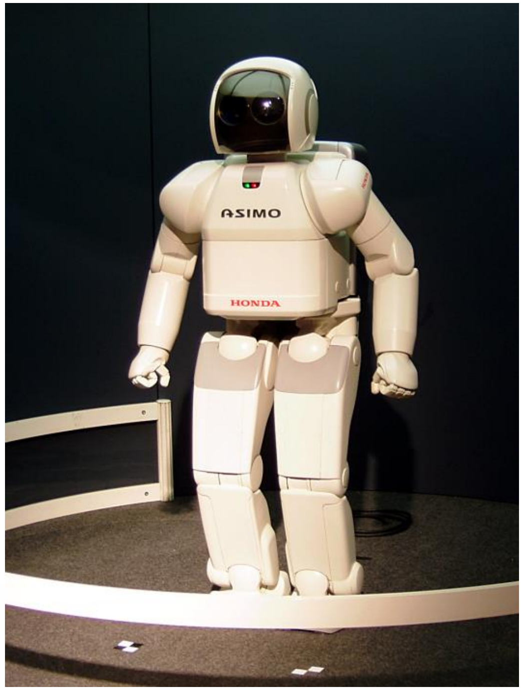
Fundamental of
Cognitive Interaction with Robots

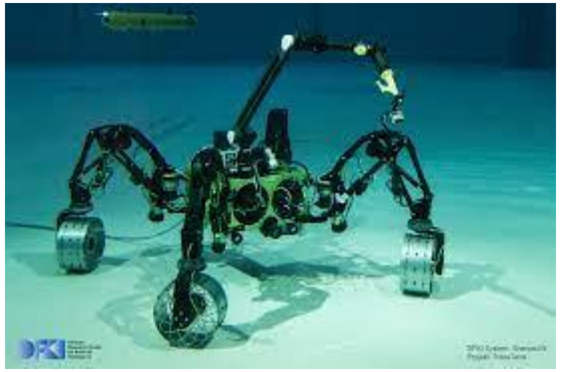
Lecture 4

Robotics

What is robotics?

- Robotics is an interdisciplinary branch of engineering and science
- Robotics integrates fields of mechanical engineering, electrical engineering, mechatronics, electronics, bioengineering, computer engineering, control engineering, software engineering, mathematics, physics, etc.
- It involves the design, manufacture and operation of robots.
- The objective of the robotics field is to create intelligent machines that can assist humans in a variety of ways.





Robots

- Robots can be used for many purposes, but today many are used in dangerous environments : inspection of radioactive materials, bomb detection and deactivation, manufacturing processes, or where humans cannot survive (e.g. in space, underwater, in high heat, and clean up hazardous materials and radiation).
- Robots can take on any form, but some are made to resemble humans in appearance (humanoid robots).
- Such robots attempt to replicate walking, lifting, speech, cognition, or any other human activity.

History of Robotics

- The word robot first appeared in 1920 by Czech writer **Karel Čapek** in his play Rossum's Universal Robots
- The word robot comes from the Czechoslovakian word robota which means worker.
- In 1940, **Isaac Asimov** coined and popularized the term robotics through many science-fiction novels and short stories.
- Asimov invented the Three Laws of Robotics:

1. Robots must never harm human beings.
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 Law.

Definitions

- **Robot:**

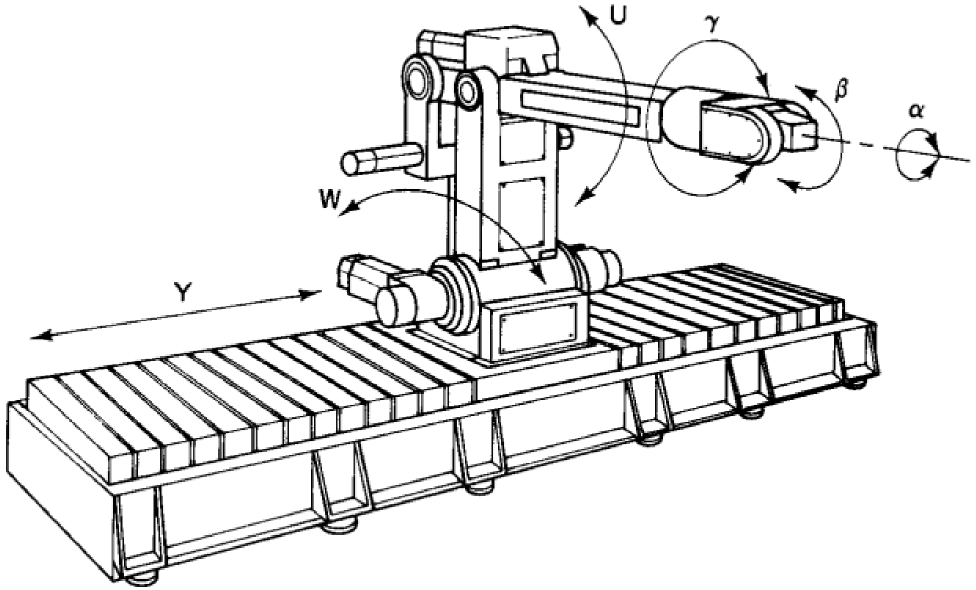
An electromechanical device with multiple degrees-of-freedom (dof) that is programmable to accomplish a variety of tasks.

- **Robotics:**

The science of robots. Humans working in this area are called roboticists.

- **DoF**:

degrees-of-freedom, the number of independent motions a device can make.



Definitions cont.

- **Manipulator**

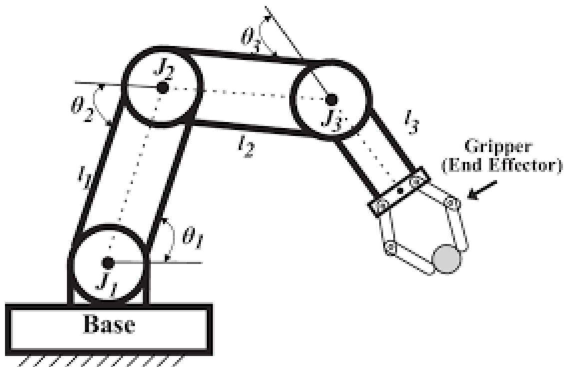
An electromechanical device with multiple degrees-of-freedom (dof) used to manipulate materials without direct physical contact by the operator. They are also commonly referred to as robotic arms.





- **End-effector:**

The tool, gripper, or other device mounted at the end of a manipulator, for accomplishing useful tasks.



Definitions cont.

- **Workspace:**

The volume in space that a robot’s end-effector can reach, both in position and orientation.

- **Humanoid robot :**

A humanoid robot is a robot like the human body in shape.

Definitions cont.

- **Position:**

The translational (straight-line) location of an object.

- **Orientation:**

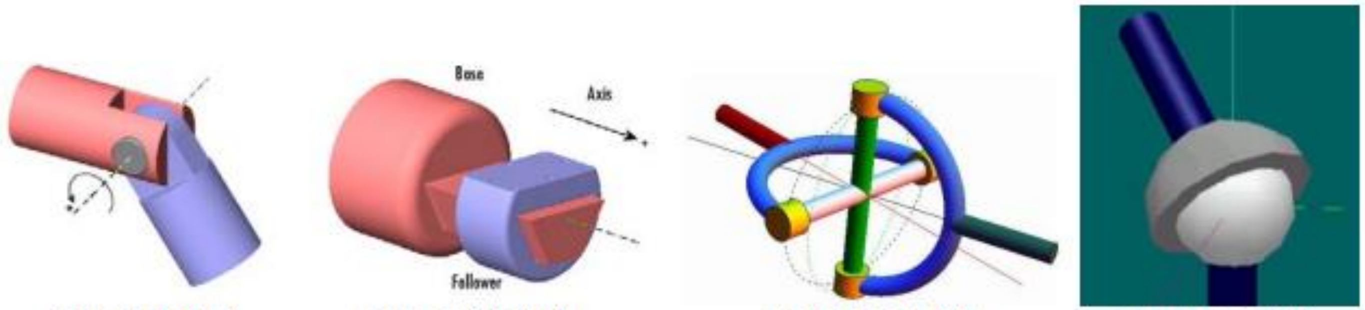
The rotational (angular) location of an object.

- **Pose:**

Position and orientation taken together.

- **Joint:**

The device which allows relative motion between two links in a robot



revolute (R) prismatic (P) universal (U) spherical (S)

Definitions cont.

- **Kinematics :**

The study of motion without regard to forces/torques.

- **Dynamics :**

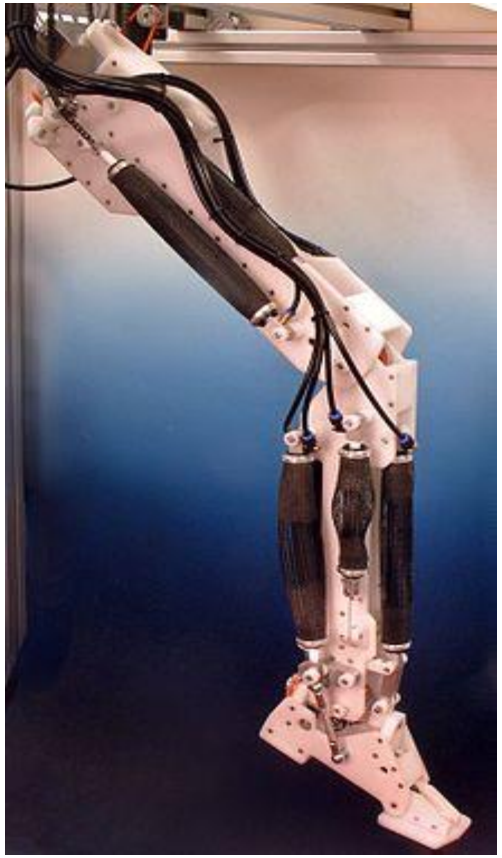
The study of motion with regard to forces/torques.

- **Actuator :**

Provides force/torque for robot motion.

- **Sensor :**

Reads actual variables in robot motion for use in control.



Applications

Traditionally, robots are applied anywhere in any job which is too dangerous, dirty, or dull for a human to perform.

- **Industry :**

Industrial robots are used in manufacturing: pick & place, assembly, welding, spray painting, etc.

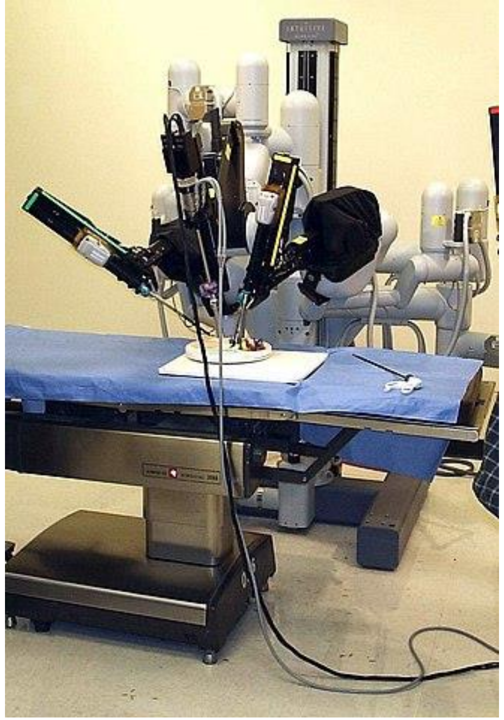
Applications

- **Military robot :**

Military robots are autonomous robots or remote-controlled mobile robots designed for military applications, from transport to search & rescue and attack.

Applications

- **Medical robot:**
- A medical robot is a robot used in the medical sciences. They include surgical robots, rehabilitation robots, disinfection robot, etc.
- Surgical robots are in most telemanipulators, which use the surgeon's activators on one side to control the "effector" on the other side.

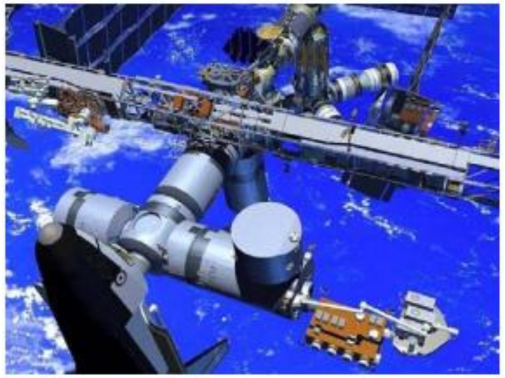
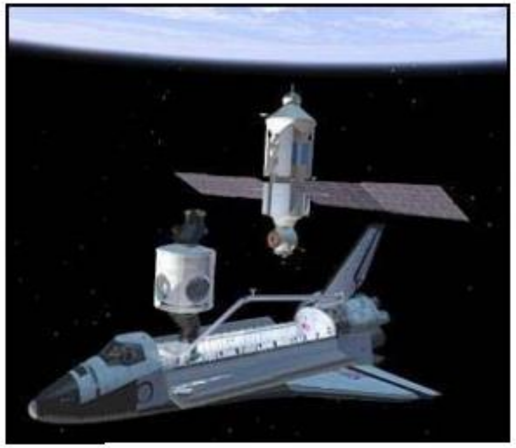


Applications

- **Agricultural robots:**
- An agricultural robot is a robot deployed for agricultural purposes. The main area of application of robots in agriculture today is at the harvesting stage.
- Emerging applications of robots or drones in agriculture include planting seeds, harvesting, environmental monitoring and soil analysis

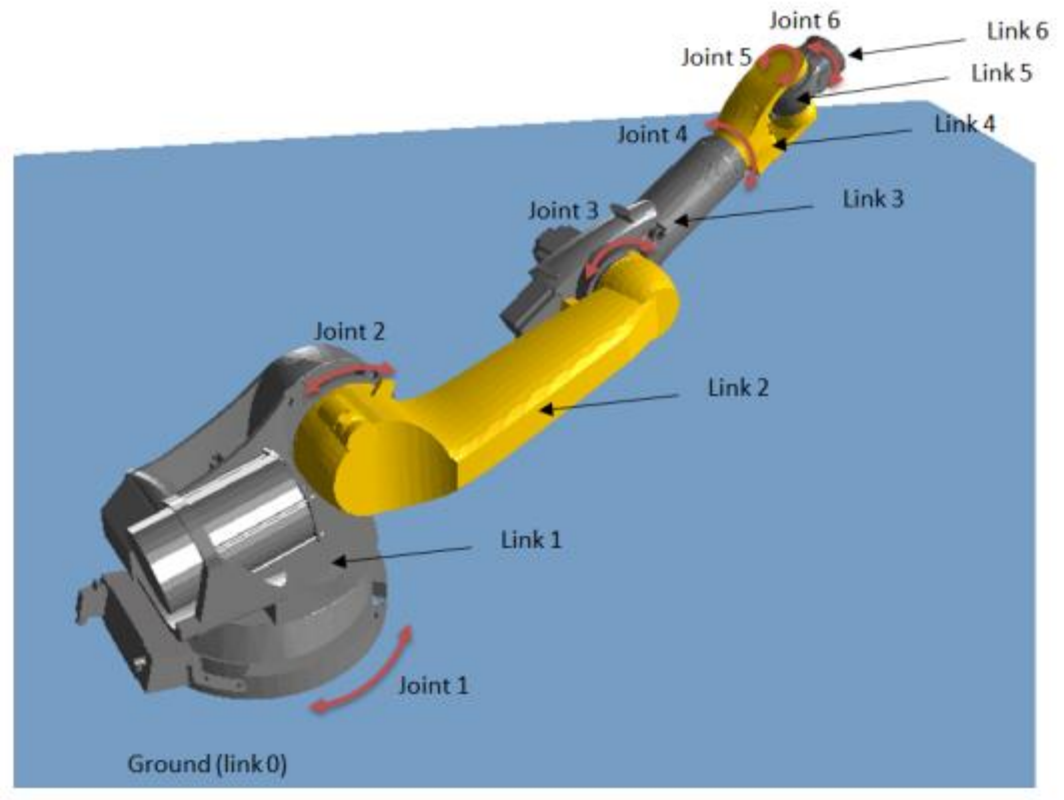
Applications

- **Tele-robots:**
- Tele-robots Applications include undersea, nuclear environment, bomb disposal, law enforcement, and outer space

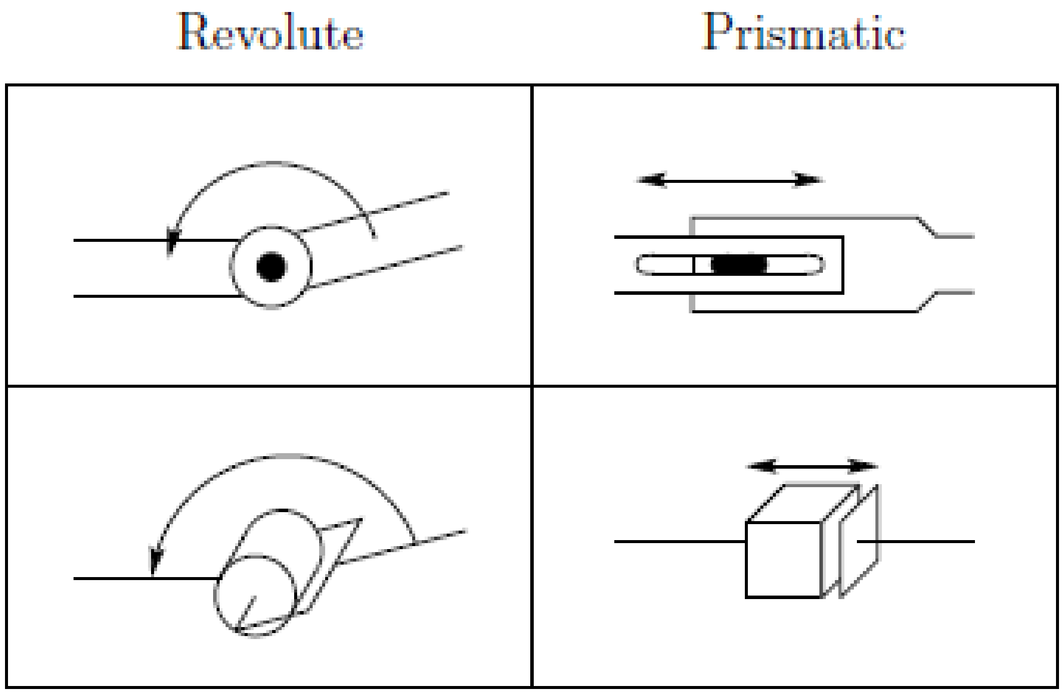

Robot Manipulators

- 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 the connection between links.
- The device attached to the manipulator which interacts with its environment to perform tasks is called the end-effector.



Types of Joints

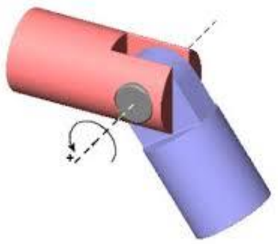
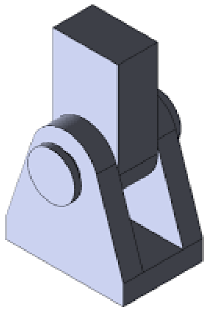
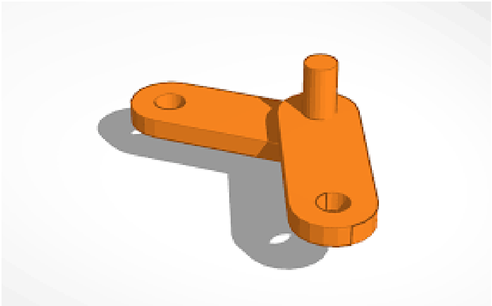
- Joints allow restricted relative motion between two links.
- Joints are typically rotary (revolute) or linear (prismatic).
- Any other joint can be represented by some combination of these two primary joints.



Types of Joints

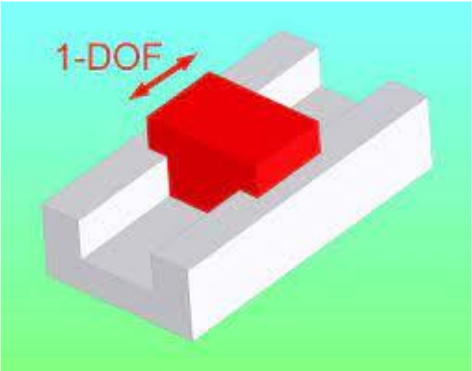
- **Revolute joint :**

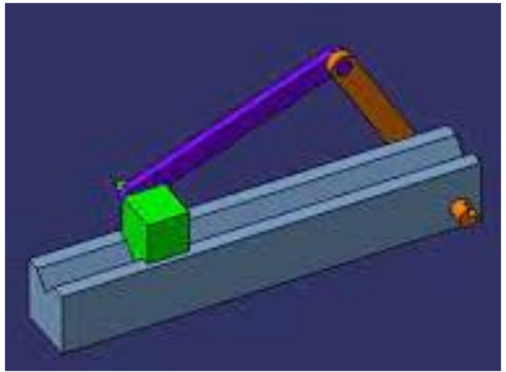
Allows relative rotation about one axis (1-DoF)

- **Prismatic (sliding) joint :**

Allows relative translation about one axis (1-DoF)





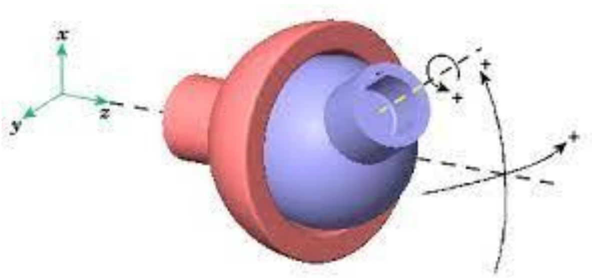
Types of Joints

- **Cylindrical joint :**

Allows relative rotation and translation about one axis (2-DoF)

- **Spherical joint :**

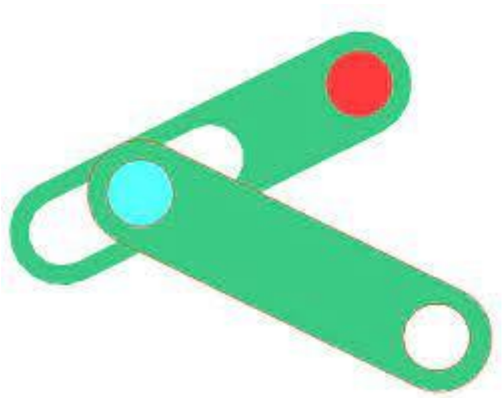
Allows three degrees of rotational freedom about the center of the joint. Also known as a ball-and-socket joint (3-DoF)



Types of Joints

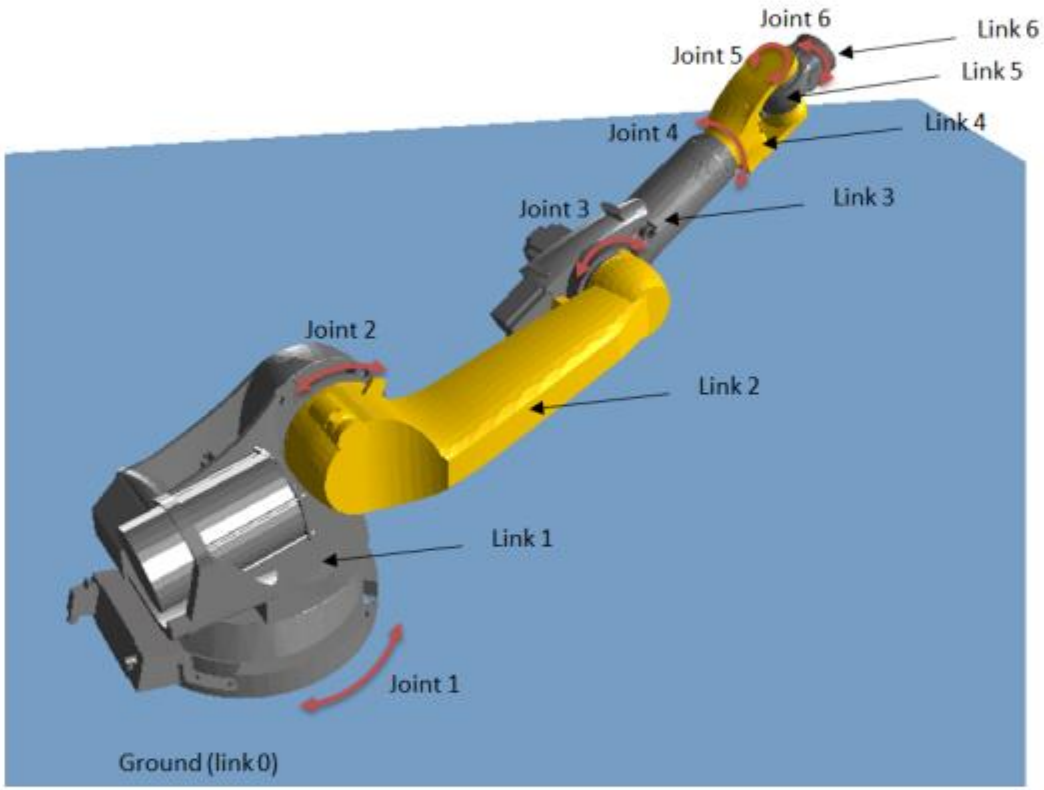
- **Planar joint :**

Allows relative translation on a plane and relative rotation about an axis perpendicular to the plane (3-DoF)

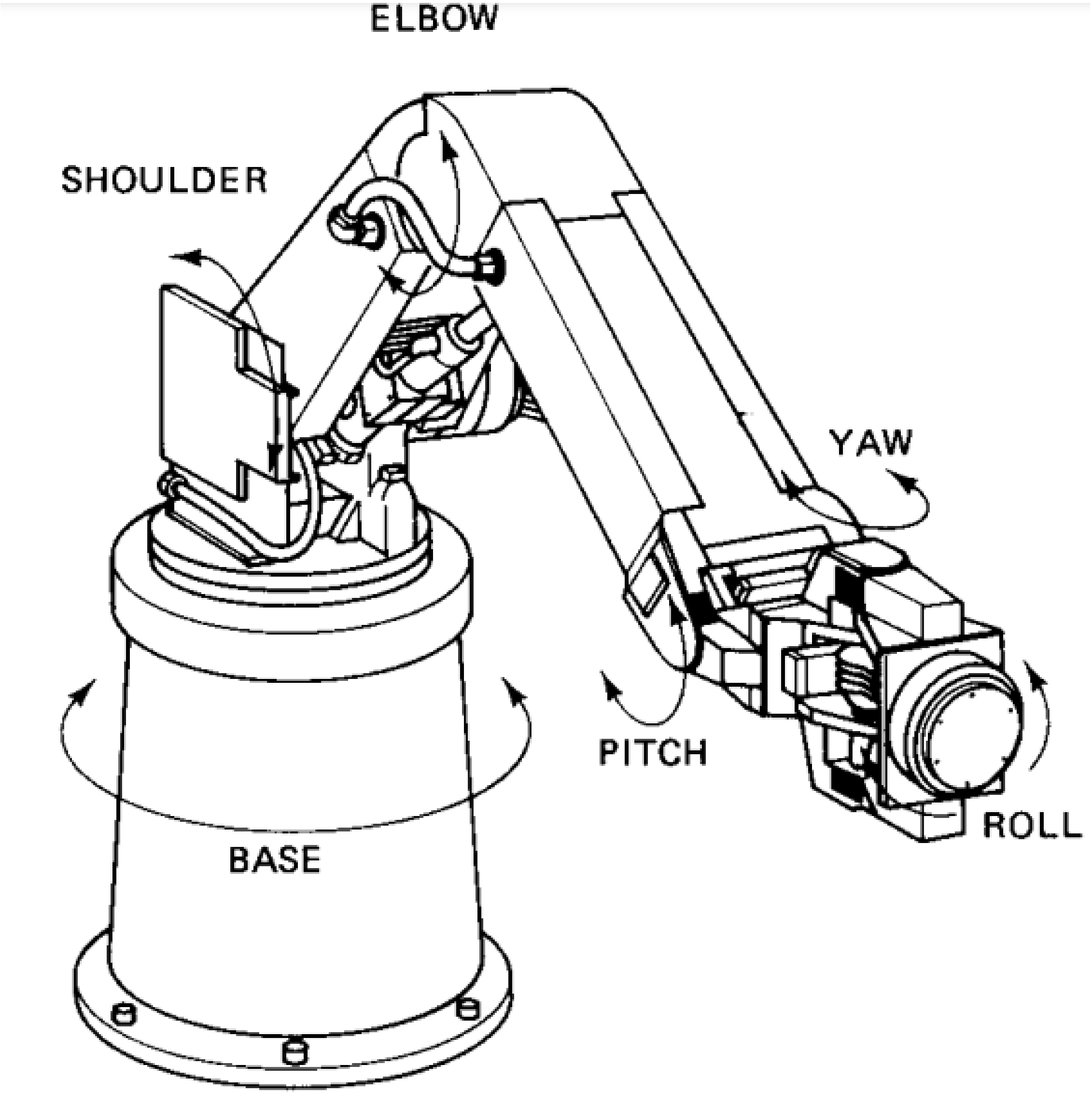


Basic Assumptions and Terminology

- A robot manipulator with n joints will have $(n + 1)$ links. Each joint connects two links.
- We number joints from 1 to n, and links from 0 to n. So that joint i connects links $(i - 1)$ and i.
- The location of joint i is fixed with respect to the link $(i - 1)$.
- When joint i is actuated, the link i moves. Hence the link $(i - 1)$ is fixed.
- Link 0 is always fixed (ground, car).



Manipulator Parts



Some Classifications of Manipulators

By Motion Characteristics

- **Planar manipulator:**

  A manipulator is called a planar manipulator if all the moving links move in planes parallel to one another.

- **Spherical manipulator:**

  A manipulator is called a spherical manipulator if all the links perform spherical motions about a common stationary point.

- **Spatial manipulator:**

  A manipulator is called a spatial manipulator if at least one of the links of the mechanism possesses a general spatial motion

Some Classifications of Manipulators

By Power Sources/ Actuators

The robot power sources determine characteristics such as speed, load-bearing, and accuracy.

- **Electric motors (DC, servo, stepper):**
  The robot uses electric motors to position the robot. These robots can be accurate, but are limited in their load-bearing capacity.

- **Hydraulic cylinders (fluid pressure):**
  A robot with a hydraulic drive system is designed to carry very heavy objects, but may not be very accurate.

- **Pneumatic cylinders (air pressure):**
  Pneumatic robots are inexpensive and simple, but cannot be controlled precisely. They can carry less weight.

Some Classifications of Manipulators

By Kinematic structure

- **Serial (open) manipulators:**

  Links and joints are connected to form open kinematic chain.

- **Parallel (closed) manipulators:**

  Links and joints are connected to form closed kinematic chain.

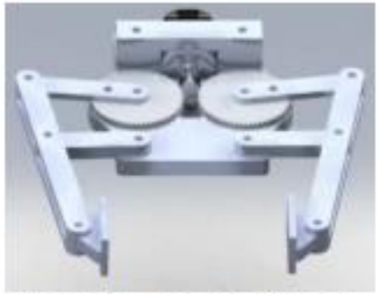
Robot End-Effectors

- End-effectors are the tools attached to the end of the robot arm that enable it to do useful work.
- Most robot manufacturers either do not include end-effectors with their robots or include a general purpose gripper to allow you to do simple tasks. Typically, the end-effectors must be purchased or designed separately.
- End-effectors require a power source (electric or pneumatic) to perform the task.

Robot End-Effectors

Grippers

- Grippers are the most common end-effectors. They provide the equivalent of a thumb and an opposing finger, allowing the robot to grasp small parts and manipulate them.

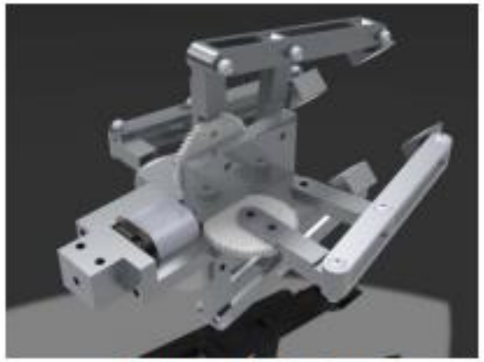


Parallel-Jaw Gripper

Versatile Planar Gripper

Suction-Cups Gripper

3-fingered Gripper



4-fingered Gripper

Humanoid Robot Hand

Robot End-Effectors

Machine Tools

- Robot end-effectors can also be machine tools such as drills, laser cutter, cutting wheels, spray-painting, welding machines, etc.


Drill Tool


Laser-beam Tool


Welding Torch

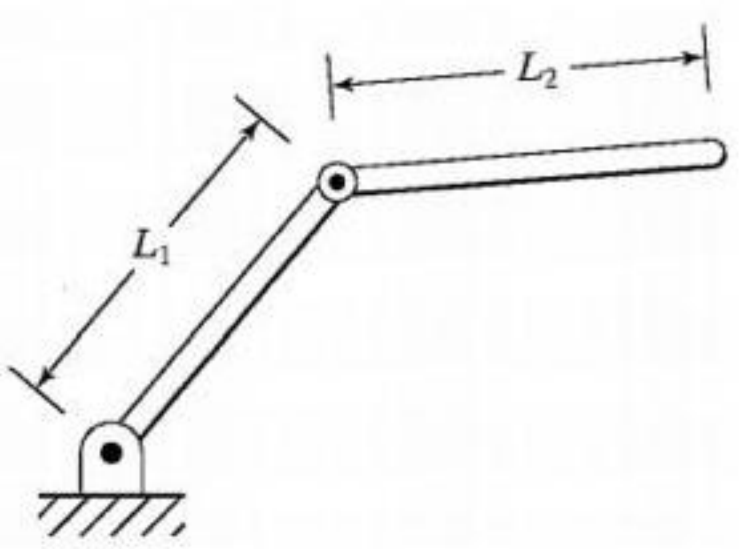

Spray-Painting Robots

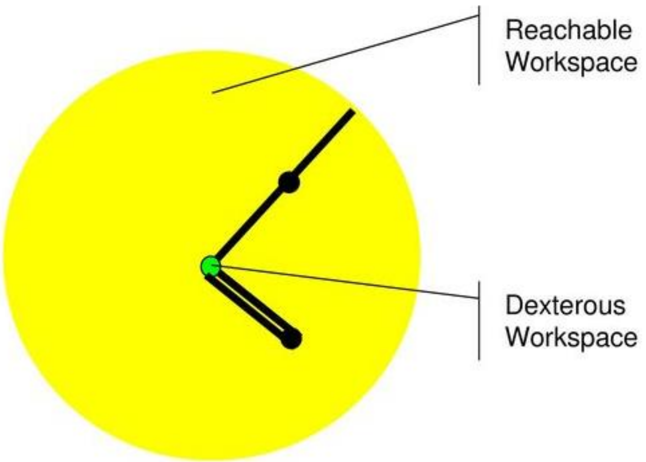
Manipulator Workspace

- The workspace of a manipulator is defined as the set of points that can be reached by its end-effector.
- The workspace is constrained by the geometry of the manipulator as well as mechanical constraints on the joints. For example, a revolute joint may be limited to less than a full 360º of motion.
- The workspace is often broken down into a **reachable workspace** and a **dexterous workspace**.
- Reachable workspace: is the set of points that the end effector can reach with at least one orientation.
- Dexterous workspace: is the set of points that the end effector can reach with all orientations.
- The dexterous workspace is a subset of the reachable workspace.

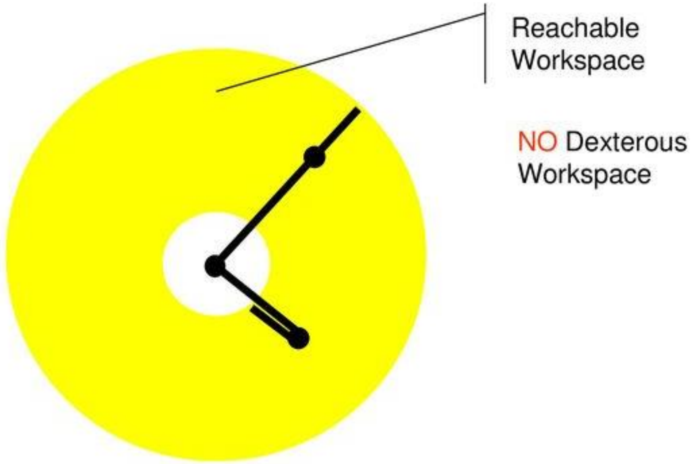
Manipulator Workspace

- If L1=L2, then the reachable workspace = full disc of radius 2L1, and the dextrous workspace = {origin}
- If L1≠L2 then the reachable workspace is a ring with inner radius |L1-L2| and an outer radius L1+L2





L1=L2



L1≠L2

Manipulator Degree of Freedom (DOF)

- Degrees of freedom defines the modes in which a mechanical device or system can move.
- The number of joints determines the manipulator degrees of freedom (DOF).
- Typically, a manipulator should possess at least six independent DOF, three for positioning and three for orientation, to move the end-effector to an arbitrary position and orientation in three dimensional space.
- With fewer than six DOF, the arm cannot reach every point in its workspace with arbitrary orientation. However, The difficulty of controlling a manipulator increases rapidly with the number of links.

Manipulator Degree of Freedom (DOF)

- The number of degrees of freedom for a manipulator can be calculated as:

$$n_{dof} = \lambda(N - 1 - J) + \sum_{i=1}^{J} f_i$$

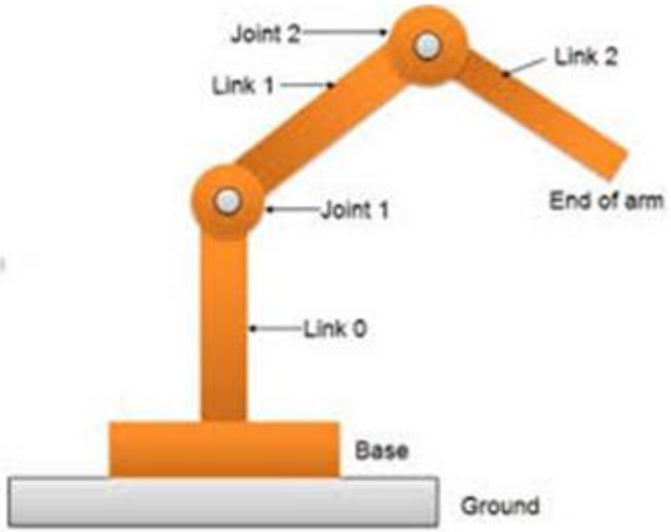
Where,

- N is the number of links (this includes the ground link),
- J is the number of joints,
- f_i is the number of degrees of freedom of the i^{th} joint
- λ is 3 for planar mechanisms and 6 for spatial mechanisms.

Manipulator Degree of Freedom (DOF)

Example

What is the number of degrees of freedom for this robot?



Solution

λ=3

N=3

J=2

f_1=1, f_2=1

$$n_{dof} = \lambda(N - 1 - J) + \sum_{i=1}^{J} f_i$$

$$n_{dof} = 3(3 - 1 - 2) + (1 + 1) = 2$$

Manipulator Degree of Freedom (DOF)

Example

What is the number of degrees of freedom for this robot?

Solution

λ=3

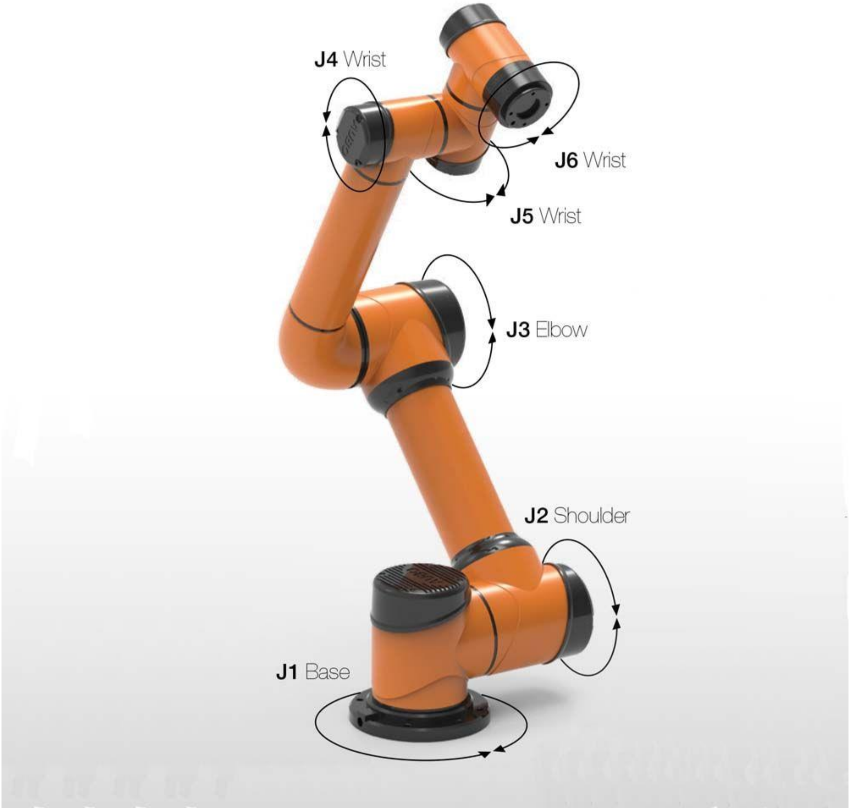
N=7

J=6

$f_1 = f_2 = f_3 = f_4 = f_5 = f_6 = 1$

$$n_{dof} = \lambda(N - 1 - J) + \sum_{i=1}^{J} f_i$$

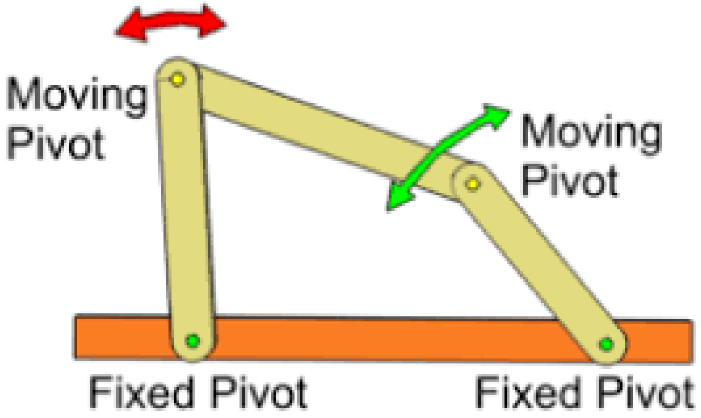
$$n_{dof} = 3(7 - 1 - 6) + 6 = 6$$



Manipulator Degree of Freedom (DOF)

Example

What is the number of degrees of freedom for this mechanism?



Solution

λ=3

N=4

J=4

$f_1 = f_2 = f_3 = f_4 = 1$

$$n_{dof} = \lambda(N - 1 - J) + \sum_{i=1}^{J} f_i$$

$$n_{dof} = 3(4 - 1 - 4) + 4 = 1$$


Any Questions