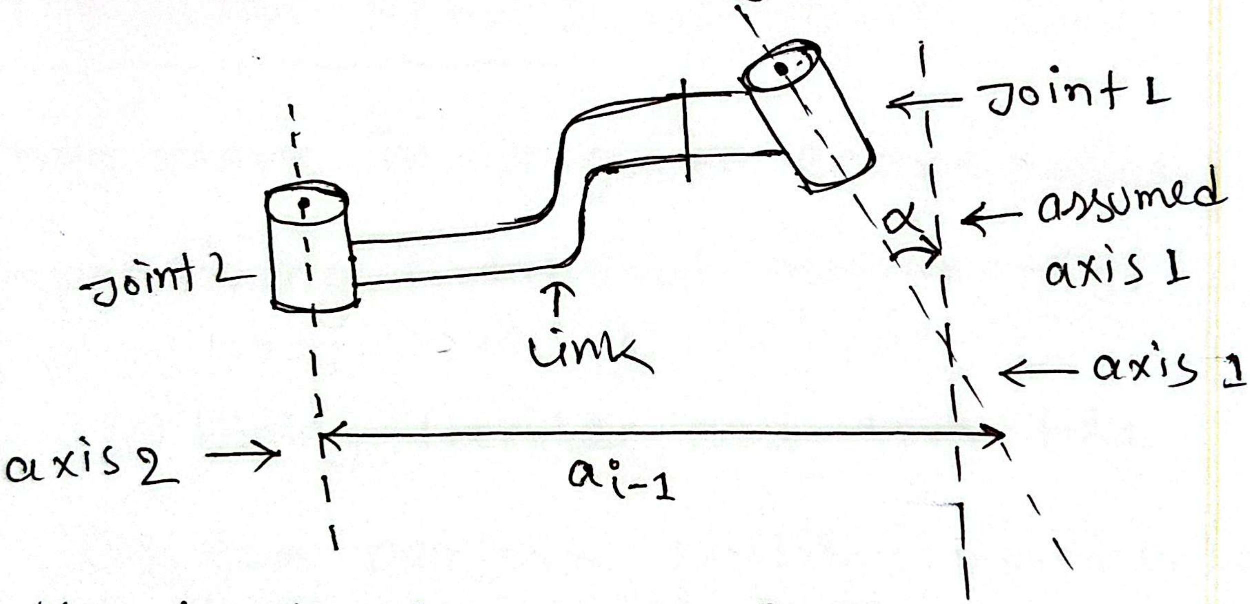
(ii) Can handle high speed work.

(iii) Used for pick and place kind of tasks.

6(a)

Joints and link parameters in robotics point of view.

There are two link parameters. We'll understand with the figure below:-



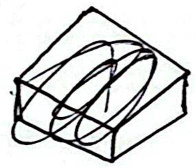
① Link Length: Link length is the mutual perpendicular distance between two axis. In figure a_{i-1} is the link length.

(ii) Link twist: The angle between two consecutive axes. In figure α is the link twist/Link angle.

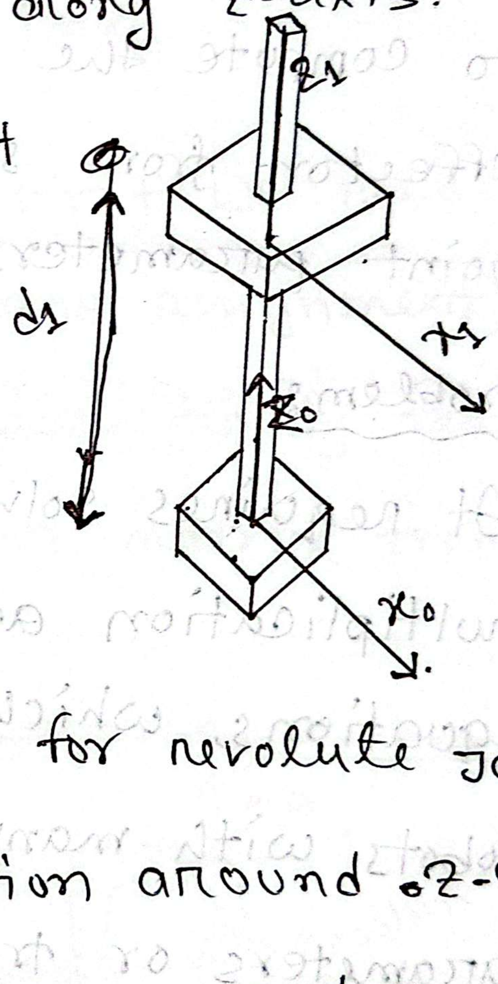
Joint parameters:

(i) **Joint offset (d):** used for prismatic joints. the linear distance along z-axis.

Here, d_1 is the joint offset



Joint দুটির মধ্যবর্তী রৈখিক দূরত্ব along z axis.



(ii) **Joint angle:** Used for revolute joint, the angle of rotation around z-axis. Here the angle between x_0 and x_1 is $0°$ about z_1-axis.

6(b)

Direct kinematics: refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters.

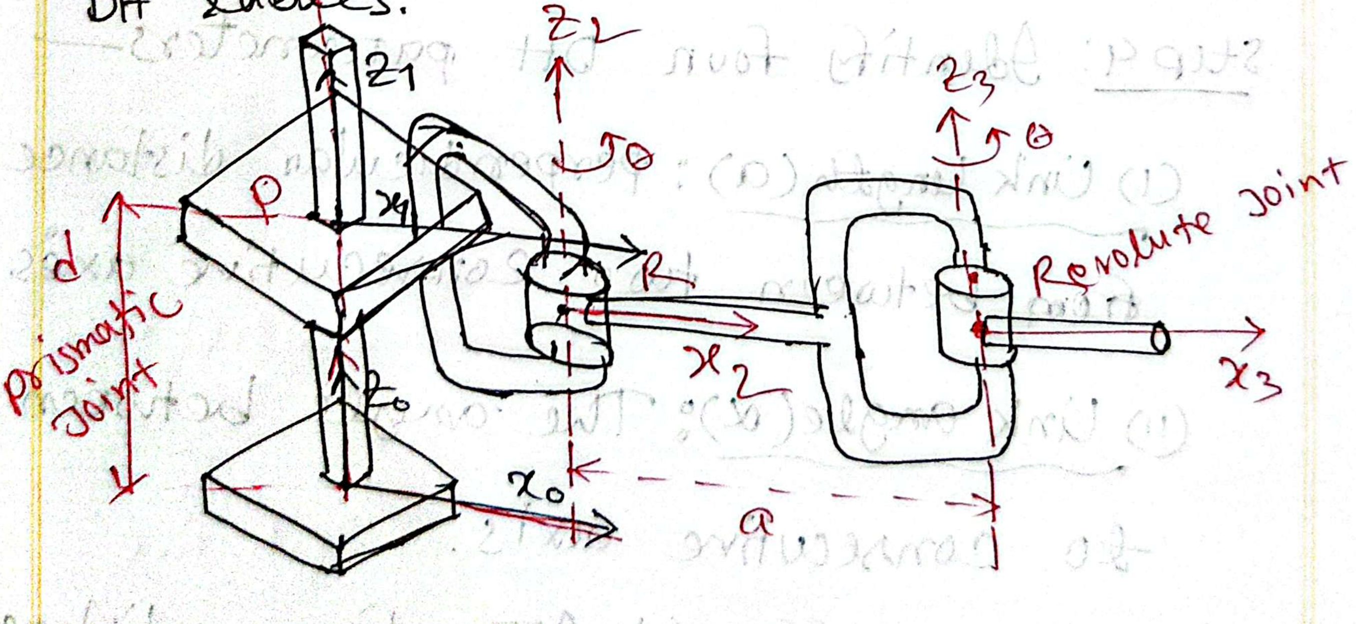
problem:

It requires solving multiple matrix multiplication and transformation equations, which become complex for robots with many joints. Errors in parameters or transformations can lead to inaccurate positions.

6 (c)

The Denavit-Hartenberg (DH) algorithm standarized how coordinate frames are assigned to robots links.

for DH algorithm at first we need to fix the frames (frame assignment) and then form a DH table. finally create a transformation matrix from the DH tables.

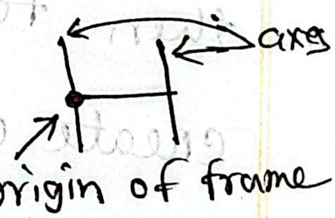


DH algorithm:-

Step-1: Identify the joint axes and draw a line along it's axis of movement.
(Dotted lines) in picture.

Step2: Assign z-axis along the joint axis.

Step3: Set the origin of the frame of the ith axis — common perpendicular between the joint axes.



Step4: Identify four DH parameters—

(i) Link Length(a): perpendicular distance ~~from~~ between two consecutive axes.

(ii) Link angle(α): The angle between ~~to~~ consecutive axis.

(iii) Joint offset(d): The linear distance along z-axis.

(iv) Joint angle (θ) : The angle of rotation around z-axis.

step 5: Now create a DH tables using DH parameters.

step 5: create transformation matrix.

7(a)

Autonomy: refers to the ability of a system or entity to operate independently, without direct human control or intervention.

Autonomy in Human-Robot Interaction:

In HRI autonomy plays a crucial role in determining the level of collaboration and cooperation between humans and robots.

Levels of autonomy:

(1) Manual control — Human control everything

(2) Assited teleoperation

(3) Shared Control with Robot initiative

(4) Full autonomy.

Assisted teleoperation: The robot perform tasks while the human gives commands.

Shared control with robot initiative:

The robot can take partial control or offer suggestion based on its sensor's data, while still allowing human input.

7(b)

In Human-Robot-Interaction, humans can play various role depending on the context, application and level of autonomy of the robot. There are several roles:-

(I) Operator/Teleoperator:

The human serves as the operator or teleoperator, directly controlling the robot's movement and actions. The operator is responsible for guiding the robot, making decisions and ensuring that the robot is doing tasks according to humans' intentions.

(II) Supervisor/Controller: The human acts as a supervisor, overseeing the robot's actions and providing high-level instructions.

(iii) Programmer/Developer:

Humans are responsible for programming and developing the software and algorithms that governs the robot's behaviour.

(iv) Trainer/Teacher:

Human can serve as a trainer/teacher, guiding the robot in learning new tasks behavior or skills.

(v) Evaluator/User:

In this role, humans use the robot as a tool or resource to perform specific tasks.

7(i)

A robot locates itself and navigates through an environment using sensors and algorithms.

(i) Localization:

Sensors like cameras, lasers or odometry help the robot to understand its position.

(ii) Mapping:

The robot create a map of the environment based on sensor data.

(iii) path planning:

Algorithms determine the best route from the robot's current position to the destination position.

(iv) Obstacle avoidance:

Sensors detect obstacles and algorithms

adjust the robot's path to avoid them.

(v) Feedback loop:

The robot continuously updates its position adjusts its map and refines its paths as it moves.

8(a)

Yes, robot's can be designed to understand human speech through the field of Natural language processing (NLP). Here's some methods of language understanding in HRI.

(i) Speech recognition: Speech recognition system convert spoken language into text. Robots equipped with speech recognition can understand spoken commands and engage in verbal interaction with users.

(ii) Natural language processing (NLP): Analyzes the structure and meaning of the text generated by speech recognition.

(iii) Machine Learning / Deep Learning: Trained on large datasets to understand intent.

sentiment and context.

(iv) Multimodal Integration:

Combines speech with gestures or facial expressions for better understanding.

8(b)

Non-verbal interaction involves communication without the use of spoken or written words. Here are some types of non-verbal interaction

(1) Body Language:

Body language encompasses the use of body movements, postures and gestures to convey information or emotions. It includes facial expressions, eye contact, hand movement and overall body posture.

(2) Facial Expressions:

Facial expressions involve the use of facial muscles. to convey emotions and feelings.

(3) movements:

Gestures involve hand movements or body motions that convey meaning. They can be symbolic.

④ Touch/ Haptics: physical contact like shaking hands. Robots use touch sensors to feel pressure or respond to human touch.

(5) Appearance:

Appearance includes clothing, grooming, and overall presentation.

8(c)

Robots perceive non-verbal cues using sensors, cameras, and AI algorithms that help them interrupt human behavior and emotions during interaction.

Key methods:

(I) Computer vision: Cameras capture visual input, robots analyze body posture, gestures and facial expressions using image processing and AI

(II) Facial expression recognition:

Detect emotions like happiness or anger using facial landmarks and deep learning models.

(III) Gesture recognition: uses depth sensors or cameras to identify hand and arm movements.

(IV) Eye gaze and head tracking:

Tracks where the human is looking or turning, useful for shared attention.

(V) Touch sensors/Haptic:

Detects physical contact, such as handshakes or taps, using pressure sensitive materials.

(VI) Audio cues (Tone & pitch):

Analyzes voice tone and volume to sense emotions or urgency even without words.

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8(a)

8(a) Classification of robot-end-effector:—

(1) Grippers: used for grasping and holding objects.

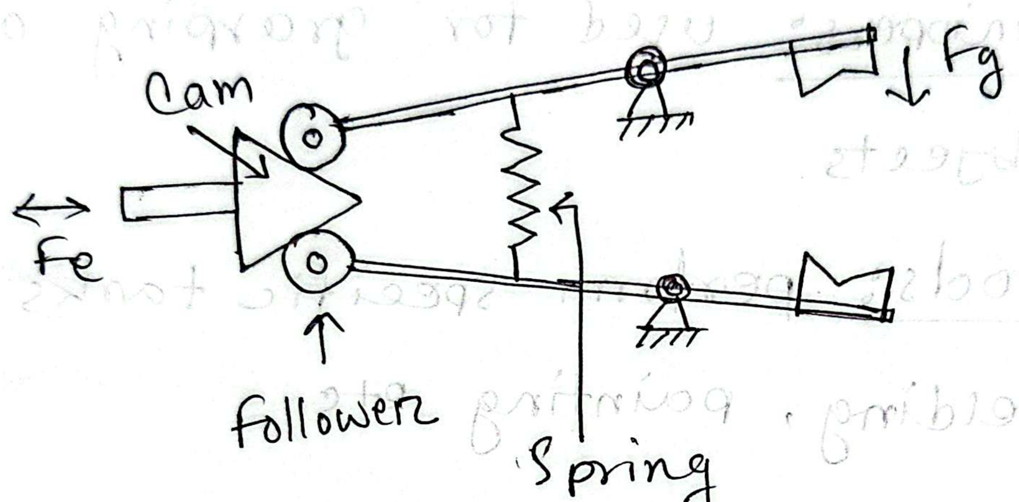
(2) Tools: perform specific tasks like welding, painting etc.

(3) Sensors: Gather information from the environment.

(4) Hybrid end-effector: Combination of grippers and tools.

Cam actuated gripper:

A cam actuated gripper uses a cam mechanism to convert rotary motion into linear motion which is used to open or close the gripper finger-positioning.



Explanation:

(1) when the cam rotates, its profile forces the followers to move.

(2) The shape of the cam controls the finger displacement and hence the gripping action.

(3) High speed and precise control.

(4) pick and place work, automated assembly.

5(b)

Jacobian matrix for planar 2DOF, 2R manipulator:-

Two rotational joints (θ_1, θ_2)

Link length: (a_1, a_2)

position of end-effector :

$$x = a_1 \cos\theta_1 + a_2 \cos(\theta_1 + \theta_2)$$

$$y = a_1 \sin\theta_1 + a_2 \sin(\theta_1 + \theta_2)$$

Jacobian matrix:

The Jacobian relates joint velocities to end-effector velocities.

$$\begin{bmatrix} x \\ y \end{bmatrix} = J \cdot \begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix}$$

$$J = \begin{bmatrix} \frac{\delta x}{\delta \theta_1} & \frac{\delta x}{\delta \theta_2} \\ \frac{\delta y}{\delta \theta_1} & \frac{\delta y}{\delta \theta_2} \end{bmatrix}$$

Calculate partial derivatives :-

$$\frac{\delta x}{\delta \theta_1} = -a_1 \sin\theta_1 - a_2 \sin(\theta_1 + \theta_2)$$

$$\frac{\delta x}{\delta \theta_2} = -a_2 \sin(\theta_1 + \theta_2)$$

$$\frac{\delta y}{\delta \theta_1} = a_1 \cos\theta_1 + a_2 \cos(\theta_1 + \theta_2)$$

$$\frac{\delta y}{\delta \theta_2} = a_2 \cos(\theta_1 + \theta_2)$$

$$\therefore J = \begin{bmatrix} -a_1 \sin\theta_1 - a_2 \sin(\theta_1+\theta_2) & -a_2 \sin(\theta_1+\theta_2) \\ a_1 \cos\theta_1 + a_2 \cos(\theta_1+\theta_2) & a_2 \cos(\theta_1+\theta_2) \end{bmatrix}$$