G H Raisoni College of Engineering

An Empowered Autonomous Institute affiliated to Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur

Accredited by NAAC with “A++” Grade (3rd Cycle)

Subject: Robotics (UECL421)

Dr. Abhijit S. Titarmare

Department : Electronics and Telecommunication Engineering

abhijit.titarmare@raisoni.net/ 9665022707

Vision of the Institute

To achieve excellent standards of quality education by keeping pace with rapidly changing technologies and to create technical manpower of global standards with capabilities of accepting new challenges.

Mission of the Institute

Our efforts are dedicated to impart quality and value based education to raise satisfaction level of all stake-holders. Our strength is directed to create competent professionals. Our endeavor is to provide all possible support to promote research and development activities.

Vision of the Department

To achieve excellent standards of quality education by keeping pace with rapidly changing technologies and to create technical manpower of global standards in electronics engineering with capabilities of accepting new challenges.

Mission of the Department

Mission of the Department is

- **To create competent professionals who are trained in the design, implementation of engineering & telecommunication systems**
- **To contribute towards the advancement of engineering, science and technology**
- **To impart quality and value based education to raise satisfaction of all stake holders**
- **To promote research & development activities in the field of electronics & telecommunication engineering and allied areas**

Programme Educational Objectives

- **PEO1: Technical Competence:** Apply their technical skills to find solution of complex problems encountered in Modern Analog & Digital Electronics Engineering practices.
- **PEO2: Competent professionals:** Function effectively in the rapidly changing world in broad context of electronics engineering to develop new products and technologies for mankind.
- **PEO3:**Satisfaction of Stake holders and quality assurance, Citizenship in the Global Community, Value based education Cater to all Stakeholders, Quality Assurance & take up higher studies in electronics and allied areas in engineering
- **PEO4:Research and development innovation:** Utilize their skills in ethical and professional manner to contribute to research & development of innovative products and achieving Higher Education

Programme Outcomes (PO)

Graduates of shall be able to

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

Programme Outcomes (PO)

5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

Programme Outcomes (PO)

10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

Programme Specific Outcomes (PSOs)

Graduates of Electronics and Telecommunication Engineering shall be able to

PSO1: Demonstrate industrial practices learned through internship and solve the industrial problem using technical knowledge acquired.

PSO2: Apply skills in multi-disciplinary area of renewable energy, automotive, agricultural & heat transfer.

PSO3: Utilize skills in developing innovative prototype concepts enabling to protect intellectual property rights.

Scheme, Objectives, Outcomes & Syllabus

UECL421- Robotics

<table>
<tr><th rowspan="2">Semester</th><td rowspan="2">VII</td><td colspan="4" rowspan="2">Teaching Scheme</td><td colspan="5">Evaluation Scheme</td></tr>
<tr><td colspan="3">Theory</td><td colspan="2">Practical</td></tr>
<tr><th>Term</th><th>ODD</th><td>TH</td><td>TU</td><td>PR</td><td>Credits</td><td>TAE</td><td>CAE</td><td>ESE</td><td>INT</td><td>EXT</td></tr>
<tr><th>Course Category</th><td>EL</td><td rowspan="2">3</td><td rowspan="2">-</td><td rowspan="2">2</td><td rowspan="2">4</td><td rowspan="2">10</td><td rowspan="2">15</td><td rowspan="2">50</td><td rowspan="2">25</td><td rowspan="2">-</td></tr>
<tr><th>Course Code</th><th>UECL421
UECP421</th></tr>
<tr><th>Teaching Mode</th><td>Offline</td><td colspan="3" rowspan="2">5</td><td rowspan="2">TOTAL</td><td colspan="3">75</td><td colspan="2">25</td></tr>
<tr><th>Duration of ESE</th><td>2 Hrs.</td><td colspan="5">100</td></tr>
</table>

Course Objectives:

1. **The objective is to impart knowledge about basic theory and mathematics related to robots.**

2. **To study robots and their control, design and application in robotics & automation Industries.**

Course Outcomes:

Upon successful completion of this course, student will be able to:

CO-1: Understand the kinematic and dynamic concept of Robots.

CO-2: Analysis the control laws for a simple robot.

CO-3: Integrate mechanical and electrical hardware for a real prototype of robotic.

CO-4: Select a robotic system for given industrial application.

Mapping of Course Outcomes with Program Outcomes:

Course Outcomes	Program Outcomes											
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	2	3	3								
CO2	3	3	3	2								
CO3	3	3	2	3								
CO4	2	2	2	2								

Contents:

UNIT-I: (8 hrs)

Introduction to Robotics: Definition of Robots, Need and purpose of Robots, Introduction to Various Industrial robot Systems, Components of Robots, Types and Classification of robots; Concept of moving robots and arm robots. Classification of robotic systems, anatomy, Specifications and configuration. Basic concepts and terminology. Basic components in a typical robot system, Industrial and other applications of robots.

UNIT-II: (8 hrs)

Robot Kinematics and Dynamics : Orientations and frames, Mappings: Changing descriptions from frame to frame, Operators: Translations, Rotations and Transformations - Transformation Arithmetic - DH Representation - Forward and inverse Kinematics Of Six Degree of Freedom Robot Arm – Robot Arm dynamics, Statics of planer arm robot, Mass and inertia of links,

UNIT-III: (8 hrs)

Robot Actuation Systems Actuators: Electric, Hydraulic and Pneumatic; Transmission: Gears, Timing Belts and Bearings, Robotic sensors/actuators, Selection parameters of actuators.

UNIT-IV: (6 hrs)

Basics of Robot Control: open loop and closed loop system, Transfer functions for both loops, Control laws: P, PD, PID, Linear and Non-linear controls, Arm and body motions, Wrist motions

UNIT-V: (10 hrs)

Implementation of Robot: Hardware and Interfacing of various communication modules above mentioned Robots, Microcontroller Architecture and integration with sensors, actuators, components, Programming of Robots, Implementation of Line Follower and Obstacle detection Robot using suitable hardware board.

Text Books:

1. J. J. Craig, Introduction to Robotics, Addision-Wesley,1989.
2. Y. Koren, Robotics for Engineers, MsGraw Hill,1985.
3. Ghosal A. Robotics: Fundamental Concepts and Analysis, Oxford University Press, 2006.
4. Microcontroller and Embedded system by Muhammad Ali *Mazidi*

Reference Books:

1. Correll N., Introduction to Autonomous Robots, v1.7, Magellan Scientific, 2016. ISBN-13: 978-0692700877.

2. Saha. S.K., Introduction to Robotics, McGraw Hill Education (India) Private Limited, 2014.

3. Spong M.W., Hutchinson S. and Vidyasagar M., Robot Modeling and Control, John Wiley Sons & Inc., 2005

UNIT-I: Introduction to Robotics:

- Definition of Robots,
- Need and purpose of Robots,
- Introduction to Various Industrial robot Systems,
- Components of Robots,
- Types and Classification of robots;
- Concept of moving robots and arm robots.
- Classification of robotic systems,
- anatomy,
- Specifications and configuration.
- Basic concepts and terminology.
- Basic components in a typical robot system,
- Industrial and other applications of robots.

Robotics Timeline

- 1922 Czech author Karel Capek wrote a story called Rossum's Universal Robots and introduced the word "Rabota"(meaning worker)
- 1954 George Devol developed the first programmable Robot.
- 1955 Denavit and Hartenberg developed the homogenous transformation matrices
- 1962 Unimation was formed, first industrial Robots appeared.
- 1973 Cincinnati Milacron introduced the T3 model robot, which became very popular in industry.
- 1990 Cincinnati Milacron was acquired by ABB

Definition for Robot:

- Defined by Robotics Industry Association (RIA) as
  - A re-programmable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motion for a variety of tasks

  possess certain anthropomorphic characteristics
  - mechanical arm
  - sensors to respond to input
  - Intelligence to make decisions

- The Robot Institute of America (1969) defines robot as a re-programmable, multifunctional manipulator designed to move materials, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks.

Asimov's laws of robotics:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

Asimov’s laws of robotics:

First Law:

A robot may not injure a human being or, through inaction, allow a human being to come to harm.

Second Law:

A robot must obey the orders given it by human beings, except where such orders would conflict with the First Law.

Third Law:

A robot must protect its own existence as long as such protection does not conflict with the First or Second Law

A general-purpose, programmable machine possessing certain anthropomorphic characteristics

- Hazardous work environments
- Repetitive work cycle
- Consistency and accuracy
- Difficult handling task for humans
- Multi shift operations
- Reprogrammable, flexible
- Interfaced to other computer systems

Need of Industrial Robots

- Repetitive tasks that robots can do 24/7.
- Robots never get sick or need time off.
- Robots can do tasks considered too dangerous for humans.
- Robots can operate equipment to much higher precision than humans.
- May be cheaper over the long term
- May be able to perform tasks that are impossible for humans

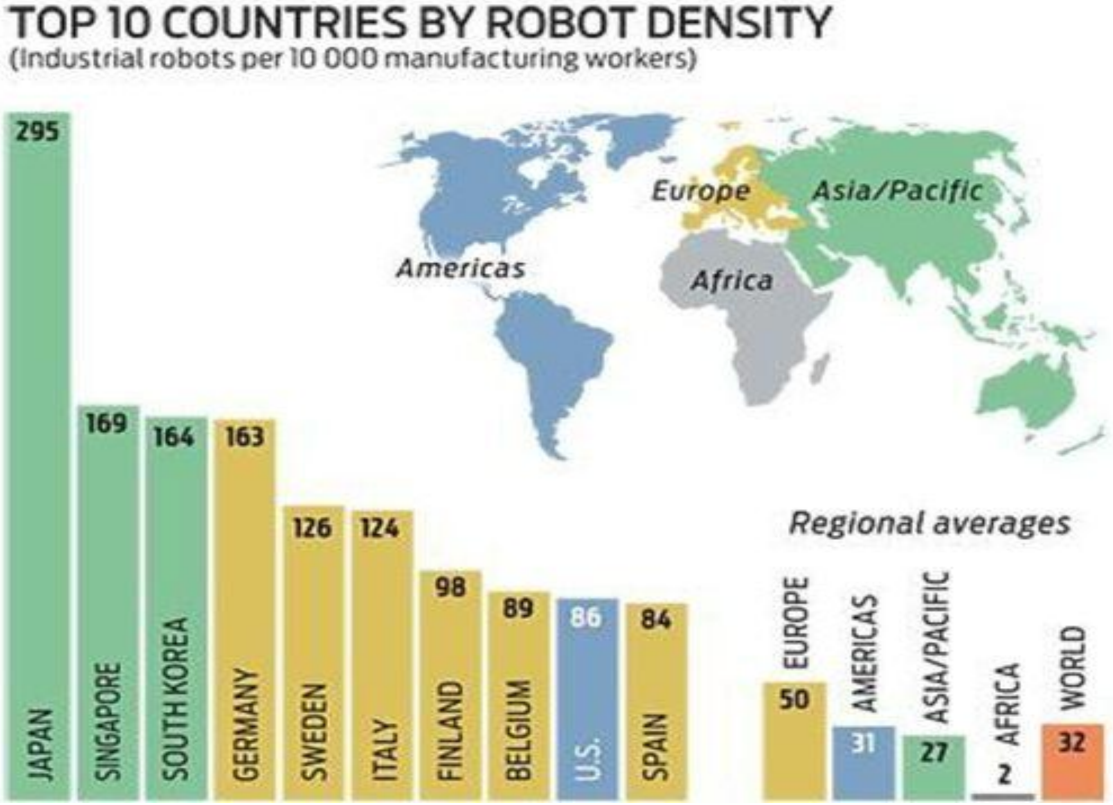
Robots are also used for the following tasks:

- Dirty Tasks
- Repetitive tasks
- Dangerous tasks
- Impossible tasks
- Robots assisting the handicapped

First, they are hardworking and reliable. They can do dangerous work or work that is very boring or tiring for humans. They can work around the clock without complaining and without needing rest, food or vacations. And robots can go places that humans cannot, such as the surface of Mars, deep under the ocean or inside the radioactive parts of a nuclear power plant

Industrial Robot Applications

1. Material handling applications
   - Material transfer – pick-and-place, palletizing
   - Machine loading and/or unloading
2. Processing operations
   - Welding
   - Spray coating
   - Cutting and grinding
3. Assembly and inspection



Introduction to Various Industrial robot Systems

- TRANSPORT
- Handling
- Pick-and-place
- Loading / Unloading machines
- Palletizing packing
- MANUFACTURE
- Selection of parts
- Spot welding
- Arc welding
- Sealing, gluing
- Assembly (assembly)
- Milling, drilling
- Pressing
- Deburring, grinding
- Screwing, wiring
- Painting
- MEASURE
- Dimensional test
- Profile detection
- Identification of manufacturing defects

Components of Robots

- Mechanical platforms or hardware base
- Sensors
- Manipulator: Joints & Links
- Controller
- Power Source
- Artificial intelligence
- Actuators

Mechanical platforms or hardware base is a mechanical device, such as a wheeled platform, arm, fixed frame or other construction, capable of interacting with its environment and any other mechanism involve with his capabilities and uses.

Sensors systems is a special feature that rest on or around the robot. This device would be able to provide judgment to the controller with relevant information about the environment and give useful feedback to the robot.

Manipulator

A robot manipulator, often called a robotic arm, is a mechanical device designed to interact with its environment by moving and manipulating objects. It's essentially a programmed arm-like structure with multiple segments and joints that can be controlled to perform repetitive tasks automatically. These manipulators are widely used in various industries for tasks like assembly, material handling, welding, and more. **It consists of joints and links**

Joints provide more versatility to the robot itself and are not just a point that connects two links or parts that can flex, rotate, revolve and translate. Joints play a very crucial role in the ability of the robot to move in different directions providing more degree of freedom.

- Joints provide relative motion
- Links are rigid members between joints
- Various joint types: linear and rotary
- Each joint provides a “degree-of-freedom”
- Body-and-arm – for positioning of objects in the robot's work volume
- Wrist assembly – for orientation of objects

Controller functions as the "brain" of the robot. Robots today have controllers that are run by programs - sets of instructions written in code. In other words, it is a computer used to command the robot memory and logic. So it, be able to work independently and automatically.

Power Source is the main source of energy to fulfill all the robots needs. It could be a source of direct current as a battery, or alternate current from a power plant, solar energy, hydraulics or gas.

Artificial intelligence represents the ability of computers to "think" in ways similar to human beings. Present day "AI" does allow machines to mimic certain simple human thought processes, but cannot begin to match the quickness and complexity of the brain. On the other hand, not all robots possess this type of capability. It requires a lot of programming and sophisticates controllers and sensorial ability of the robot to reach this level.

Actuators are the muscles of robot. An actuator is a mechanism for activating process control equipment by the use of pneumatic, hydraulic or electronic signals. There are several types of actuators in robotic arms namely synchronous actuator – brush and brushless DC servo, stepper motor and asynchronous actuator – AC servo motor, traction motor, pneumatic, hydraulic.

Types And Classification of Robots

1) **According to the structural capability of robot** –

i) **Mobile robot**: A mobile robot is an automatic machine that is capable of locomotion. . Example: spying robot. Mobile robots have the capability to move around in their environment and are not fixed to one physical location. Mobile robots can be "autonomous" (AMR - autonomous mobile robot) which means they are capable of navigating an uncontrolled environment without the need for physical or electro-mechanical guidance devices. Alternatively, mobile robots can rely on guidance devices that allow them to travel a pre-defined navigation route in relatively controlled space (AGV - autonomous guided vehicle). By contrast, industrial robots are usually more-or-less stationary, consisting of a jointed arm (multi-linked manipulator) and gripper assembly (or end effector), attached to a fixed surface

ii) **Fixed Robot**: Most industrial robots are fixed with the base but the arms are moving.

2) According to the control

To perform as per the program instructions, the joint movements an industrial robot must accurately be controlled. Micro-processor-based controllers are used to control the robots. Different types of control that are being used in robotics are given as follows.

a. Limited Sequence Control:

It is an elementary control type. It is used for simple motion cycles, such as pick-and- place operations. It is implemented by fixing limits or mechanical stops for each joint and sequencing the movement of joints to accomplish operation. Feedback loops may be used to inform the controller that the action has been performed, so that the program can move to the next step. Precision of such control system is less. It is generally used in pneumatically driven robots.

b. Playback with Point-to-Point Control

Playback control uses a controller with memory to record motion sequences in a work cycle, as well as associated locations and other parameters, and then plays back the work cycle during program execution. Point-to-point control means individual robot positions are recorded in the memory. These positions include both mechanical stops for each joint, and the set of values that represent locations in the range of each joint. Feedback control is used to confirm that the individual joints achieve the specified locations in the program.

c. Playback with Continuous Path Control

Continuous path control refers to a control system capable of continuous simultaneous control of two or more axes. The following advantages are noted with this type of playback control: greater storage capacity—the number of locations that can be stored is greater than in point-to-point; and interpolation calculations may be used, especially linear and circular interpolations.

d. Intelligent Control

An intelligent robot exhibits behavior that makes it seems to be intelligent. For example, it may have capacity to interact with its ambient surroundings; decision-making capability; ability to communicate with humans; ability to carry out computational analysis during the work cycle; and responsiveness to advanced sensor inputs. They may also possess the playback facilities. However, it requires a high level of computer control, an advanced programming language for decision-making logic and other intelligence' into the memory.

Concept of Moving robots and Arm robots.

Moving robots

Robots that can navigate in an environment.

- Types:
  - Wheeled Robots
  - Tracked Robots
  - Legged Robots
- Sensors: LIDAR,Ultrasonic,Infrared,Camera
- Components:
  - Microcontroller
  - Motors and Drivers
  - Sensors (Obstacle detection, Positioning)
- Navigation methods:
  - Line Following
  - GPS / SLAM based

Arm robots

Stationary robots with mechanical arms.

- Features:
  - Multiple joints (Degrees of Freedom)
  - Base, Arm, End-effector, Actuators
- Used for object manipulation and precision tasks.
- Arm Robot Configurations
  - RRR (Articulated Arm)
  - PPP (Cartesian Arm)
  - RRP / RPP / PRP (Cylindrical, Polar types)

Configurations define motion capabilities and structure.

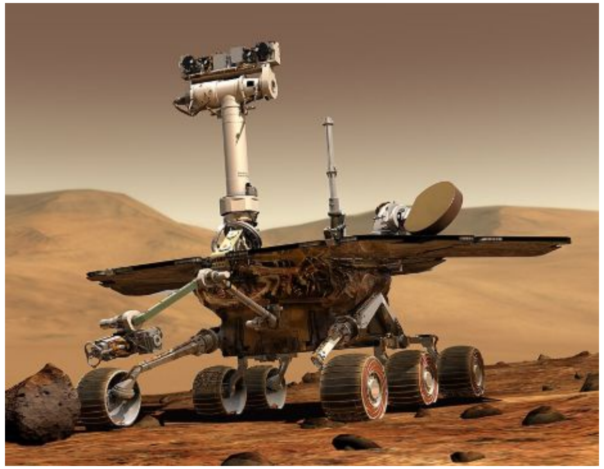
Comparison: Moving vs Arm Robots

	Moving Robots	Arm Robots
Mobility	Yes	No
Task	Navigation	Manipulation
Examples	Delivery robot	Industrial arm
Sensors	Navigation-based	Precision-based

- Moving robots offer mobility; Arm robots provide manipulation.
- Applications span across industries and research.
- Future is heading toward intelligent, collaborative robots.

Applications

Moving Robots	Arm Robots
- Warehouse automation (Amazon) - Surveillance and rescue - Boston Dynamics’ Spot - Mars Rover	- Assembly and welding - Medical surgeries - KUKA, ABB Industrial Arms - Da Vinci Surgical Robot



Future Trends:

-Integration of AI and Machine Learning

-Cobots (Collaborative Robots)

-Swarm robotics

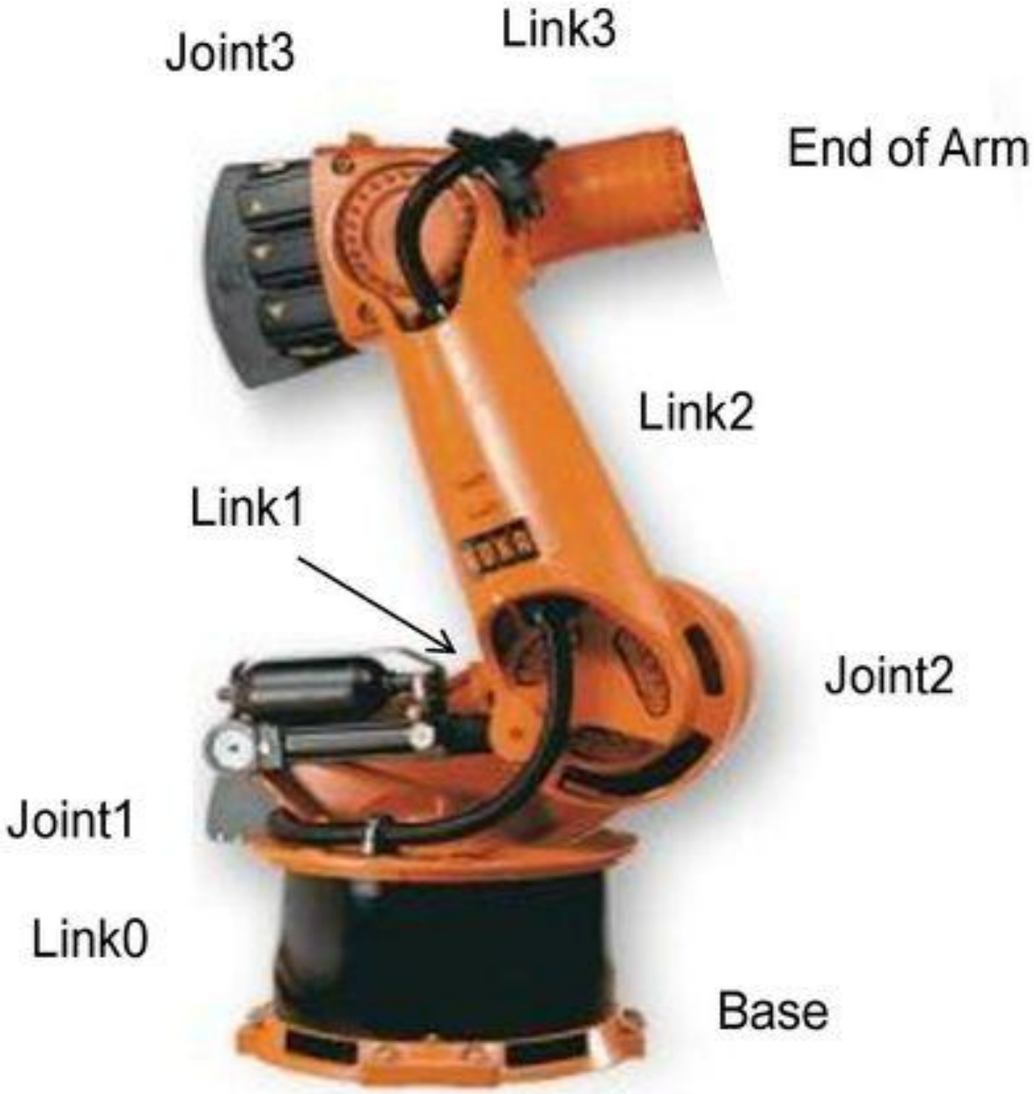
-Multi-robot systems and autonomy

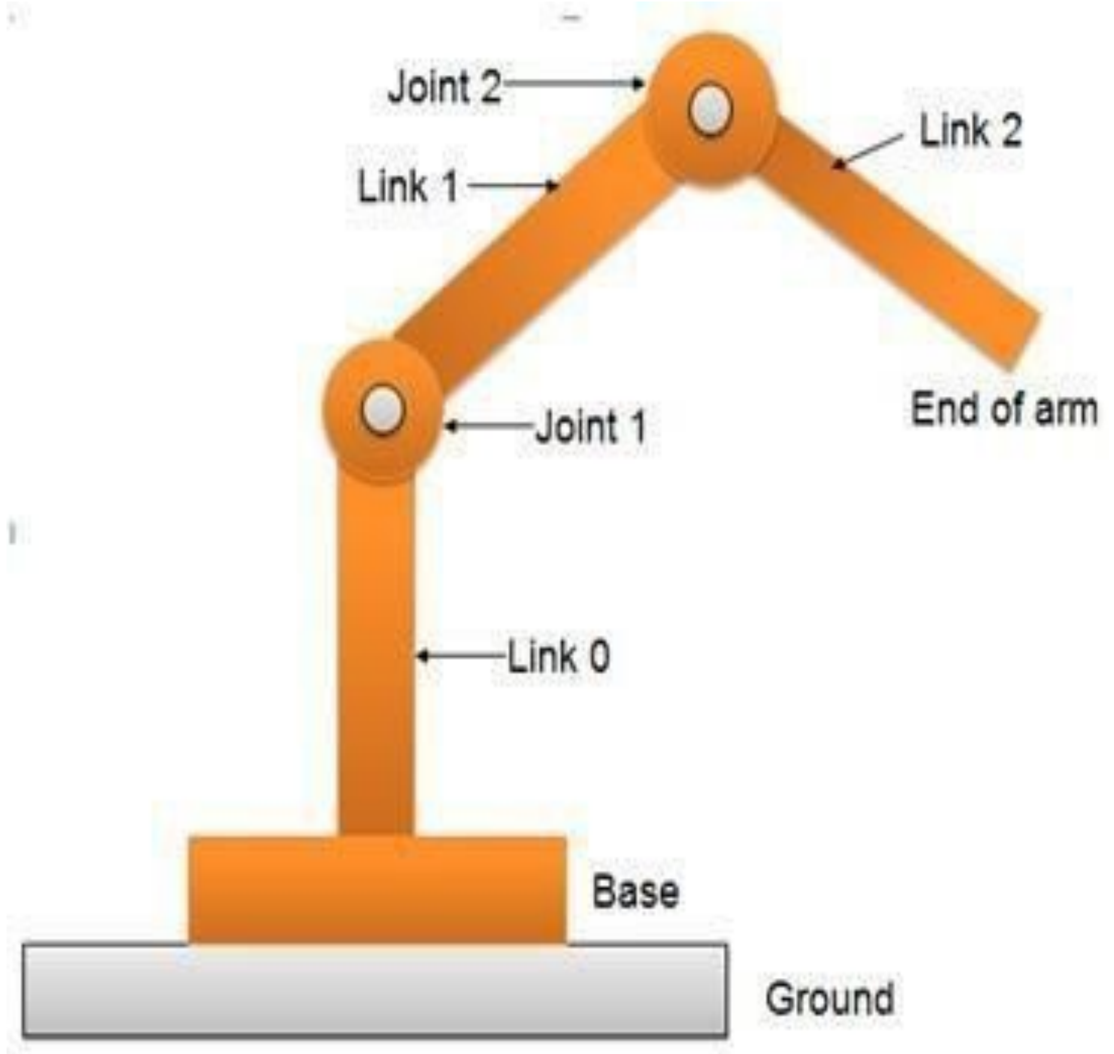
Robot Anatomy

- The manipulator of an industrial robot consists of a series of joints and links.
- Robot anatomy deals with the study of different joints and links and other aspects of the manipulator's physical construction.
- A robotic joint provides relative motion between two links of the robot.
- Each joint, or axis, provides a certain degree-of-freedom (DOF) of motion.
- In most of the cases, only one degree-of- freedom is associated with each joint.
- The robot's complexity can be classified according to the total number of degrees-of-freedom they possess.

- Each joint is connected to two links, an input link and an output link.
- Joint provides controlled relative movement between the input link and output link.
- A robotic link is the rigid component of the robot manipulator.
- Most of the robots are mounted upon a stationary base, such as the floor. From this base, a joint-link numbering scheme may be recognized as shown in Figure

Robot Anatomy





Joint-link scheme for robot manipulator

- The robotic base and its connection to the first joint are termed as link-0.
- The first joint in the sequence is joint-1. Link-0 is the input link for joint-1, while the output link from joint-1 is link-1 which leads to joint-2.
- The link 1 is simultaneously the output link for joint-1 and the input link for joint-2. This joint-link-numbering scheme is further followed for all joints and links in the robotic systems.

Industrial robots have mechanical joints that can be classified into

following five types

a) **Linear joint (type L)**

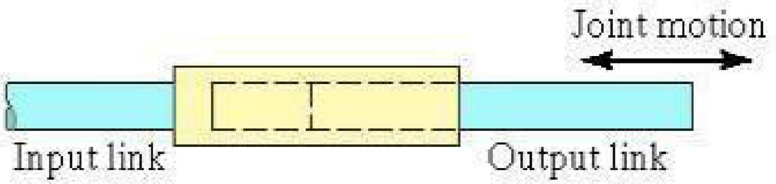
b) **Orthogonal joint (type O)**

c) **Rotational joint (type R)**

d) **Twisting joint (type T)**

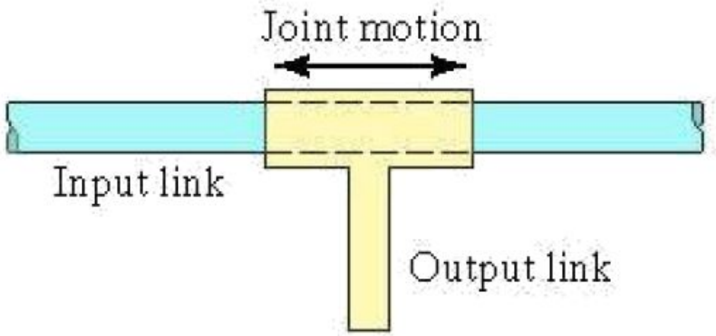
e) **Revolving joint (type V)**

a) Linear joint (type L joint)



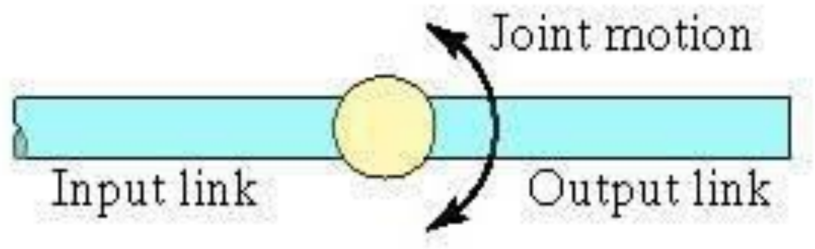
The relative movement between the input link and the output link is a translational sliding motion, with the axes of the two links being parallel.

b) Orthogonal joint (type U joint)



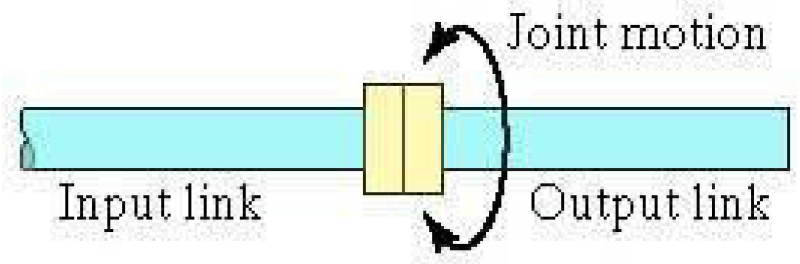
This is also a translational sliding motion, but the input and output links are perpendicular to each other during the movement.

c) Rotational joint (type R joint)



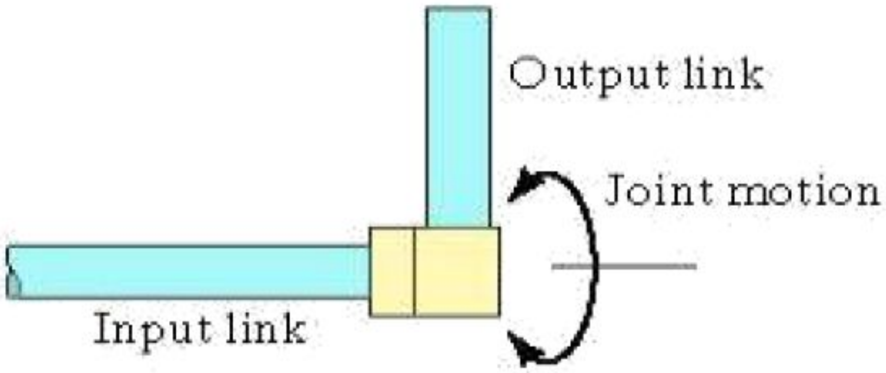
This type provides rotational relative motion, with the axis of rotation perpendicular to the axes of the input and output links.

d) Twisting joint (type T joint)



This joint also involves rotary motion, but the axis or rotation is parallel to the axes of the two links.

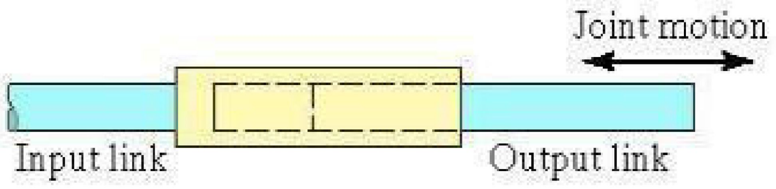
e) Revolving joint (type V-joint, V from the "v" in revolving)



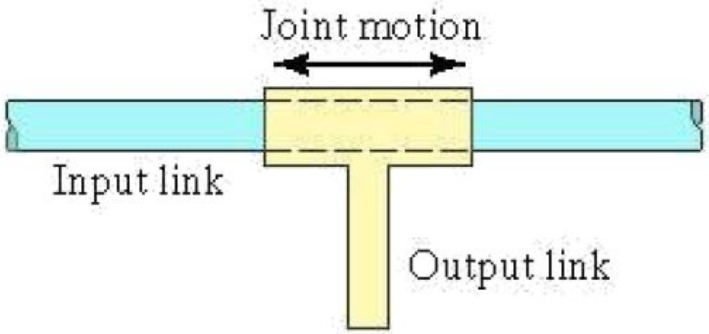
In this type, axis of input link is parallel to the axis of rotation of the joint. However the axis of the output link is perpendicular to the axis of rotation.

Translational motion

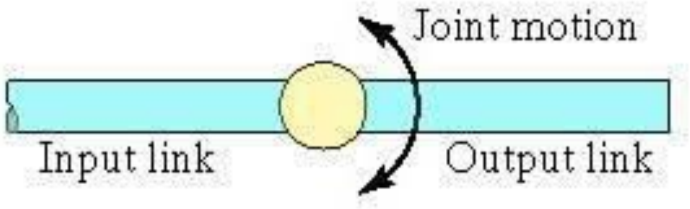
a) Linear joint (type L)



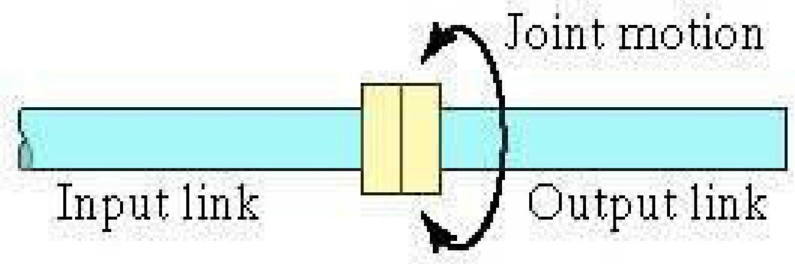
b) Orthogonal joint (type O)



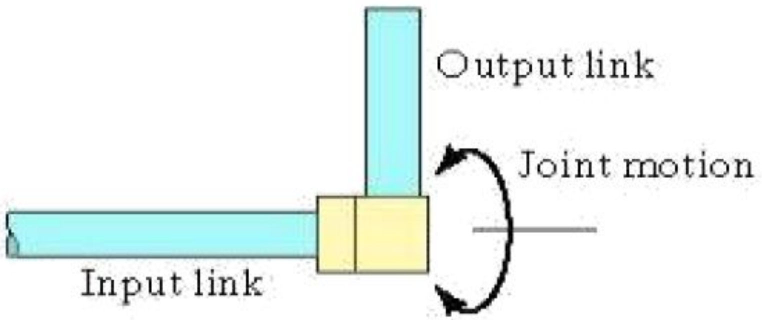
c) Rotational joint (type R)



d) Twisting joint (type T)



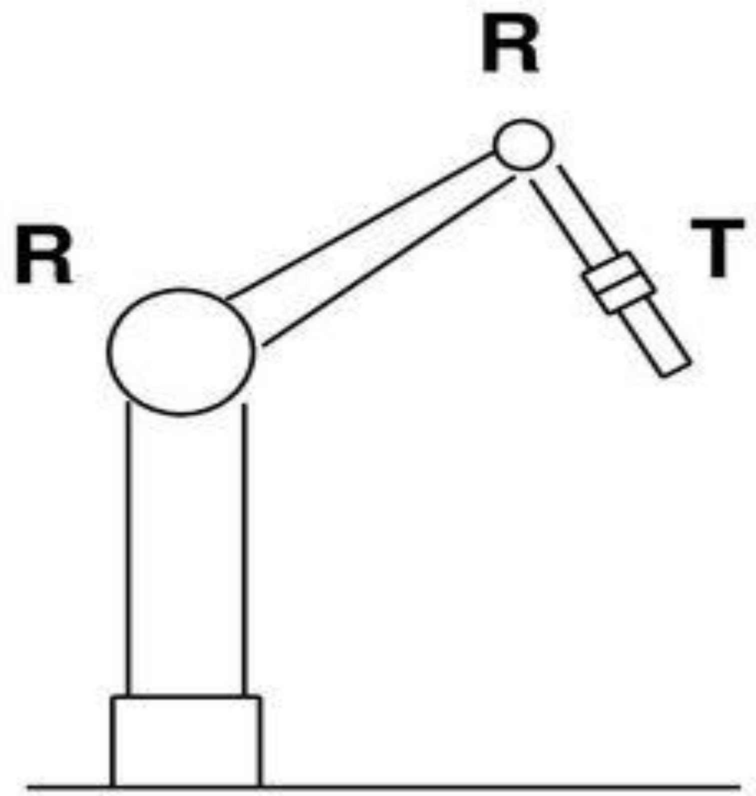
e) Revolving joint (type V)



Example

- Sketch following manipulator configurations
- (a) TRT:R, (b) TVR:TR, (c) RR:T.

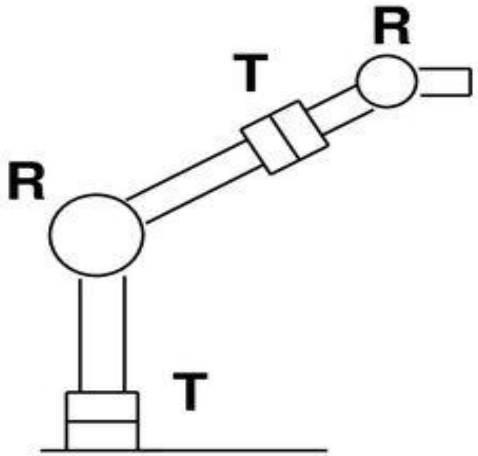
RR:T Configuration



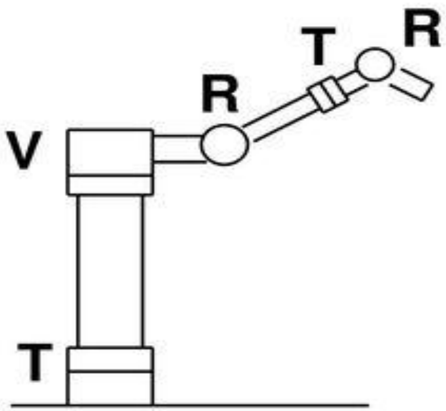
Example

- Sketch following manipulator configurations
- (a) TRT:R, (b) TVR:TR, (c) RR:T.

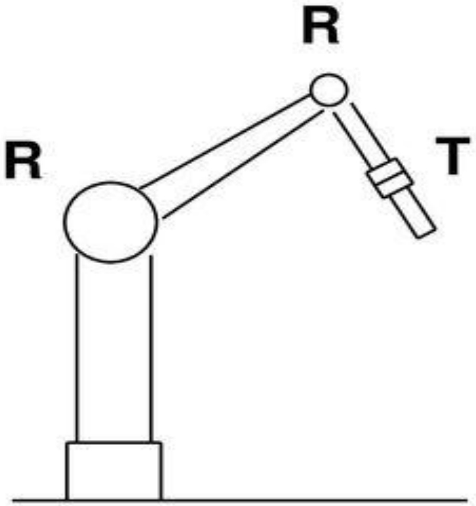
Solution:



(a) TRT:R



(b) TVR:TR



(c) RR:T

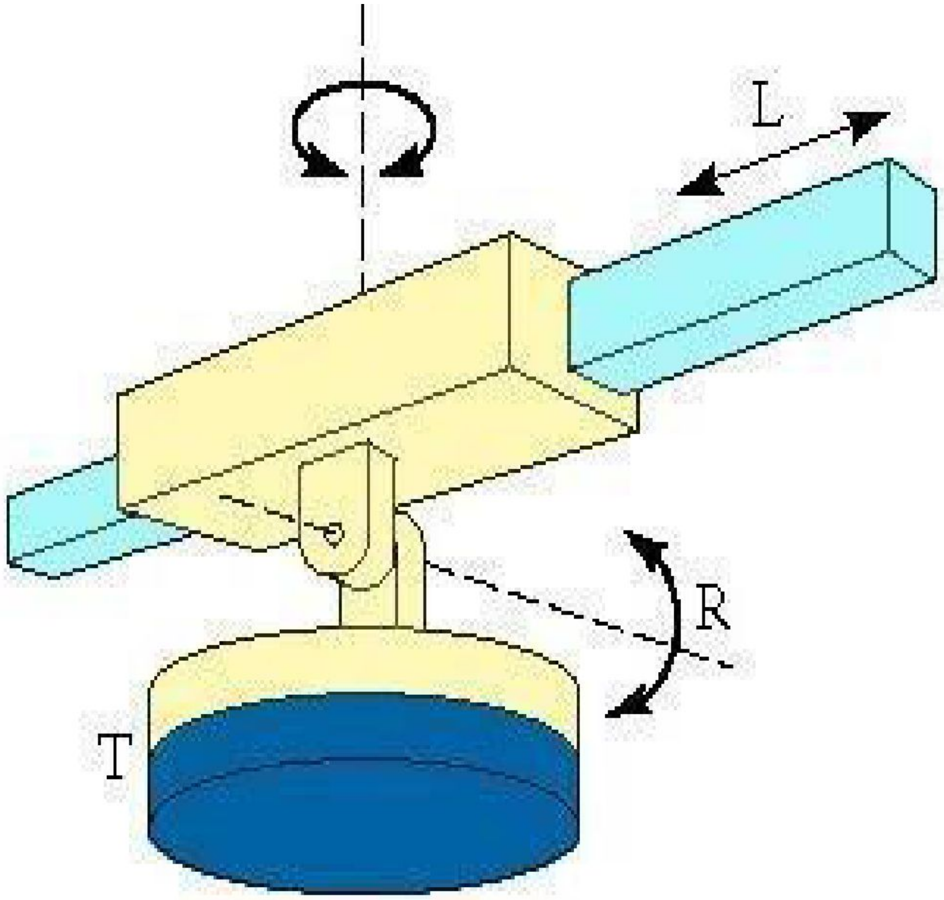
Robotic arm configurations

For body-and-arm configurations, there are many different combinations possible for a three-degree-of-freedom robot manipulator, comprising any of the five joint types.

Common body-and-arm configurations are as follows.

1) Polar coordinate arm configuration
2) Cylindrical coordinate arm configuration
3) Cartesian coordinate arm configuration
4) Jointed arm configuration

1) Polar coordinate arm configuration(RRP):



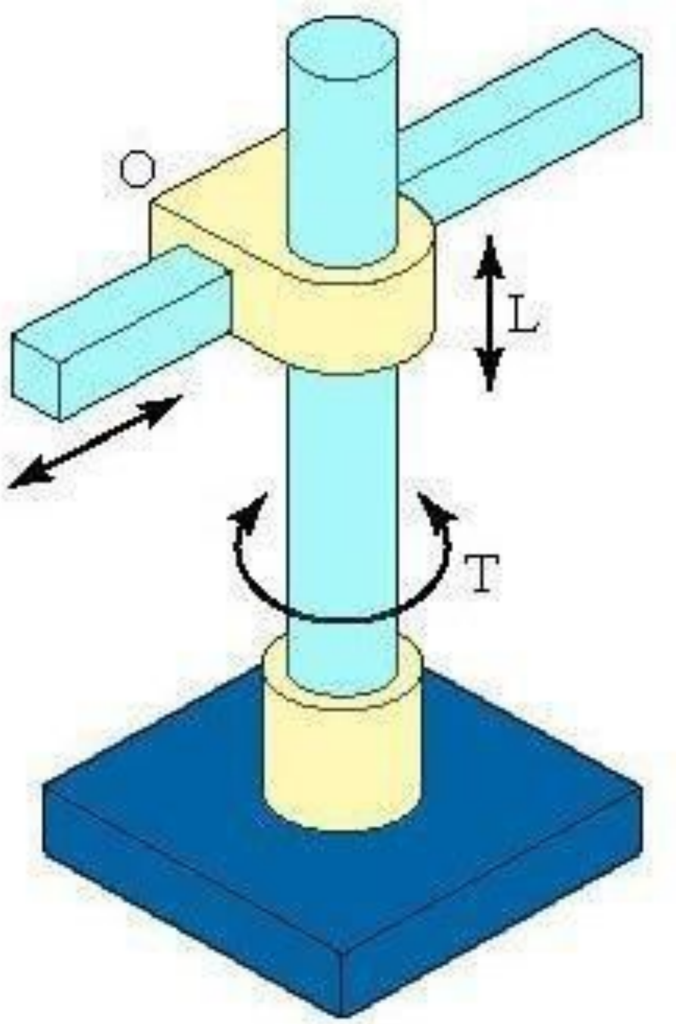
- The polar arm configuration is shown in the figure It consists of a prismatic joint that can be raised or lowered about a horizontal revolute joint.
- The two links are mounted on a rotating base. These various joints provide the capability of moving the arm endpoint within a partial spherical space. Therefore it is called as Spherical coordinated configuration.
- This configuration allows manipulation of objects on the floor.

Drawbacks:

i. Low mechanical stiffness
ii. Complex construction
iii. Position accuracy decreases with the increasing radial stroke.

Applications:
Machining, spray painting
Example: Unimate 2000 series, MAKER 110

2) Cylindrical coordinate arm configuration (RPP):



- The cylindrical configuration uses two perpendicular prismatic joints and a revolute joint as shown in figure.
- This configuration uses a vertical column and a slide that can be moved up or down along the column.
- The robot arm is attached to the slide, so that it can be moved radially with respect to column. By rotating the column, the robot is capable of achieving a workspace that approximates a cylinder. The cylindrical configuration offers good mechanical stiffness.
- **Drawback**: Accuracy decreases as the horizontal stroke increases.
- **Applications**: suitable to access narrow horizontal capabilities, hence used for machine loading operations. **Example**: GMF model M-1A.

RRP = Revolute – Revolute – Prismatic

R (Revolute Joint) –

1. The **first joint** allows the robot to **rotate horizontally** at the base (θ-axis rotation).
2. This gives the robot a sweeping motion around a vertical axis.

R (Revolute Joint) –

1. The **second joint** allows the arm to **rotate vertically** (pitch motion), raising or lowering the arm in an arc.

P (Prismatic Joint) –

1. The **third joint** allows for **linear extension or retraction** of the arm (in and out movement).

RPP = Revolute - Prismatic - Prismatic

R (Revolute Joint) –

1. A rotational joint at the base that allows the robot arm to rotate around a vertical axis (θ-axis).
2. This enables the robot to sweep in a circular fashion, giving it **cylindrical symmetry**.

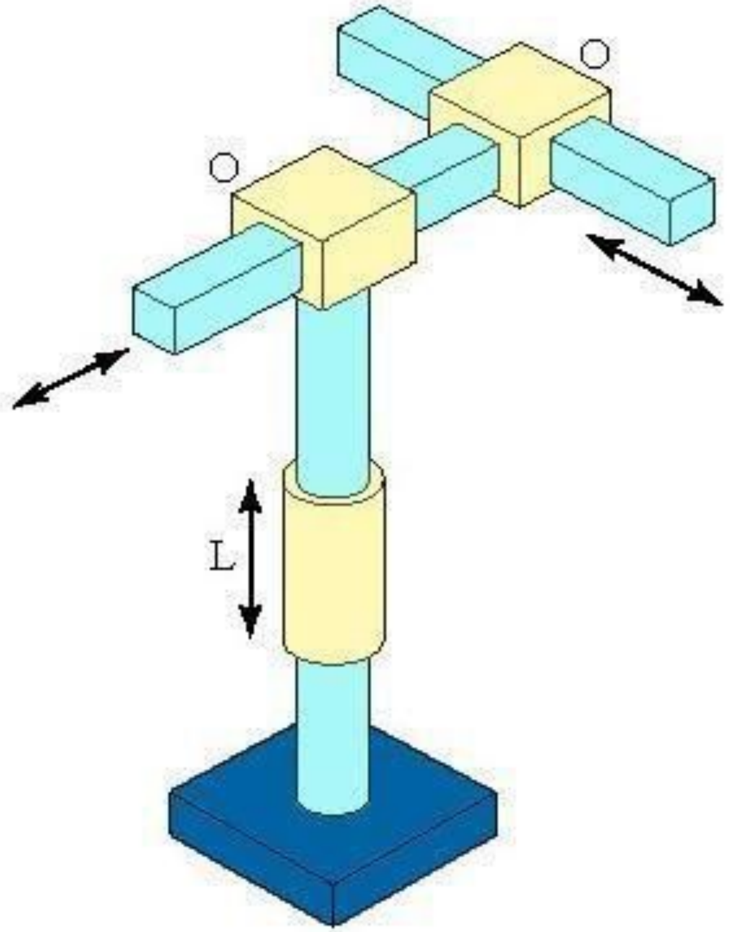
P (Prismatic Joint) –

3. A linear joint that allows **extension or retraction** along a straight line.
4. The first prismatic joint usually provides **radial movement** (outward/inward from the center).

P (Prismatic Joint) –

5. Another linear joint that allows **vertical movement** (up and down along the Z-axis).

3) Cartesian coordinate arm configuration (PPP):



From figure Cartesian coordinate or rectangular coordinate configuration is constructed by three perpendicular slides, giving only linear motions along the three principal axes.

It consists of three prismatic joints. The endpoints of the arm are capable of operating in a cuboidal space. Cartesian arm gives high precision and is easy to program.

Drawbacks:

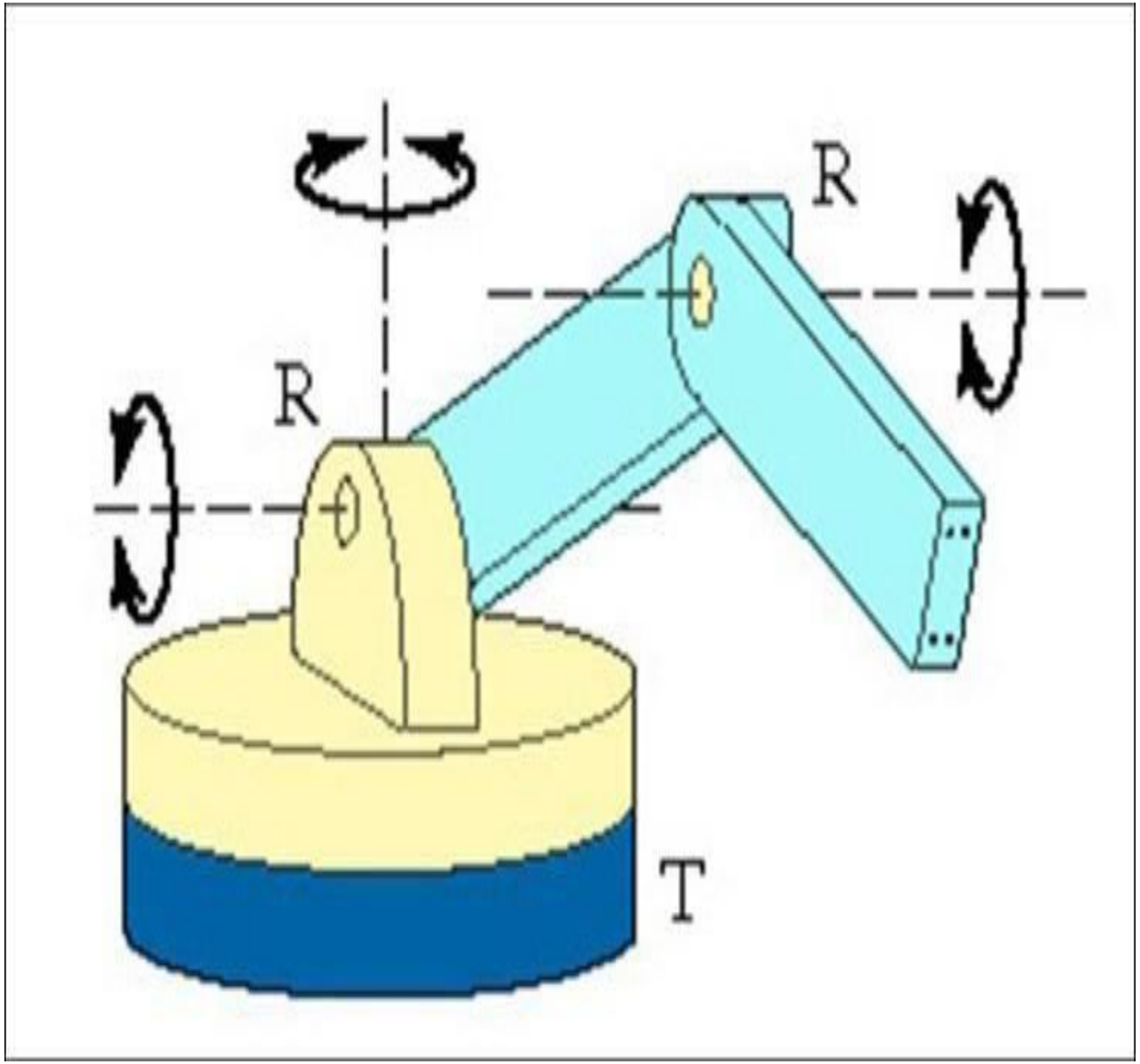
o limited manipulatability

o low dexterity (not able to move quickly and easily)

Applications: use to lift and move heavy loads.

Example: IBM RS-1

4) Jointed arm configuration (RRR) or articulated configuration:

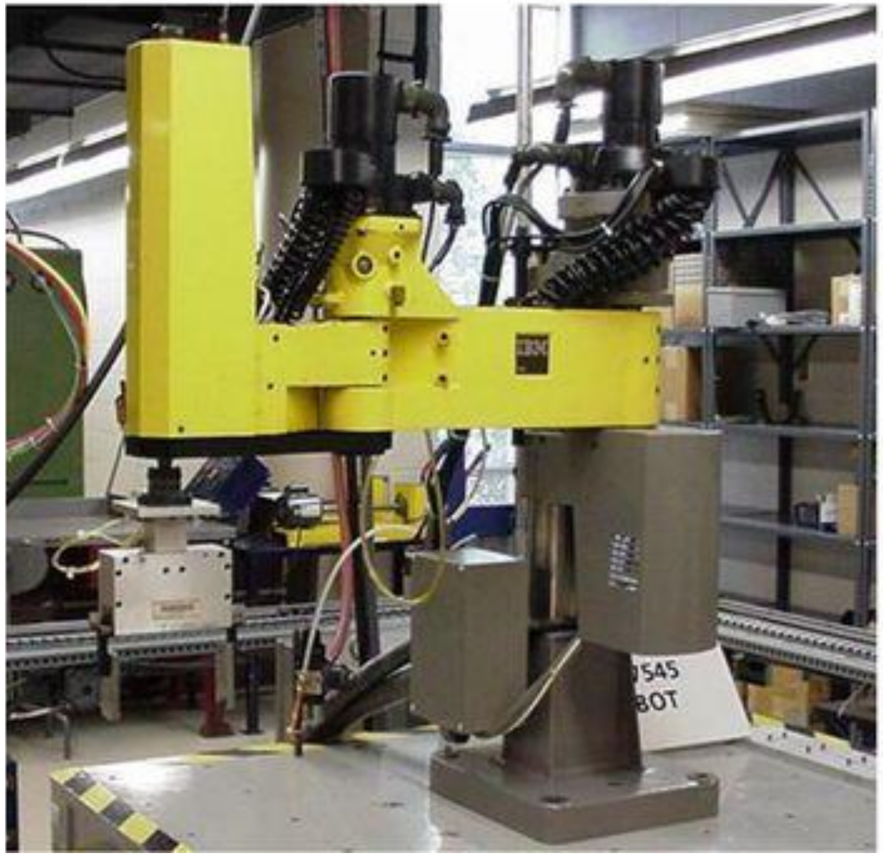


From figure jointed arm configurations are similar to that of human arm. It consists of two straight links, corresponding to human fore arm and upper arm with two rotary joint corresponding to the elbow and shoulder joints. These two are mounted on a vertical rotary table corresponding to human waist joint. The work volume is spherical. This structure is the most dexterous one. This configuration is very widely used.

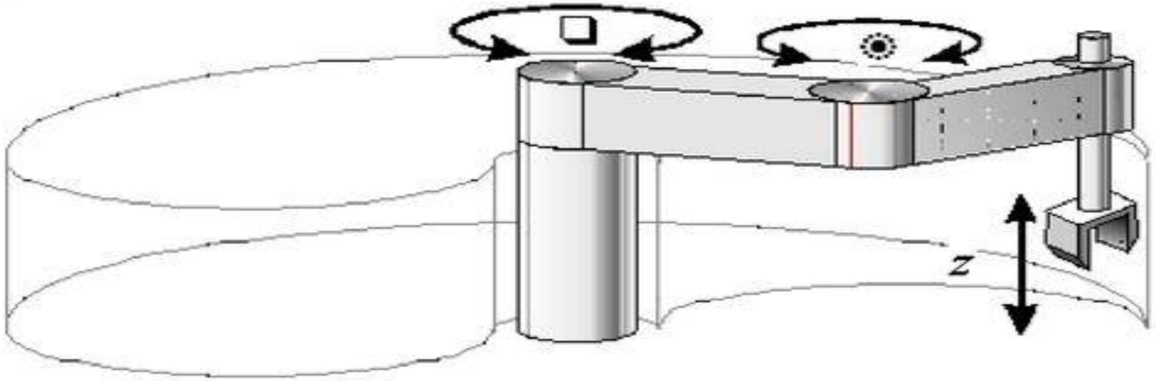
Applications: Arc welding, Spray coating.

Example: **SCARA** robot
(Selective compliance Assembly Robot Arm)

Example: **SCARA** robot (Selective compliance Assembly Robot Arm)
Its full form is- Selective Compliance Assembly Robot Arm'. It is similar in construction to the jointed-arm robot, except the shoulder and elbow rotational axes are vertical. It means that the arm is very rigid in the vertical direction, but compliant in the horizontal direction.



The SCARA System



- Selective Compliant Assembly Robot Arm
- All revolute joints in the arm rotate about the vertical axes
- Three degrees of freedom
- Used for assembly operations

PPP = Prismatic – Prismatic – Prismatic

P (Prismatic Joint) – Moves the arm **along the X-axis** (left-right)

P (Prismatic Joint) – Moves the arm **along the Y-axis** (forward-backward)

P (Prismatic Joint) – Moves the arm **along the Z-axis** (up-down)

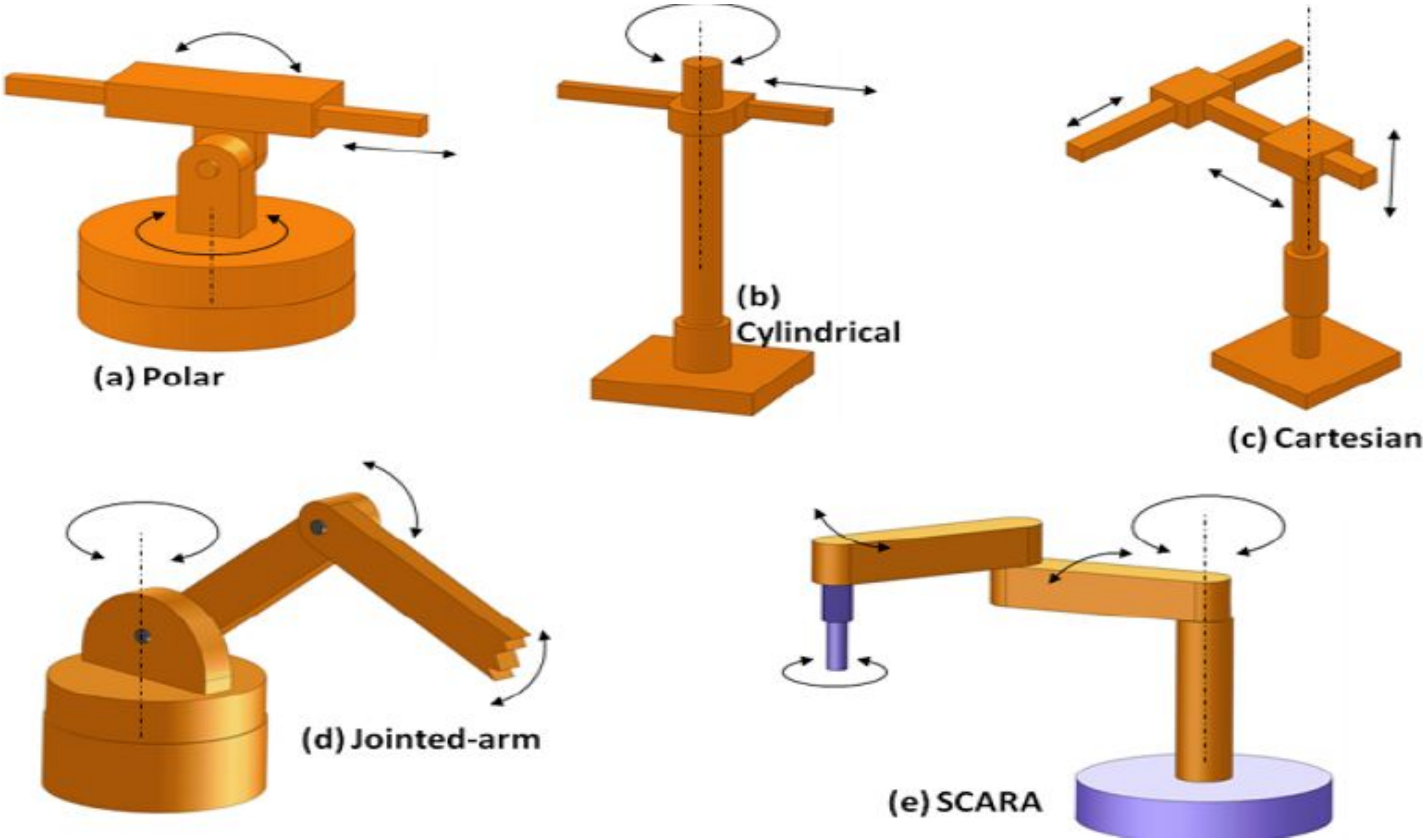
RRR = Revolute – Revolute – Revolute

R (Base Revolute Joint) – Allows the entire arm to **rotate horizontally** at the base (like rotating your shoulder left/right).

R (Shoulder Revolute Joint) – Allows the arm to **pivot vertically** at the shoulder (raising/lowering upper arm).

R (Elbow Revolute Joint) – Allows **bending at the elbow**, giving reach and positioning capability.

Five common body-and-arm configurations:



Robot Type	Joint Type	Workspace	Key Feature	Typical Use
Cartesian (PPP)	Linear	Rectangular	High precision	CNC, 3D printing
Cylindrical (RPP)	1 Rot + 2Linear	Cylindrical	Vertical reach	Spot welding, assembly
Polar (RRP)	2 Rot + 1 Lin	Spherical	Long reach	Foundry, die casting
Articulated (RRR)	Rotary	Flexible 3D	Versatile, flexible	Welding, painting
SCARA	2 Rot + 1 Lin	Cylindrical	Fast planar movement	Electronics assembly
Delta	Parallel	Dome-shaped	Ultra-fast handling	Food, pharma pick-place
Cobots	Varies	Shared	Human-friendly	Light tasks, co-working

Robot Wrist:

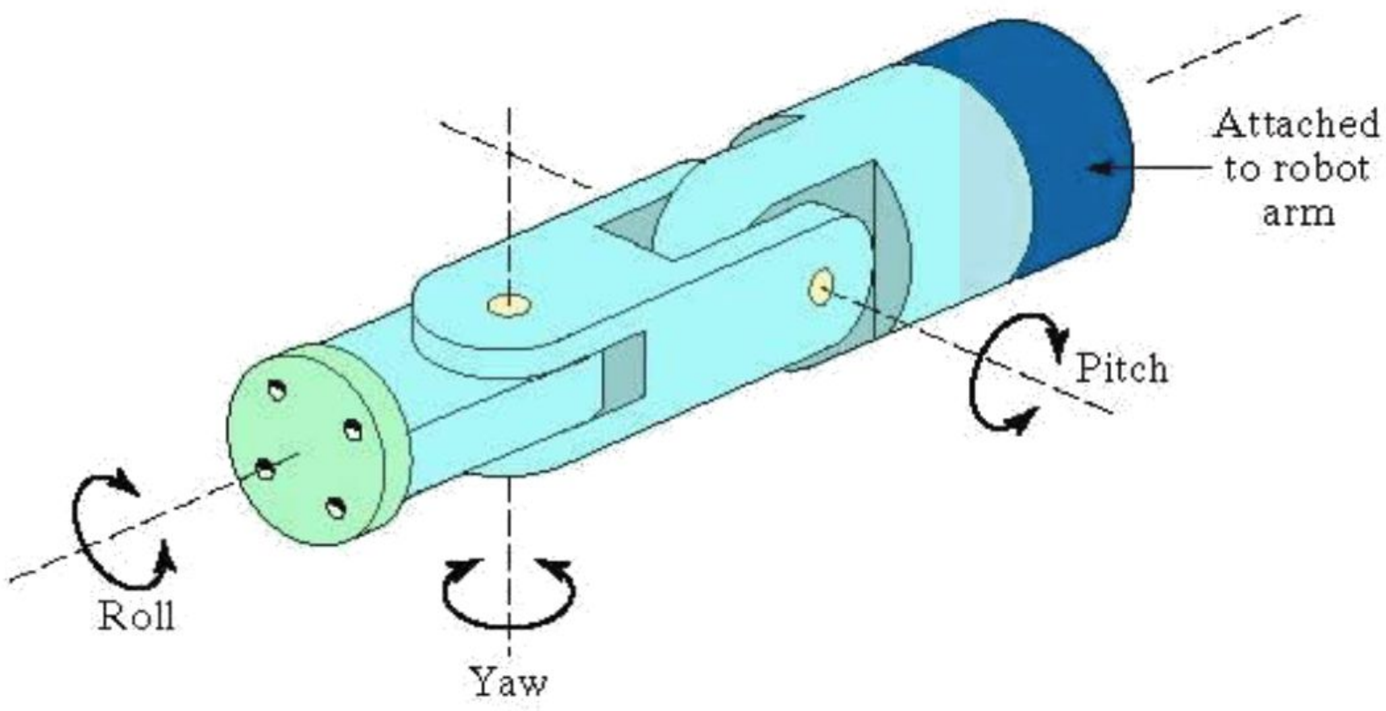
- Wrist assembly is attached to end-of-arm.
- End effectors are attached to wrist assembly.
- Function of wrist assembly is to orient end effectors.
- Body-and-arm determines global position of end effector

It has three degrees of freedom:

- **Roll (R)** axis – involves rotation of the wrist mechanism about the arm axis.
- **Pitch (P)** axis – involves up or down rotation of the wrist.
- **Yaw (Y)** axis - involves right or left rotation of the wrist.

- **Roll joint** is accomplished by use of a T joint;
- **Pitch joint** is achieved by recourse to an R joint; and
- **Yaw joint** a right-and-left motion, is gained by deploying a second R joint.

Pitch and Yaw motions, both utilize R joints.



Gripper Configurations:

Three- Degree-of-Freedom wrist joint (RRT)

Degree of freedom:

In mechanics, the degree of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration.

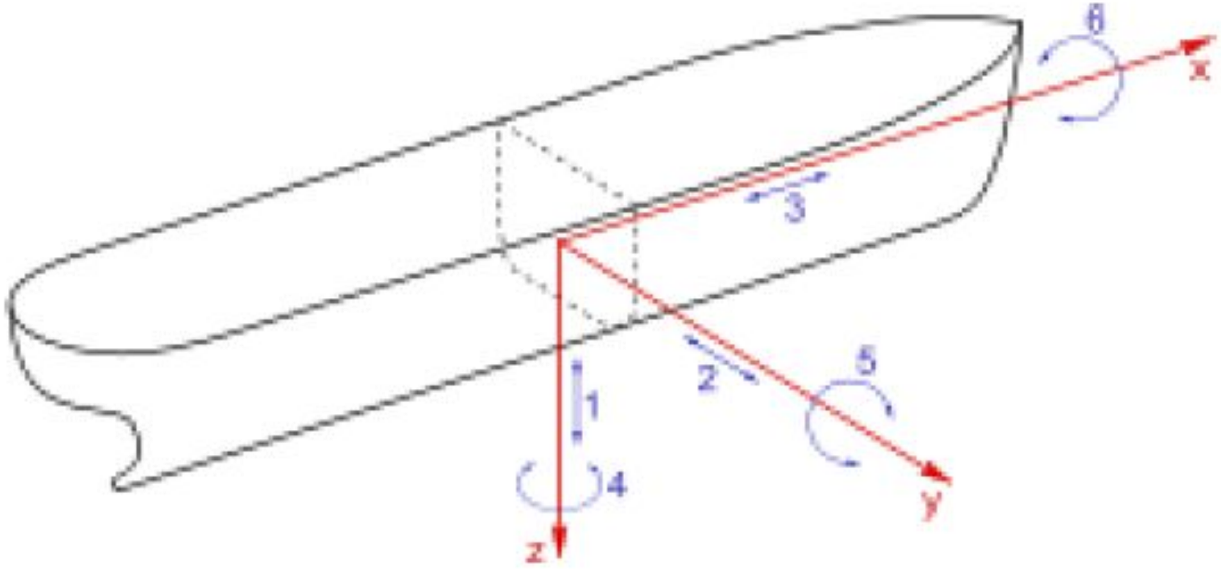
It is the number of parameters that determine the state of a physical system and is important to the analysis of systems of bodies in mechanical engineering, aeronautical engineering, robotics, and structural engineering.

The position and orientation of a rigid body in space is defined by three components of **translation** and three components of **rotation**, which means that it has six degrees of freedom.

The motion of a ship at sea has the six degrees of freedom of a rigid body, and is described as shown in figure

Translation:

1. Moving up and down (heaving);
2. Moving left and right (swaying);
3. Moving forward and backward (surging);

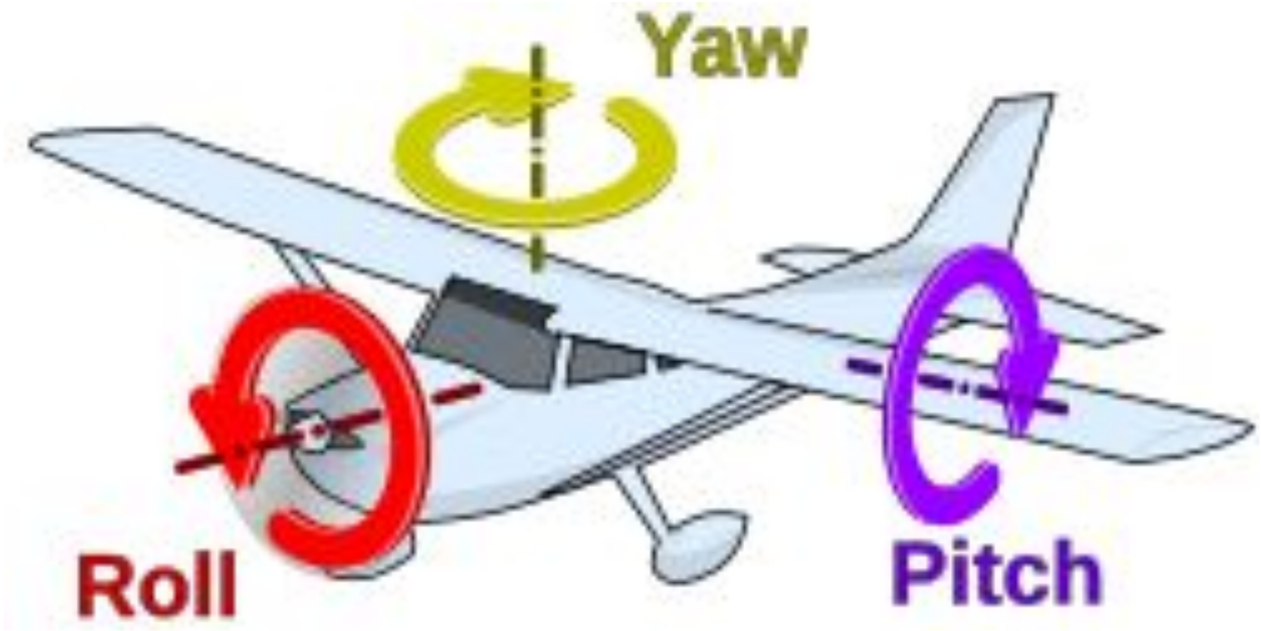


Six degrees of freedom of movement of a ship

Rotation:

4. Tilts forward and backward (pitching);
5. Swivels left and right (yawing);
6. Pivots side to side (rolling).

The trajectory of an airplane in flight has three degrees of freedom and its attitude along the trajectory has three degrees of freedom, for a total of six degrees of freedom.



Attitude degrees of freedom for an airplane.

Robot work volume / envelop:

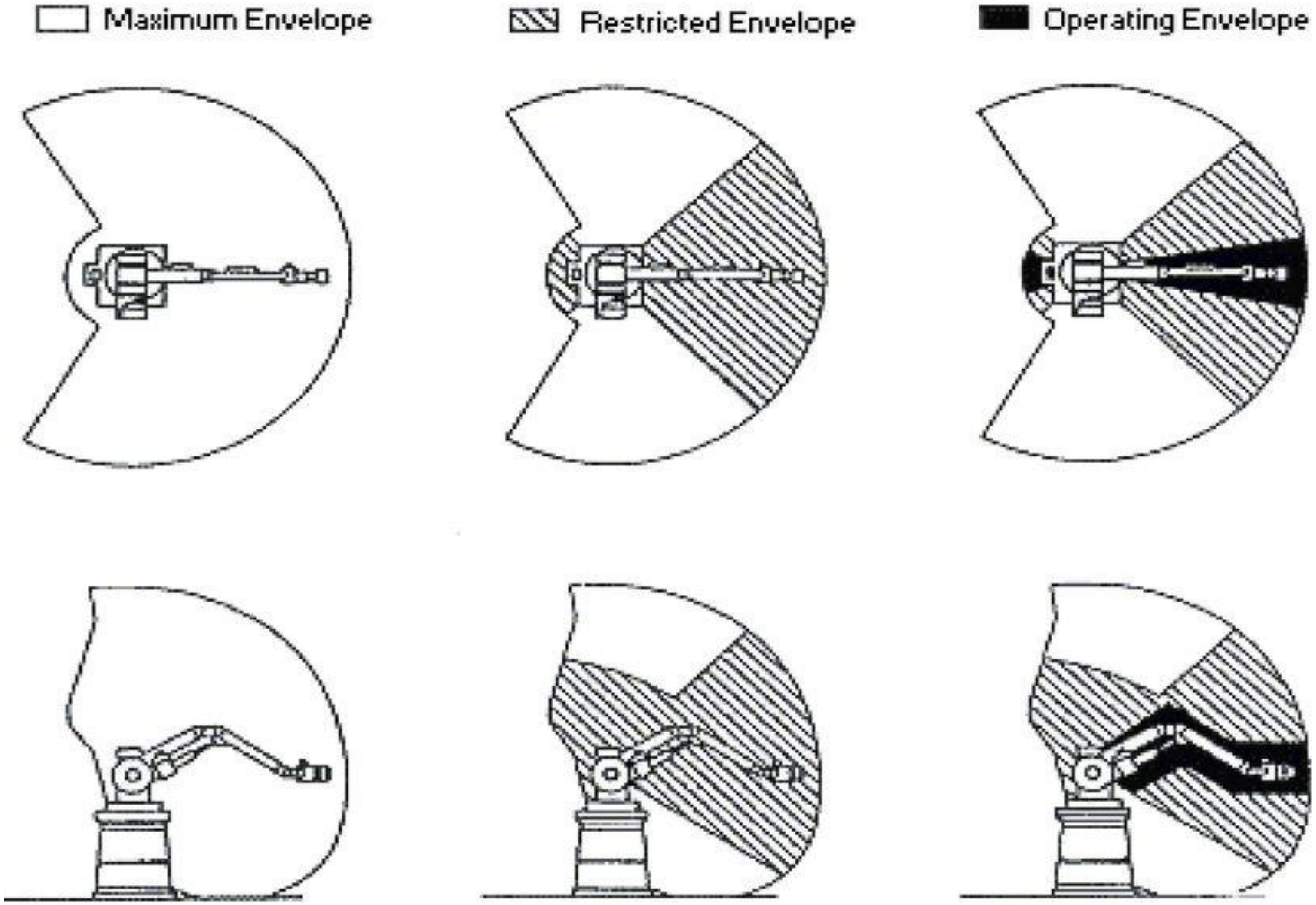
The robot's work envelope, also known as the work volume, defines the three-dimensional space within which the robot's end effector can reach and operate. Also a space on which a robot can move and operate its wrist end is called as a work volume.

For developing a better work volume, some of the physical characteristics of a robot should be considered such as:

- The anatomy of various robots
- The maximum value for moving a robot joint
- The size of the robot components like wrist, arm, and body

It's a crucial factor in robotic system design and programming, as it dictates the robot's operational area for specific tasks. The shape and size of the work envelope are determined by the robot's physical characteristics, including its joint types, arm length, and joint ranges.

Working Envelope



Exploring the Future of Robotics – One Step at a Time…..

If you have any questions or would like to discuss more,
feel free to ask..!

📘 **Topic Covered:** Introduction to Robotics – Unit 1
📍 **Presented by:** Dr. Abhijit S. Titarmare
🏫 **Department of Electronics & Telecommunication Engineering**


G H Raisoni College of Engineering, Nagpur