Mechatronics Engineering Department
Faculty of Engineering
Ain Shams University


# MCT344/MCT342/CSE373/CSE471: Robotics

## Lecture 1: Introduction

Presented by : Prof. Mohammed Ibrahim Awad

# Course Assessment

## Assessment Scheme

| | | |
|---|---|---|
| Mid-term Exam | = | 20 |
| Quiz(zes) | = | 10 |
| Assignments | = | 10 |
| Project activities | = | 20 |
| Final Exam | = | 40 |
| | | 100 |

## Textbooks

1. M.W. Spong, S. Hutchinson, and M.Vidyasagar, "**Robot Modeling and Control**", 2nd ed., John Wiley & Sons, **2020**. ISBN: 978-1119523994.

# Lab Plan

| Week # | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Exp 5 | Progress |
|---|---|---|---|---|---|---|
| 1_ODD | | | | | | |
| 2_Even | GA | G B | G C + GD | | | |
| 3_ ODD | GA | G B | G C + GD | | | |
| 4_ Even | GC | G D | G A +G B | | | |
| 5_ ODD | GC | G D | G A +G B | | | |
| 6_ Even | GB | G A | | G C + G D | | |
| 7_ ODD | GB | G A | | G C + G D | | |
| 8 | | | | Midterm | | |
| 9_ Even | GD | G C | | G A + G B | | |
| 10_ODD | GD | G C | | G A + G B | | |
| 11_Even | | | | | GA+B+C+D | |
| 12_ODD | | | | | | Progress |
| 13_Even | | | | | | Progress |
| 14 | | | | Project Submission | | |

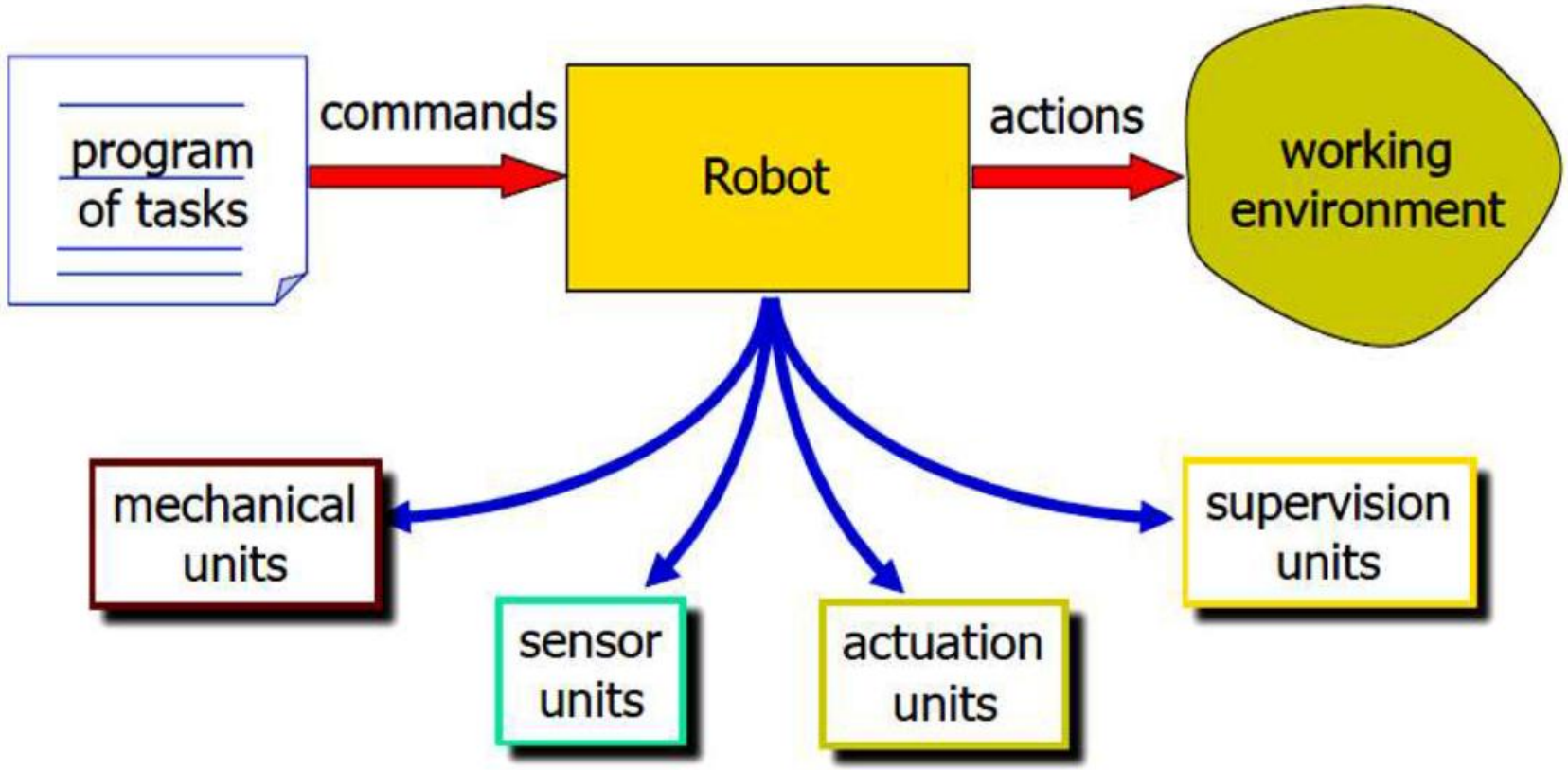
# Robotic History

- The term robot was first introduced by the Czech playwright **Karel Capek** in his **1920** play Rossum's Universal Robots, the word **robota** being the Czech word for worker. Since then the term has been applied to a great variety of mechanical devices, such as teleoperators, mobile robots, underwater vehicles, autonomous cars, drones, etc.
- Anything that operates with some degree of autonomy under computer control has at some point been called a robot.
- In this course we will focus on industrial manipulators analysis.

# Robot Definition and Structure

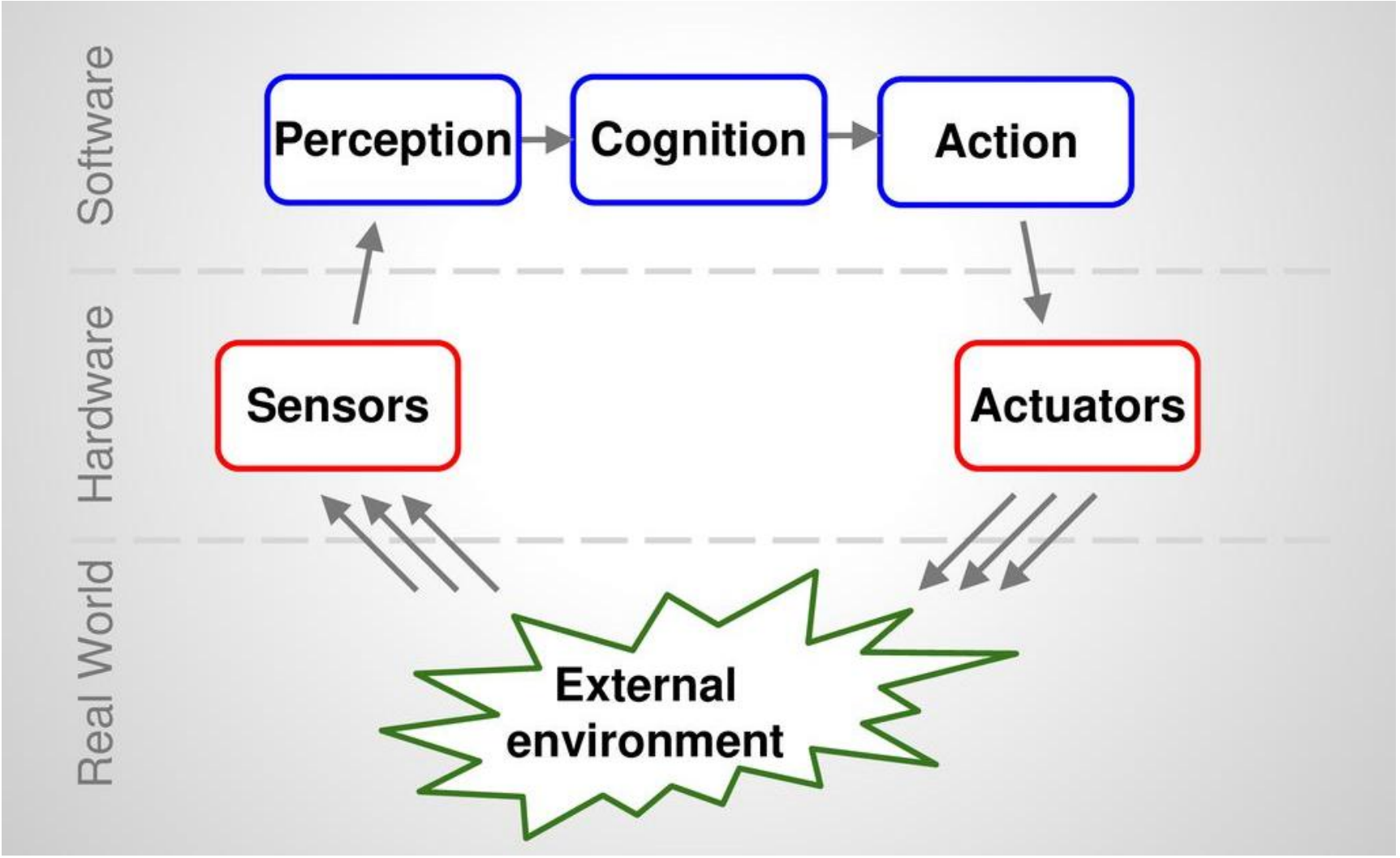
Robot Institute of America (RIA):

A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

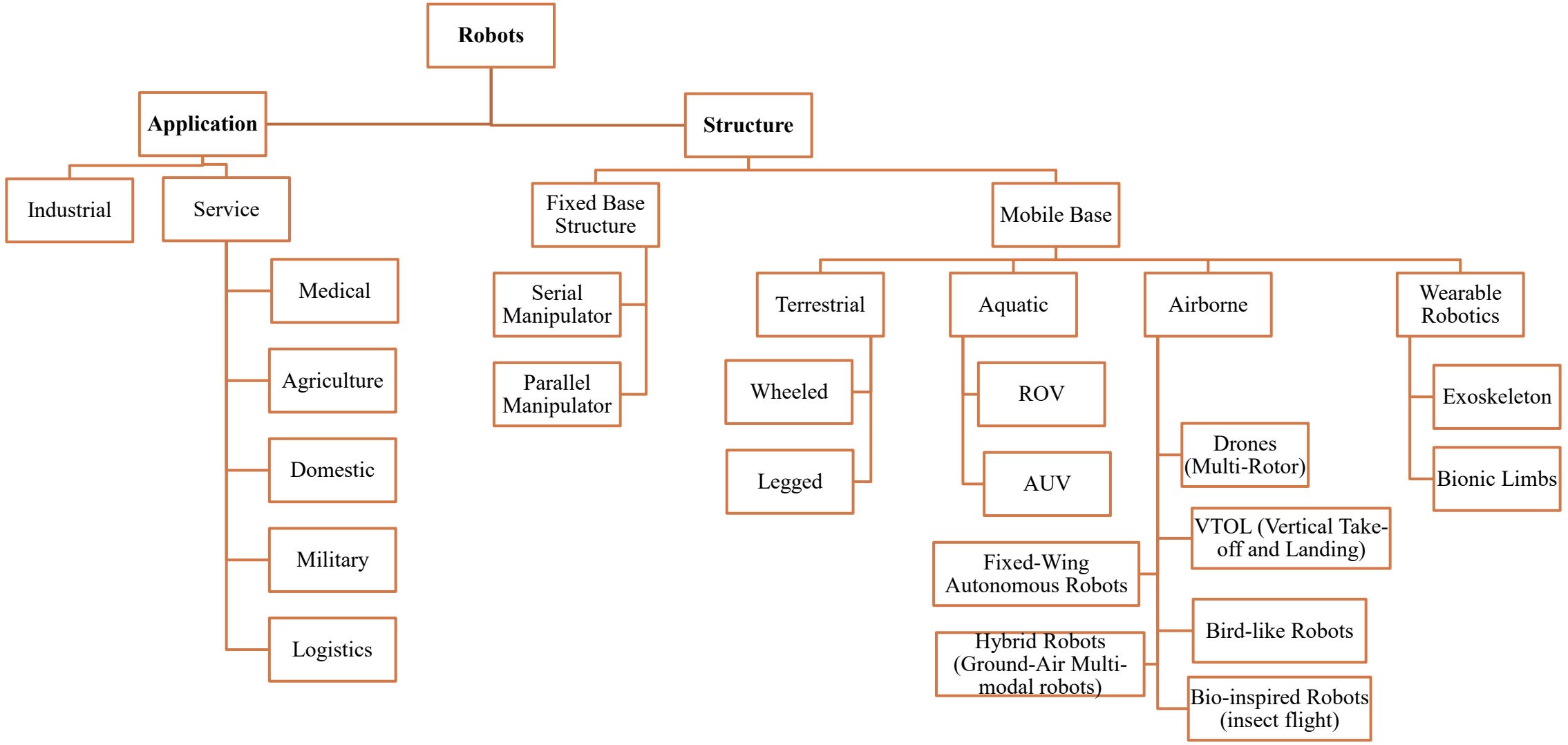


# How does Intelligent Robot Work?

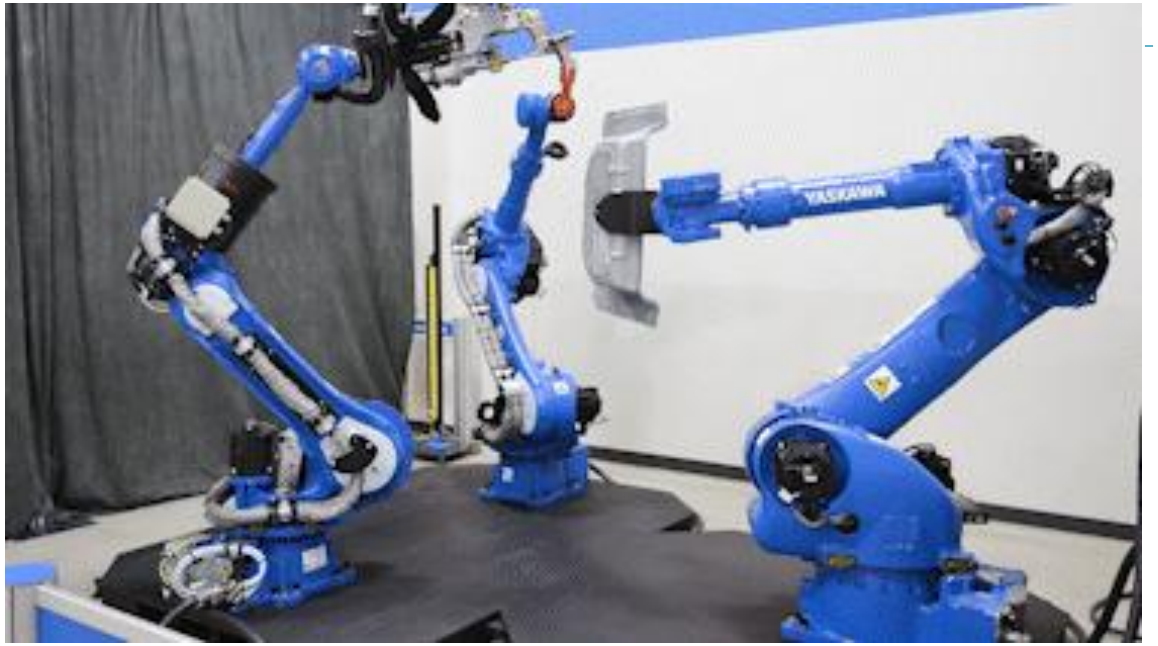
Robotics is the intelligent connection from perception to action.

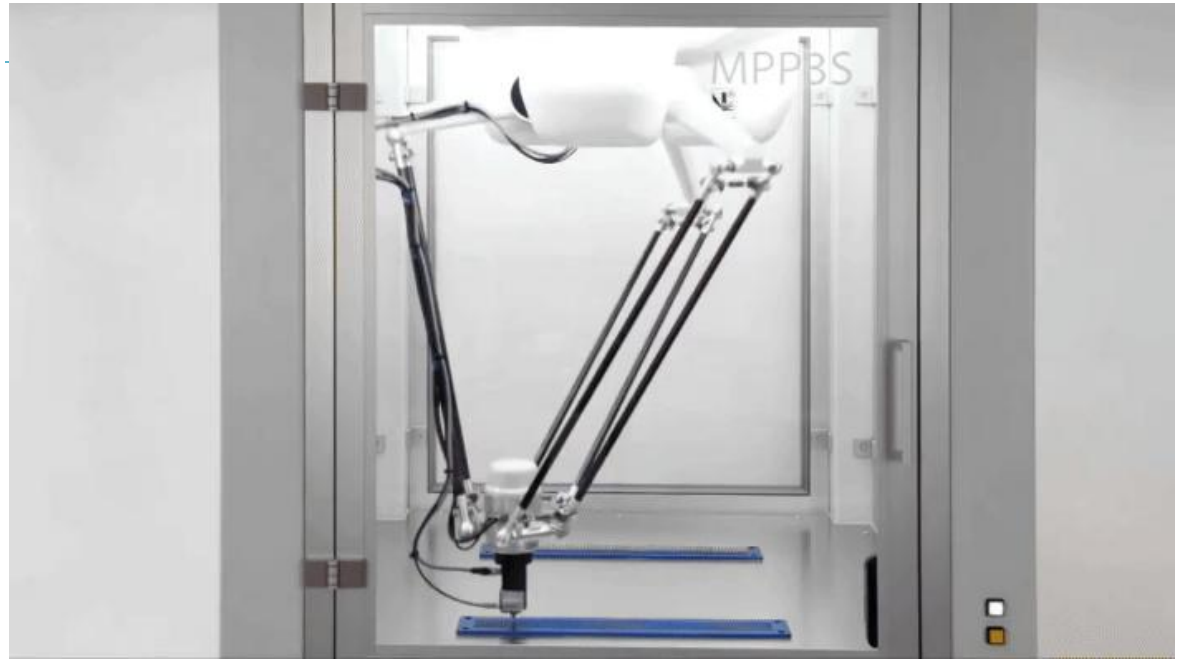


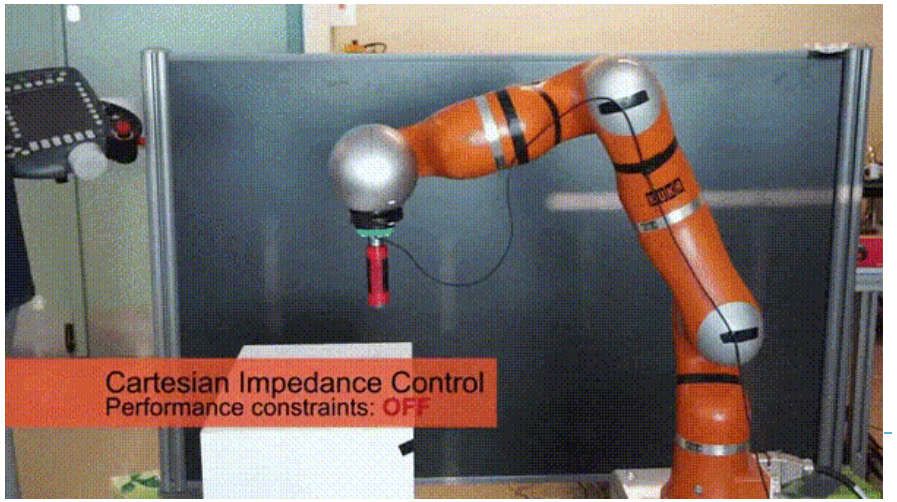
# Robot Classifications



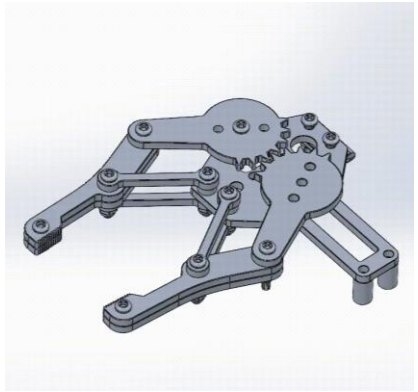
# Fixed Base Structure Robots

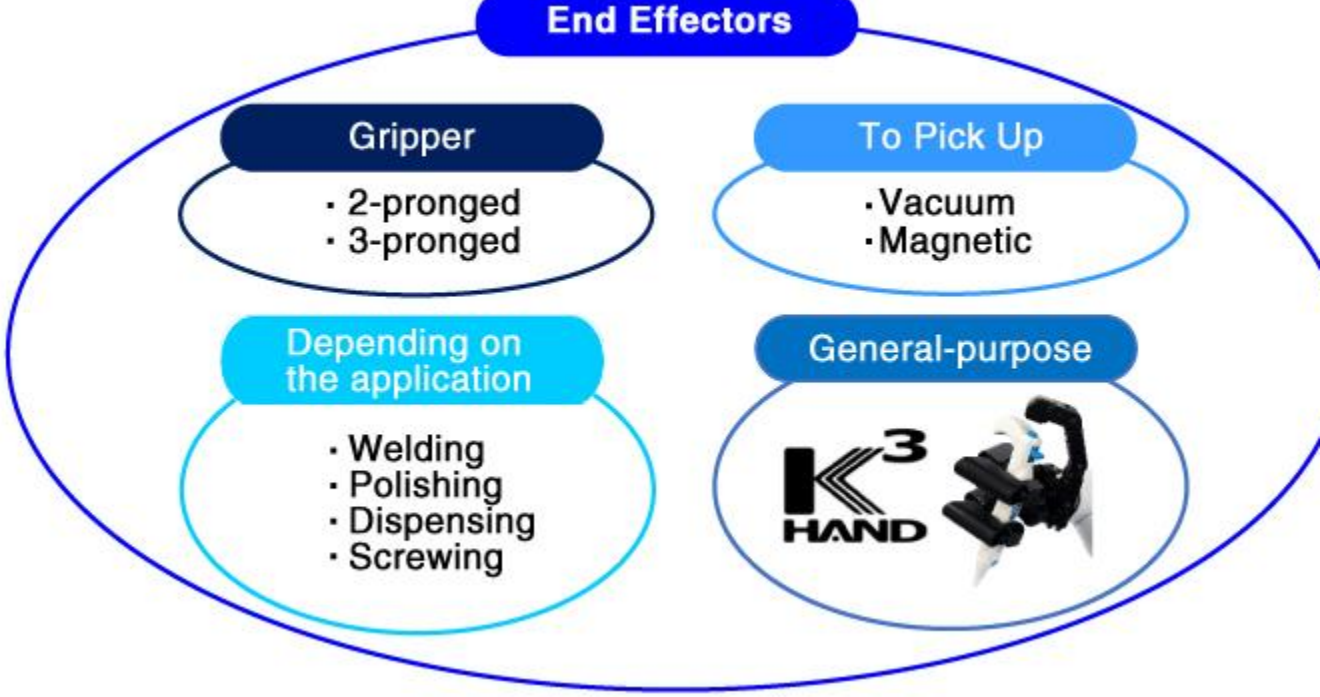


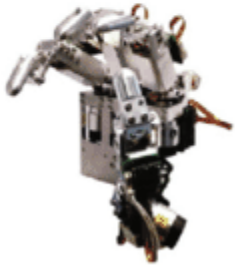



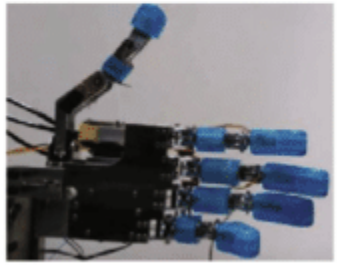

# End Effectors/ Grippers





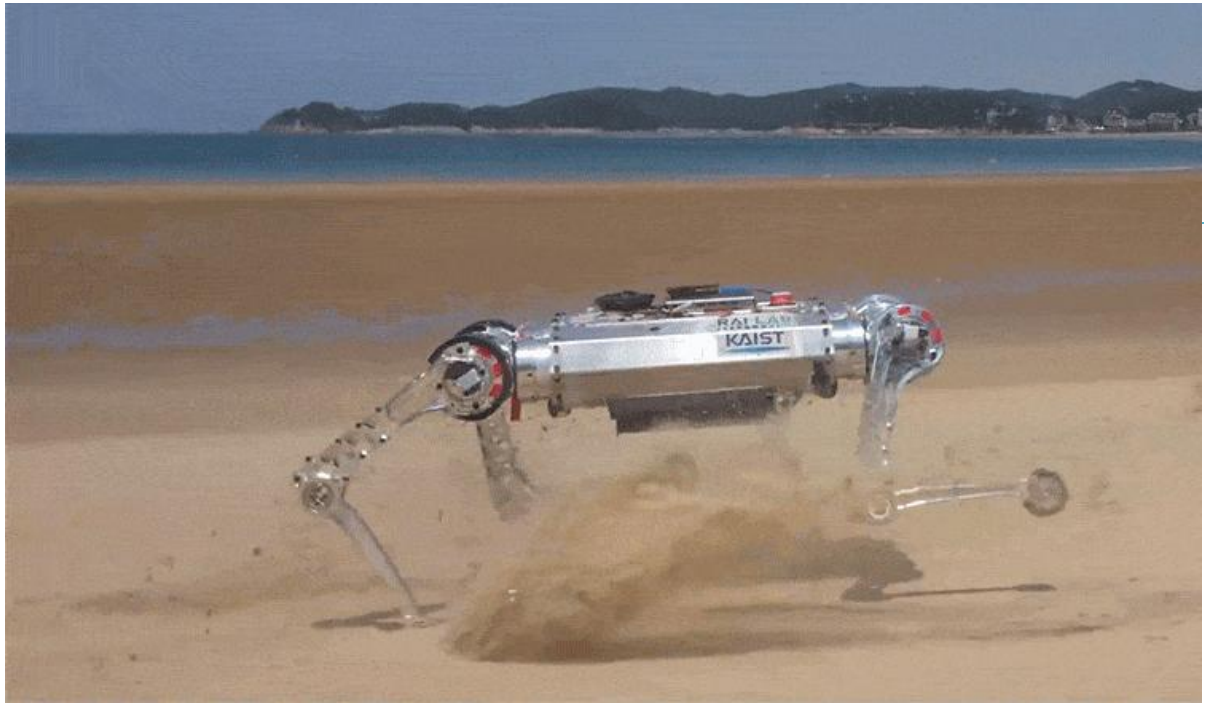

(a)

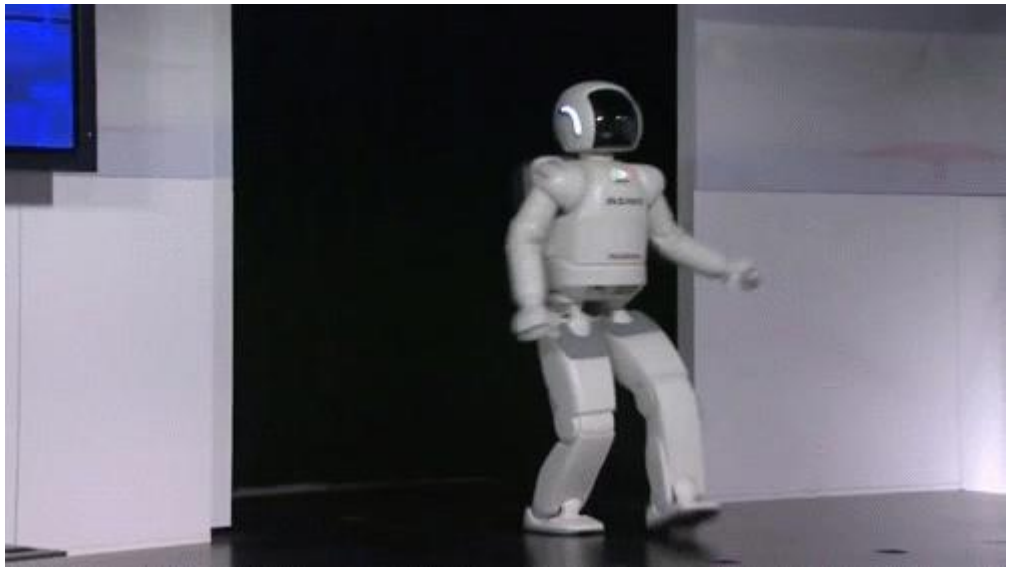




(b)

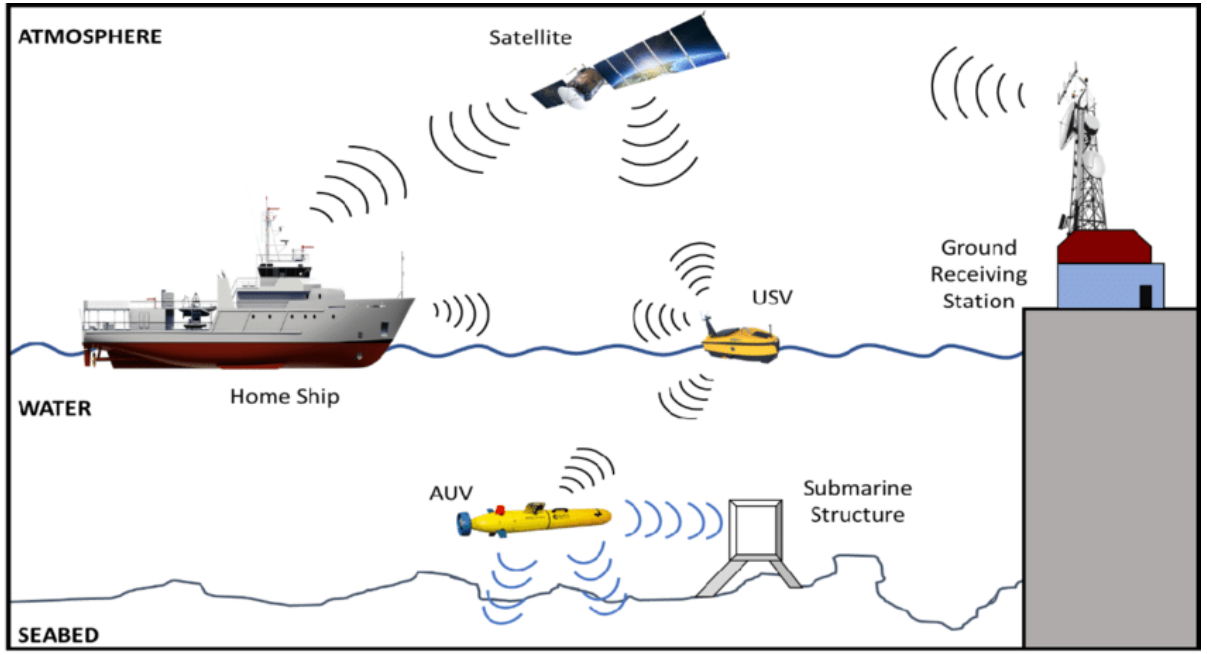
# Terrestrial Robots

# Terrestrial Robots
## Self Driving Vehicle

# ROV (Remotely Operated Vehicle)/AUV (Autonomous Underwater Vehicle

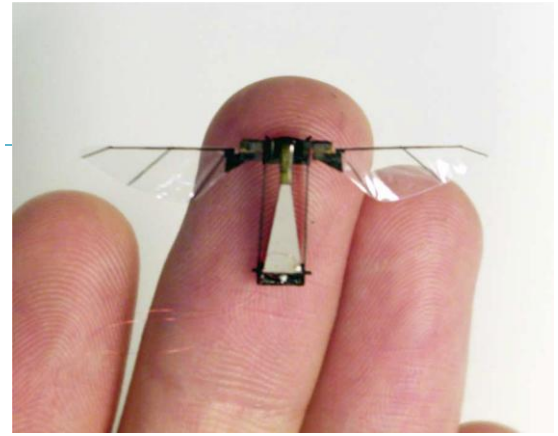
# Drones/UAV (Unmanned Aerial Vehicles)

Fixed Wing drones

Multi-rotor drones

a)

b)



insect flight


c)

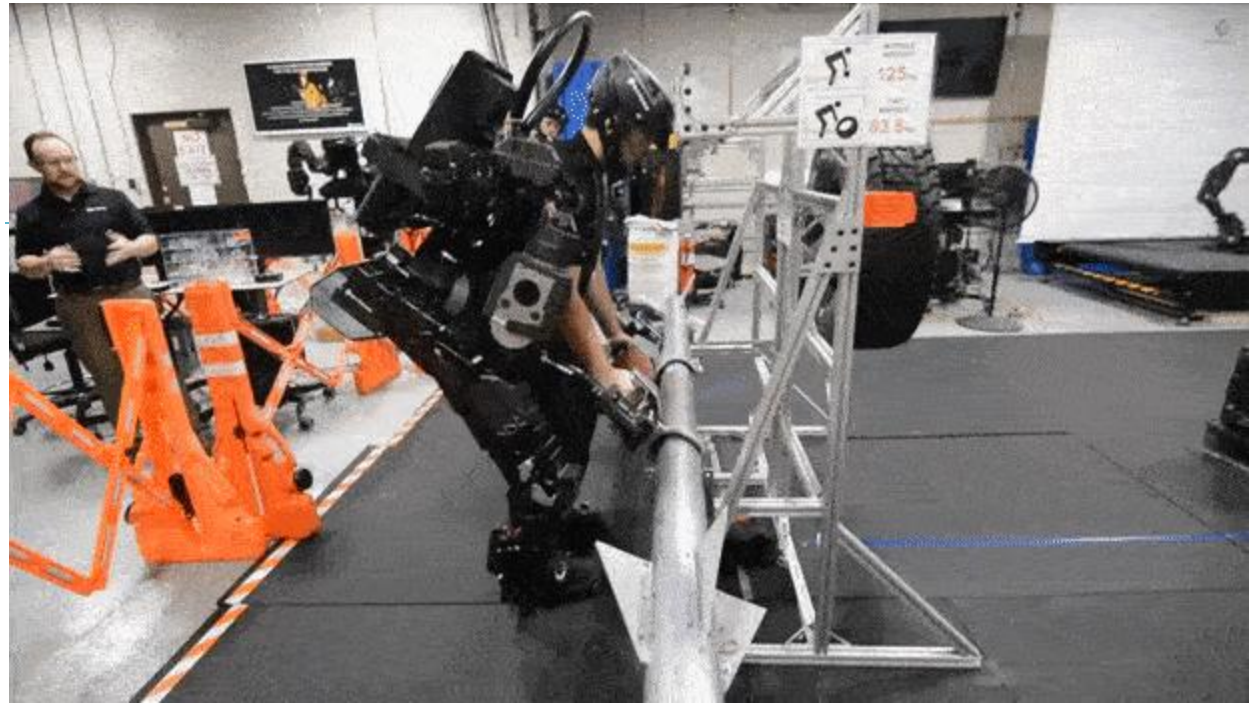
d)

Bird-like Robots

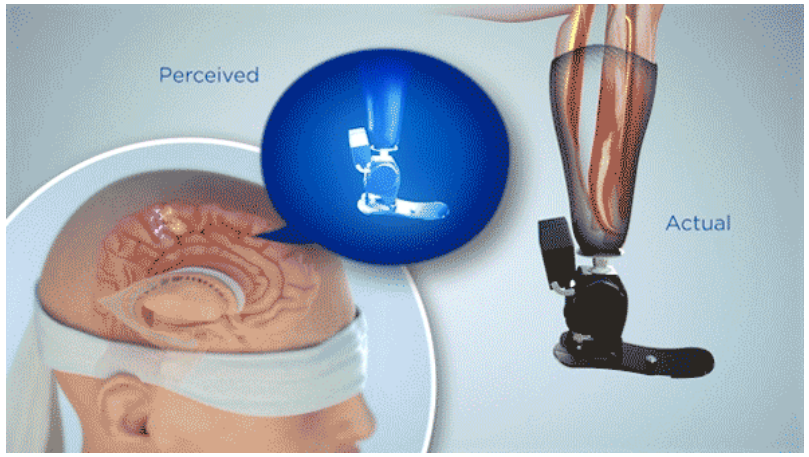
Single-rotor drones

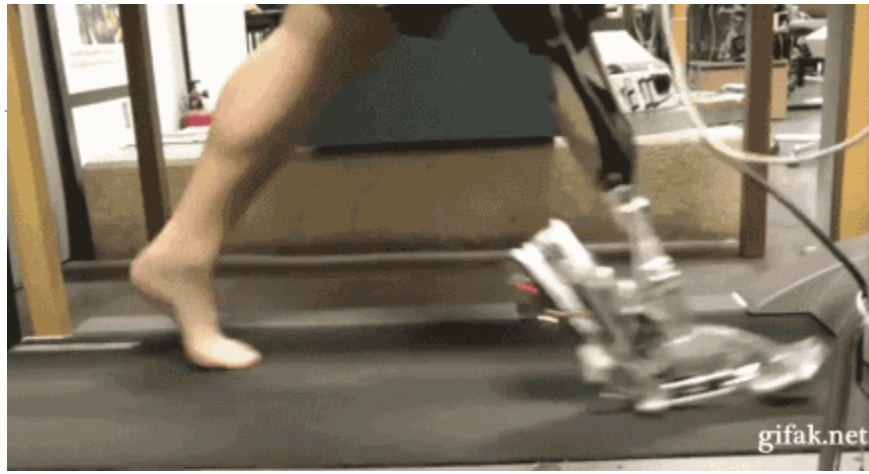
Vertical Take-Off and Landing (VTOL)

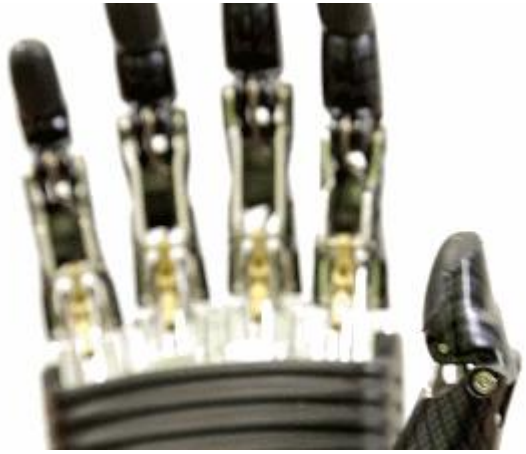
# Wearable Robots

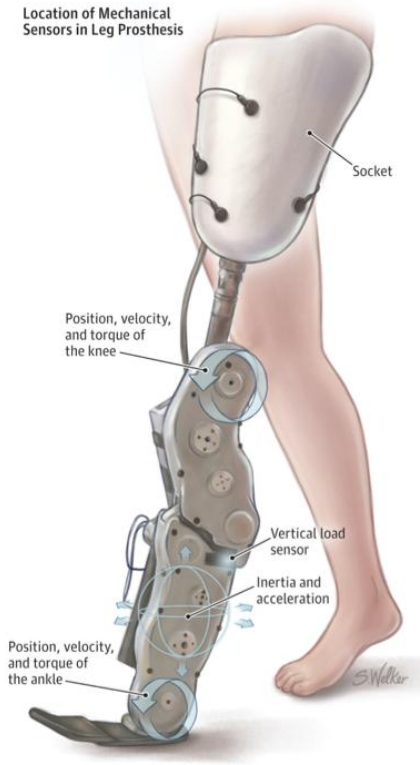



# Wearable Robots

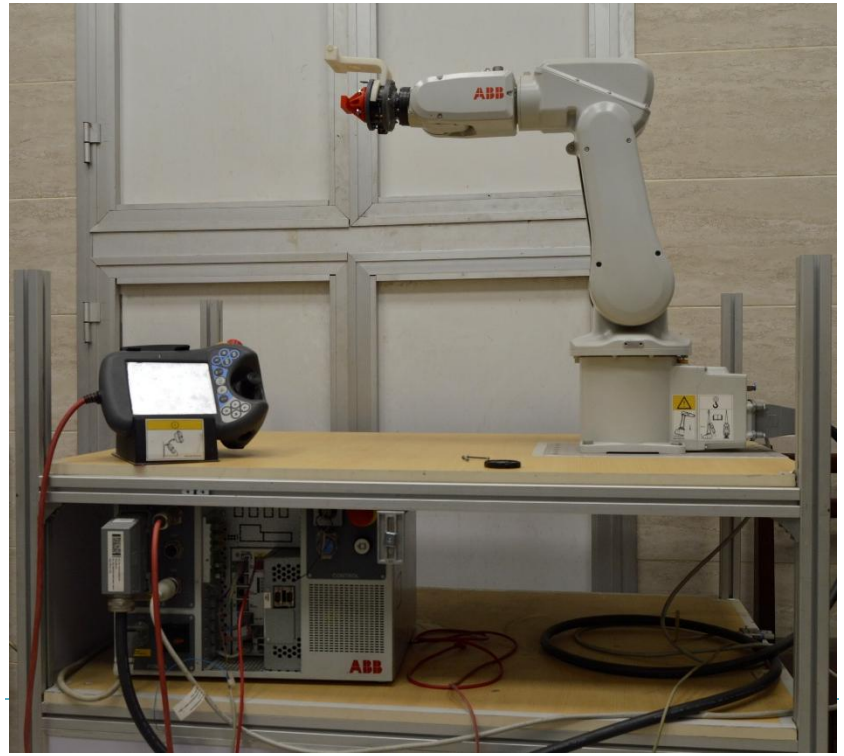




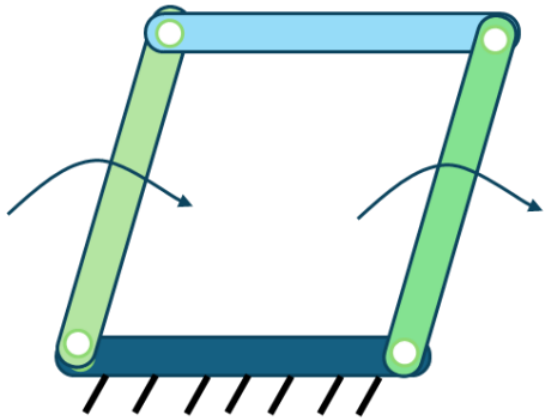
# Robotics at ASU Mechatronics



# Open Kinematic Chian Vs Closed Kinematic Chian

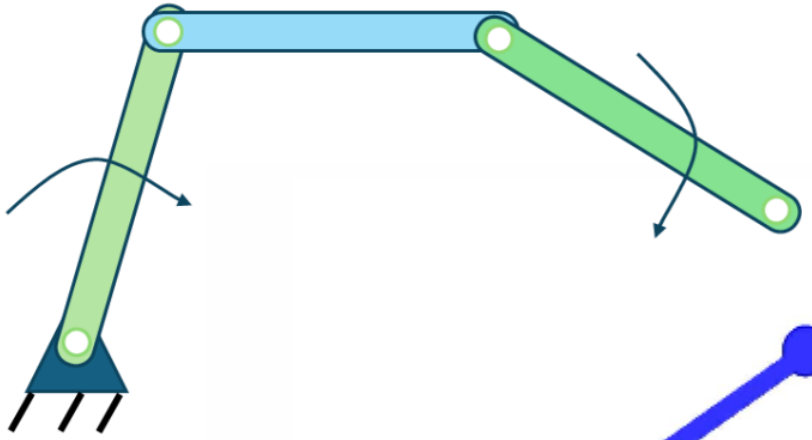
Closed kinematic chain

4 bar link mechanism

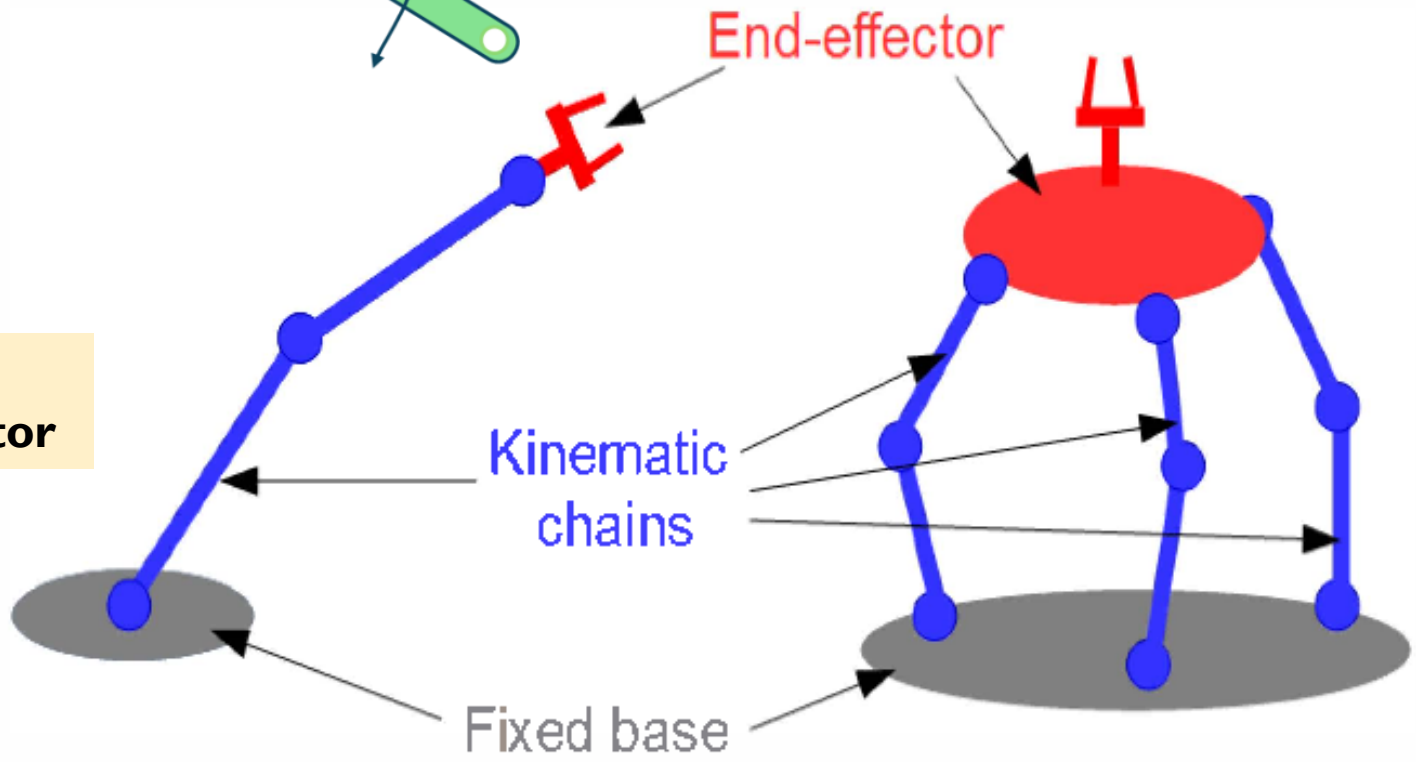


Open kinematic chain

Robotic arm

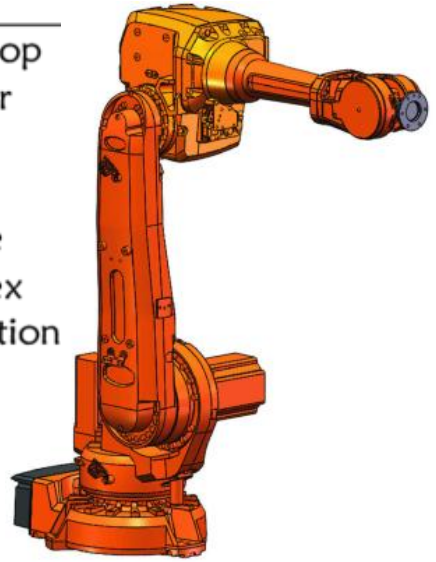


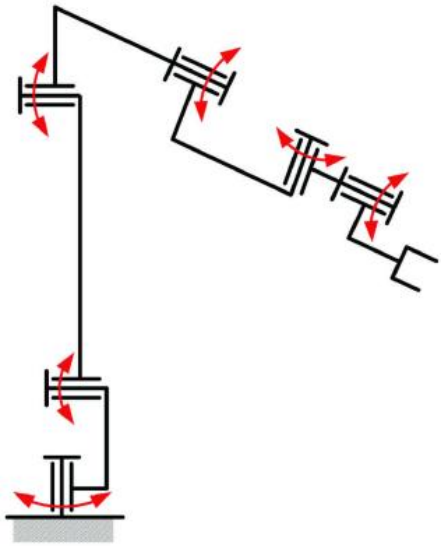
**Open Kinematic Chian = Serial Manipulator**
**Closed Kinematic Chian = Parallel Manipulator**



# Serial Manipulator Vs Parallel Manipulator

| Factor/Aspect | Parallel | Serial |
|---|---|---|
| Type Of Loop | Closed Loop | Open Loop |
| End Effectors | Platform | Gripper |
| Inertia | Low | High |
| Stiffness | High | Low |
| Direct Kinematics | Complex | Simple |
| Inverse Kinematics | Simple | Complex |
| Preferred Application | Precise Positioning | Gross Motion |

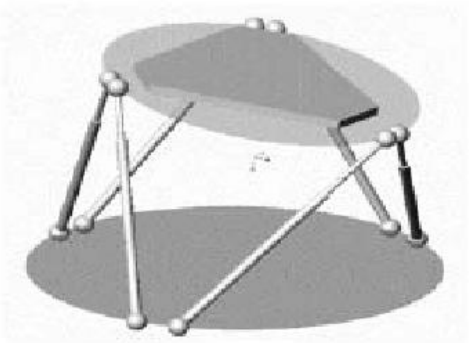




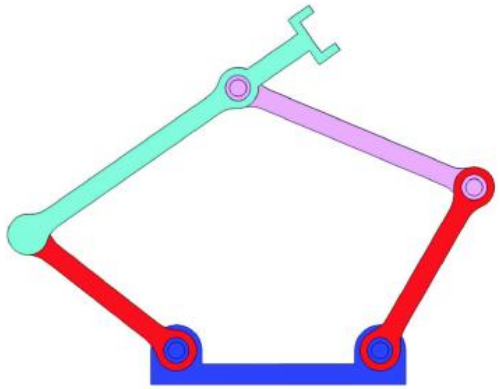
(a)

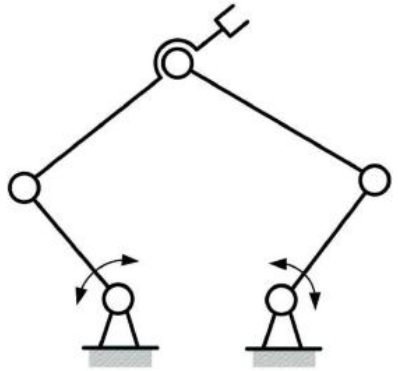


a



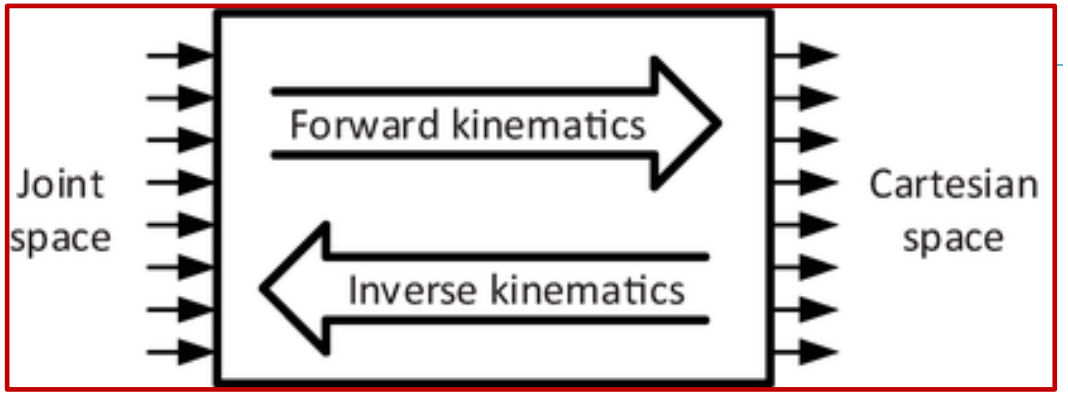
b

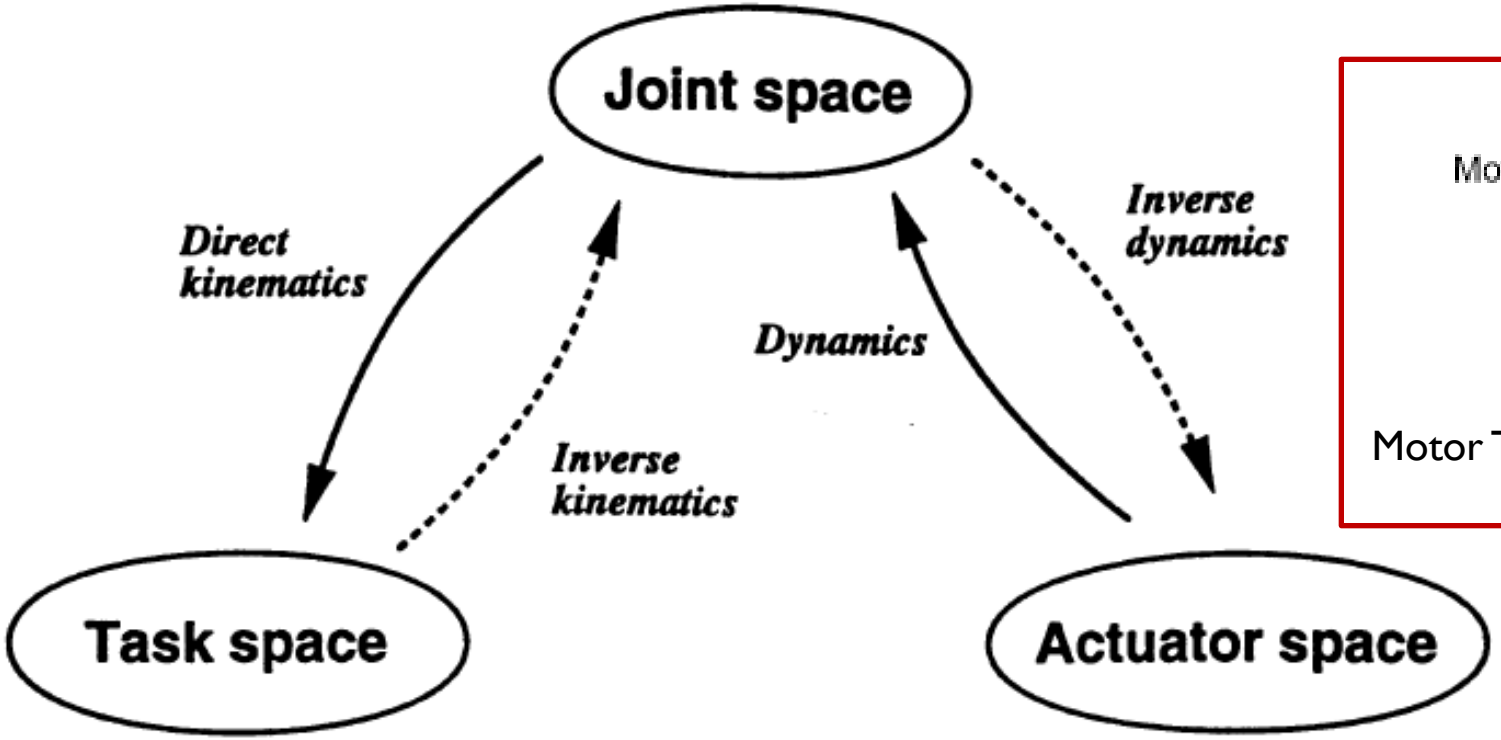


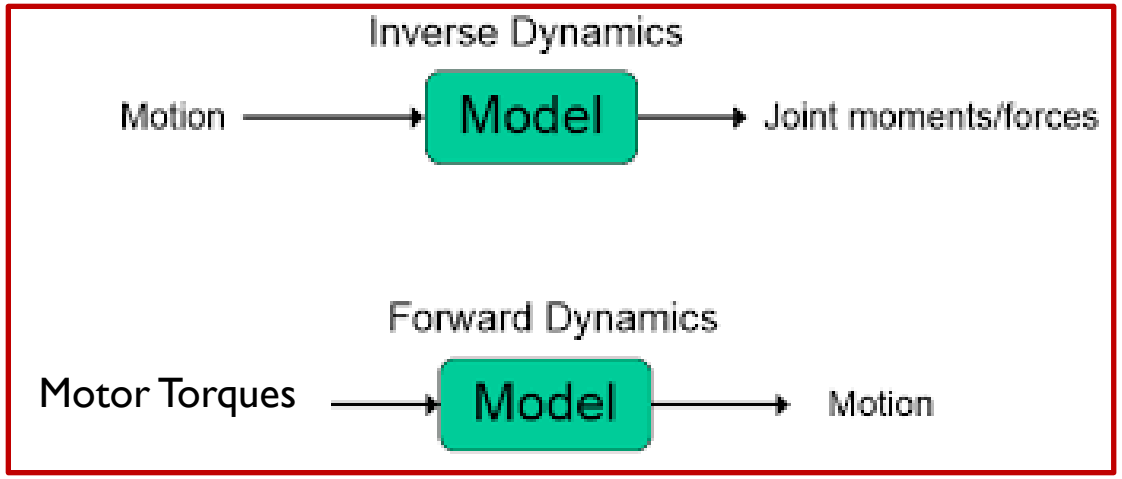


(b)

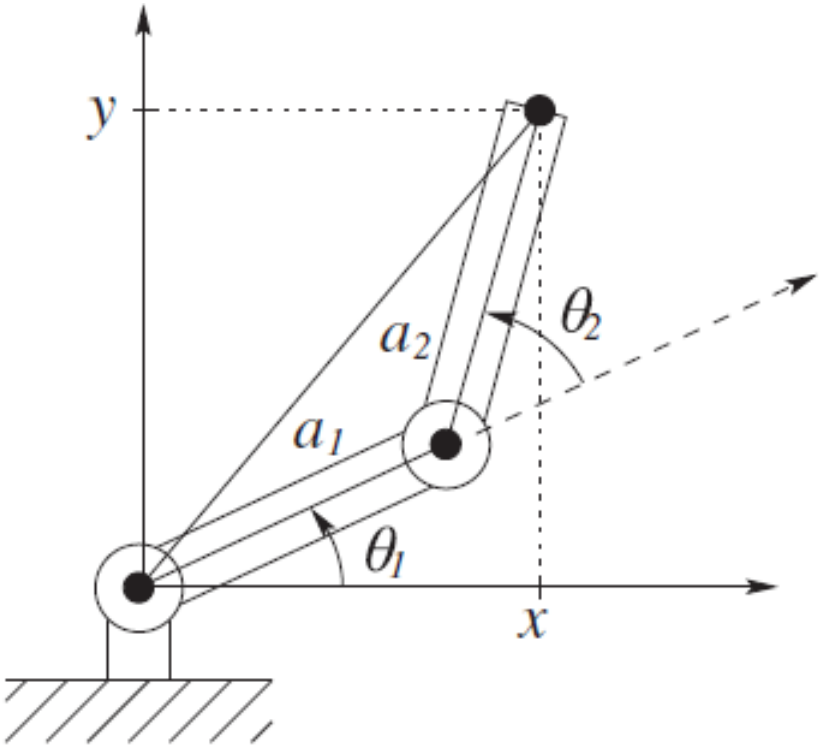
# Spaces in which motion can be observed and mappings between them



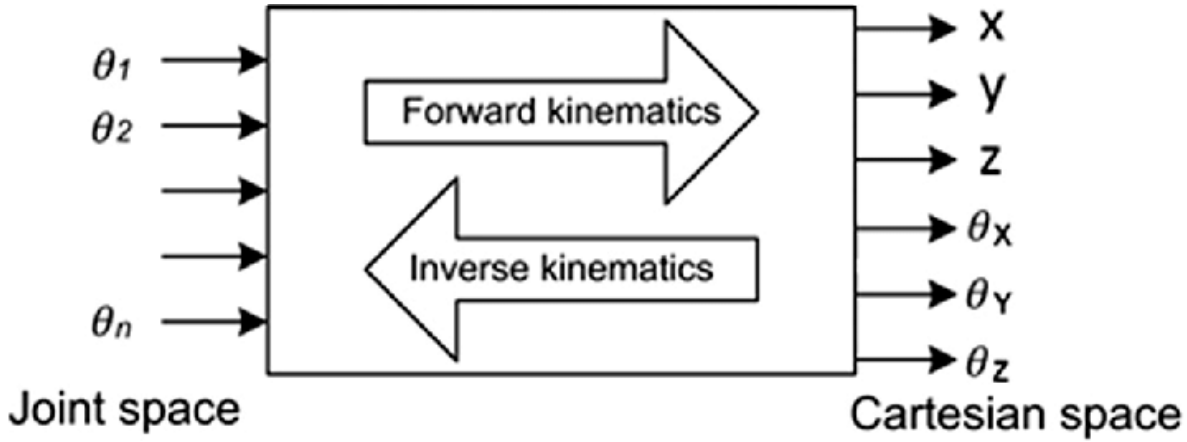



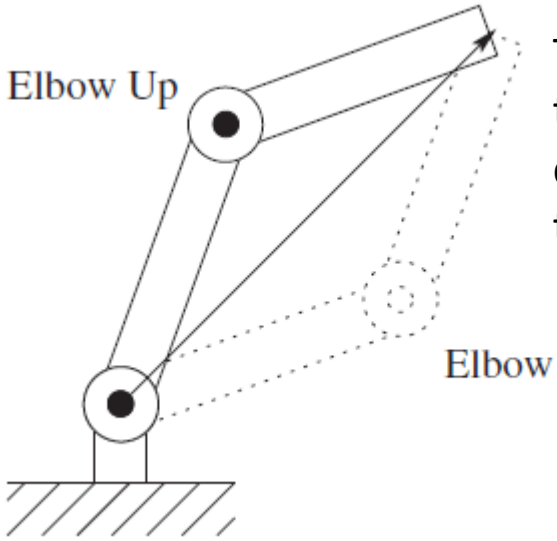



# Forward Kinematics Versus Inverse Kinematics in 2DoF Robot



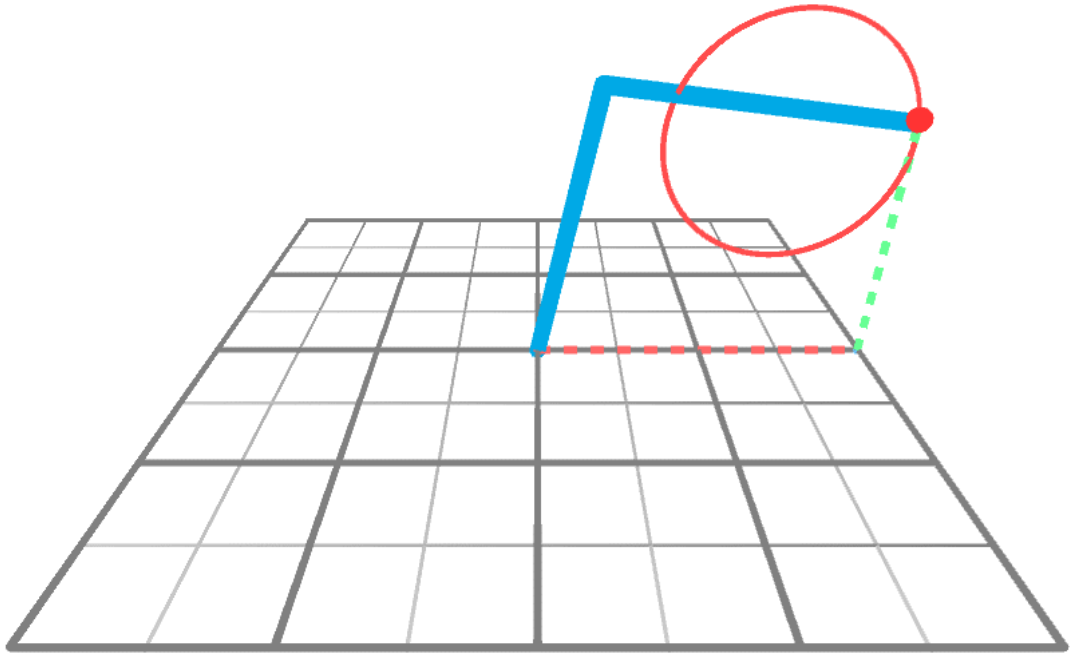

$$x = a_1 \cos\theta_1 + a_2 \cos(\theta_1 + \theta_2)$$
$$y = a_1 \sin\theta_1 + a_2 \sin(\theta_1 + \theta_2)$$

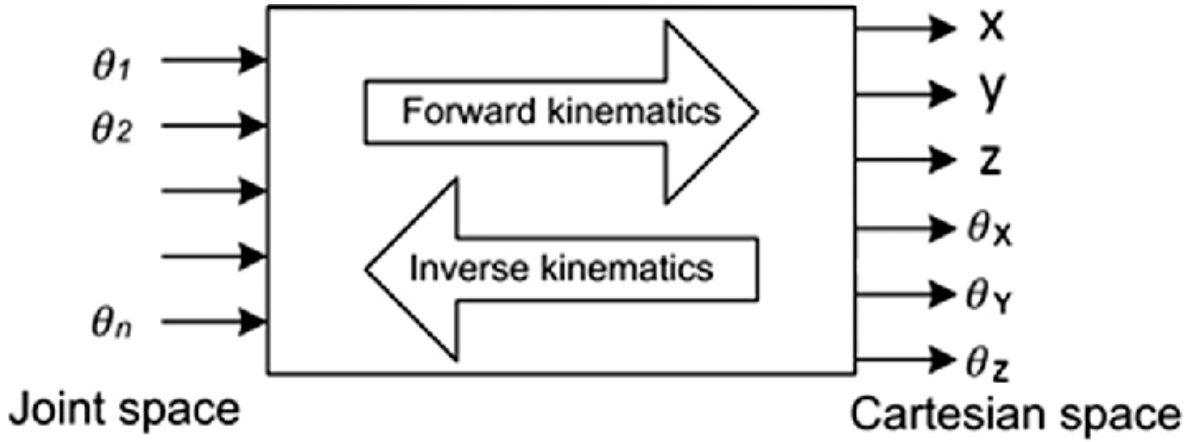



The two-link elbow robot has **two solutions** to the **inverse kinematics** except at singular configurations, the elbow up solution and the elbow down solution.

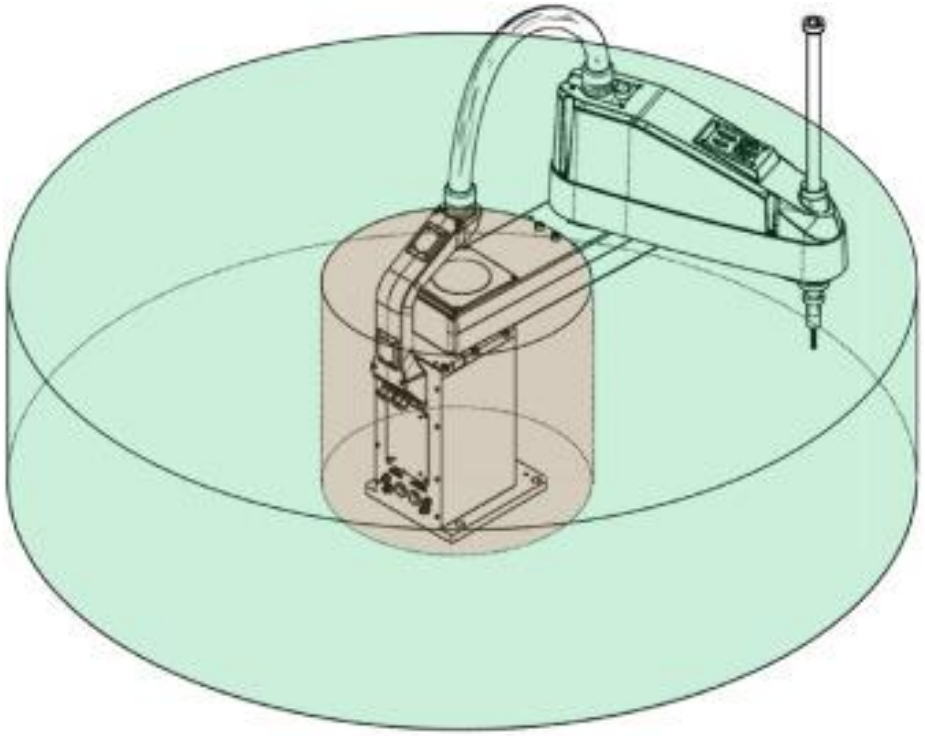
# Inverse Kinematics Problem in 2DoF Robot



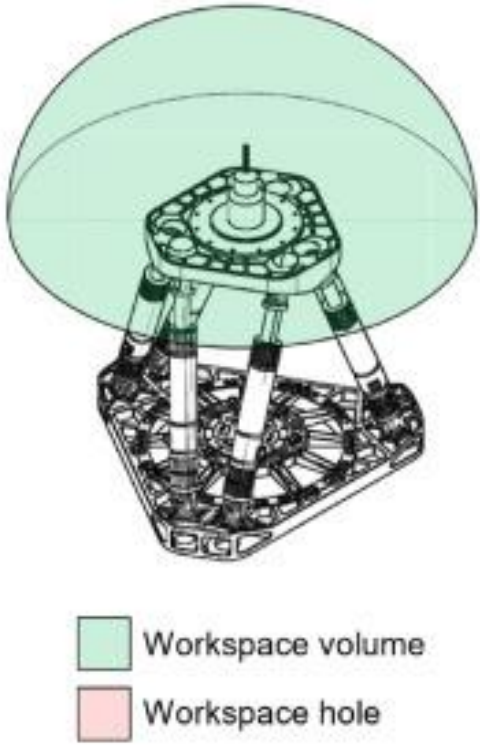


# Workspace

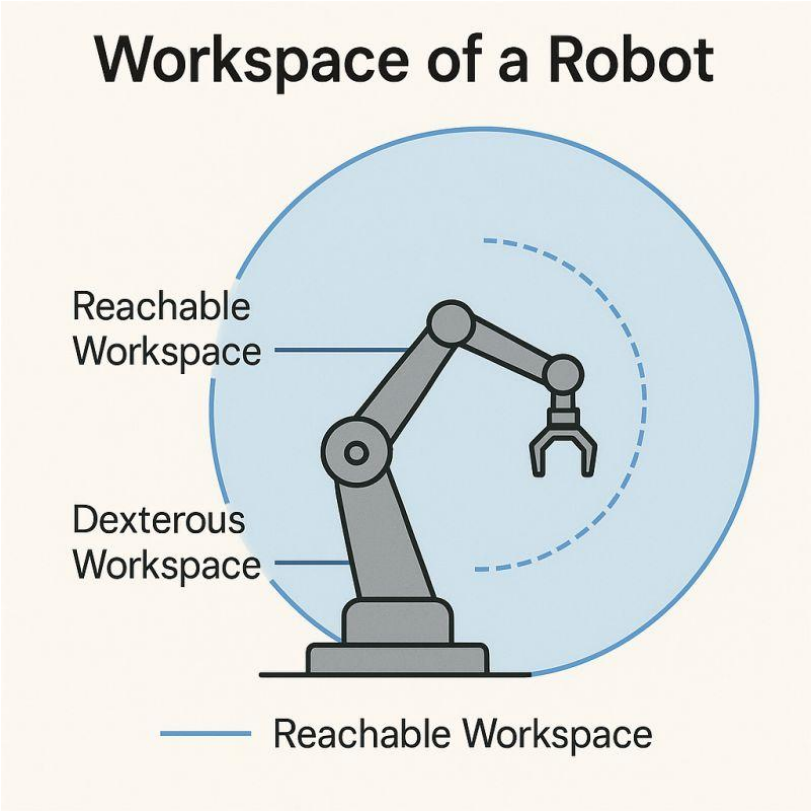
A robot's **workspace** is the three-dimensional region of space that the robot's end-effector (tool center point) can reach, given the robot's joint limits, link geometry, and any physical constraints.



A. Serial



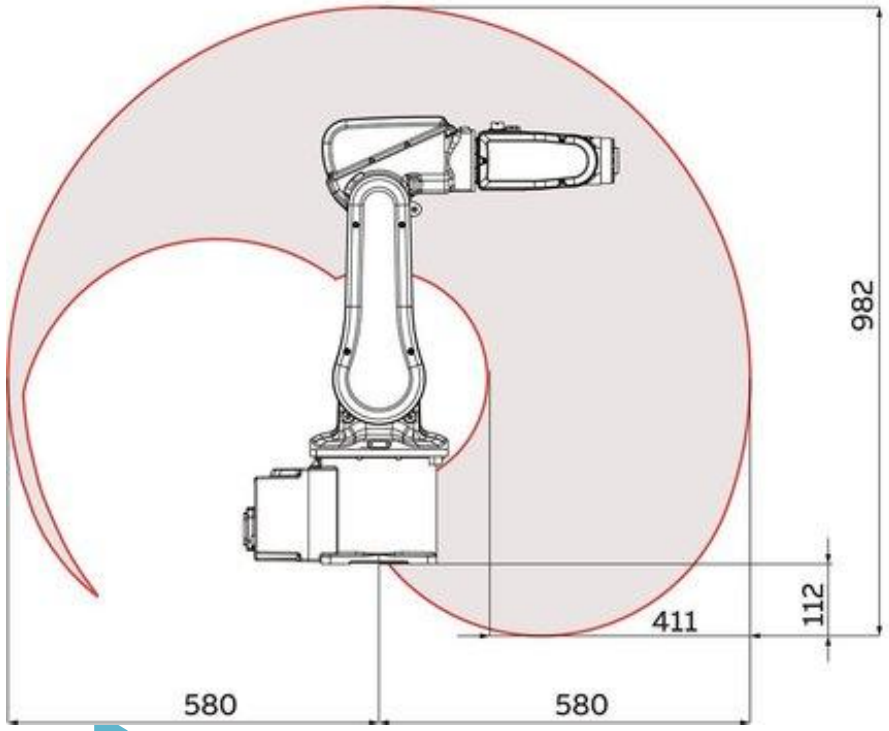

B. Parallel

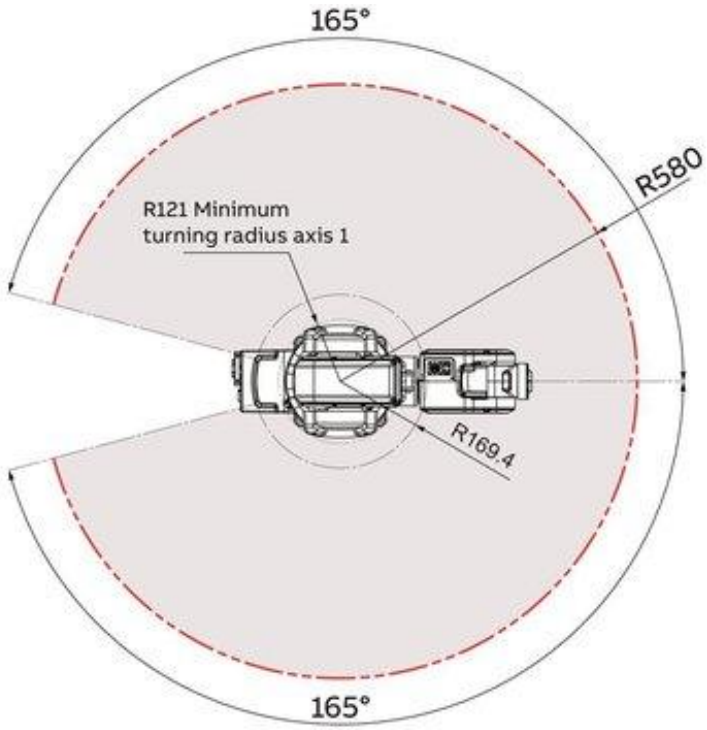


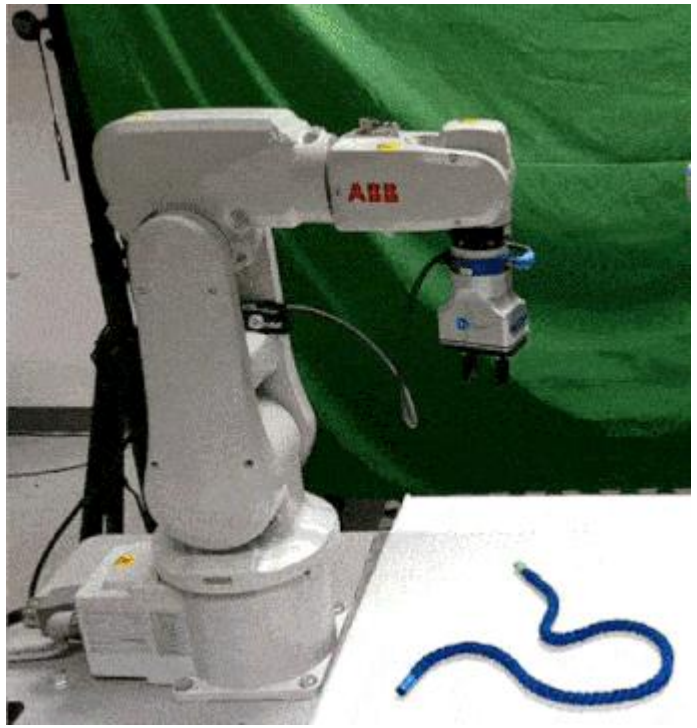
# Workspace

**Reachable workspace:**
The set of all positions (points in space) that the robot's end-effector can reach with **at least one** valid joint configuration (ignoring orientation, or allowing any orientation that happens to be possible).

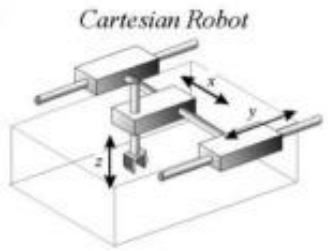
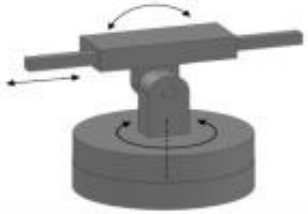
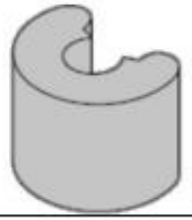
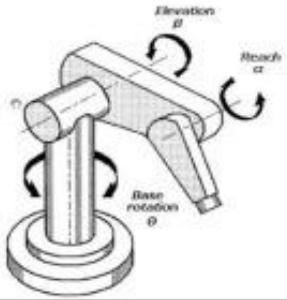
**Dexterous workspace:**
The set of all positions that the robot's end-effector can reach where it can also achieve **all (or a specified range of)** end-effector orientations at that position (i.e., the robot has full/adequate orientation capability there).

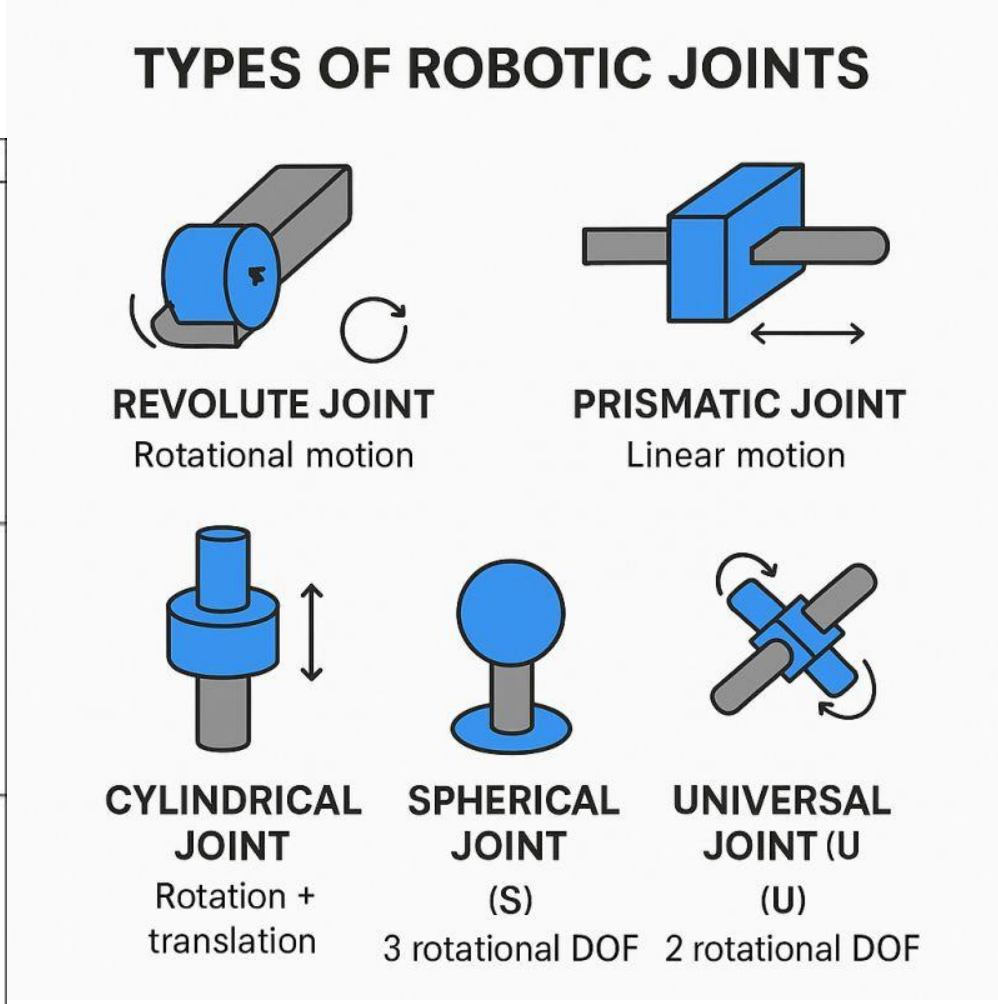


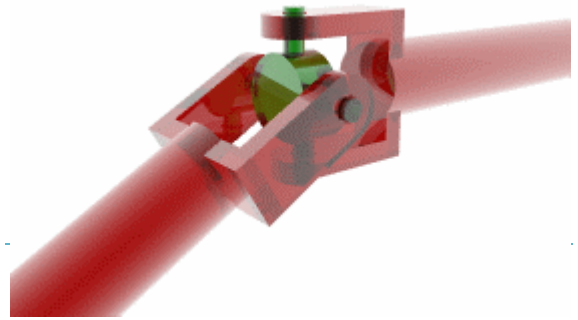



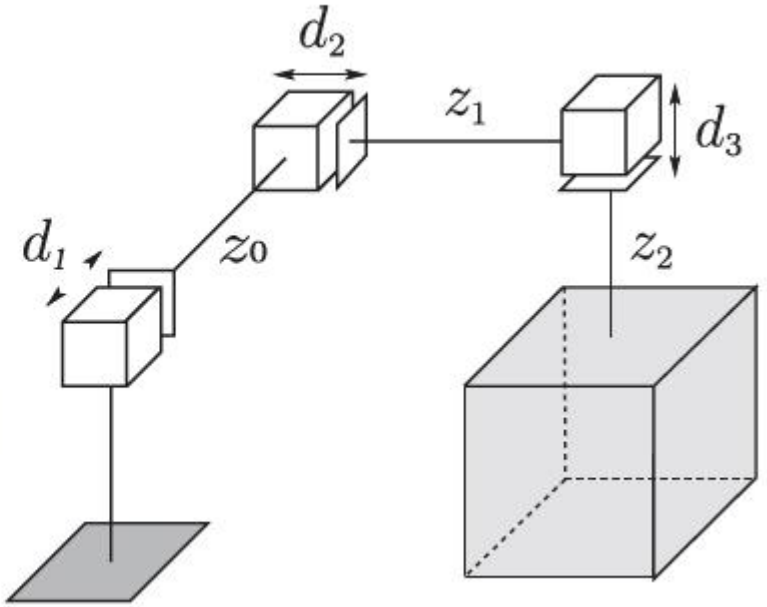
# Types of Joints in Robotics

| Types of Robots | Structure | Joint type | Shape of the workspace |
|---|---|---|---|
| Cartesian |   | P-P-P |  |
| Cylindrical |  | R-P-P |  |
| Spherical |  | R-R-P |  |
| Articulated Robot |  | R-R-R |  |



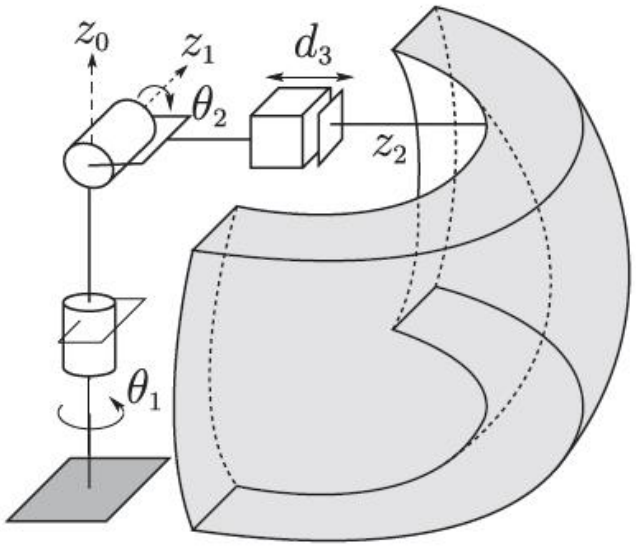



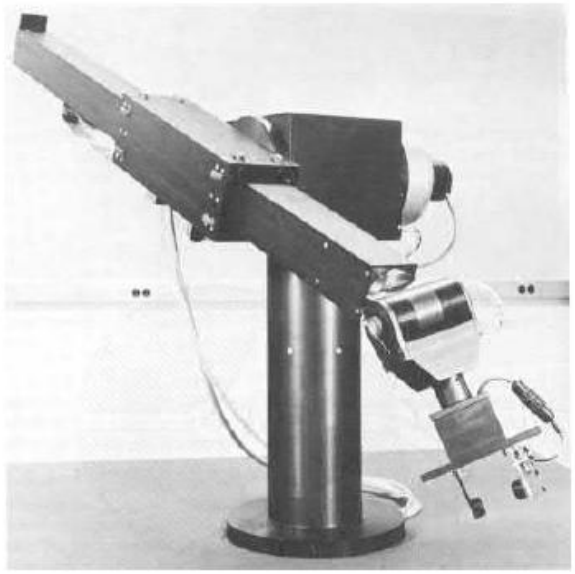
# Manipulator Examples



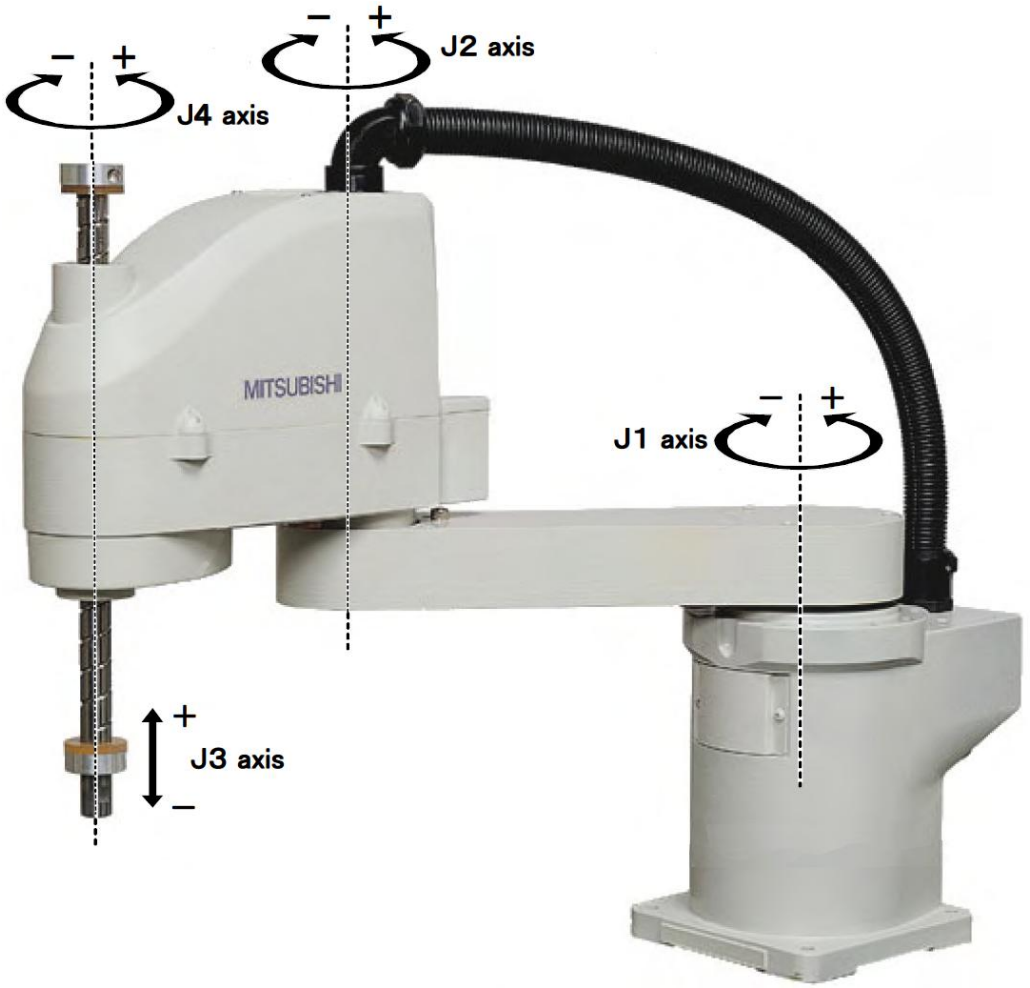

Cartesian robot (PPP)

# Manipulator Examples



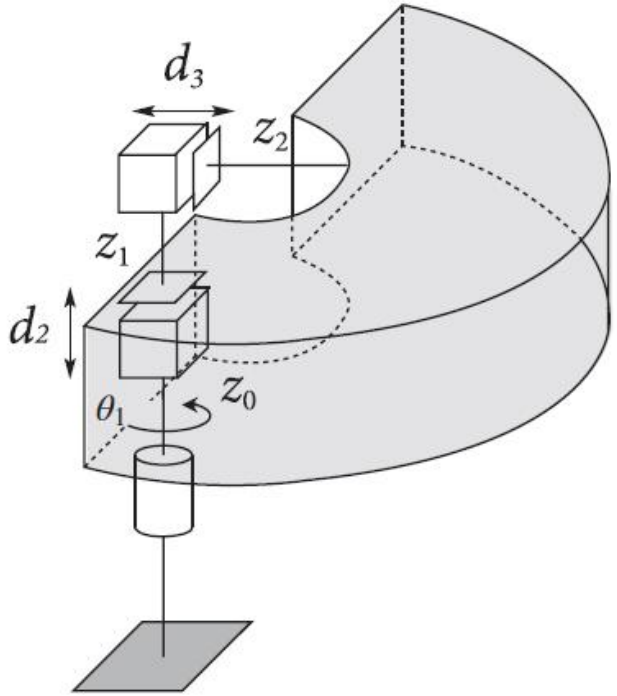



**Schematic representation of an RRP manipulator, referred to as a spherical robot**

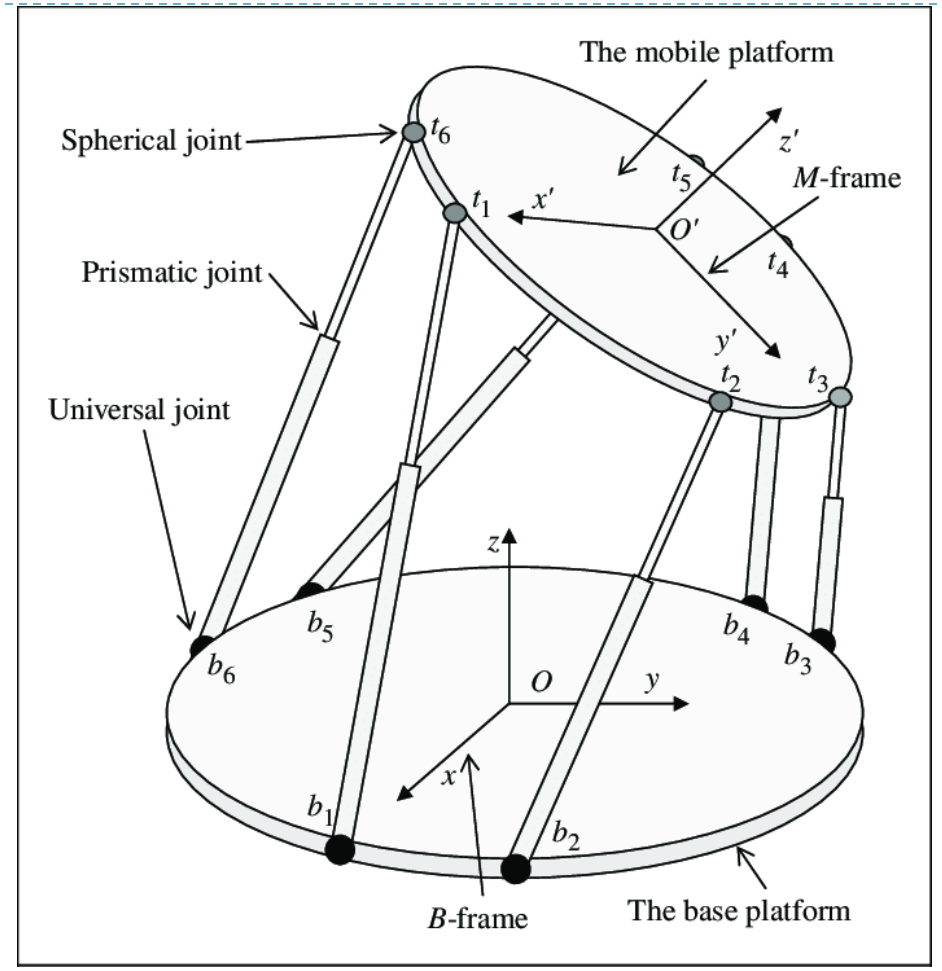



**SCARA robot (RRP or RRPR)**

# Manipulator Examples

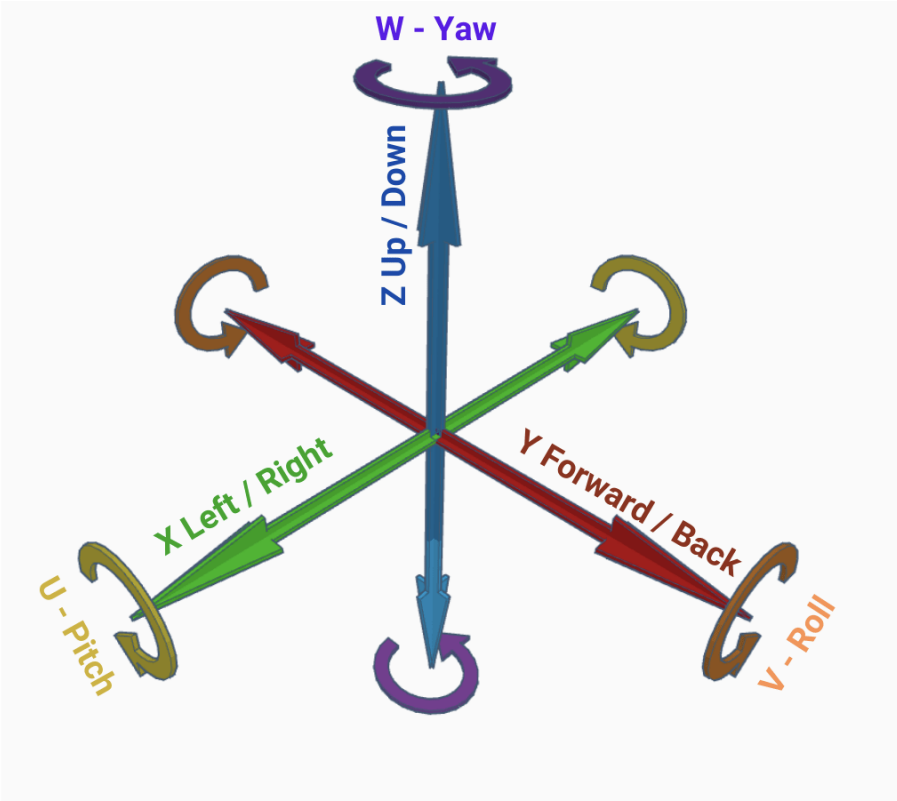


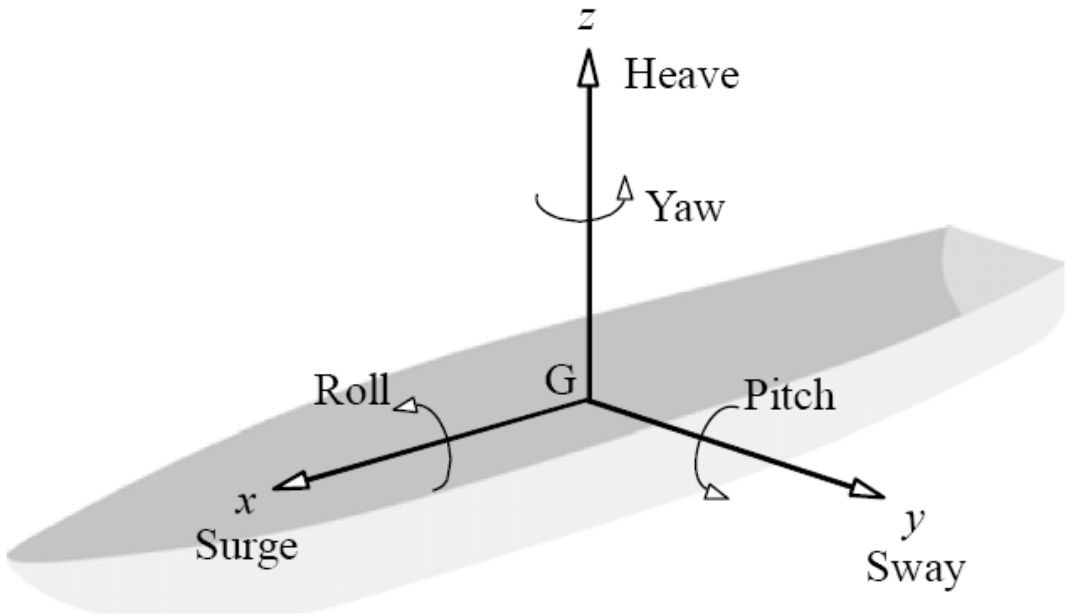

Cylindrical robot (RPP)

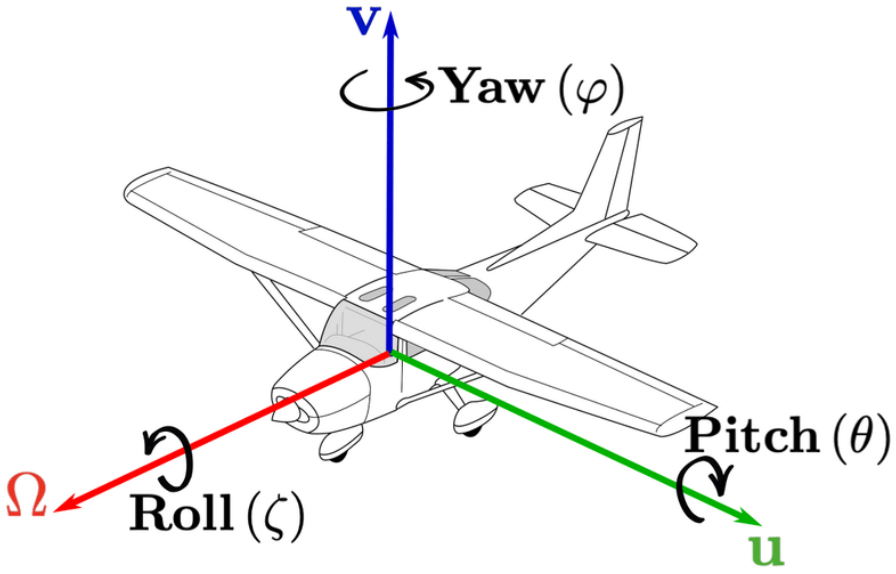



Stewart Platform (6-UPS)

# Degrees of Freedom



# Degrees of Freedom (DoF)

## Grubler's criterion

$$F = \lambda(n-1) - \sum_{i=1}^{j} c_i .$$

Grubler's criterion

$$F = \lambda(n-j-1) + \sum_{i} f_i - f_p .$$

$c_i$: number of constraints imposed by joint $i$.

$F$: degrees of freedom of a mechanism.

$f_i$: degrees of relative motion permitted by joint $i$.

$j$: number of joints in a mechanism, assuming that all the joints are binary.

$j_i$: number of joints with $i$ degrees of freedom.

$L$: number of independent loops in a mechanism.

$n$: number of links in a mechanism, including the fixed link.

$\lambda$: degrees of freedom of the space in which a mechanism is intended to function.

$f_p$ be the number of passive degrees of freedom in a mechanism

# Degrees of Freedom (DoF)

**DOF conditions** for a robot/mechanism (DOF = mobility = number of independent motions the mechanism can make).

1. **DOF > 0**

✓ The mechanism is **movable**.
✓ It has **DOF** independent motions (you need that many independent inputs to fully "command" its motion).
✓ Example: a planar 2-link arm typically has DOF = 2.

2. **DOF = 0**

✓ The mechanism is a **structure** (no motion).
✓ It's **fully constrained**.
✓ Example: a rigidly braced frame.

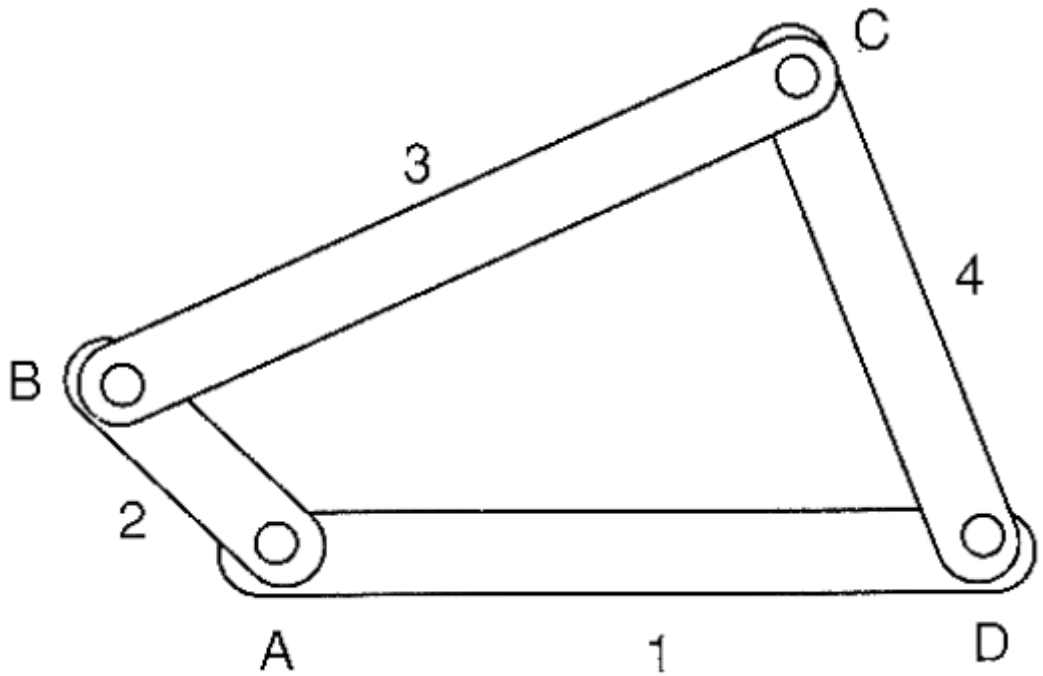
3. **DOF < 0**

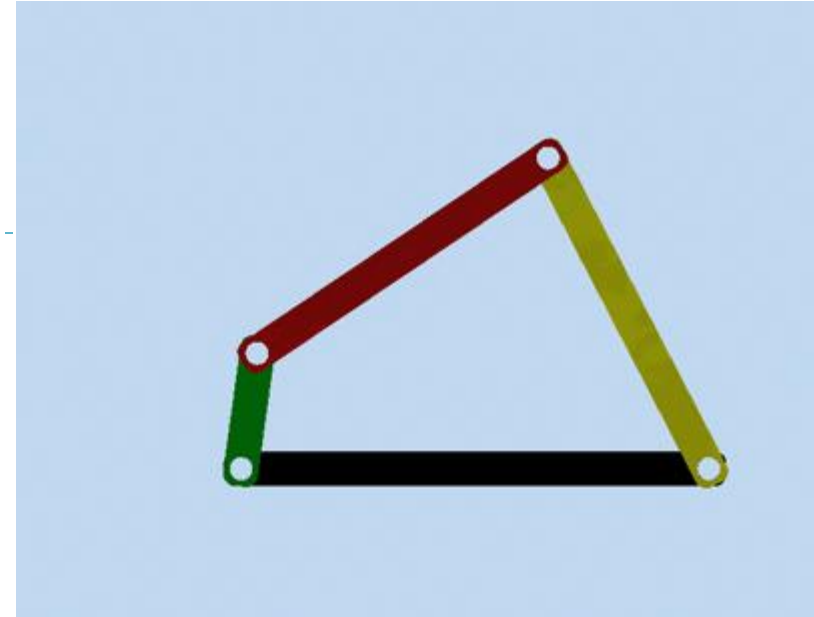
✓ The mechanism is **overconstrained** (more constraints than needed).
✓ Often indicates **assembly stress**, binding, or that the simple DOF formula doesn't capture special geometry (some mechanisms still move due to compliant parts or special constraints).
✓ Practically: "you tried to constrain it too much."

- **DOF > 0**: moves
- **DOF = 0**: fixed structure
- **DOF < 0**: overconstrained (likely problematic / special case)
- **DOF = actuators**: fully actuated
- **DOF > actuators**: underactuated

# Degrees of Freedom (DoF)

## Four bar Mechanism



$$\lambda = 3, n = 4, j = j_1 = 4,$$

$$F = \lambda(n-1) - \sum_{i=1}^{j} c_i.$$

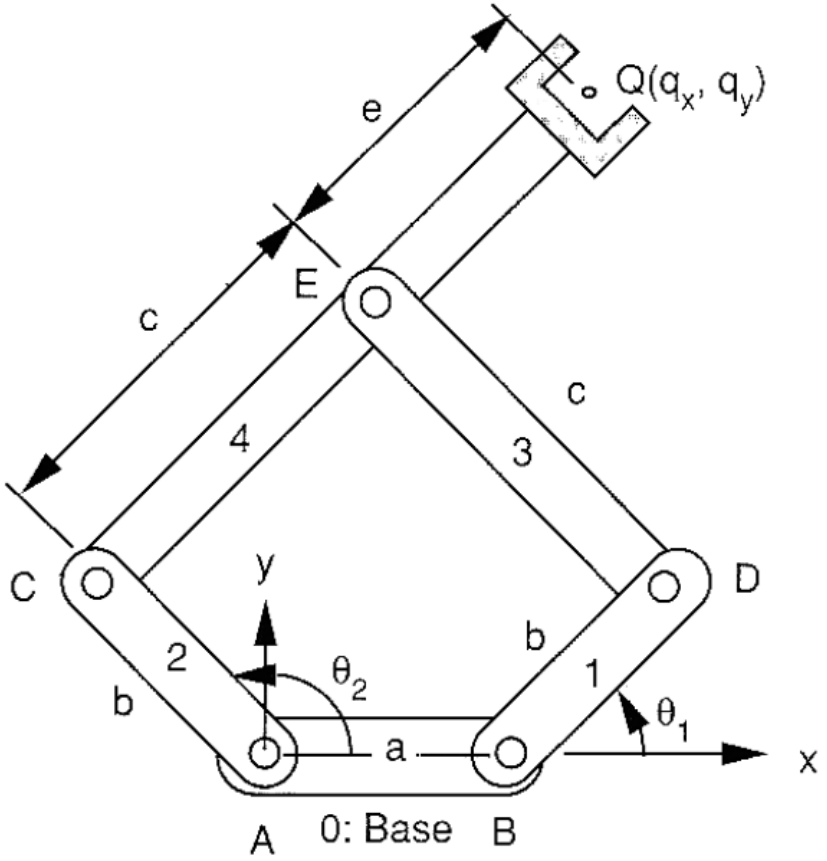
OR Grubler's criterion

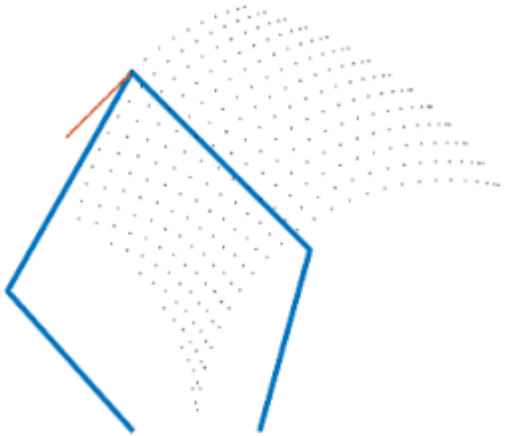
$$F = \lambda(n-j-1) + \sum_{i} f_i - f_p.$$

$$F = 3(4-4-1)+4\times 1 = 1.$$

# Degrees of Freedom (DoF)

## Five bar mechanism



$$F = \lambda(n-1) - \sum_{i=1}^{j} c_i.$$

OR Grubler's criterion

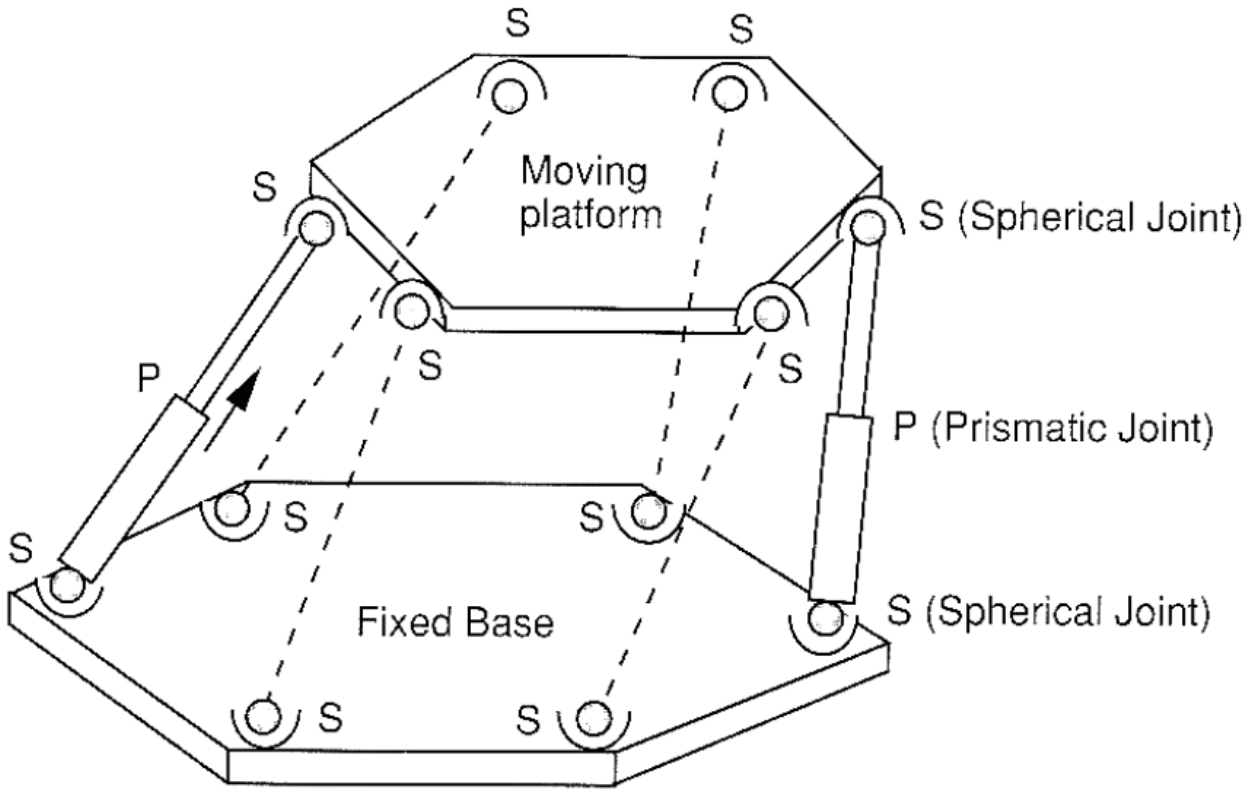
$$F = \lambda(n-j-1) + \sum_{i} f_i - f_p.$$

$\lambda = 3, n = 5,$ and $j = 5$

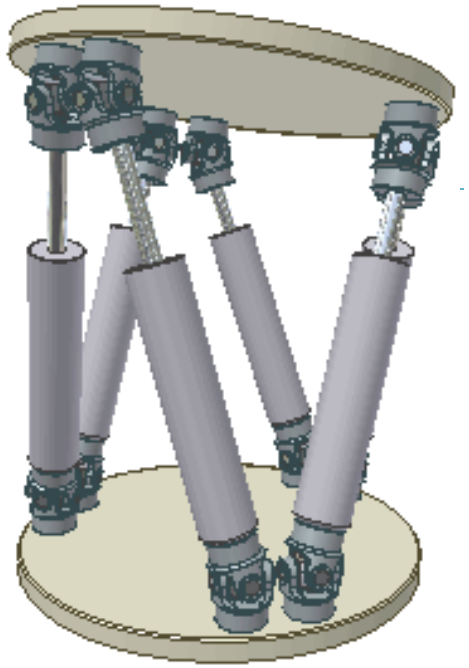
$$F = 3(5-5-1) + 5 \times 1 = 2$$

# Degrees of Freedom (DoF)

## Grubler's criterion




**6-SPS**



**6-UPU**

Apply Grubler's criterion to calculate DoF **in 6-SPS** Stewart Platform

$$F = \lambda(n - j - 1) + \sum_i f_i - f_p.$$

$$\lambda = 6, n = 14, j_1 = 6, j_3 = 12, \text{ and } f_p = 6.$$

$$F = 6(14 - 18 - 1) + (12 \times 3 + 6) - 6 = 6.$$

# Underactuated Robotics/Passive Dynamics Walking


ABB
FLEXPENDANT

CONTROLLER

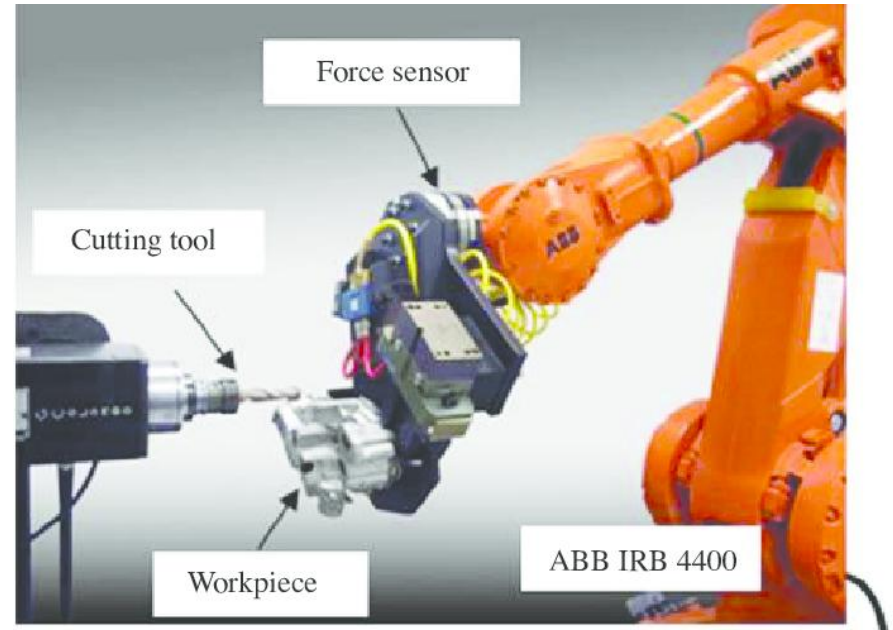
ABB
IRC5

VELOCIO
PLC

ABB
IRB 6620

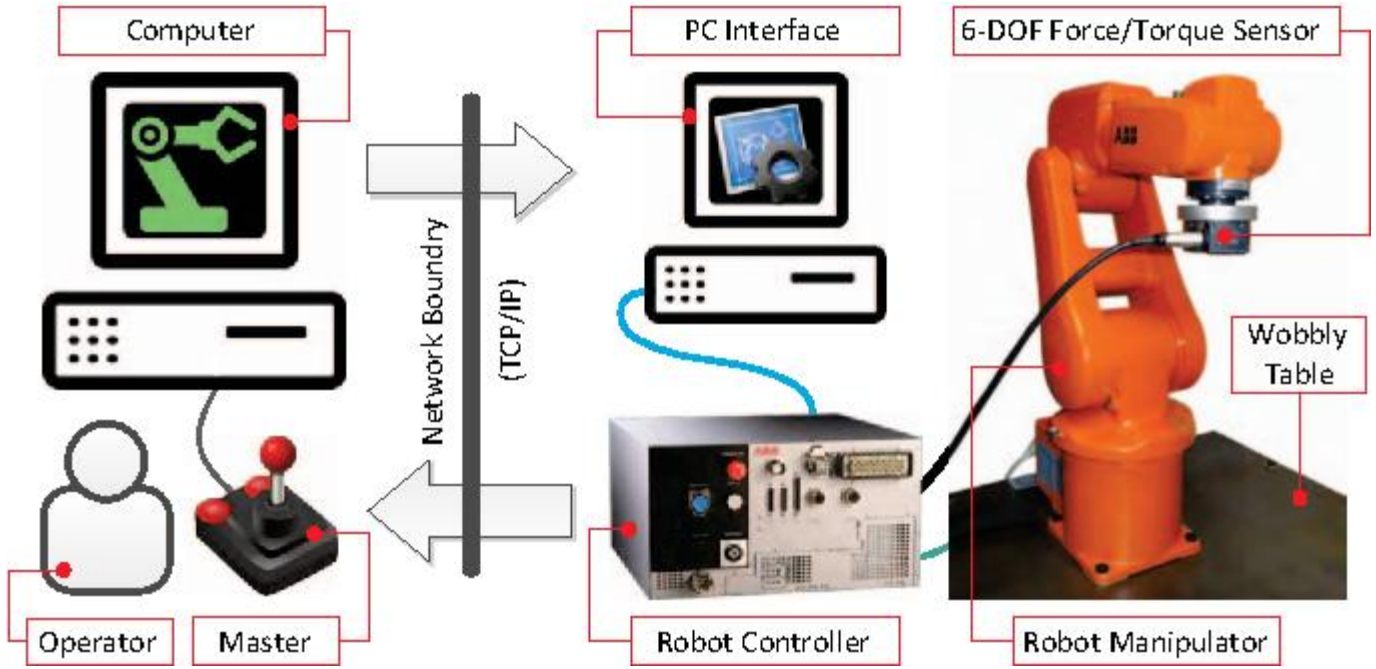
ABB
DSQC 652
I/O UNIT

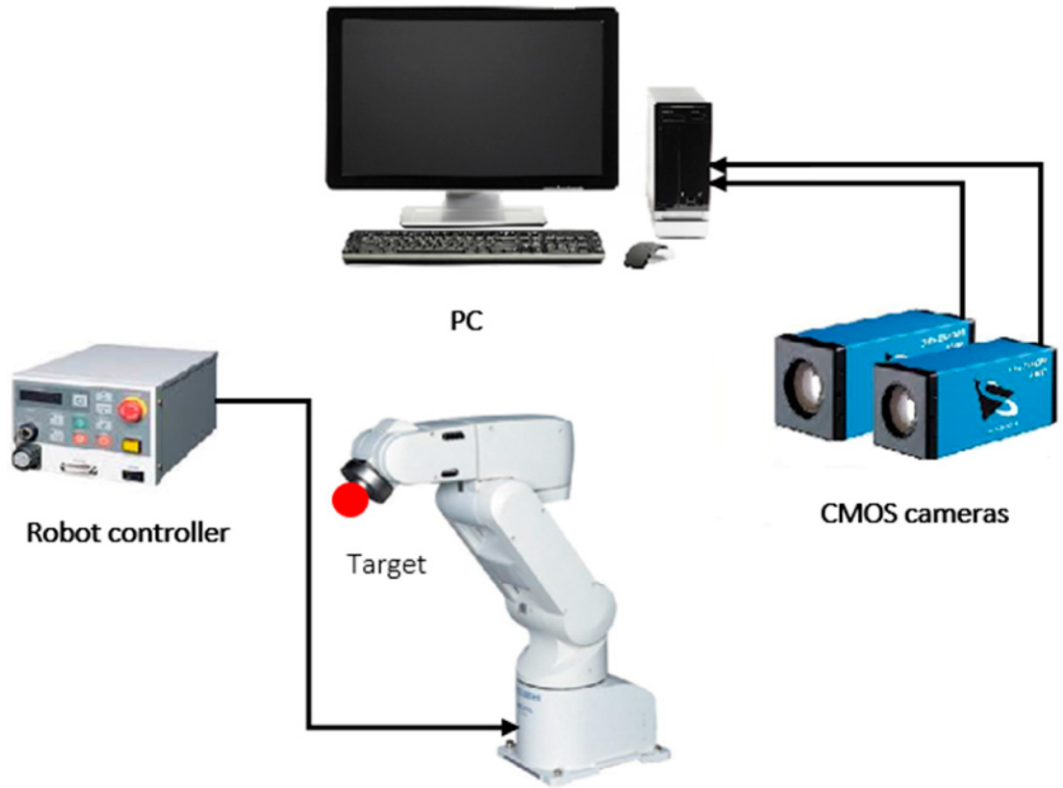

MASSIVE DIMENSION
PELLET EXTRUDER

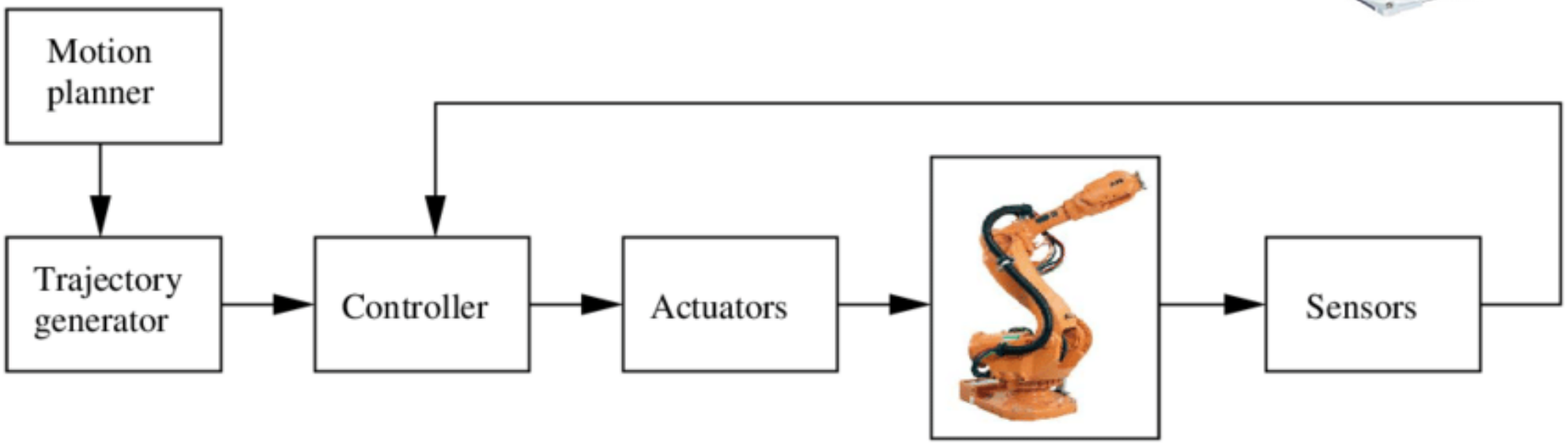



Flex Pendant

IRC5 Controller


Computer
PC Interface
6-DOF Force/Torque Sensor
Network Boundry
(TCP/IP)
Wobbly Table
Operator
Master
Robot Controller
Robot Manipulator


PC
Robot controller
CMOS cameras
Target


Motion planner
Trajectory generator
Controller
Actuators
Sensors

# Questions

**Thank You**