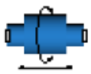
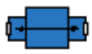
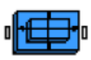
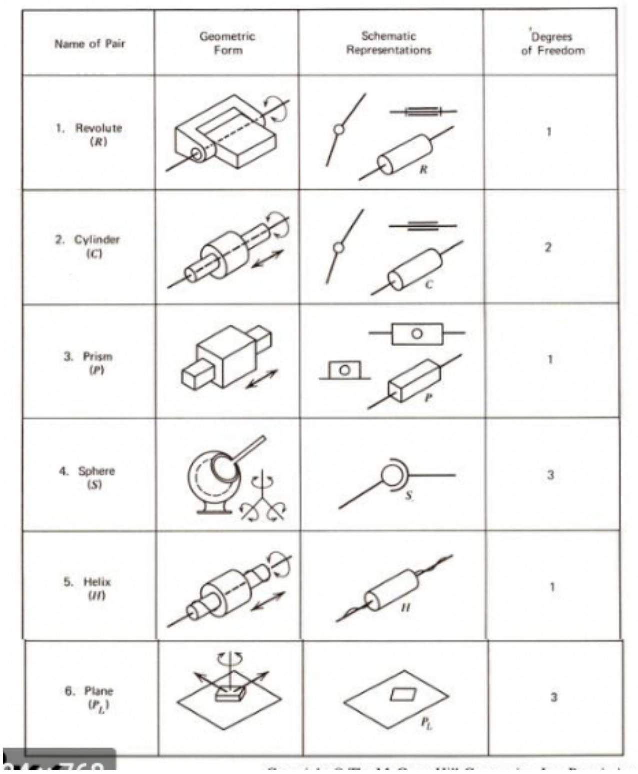
Robotics

Section A

3. What are the degrees of freedom associated with every joint motion

Name of joint	Representation	Description
Revolute		Allows relative rotation about one axis.
Cylindrical		Allows relative rotation and translation about one axis.
Prismatic		Allows relative translation about one axis.
Spherical		Allows three degrees of rotational freedom about the center of the joint. Also known as a ball-and-socket joint.
Planar		Allows relative translation on a plane and relative rotation about an axis perpendicular to the plane.



Name of Pair	Geometric Form	Schematic Representations	Degrees of Freedom
1. Revolute (R)		R	1
2. Cylinder (C)		C	2
3. Prism (P)		P	1
4. Sphere (S)		S	3
5. Helix (H)		H	1
6. Plane (P_L)		P_L	3

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Helical joints: Allow the motions of a cylindrical joint where the rotation angle and the translation length are coupled by a linear equation.

4. What are the performance parameters that must be addressed before choosing an actuator for a specific action?

To choose the most effective actuator for a particular application, critical information must first be ascertained. Factors such as **load capacity, operation speed, stroke length, environment, orientation, and positional accuracy** have to be identified and quantified.

5. Explain working of a robot in terms of forward and reverse kinematics

Pg 56-61

2.2 Discuss Forward and Reverse kinematics of 3DOF Robot arm.

❑ **Forward and Reverse Kinematics (Transformation) of Three Degree of Freedom Robot ARM**

- The position and orientation of the end-effector shown in Figure 2.3 in world space.

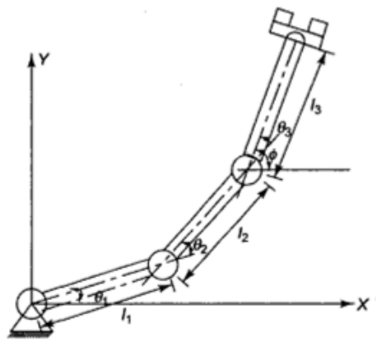


Fig. 2.3 Three DOF 2-D manipulator

Forward Transformation:

- The position of the end-effector shown in Figure 2.3 in world space can be determined from the joint angles and link parameters by the following equations,

$$x_3 = l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3)$$

$$y_3 = l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3)$$

- The orientation of the end-effector shown in Figure 2.3 in world space can be determined from the joint angles and link parameters by the following equations,

$$\varphi = \theta_1+\theta_2+\theta_3$$

❑ Reverse Transformation

- The joint angles can also be determined from the end-effector position (x_3, y_3) and the orientation position (φ), using reverse transformation in the following way

$$x_2 = x_3 - l_3\cos\varphi$$

$$= l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) - l_3\cos\varphi$$

$$= l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) - l_3\cos(\theta_1+\theta_2+\theta_3)$$

$$= l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2)$$

$$= l_1\cos\theta_1 + l_2[\cos\theta_1\cos\theta_2 - \sin\theta_1\sin\theta_2]$$

$$= l_1\cos\theta_1 + l_2\cos\theta_1\cos\theta_2 - l_2\sin\theta_1\sin\theta_2$$

Now $x^2{}_2 = (l_1\cos\theta_1 + l_2\cos\theta_1\cos\theta_2 - l_2\sin\theta_1\sin\theta_2)^2$

$$= (l_1\cos\theta_1 + l_2\cos\theta_1\cos\theta_2)^2 - 2(l_1\cos\theta_1 + l_2\cos\theta_1\cos\theta_2)l_2\sin\theta_1\sin\theta_2 + l^2{}_2\sin^2\theta_1\sin^2\theta_2$$

$$= l^2{}_1\cos^2\theta_1 + l^2{}_2\cos^2\theta_1\cos^2\theta_2 + 2l_1l_2\cos^2\theta_1\cos\theta_2 - 2l_1l_2\cos\theta_1\sin\theta_1\sin\theta_2 n^2\theta_2$$

$$- 2l^2{}_2\cos\theta_1\cos\theta_2\sin\theta_1\sin\theta_2 + l^2{}_2\sin^2\theta_1 si$$

$$x^2{}_2 = l^2{}_1\cos^2\theta_1 + l^2{}_2\cos^2\theta_1\cos^2\theta_2 + l^2{}_2\sin^2\theta_1\sin^2\theta_2 in\theta_2$$

$$+ 2l_1l_2\cos^2\theta_1\cos\theta_2 - 2l_1l_2\cos\theta_1\sin\theta_1\sin\theta_2 - 2l^2{}_2\cos\theta_1\cos\theta_2\sin\theta_1 s$$

(1)

$$y_2 = y_3 - l_3\sin\varphi$$

$$= l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3) - l_3\sin\varphi$$

$$= l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3) - l_3\sin(\theta_1+\theta_2+\theta_3)$$

$$= l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2)$$

$$= l_1\sin\theta_1 + l_2[\sin\theta_1\cos\theta_2 + \cos\theta_1\sin\theta_2]$$

$$= l_1\sin\theta_1 + l_2\sin\theta_1\cos\theta_2 + l_2\cos\theta_1\sin\theta_2$$

Now $y^2{}_2 = (l_1\sin\theta_1 + l_2\sin\theta_1\cos\theta_2 + l_2\cos\theta_1\sin\theta_2)^2$

$$= (l_1\sin\theta_1 + l_2\sin\theta_1\cos\theta_2)^2 + l^2{}_2\cos^2\theta_1\sin^2\theta_2 + 2(l_1\sin\theta_1 + l_2\sin\theta_1\cos\theta_2)l_2\cos\theta_1\sin\theta_2$$

$$y^2{}_2 = l^2{}_1\sin^2\theta_1 + l^2{}_2\sin^2\theta_1\cos^2\theta_2 + l^2{}_2\cos^2\theta_1\sin^2\theta_2 + 2l_1l_2\sin^2\theta_1\cos\theta_2 in\theta_2$$

6. Explain the 2 types of robotic kinematic movement.
2.1, pg-53

7. Describe the basic components of a robot with a neat sketch
No. 1.7 , pg -10
8. In what ways joints can be connected at a particular point at a particular orientation

https://robotacademy.net.au/masterclass/robotic-arms-and-forward-kinematics/?lesson=264

9. What is Cartesian control in robot manipulators? How does 3 dof Cartesian robot work?

WHAT IS 'CARTESIAN CONTROL'?
Cartesian Control is the ability to move a robotic manipulator arm, along linear cartesian axes. Or in simple terms, to move the robot arm forward, back, left, right, up, down in a straight line. Some robotic systems, namely 'Cartesian coordinate robots', are constrained to linear motion along defined axes. A good example of this is a CNC machine, or the claw game at your local arcade. For a more dexterous manipulator, that is predominately made up of revolute joints, this is less trivial and where Inverse Kinematics is absolutely required.

https://robotacademy.net.au/masterclass/robotic-arms-and-forward-kinematics/?lesson=264

2. Method for determining dynamics of a three-link manipulator

Matrix Lagrange equations of the second kind are widely used in the study of the dynamics of a robotic manipulator [19]. In kinematics, transition matrices are used to describe the transition from a coordinate system associated with a manipulator link to a subsequent coordinate system of another link. In the general case, the spatial transition from one coordinate system to another is described by six parameters. In [20] it is shown that the number of parameters for the transition can be reduced to four parameters.

We denote the origin O_i of the local coordinate system for the i-link of manipulator. The origin of the fixed global coordinate system is denoted by O_0.

In general form, the transition matrix is presented:

$$A_{i,i+1}=\begin{bmatrix}\cos(\alpha) & -\cos(\beta)\sin(\alpha) & \sin(\alpha)\sin(\beta) & b\cos(\alpha)\\ \sin(\alpha) & \cos(\alpha)\cos(\beta) & -\cos(\alpha)\sin(\beta) & b\sin(\alpha)\\ 0 & \sin(\beta) & \cos(\beta) & a\\ 0 & 0 & 0 & 1\end{bmatrix}$$

To determine the transition matrix from the global to the local coordinate system, it is necessary to multiply the matrices: $A_{0i}=A_{01}A_{12}\dots A_{i-1\,i}$

To compile a mathematical model of manipulator dynamics, matrix Lagrange equations of the form: $LT+DP=Q$, where

$L=\left[\frac{d}{dt}\left(\frac{\partial}{\partial\dot{q}_1}\right)-\frac{\partial}{\partial q_1},\dots,\frac{d}{dt}\left(\frac{\partial}{\partial\dot{q}_i}\right)-\frac{\partial}{\partial q_i}\right]$ - row vector of Lagrange operators,

q_i - generalized coordinates for manipulator links,

$T=\frac{1}{2}\sum_{i=1}^{n} tr\left(\frac{dA_{0i}}{dt}H_i\frac{dA_{0i}}{dt}^T\right)$ - kinetic energy of all links of manipulator,

$Q=[Q_1,...,Q_i]$ - generalized forces for manipulator links,

$D=\left[\frac{\partial}{\partial q_1},...,\frac{\partial}{\partial q_i}\right]$ - row vector of derivatives, H_i - link inertia matrix.

$P=-\sum_{i=1}^{n} m_i\begin{bmatrix}0 & 0 & g & 0\end{bmatrix}A_i\begin{bmatrix}x_i & y_i & z_i & 1\end{bmatrix}^T$ - potential energy for the gravity forces of all links of manipulator.

One of the most difficult tasks is the construction of an analytical solution to the system of equations for the manipulator dynamics. If it is possible to construct an analytical solution, then the task of research and design of manipulator is greatly simplified. The analytical solution can be constructed by various methods: linearization, averaging, Krylov-Bogolyubov, Van der Pol, small parameter, harmonic balance, Poincare perturbations, the method of differential inequalities. If it is not possible to construct an analytical solution to a nonlinear system with acceptable accuracy, then the numerical Runge-Kutta method is used.

In this work, we develop a mathematical model of a three-link manipulator for the study of which we use the method of transformations presented in the authors' work [21]. Having constructed an analytical solution, we obtain the dependences for the generalized coordinates, speeds and accelerations on the generalized forces of manipulator's electric drives. Using analytical dependences, we find the values of the generalized forces of electric drives, necessary for moving the gripper of manipulator along a given trajectory. To control the movement of manipulator along a given trajectory, it is necessary to solve the problem of the dynamics of manipulator.

Let us investigate the motion of a three-link manipulator with control. We will construct a mathematical model of manipulator in the form of a system of nonlinear differential equations of motion.

We represent the control action in the form of a piecewise-smooth function and control signals in the electric drive, providing uniform movement of manipulator grip at a constant height with a constant working speed.

Consider a three-link manipulator with cylindrical

The kinematic diagram of manipulator consists of three rotational kinematic pairs (Figure 1).

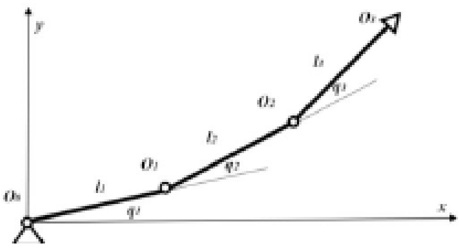


Fig. 1. Kinematic diagram of a three-link manipulator.

Let us denote the relative coordinate systems of the robot links in points O_1, O_2, O_3.

Define the angles of rotation of the links q_1, q_2, q_3 three-link manipulator as a function of time measured in radians.

Transition matrices are:

$$A_{01}=\begin{bmatrix} cos(q_1) & -sin(q_1) & 0 & l_1 cos(q_1) \\ sin(q_1) & cos(q_1) & 0 & l_1 sin(q_1) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, A_{12}=\begin{bmatrix} cos(q_2) & -sin(q_2) & 0 & l_2 cos(q_2) \\ sin(q_2) & cos(q_2) & 0 & l_2 sin(q_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

$$A_{13} = \begin{bmatrix} cos(q_3) & -sin(q_3) & 0 & l_3 cos(q_3) \\ sin(q_3) & cos(q_3) & 0 & l_3 sin(q_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

$$A_{02} = A_{01}A_{12} = \begin{bmatrix} C_{12} & -S_{12} & 0 & l_1C_1 + l_2C_{12} \\ S_{12} & C_{12} & 0 & l_1S_1 + l_2S_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad A_{03} = A_{01}A_{12}A_{23} = \begin{bmatrix} C_{123} & -S_{123} & 0 & l_1C_1 + l_2C_{12} + l_3C_{123} \\ S_{123} & C_{123} & 0 & l_1S_1 + l_2S_{12} + l_3S_{123} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Here, for brevity denoted: $C_k = cos(q_k), S_k = sin(q_k)$,

$C_{12} = \cos(q_1 + q_2), S_{12} = \sin(q_1 + q_2), C_{123} = \cos(q_1 + q_2 + q_3), S_{123} = \sin(q_1 + q_2 + q_3)$,

The equations of the kinematics of the 3-DOF manipulator are obtained.

The absolute coordinates of the grip of manipulator are determined as a function of the generalized coordinates:

$x_{03} = l_1 cos(q_1) + l_2 cos(q_1 + q_2) + l_3 cos(q_1 + q_2 + q_3)$, $y_{03} = l_1 sin(q_1) + l_2 sin(q_1 + q_2) + l_3 sin(q_1 + q_2 + q_3)$, $z_{03} = 0$.

11. List at least 5 types of lower pair connectors with their dof

No.1.9, pg-16-20

- A robot is essentially a moveable open chain of successively coupled bodies with one end fixed to the ground and the free end containing an end effector.
- The bodies of the open chain are usually links which are joined together by some lower pair connectors.
- The most common types of lower pair connectors are:
  - Revolute pair (1 DOF)
  - Prismatic pair (1 DOF)
  - Cylindrical pair (2 DOF)
  - Spherical pair (3 DOF)
  - Hooke joint (2 DOF)

❑ Revolute pair (1 DOF)

- The revolute pair (R)as shown in Figure 1.6
    - Permits relative rotation about a unique pair axis and
    - Has a single degree of freedom.

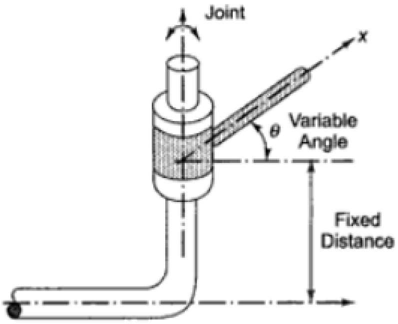


Fig. 1.6 Revolute pair (R)

❑ Prismatic pair (1 DOF)

- The prismatic pair (P) as shown in Figure 1.7
    - Allows relative sliding parallel with a unique pair axis and
    - Has one degree of freedom.

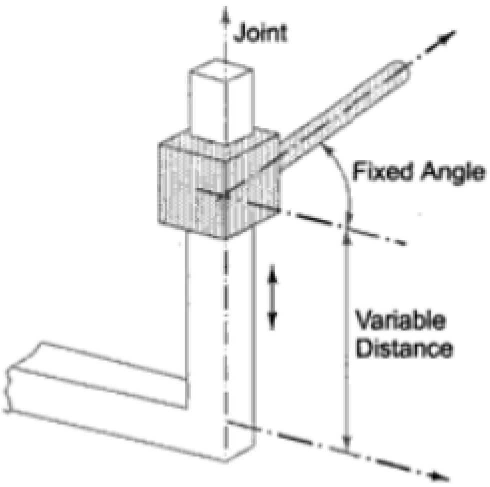


Fig. 1.7 Prismatic pair (P)

❑ Cylindrical pair (2 DOF)

- The cylindrical pair (C) illustrated in Figure 1.8
  - Permits independent relative rotation about and relative sliding parallel to a pair axis and
  - It has two degrees of freedom.

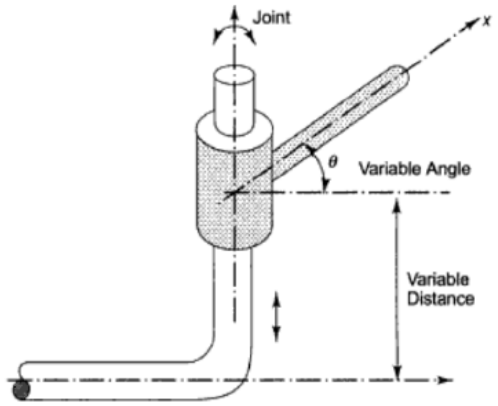


Fig. 1.8 Cylindrical pair (c)

❑ Spherical pair (3 DOF)

- The spherical pair (S) as shown in Figure 1.9 is a ball and socket joint that
  - Permits relative rotation about three non-coplanar interacting axes and
  - Has three degrees of freedom.

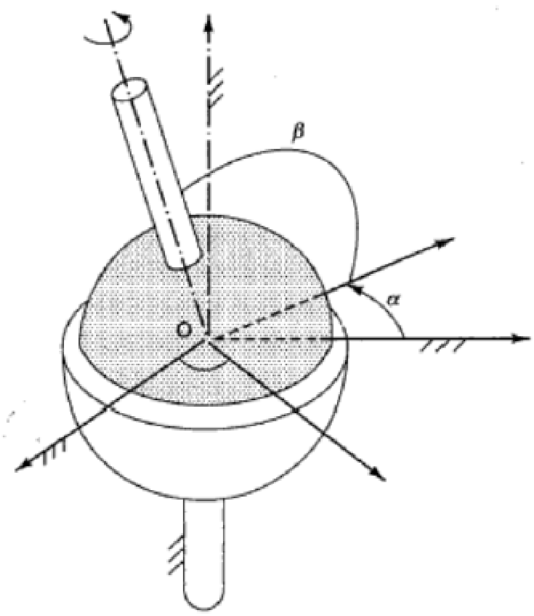


Fig. 1.9 Spherical pair (s)

❑ **Hooke joint (2 DOF)**

- Hooke's joint (T) as shown in Figure 1.10
    - Permits independent rotation about: two intersecting axes offset by an angle α and
    - Has two degrees of freedom.

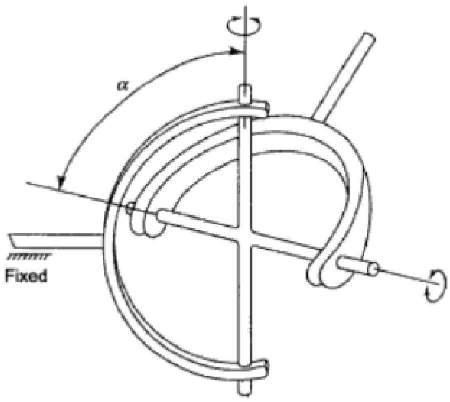


Fig. 1.10 Hooke's joint

12. How to assign denavit hartenberg frame to robotic arm with 2 dof?

https://robotacademy.net.au/lesson/denavit-hartenberg-notation/

13. Define the following parts of a robot - manipulator, end effector, actuator, gripper, sensors, control

Manipulator:
A robot manipulator is an electronically controlled mechanism, consisting of multiple segments, that performs tasks by interacting with its environment. They are also commonly referred to as robotic arms. Robot manipulators are extensively used in the industrial manufacturing sector and also have many other specialized applications (for example, the Canadarm was used on space shuttles to manipulate payloads). Manipulators are composed of an assembly of links and joints. Links are defined as the rigid sections that make up the mechanism and joints are defined as the connection between two links.

End Effector:
In robotics, an end effector is the device at the end of a robotic arm, designed to interact with the environment. The exact nature of this device depends on the application of the robot. In the strict definition, which originates from serial robotic manipulators, the end effector means the last link of the robot.

Actuators in robotics

An actuator is **a device that converts energy into physical motion**, and most actuators produce rotary or linear motion. The three major types of actuators are hydraulic, pneumatic, and electric, and picking the best one depends on what kind of robotic structure you are designing.

Gripper in robotics

Robot grippers are **the physical interface between a robot arm and the workpiece**. This end-of-arm tooling (EOAT) is one of the most important parts of the robot. One of the many benefits of material handling robots is the reduction of part damage.

- **Sensors -** Sensors provide real time information on the task environment. Robots are equipped with tactile sensor it imitates the mechanical properties of touch receptors of human fingerprints and a vision sensor is used for computing the depth in the environment.
- **Controller -** Controller is a part of robot that coordinates all motion of the mechanical system. It also receives an input from immediate environment through various sensors. The heart of robot's controller is a microprocessor linked with the input/output and monitoring device. The command issued by the controller activates the motion control mechanism, consisting of various controller, actuators and amplifier.

19. Define and classify robot end effectors.

In the robotics industry, an end effector is a tool, device or process sub-system attached to the end of a robot arm. End-of-arm devices are specially designed to interact with the working environment in which the robot operates. The tool and its programming depend on the project the robot is accomplishing. The tasks performed by end effectors in robotics can be complex and intricate.

Types of end effectors most commonly used in manufacturing processes include:

- Grippers
- Magnets
- Vacuum Heads
- Cameras
- Drills or Cutting Tools
- Brushes
- Force Sensors
- Screwdrivers
- Weld Tooling
- Adhesive Dispensing
- Paint Spray Guns

20. Explain working of stepper motor list 2 unique feature of stepper motor.

Stepper motor: Stepper motors are used for precise control of position of shaft. The shaft of motor rotates incrementally in equal steps in response to a programmed input pulse train.

To know the final position of the rotor all that is required is to count the no. of pulses fed into the motor stator phase winding.

— The no. of pulses per time unit determine the motor speed.,

— The step angles of the shaft are obtainable typically from 1.8° to 90° depending on the particular motor choice. Thus with a nominal step angle of 1.8° to stream of 1000 pulses with give an angular displacement Of 1800° or five complete revolutions.

— If more than one motor is driven from the same source then they will maintain perfect synchronization.

— Stepper motor can rotate in both directions.

— It can sustain a holding torque at zero speed.

— Stepper motor can be interfaced with digital circuit directly.

— It is used for lo power position control applications.

— For controlling motor feedback is not required but an encoder or position sensor is used to control motor accurately. This reduces feedback control complexity.

— Stepper motor has a lower output and efficiency as compared to other motors.

21. List our common imaging devices used for robot vision system. Explain working of segmentation and thresholding

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

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

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

22. What is a robot. Is robotics an automation?
1.6
Pg - 7
24. Define the types of servo motor controller and it's mode of operation.

Servomotors come in many sizes and in three basic types. The three types include positional rotation, continuous rotation, and linear.

- **Positional Rotation** Servos rotate 180 degrees. They also have stops in the gearbox to protect the output shaft from over-rotating.
- A **continuous rotation** servo motor is a servo whose range of motion is not limited. Instead of letting the input signal determine which position the servo should turn. The continuous rotation of the servo relates the input to the speed of the output and the direction. The limitless movement of these motors allows them to move in both CW and CCW directions.
- **Linear servos** use a rack and pinion mechanism to change their performance. The rack and pinion convert rotary motion into linear motion.

https://www.engineeringchoice.com/servo-motor/

10 marks

1. What are the applications of stand alone robotic systems/industrial robots? (Welding, machine loading, pick and place operation, painting, inspection of parts, sampling and sorting, assembly task)

1. Arc Welding
Arc welding, or robot welding, became commonplace in the 1980s. One of the driving forces for switching to robot welding is improving the safety of workers from arc burn and inhaling hazardous fumes.

2. Spot Welding
Spot welding joins two contacting metal surfaces by directing a large current through the spot, which melts the metal and forms the weld delivered to the spot in a very short time (approximately ten milliseconds).

3. Materials Handling
Material handling robots are utilized to move, pack and select products. They also can automate functions involved in the transferring of parts from one piece of equipment to another. Direct labor costs are reduced and much of the tedious and hazardous activities traditionally performed by human labor are eliminated.

4. Machine Tending
Robotic automation for machine tending is the process of loading and unloading raw materials into machinery for processing and overseeing the machine while it does a job.

5. Painting
Robotic painting is used in automotive production and many other industries as it increases the quality and consistency of the product. Cost savings are also realized through less rework.

6. Picking, Packing and Palletizing
Most products are handled multiple times prior to final shipping. Robotic picking and packaging increases speed and accuracy along with lowering production costs.

7. Assembly
Robots routinely assemble products, eliminating tedious and tiresome tasks. Robots increase output and reduce operational costs.

8. Mechanical Cutting, Grinding, Deburring and Polishing
Building dexterity into robots provides a manufacturing option that is otherwise very difficult to automate. An example of this is the production of orthopedic implants, such as knee and hip joints. Buffing and polishing a hip joint by hand can normally take 45-90 minutes while a robot can perform the same function in just a few minutes.

9. Gluing, Adhesive Sealing and Spraying Materials
Sealer robots are built with numerous robotic arm configurations that enable the robot to apply adhesives to any type of product. The primary benefit in this application is increased quality, speed and consistency of the final product.

10. Other Processes
These include inspection, waterjet cutting and soldering robots.

2. Discuss the classification of Robot languages. List and explain 3 basic modes of operation of robots

6.2 Discuss the classification of Robot languages.

❑ Classification of Robot Languages

- Robot languages can be grouped broadly into three major classes:

1. First generation language
2. Second generation language
3. World modeling and task-oriented object level language

6.2 , 6.3
Pg - 104 to 107

3. What is robot locomotion(walk, run, roll, swim, slithering)? How do autonomous robots function?

Robot locomotion is the collective name for the various methods that robots use to transport themselves from place to place.

Wheeled robots are typically quite energy efficient and simple to control. However, other forms of locomotion may be more appropriate for a number of reasons, for example traversing rough terrain, as well as moving and interacting in human environments. Furthermore, studying bipedal and insect-like robots may beneficially impact on biomechanics.

Walking

Walking robots simulate human or animal gait, as a replacement for wheeled motion. Legged motion makes it possible to negotiate uneven surfaces, steps, and other areas that would be difficult for a wheeled robot to reach, as well as causes less damage to environmental terrain as wheeled robots, which would erode it.[1]

Hexapod robots are based on insect locomotion, most popularly the cockroach[2] and stick insect, whose neurological and sensory output is less complex than other animals. Multiple legs allow several different gaits, even if a leg is damaged, making their movements more useful in robots transporting objects.

Examples of advanced running robots include ASIMO, BigDog, HUBO 2, RunBot, and Toyota Partner Robot.

Rolling

In terms of energy efficiency on flat surfaces, wheeled robots are the most efficient. This is because an ideal rolling (but not slipping) wheel loses no energy. A wheel rolling at a given velocity needs no input to maintain its motion. This is in contrast to legged robots which suffer an impact with the ground at heel strike and lose energy as a result.

For simplicity most mobile robots have four wheels or a number of continuous tracks. Some researchers have tried to create more complex wheeled robots with only one or two wheels.

These can have certain advantages such as greater efficiency and reduced parts, as well as allowing a robot to navigate in confined places that a four-wheeled robot would not be able to.

Examples: Boe-Bot, Cosmobot, Elmer, Elsie, Enon, HERO, IRobot Create, iRobot's Roomba, Johns Hopkins Beast, Land Walker, Modulus robot, Musa,Omnibot, PaPeRo, Phobot, Pocketdelta robot, Push the Talking Trash Can, RB5X, Rovio, Seropi, Shakey the robot, Sony Rolly, Spykee, TiLR, Topo, TR Araña, and Wakamaru.

Hopping

Several robots, built in the 1980s by Marc Raibert at the MIT Leg Laboratory, successfully demonstrated very dynamic walking. Initially, a robot with only one leg, and a very small foot, could stay upright simply by hopping. The movement is the same as that of a person on a pogo stick. As the robot falls to one side, it would jump slightly in that direction, in order to catch itself.[3] Soon, the algorithm was generalised to two and four legs. A bipedal robot was demonstrated running and even performing somersaults.[4] A quadruped was also demonstrated which could trot, run, pace, and bound.[5]

Examples:

- The MIT cheetah cub is an electrically powered quadruped robot with passive compliant legs capable of self-stabilizing in large range of speeds.[6]
- The Tekken II is a small quadruped designed to walk on irregular terrains adaptively.[7]

Metachronal motion

Coordinated, sequential mechanical action having the appearance of a traveling wave is called a metachronal rhythm or wave, and is employed in nature by ciliates for transport, and by worms and arthropods for locomotion.

Slithering

Several snake robots have been successfully developed. Mimicking the way real snakes move, these robots can navigate very confined spaces, meaning they may one day be used to search for people trapped in collapsed buildings.[8] The Japanese ACM-R5 snake robot[9] can even navigate both on land and in water.[10]

Examples: Snake-arm robot, Roboboa, and Snakebot.

Swimming

An **autonomous underwater vehicle** (**AUV**) is a robot that travels underwater without requiring input from an operator. AUVs constitute part of a larger group of undersea systems known as unmanned underwater vehicles, a classification that includes non-autonomous remotely operated underwater vehicles (ROVs) – controlled and powered from the surface by an operator/pilot via an umbilical or using remote control. In military applications an AUV is more often referred to as an **unmanned undersea vehicle** (**UUV**). Underwater gliders are a subclass of AUVs.

Brachiating

Brachiation allows robots to travel by swinging, using energy only to grab and release surfaces.[11] This motion is similar to an ape swinging from tree to tree. The two types of brachiation can be compared to bipedal walking motions (continuous contact) or running (ricochetal). Continuous contact is when a hand/grasping mechanism is always attached to the surface being crossed; ricochetal employs a phase of aerial "flight" from one surface/limb to the next.

Hybrid

Robots can also be designed to perform locomotion in multiple modes. For example, the Reconfigurable Bipedal Snake Robot[12] can both slither like a snake and walk like a biped robot.

Autonomous robots have the ability to gain information about their environments, and work for an extended period of time without human intervention. Examples of these robots range from autonomous helicopters to robot vacuum cleaners. These self-reliant robots can move themselves throughout the operation without human assistance, and are able to avoid situations that are harmful to themselves or people and property. Autonomous robots are also likely to adapt to changing surroundings.

Simpler autonomous robots use infrared or ultrasound sensors to see obstacles, allowing them to navigate around the obstacles without human control. More advanced robots use stereo vision to see their environments; cameras give them depth perception, and software allows them to locate and classify objects in real time.

5. Explain image processing and analysis. Identify the techniques used in image processing and analyse the output from a robotic machine vision model

Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it. It is a type of signal processing in which input is an image and output may be image or characteristics/features associated with that image. Nowadays, image processing is among rapidly growing technologies. It forms core research area within engineering and computer science disciplines too.

Image processing basically includes the following three steps:

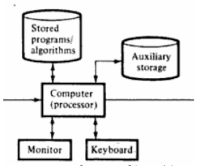
- Importing the image via image acquisition tools;
- Analysing and manipulating the image;
- Output in which result can be altered image or report that is based on image analysis.

There are two types of methods used for image processing namely, analogue and digital image processing. Analogue image processing can be used for the hard copies like printouts and photographs. Image analysts use various fundamentals of interpretation while using these visual techniques. Digital image processing techniques help in manipulation of the digital images by using computers. The three general phases that all types of data have to undergo while using digital technique are pre-processing, enhancement, and display, information extraction.

Image processing and Analysis

2) Image processing and Analysis

- Hardware



- Typical techniques and applications

1. Data reduction

Windowing

File formats and Compressions

Digital conversion

Image processing and Analysis

2. Segmentation

Thresholding

Region oriented Segmentation

Edge linking and boundary detection

Motion based segmentation

3. Feature extraction

Boundary and Regional Descriptors

4. Object recognition

Template matching etc.

1. Image data reduction

Objective is to reduce the volume of data.

Digital Conversion

It reduces the number of grey levels used.

Windowing

Portion of the total image for analysis.

File formats and Compression

Orderly sequence of data used to encode digital information for storage or exchange.

6. Derive forward and reverse transformation of a 2 degree of freedom arm of a robot

7. Define sensor, describe 5 characteristics of a sensing device?

5.3

Pg - 80

8. Write the advantages and disadvantages of robot. What are the types of sensors embedded in a robot?

5.2 pg - 74

9. Explain working of servo/stepper motor . How does application of stepper motor vary for forward and backward rotation.

3.4. Page - 64 (Stepper)

1.18. Page - 41 (Servo)

10. Explain the various types of joint pairs used in robot technology. How does linear, Cartesian and gantry robot vary from each other.

Cartesian robots consist of either a two axis or a three axis configuration. Two axis cartesian robots may be configured as either an X, Y setup or an X, Z setup. Three axis cartesian robots will have all three X, Y, and Z axes.

Workload positioning for cartesian robots is always supported on one of the outer axes, either the Y or Z axis. With a two axis cartesian X, Y robot the workload will be supported by the Y axis while a three axis cartesian the workload can be supported by either the Y or Z axis. Since cartesian robots use only their outer axes for supporting workloads their payload capacity can be limited.

Cartesian robots are commonly used for automating pick and place, assembly, and dispensing applications. Cartesian industrial robots are mainly used to automate processes requiring a travel distance of one meter or less.

The advantages of cartesian robots include their ease of programming and well defined work envelope. Since cartesian robots only move linearly, programming is simplified as there are fewer motions to calculate and only two to three axes to consider, unlike with the FANUC Lr Mate 200ic and other traditional robots. The rectangular work envelope of cartesian robots is well defined by their grid system making it easy to visualize, which can help with safeguarding and part placement.

Gantry Robots

While the number of axes for cartesian robots can vary between two and three, gantry robot grid systems always consist of all three X, Y, and Z axes. Another difference between gantry and cartesian configurations is gantry robots use two X axes. Some robots feature two X axes classifying it as a gantry robot as opposed to a cartesian robot. Some gantry robot systems may also have two Y or two Z axes.

Workload placement for a gantry robot is centralized within its footprint as opposed to only being supported by an outer axis as is the case with cartesian robots. The centralized workload placement allows gantry robots to overcome one of the limitations of cartesian robots which is payload capacity.

Gantry robots are used to automate applications requiring a travel distance greater than one meter. Gantry robots are commonly used for part transfer, palletizing, picking, machine loading, and assembly applications.

The advantages of gantry robots are their higher payload capacity and longer reach capabilities. The extra X axis provides additional support allowing gantry robots to handle heavier workloads for their size. Centralized workload positioning also helps increase their payload capacities. Their workload positioning also allows them to overcome the reach limitations of cartesian robots to cover greater distances.

16 marks

1. What are the various stages for implementating robotics for a company? Describe 3 stages of robotic technology development. Write the 3 basic laws of robotics. (4+4)

1. **Identify opportunities to automate.** It is essential to determine process adaptability to automation. Each unique process is more open/ viable to automation or not based on various factors such as process size, industry, current process, and SLAs.
2. **Validate the opportunity**. Check how adaptable the process is to being automated. If we look at most processes, we notice that they typically comprise both transaction and decision parts. Automation can be designed to achieve some quick wins on the transactional part which is the more time-consuming repetitive task.
3. **Select a design model**. Select the best model for your requirement. You may need to redesign the process to maximize the scope for automation. In some cases, this yields additional benefits. Design the automation plan that suits the business structure. Customize the automation model to suit the process needs. As one example of customizing a model, in one of the processes HGS recently automated for product build, we split the process into three distinct subprocesses: capturing the input, building the right codes, and then updating the systems. While building the right codes is where we need the product build experts, a lot of time was also spent on capturing the input and on updating the systems. In this case, we redesigned the process using automation to capture the inputs. Then our experts built codes, and automation was used to update the systems. This result was a 75 percent increase in efficiency for this particular process.
4. **Develop the automation plan.** Conduct a thorough study of the process and understand all the “exception” scenarios. Automate time-consuming repetitive tasks in processes that include these. Develop the automation implementation plan in phases, considering all of the level 3 scenarios. Instead of automating all scenarios, automate about 75% and have experts handling the rest of the scenarios. Evaluate plan performance at every phase and move to the next phase.
5. **Deploy the pilot phase.** When you develop an automation plan and are ready to implement it, run a pilot project first. This allows you to observe the effectiveness and overall performance of your automation plan with an actual process in real-time. Take the results of the pilot project and make improvements accordingly. Look at the results of the pilot and then include those scenarios that need to be automated and those that can remain an exception. It is good to involve the right stakeholders to understand the long-term plan and then plan the next steps. That has been a key takeaway: collaboration and involvement of client and relevant stakeholders. Sometimes there is a difference in testing and live environment, and there could be training for roll out.
6. **Roll out the plan**. Besides development of automation, build a plan needs for training and handling contingency depending on the criticality of the process. It is good to ensure that while people are trained on the revised process there is also documentation on the process before automation to handle any contingency due to a change in applications or systems.
7. **Maintain your automation activity**. Automation isn’t always a one-time activity, and it isn’t something you execute and then forget about. There will be changes in the process and systems, and there should be a good change management process to handle any changes. Estimate the impact of change in systems or process and have a plan ready for this. At this last phase, prepare a change management plan. It is critical to get all stakeholders to buy in. In some systems, even a field included in a drop-down menu may have an impact on the output, so there should be a plan to manage these.

—---OR—---

• Analyze your production process - You may already know which application you want to automate with robots, or you may have no idea. In either scenario it is a good idea to analyze your productions to ensure the application you have in mind will be a good candidate for automation or to identify a process that will benefit from robots. Applications that are repetitive, hazardous, or time-consuming usually are best for automation.

• Define Application - Once you have identified an application for automation you should define and document it. This will help identify materials, workpieces, and any additional equipment involved. This will help when it comes to selecting a robot.

• Determine robot requirements - Defining your application will help you identify the type of robot you will need, the maximum payload capacity, axes, reach requirements, etc. It will also help you determine what options will be needed for your robot. For instance, if your application involves some degree of variability then your robot will need to be integrated with a vision system.

• Conduct a risk assessment - A risk assessment is required by most robotic safety standards prior to robot installation. Risk assessments are used to ensure a safe work environment by identifying potential hazards and actions that can be taken to prevent them.

• Set budget - Determining your budget will likely determine if you will be purchasing a new or used robot. Setting your budget also ensures you do not exceed what is financially feasible for your company.

• Find a reputable robot seller - Once you have determined your budget the next step is deciding where to buy. There are many different options for buying robots including directly from the manufacturer, a robotic equipment company, a robotic integrator, or through an auction.

• Install robot - Once you have purchased your industrial robot it will need to be installed on your production floor. Depending on where you purchased your articulated robot and your technical training with robots you may need assistance form a third party, either a robotic engineer or technician.

• Train employees - It is important to properly train any employees that will be operating or working around the robot. They should have an understanding of programming, operating, and the safety features of the robotic system. This will help ensure a safe work environment and successful automation.

• Program and test - Prior to going live with your six-axis robot you will need to program it and test the program. The main programming methods for robots are taught pendants, offline software, and hand guidance. You will want a programming method that matches your level of expertise and also ensures efficiency. Testing the program allows for any bugs or inefficacies to be worked out for the most optimal operation.

1.4,1.5
Pg - 4-8

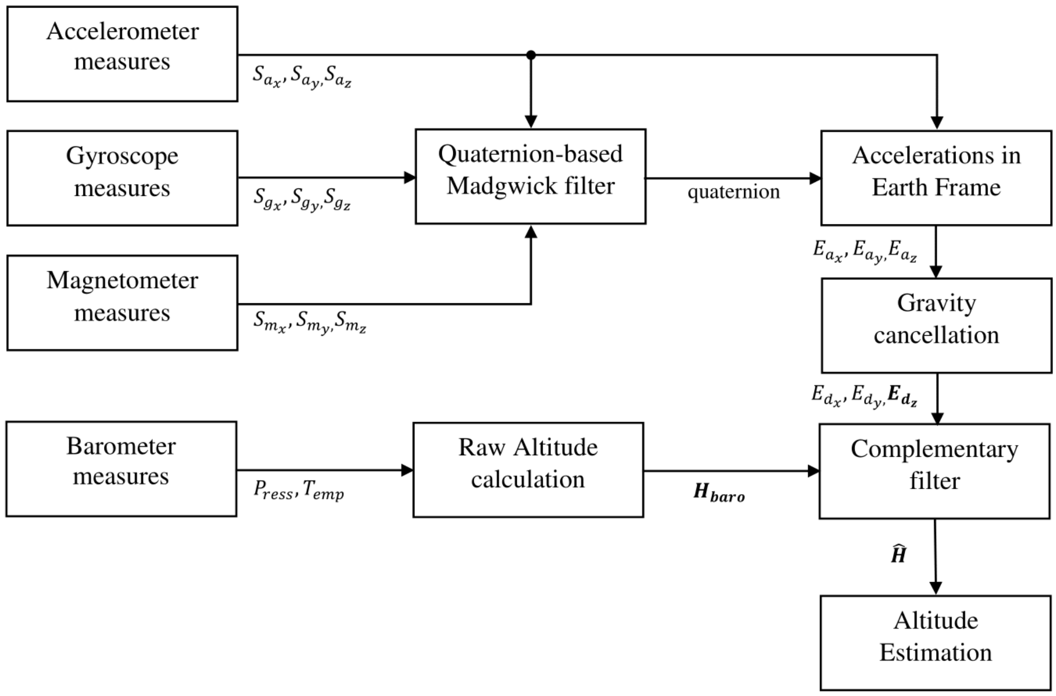
Stage 1: In the first stage, the organization sets out to test and pilot RPA in its processes. In this stage, it is usually a good idea to use a consultant and an expert with special know-how in the field of RPA as well as a vision about how Robotic Process Automation could benefit your company. It is typical to select one function and a few processes as starting points for piloting. With the help of the consultant, the benefits of RPA can be estimated quickly, and an action plan can be prepared for the development of RPA automation. The key is to increase your organization's understanding of RPA and gather experiences.

Stage 2: In the second stage, the organization expands the utilization of RPA to several functions and processes. The consultant can help to define complex sets of rules and assume part of the workload in training the robots. In this stage, the key is to share the information and know-how obtained in the pilot with the organization and to increase internal RPA capabilities in a determined manner.

Stage 3: In the third stage, RPA has become the standard procedure for increasing the organization's productivity, and it is managed through a centralized center of excellence or function-specific RPA teams. The organization possesses plenty of internal intellectual and knowledge capital on robotics and is able to maintain and develop these self-sufficiently. The key is to standardize RPA and to measure and manage competence and capabilities.

2. Describe robot vision. Describe 3 functions of its operation. List the operation under low and high vision. Distinguish between low-level and high-level vision. Explain sensor for localisation using block diagram

5.10, 5.11, 5.13
Pg - 93-98



The knowledge about the orientation of a body is very important for systems such as falls detection, human motion analysis and robotics ones. In order to describe the spatial orientation of the human body we adopt a representation through Yaw, Pitch and Roll angles. Starting from these angles, it is possible to describe rotations between two different reference systems, following a Z-Y-X rotation sequence.

AHRS system

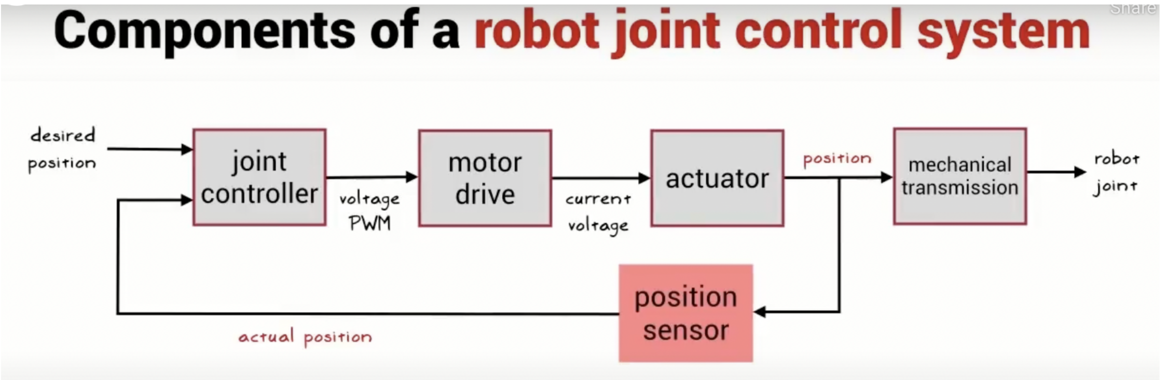
A combination of 3-axis magnetometer, gyroscope and accelerometer is required to realize a AHRS system which measures the local magnetic field, acceleration and angular rate in three dimensions.

Yaw describes a rotation around the Z-axis of the Earth frame, Pitch describes a rotation around the Y-axis of the Earth frame and Roll describes a rotation around the X-axis of the Earth frame.

An IMU (Inertial Measurement Unit) sensor combines the features of 3-axis accelerometer and a 3-axis gyroscope in order to provide complete information about acceleration, orientation, speed, position, etc. of a rigid body. Pitch and Roll angles are estimated by fusing angular displacements obtained by integration of the gyro and the accelerometer measurements. This solution allows to compensate the problem due to the influence of external vibrations and accelerations on gravity measurements. Again, the Yaw angle is subject to a very small amount of drift since there is no absolute reference point available for the heading.
An accurate estimation of the Yaw angle can be obtained by using an AHRS system that combine an IMU sensor with a 3-axis magnetic sensor. Through information coming from these sensors, the AHRS implements a filter able to provide an accurate estimation of the device orientation. The drift error introduced by the gyro sensor is compensated by two reference vectors, which are the gravity vector, measured by the accelerometer, and Earths magnetic field vector, measured by the magnetometer.

3. Explain the working of robotic joint control architecture. Compare the join torques given the robot joint position, velocities and acceleration and link Inertial parameters for a serial

link manipulator arm of a robot. Derive the equation of motion of a manipulator's arm using the Lagrangian equation of motion



The actuator is the device actually makes the robot joint move, it's the motor. The output of the motor is some position and we have a mechanical transmission which connects the output of the motor to the robot joint itself. The mechanical transmission itself is commonly a gearbox and some types of robots, it might be a cable drive.

The position of the motor is monitored by a position sensor and that gives a signal that says what is the actual position of the robot joint motor. An input to the system is the desired position and what we want to do is to move the motor until the actual position is equal to the desired position and that's the job of the joint controller and typically that's an imbedded micro controller. It's a piece of code running on a micro processor that provides the appropriate commands to the motor so that the actual position matches the desired position.

The output of the joint controller is typically some electronic signal. It might be a voltage or it might be a pulse with modulated waveform. This is input to the motor drive which is a lot of power electronics which controls the current or the voltage that's applied to the actuator.

The most important part of this robot joint control system is this feedback loop. It's where we compare the actual position of the motor with the desired position and compute a control signal to the actuator to make those two things equal.