ECE447: Robotics Engineering

Lecture 2: Introduction to Robot Manipulator

Dr. Haitham El-Hussieny

Electronics and Communications Engineering
Faculty of Engineering (Shoubra)
Benha University

Spring 2019

Non-Industrial Applications of Robot Manipulators:

Rehabilitation

Service (Cooking)

Service (Folding Clothes)

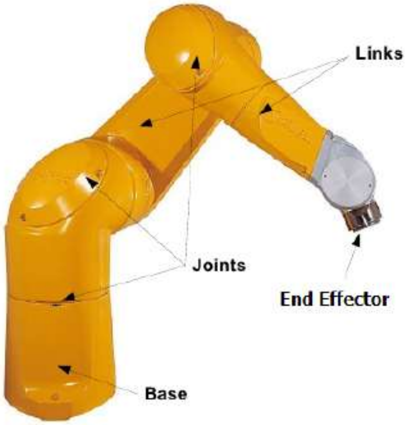
Table of Contents

Table of Contents

Structure of Robot Manipulators:

The robotic manipulators are composed of:

- **Kinematic open chain** composed of **Rigid Links** and **Joints**.

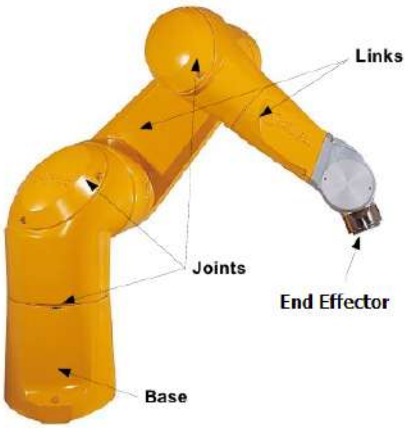


Each joint connects two links together.

Structure of Robot Manipulators:

The robotic manipulators are composed of:

- **Kinematic open chain** composed of **Rigid Links** and **Joints**.
- The **BASE**: can be either **fixed** in the work environment or placed on a **mobile** platform.

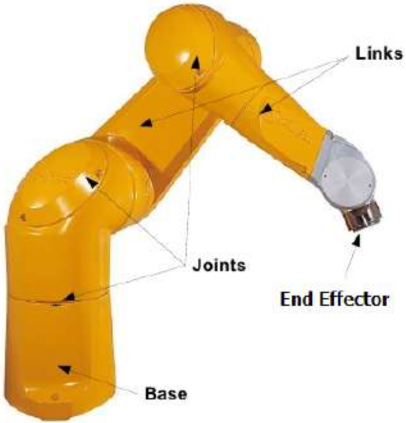


Each joint connects two links together.

Structure of Robot Manipulators:

The robotic manipulators are composed of:

- **Kinematic open chain** composed of **Rigid Links** and **Joints**.
- The **BASE**: can be either **fixed** in the work environment or placed on a **mobile** platform.
- **End-Effector:** Tool is located at the end, used to execute the desired operations [gripper or specific tool].

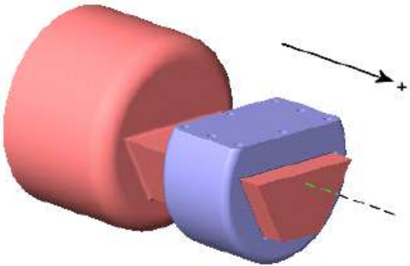


Each joint connects two links together.

Structure of Robot Manipulators:

Types of Joints:

Linear (Prismatic) Joint

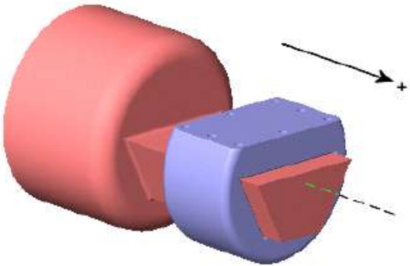


- Allows **translation** between two links.
- It is represented by symbol P.
- The joint variable is displacement d.

Structure of Robot Manipulators:

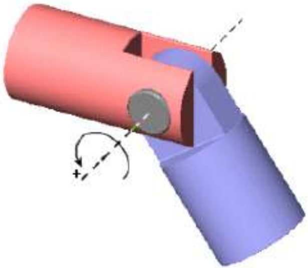
Types of Joints:

Linear (Prismatic) Joint



- Allows **translation** between two links.
- It is represented by symbol P.
- The joint variable is displacement d.

Rotary (Revolute) Joint

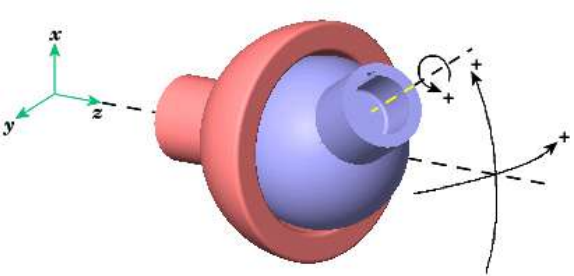


- Allows **rotation** between two links.
- It is represented by symbol R.
- The joint variable is angle θ.

Structure of Robot Manipulators:

Types of Joints:

Spherical Joint

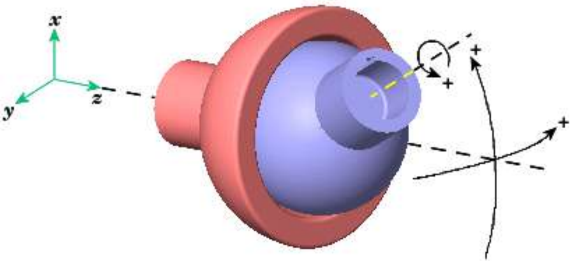


- Allows rotation around three axes.
- It is represented by symbol S.
- The joint variables are θ, γ and ψ.

Structure of Robot Manipulators:

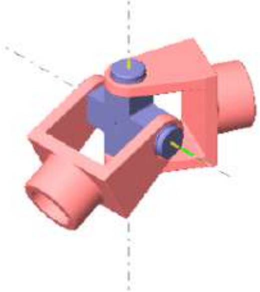
Types of Joints:

Spherical Joint



- Allows rotation around three axes.
- It is represented by symbol S.
- The joint variables are θ, γ and ψ.

Universal Joint

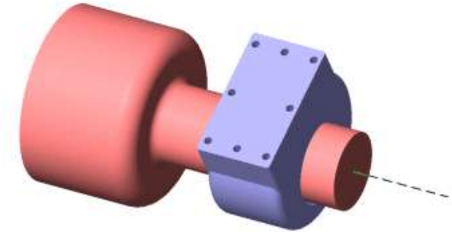


- Allows rotation around two axes.
- It is represented by symbol U.
- The joint variables are θ_1 and θ_2.

Structure of Robot Manipulators:

Types of Joints:

Cylindrical Joint

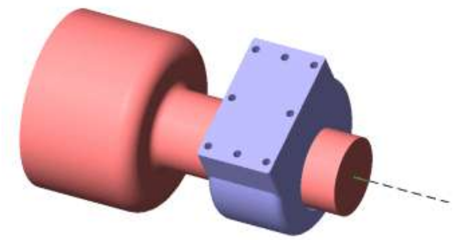


- Allows rotation and translation.
- It is represented by symbol C.

Structure of Robot Manipulators:

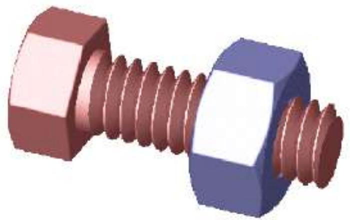
Types of Joints:

Cylindrical Joint



- Allows rotation and translation.
- It is represented by symbol C.

Screw Joint

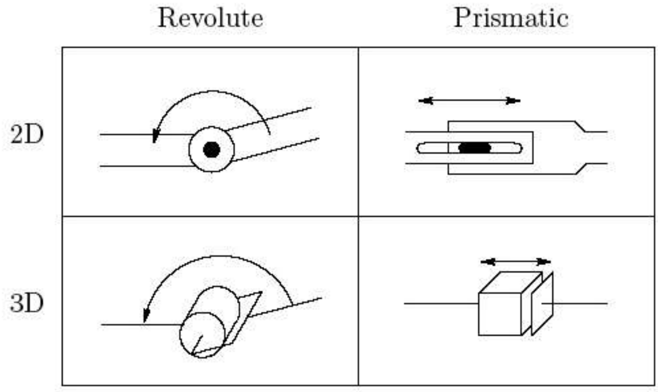


- Allows rotation and a constrained translation.
- It is represented by symbol SC.

Structure of Robot Manipulators:

Types of Joints:

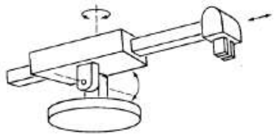
The two common joints in serial robot manipulators are (Prismatic and Revolute) joints.



Structure of Robotic Manipulators:

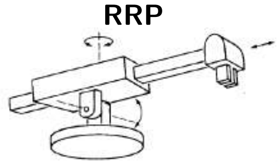
Example of Robotic Manipulators:

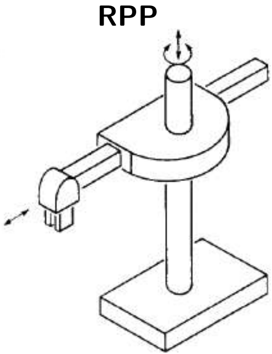
RRP



Structure of Robotic Manipulators:

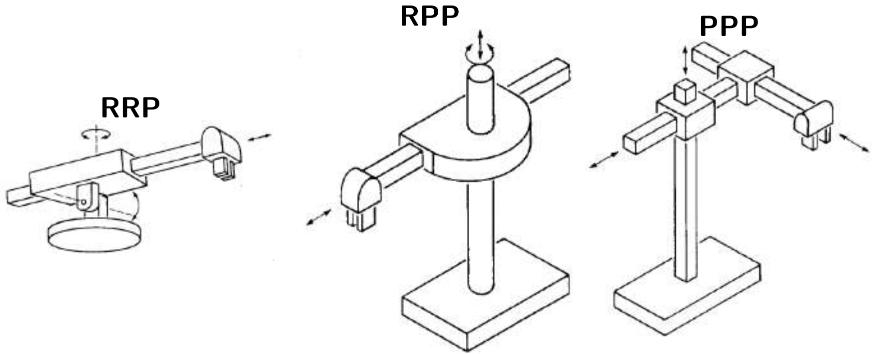
Example of Robotic Manipulators:





Structure of Robotic Manipulators:

Example of Robotic Manipulators:



Structure of Robotic Manipulators:

Example of Robotic Manipulators:

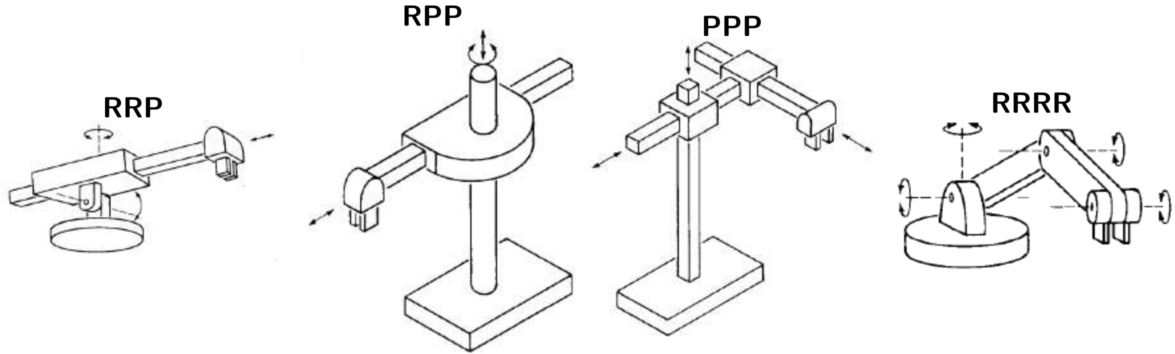


Table of Contents

Degree of Freedom (DoF):

Configuration Space:

- **Robot's configuration**: a specification of the positions of all points of the robot.

Degree of Freedom (DoF):

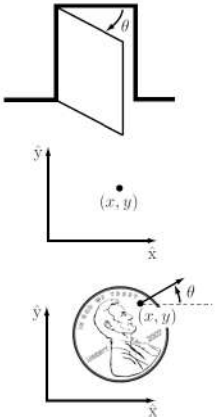
Configuration Space:

- **Robot's configuration**: a specification of the positions of all points of the robot.
- Since the robot is **rigid**, only a few numbers are needed to represent its configuration.

Degree of Freedom (DoF):

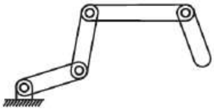
Configuration Space:

- **Robot's configuration**: a specification of the positions of all points of the robot.
- Since the robot is **rigid**, only a few numbers are needed to represent its configuration.
- The n-dimensional space containing all possible configurations of a robot is called the **configuration space** (C-space).



Examples of configuration spaces

Degree of Freedom (DoF):



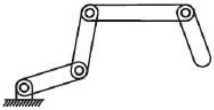
Robot's Degrees of Freedom (n):

Is the smallest number n of real-valued coordinates needed to represent the robot's configuration.

Degree of Freedom (DoF):

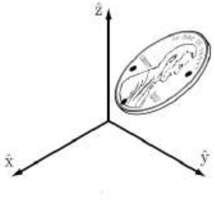
Robot's Degrees of Freedom (n):

Is the smallest number n of real-valued coordinates needed to represent the robot's configuration.



Rigid Body DoF (m):

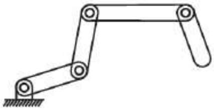
- A rigid body in three-dimensional space, which we call a **spatial rigid body**, has six degrees of freedom, $m = 6$ (three for position and three for orientation).



Degree of Freedom (DoF):

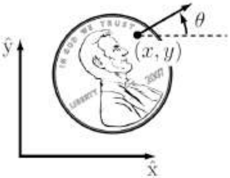
Robot's Degrees of Freedom (n):

Is the smallest number n of real-valued coordinates needed to represent the robot's configuration.



Rigid Body DoF (m):

- A rigid body in three-dimensional space, which we call a **spatial rigid body**, has six degrees of freedom, $m = 6$ (three for position and three for orientation).
- A rigid body moving in a two-dimensional plane, which we call a **planar rigid body**, has three degrees of freedom, $m = 3$ (two for position and one for orientation).



Degree of Freedom (DoF):

Defective manipulators:

If $n < m$, e.g. $n = 4, 5$ and $m = 6$ (spatial). It is not possible to execute all the possible tasks in the workspace, but only those defined in a proper subspace (e.g. SCARA).

SCARA Robot

Degree of Freedom (DoF):

Defective manipulators:

If $n < m$, e.g. $n = 4, 5$ and $m = 6$ (spatial). It is not possible to execute all the possible tasks in the workspace, but only those defined in a proper subspace (e.g. SCARA).

SCARA Robot

Redundant manipulators:

If $n > m$, for example $n = 7, 8$, and $m = 6$. A given task can be executed in infinite different manners.

Redundant Robots

Degree of Freedom (DoF):

Grübler's Formula:

- The number of degrees of freedom of a mechanism with links and joints can be calculated using **Grübler's formula**:

$$\text{DoF} = \text{(sum of freedoms of the bodies) - (number of independent constraints)}$$

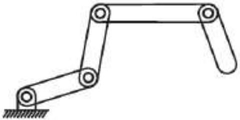
- If a mechanism has N links including ground, and J joints, its DoF is determined by:

$$\boxed{\text{DoF} = m(N - 1 - J) + \sum_{i=1}^{J} f_i}$$

- $m = 3$ for planar and $m = 6$ for rigid mechanisms.
- f_i is the number of freedoms provided by joint i.

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J) + \sum_{i=1}^{J} f_i$



$m = 3$

$N = 5$ links

$J = 4$ joints

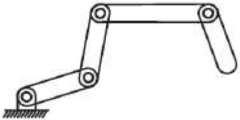
DoF $= 3(5-1-4)+4$

DoF $= 4$

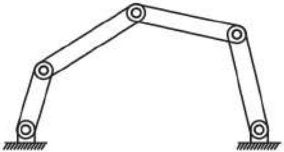
Redundant robot

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$



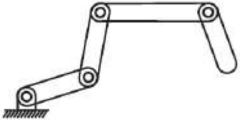
$m = 3$
$N = 5$ links
$J = 4$ joints
DoF $= 3(5-1-4)+4$
DoF $= 4$
Redundant robot



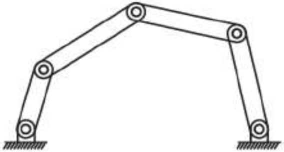
$m = 3$
$N = 5$ links
$J = 5$ joints
DoF $= 3(5-1-5)+5$
DoF $= 2$

Degree of Freedom (DoF):

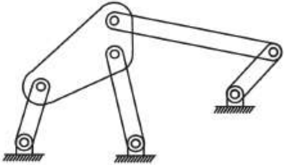
Grübler's Formula (Examples)   DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$



$m = 3$
$N = 5$ links
$J = 4$ joints
DoF $= 3(5-1-4)+4$
DoF $= 4$
Redundant robot



$m = 3$
$N = 5$ links
$J = 5$ joints
DoF $= 3(5-1-5)+5$
DoF $= 2$

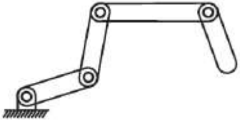


$m = 3$
$N = 6$ links
$J = 7$ joints
DoF $= 3(6-1-7)+7$
DoF $= 1$

Degree of Freedom (DoF):

Grübler's Formula (Examples)

DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$



$m = 3$

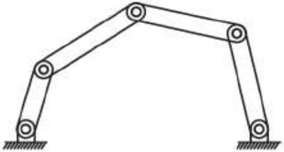
$N = 5$ links

$J = 4$ joints

DoF $= 3(5-1-4)+4$

DoF $= 4$

Redundant robot



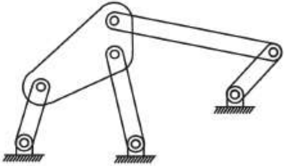
$m = 3$

$N = 5$ links

$J = 5$ joints

DoF $= 3(5-1-5)+5$

DoF $= 2$



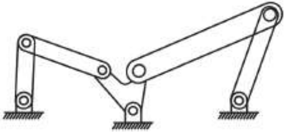
$m = 3$

$N = 6$ links

$J = 7$ joints

DoF $= 3(6-1-7)+7$

DoF $= 1$



$m = 3$

$N = 6$ links

$J = 7$ joints

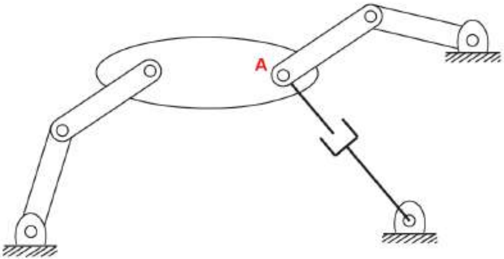
DoF $= 3(6-1-7)+7$

DoF $= 1$

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N - 1 - J) + \sum_{i=1}^{J} f_i$

- Three links are connected at a single point A.
- Since a joint connects exactly two links, the joint at A is correctly interpreted as **two revolute joints overlapping each other**.



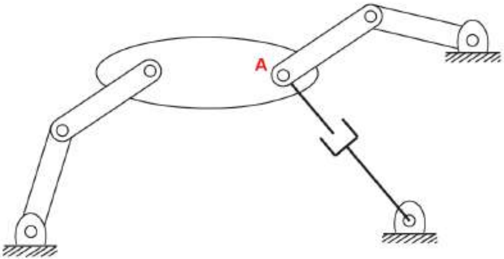
Mechanism with two overlapping joints

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J) + \sum_{i=1}^{J} f_i$

- Three links are connected at a single point A.
- Since a joint connects exactly two links, the joint at A is correctly interpreted as **two revolute joints overlapping each other**.

$m = 3$
$N = 8$ links
$J = 9$ joints
DoF $= 3(8-1-9)+9$
DoF $= 3$



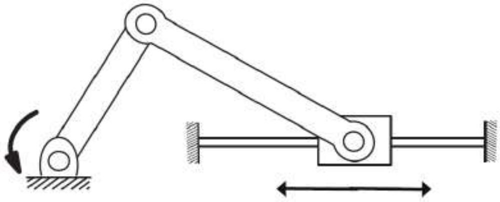
Mechanism with two overlapping joints

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J) + \sum_{i=1}^{J} f_i$

- The fixed link connected with the slider is considered as ground.

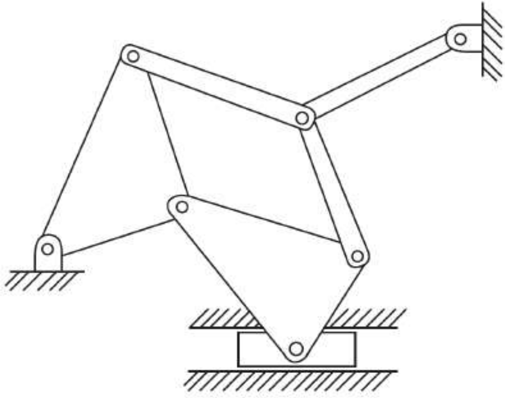
$m = 3$
$N = 4$ links
$J = 4$ joints
DoF $= 3(4-1-4)+4$
DoF $= 1$



Slider-crank mechanism

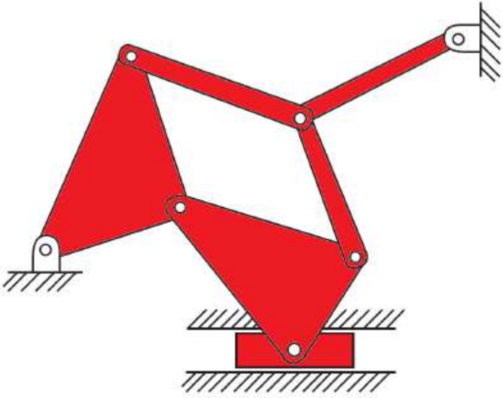
Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N - 1 - J) + \sum_{i=1}^{J} f_i$



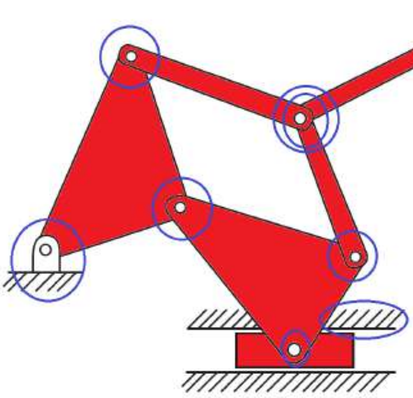
Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J) + \sum_{i=1}^{J} f_i$



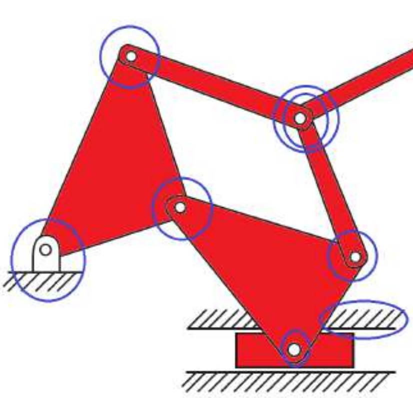
Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N - 1 - J) + \sum_{i=1}^{J} f_i$



Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J) + \sum_{i=1}^{J} f_i$



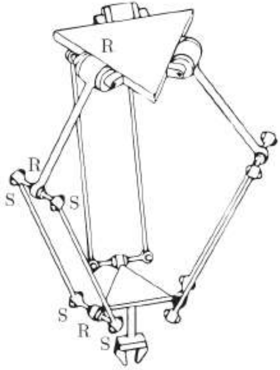
$m = 3$
$N = 7$ links
$J = 9$ joints
DoF $= 3(7-1-9) + 9(1)$
DoF $= 3$

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J) + \sum_{i=1}^{J} f_i$

Parallel Robots:

$m = 6$
$N = 17$ links
$J = 21$ joints
DoF $= 6(17-1-21) + 9(1) + 12(3)$
DoF $= 15$
However, **only three DoF are visible** at the end effector that moves parallel to the fixed platform. So, the Delta robot acts as an $x - y - z$ Cartesian positioning device.



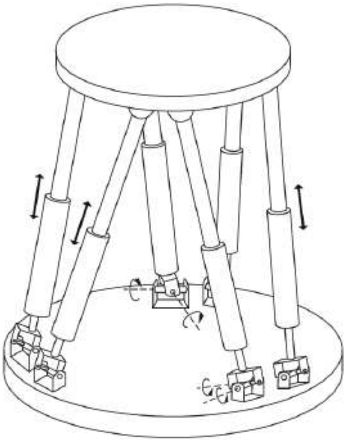
Delta robot

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$

$m = 6$
$N = 14$ links
$J = 18$ joints $(6\times P,\ 6\times U,\ 6\times S)$
DoF $= 6(14-1-18)+6(1)+6(2)+6(3)$
DoF $= 6$

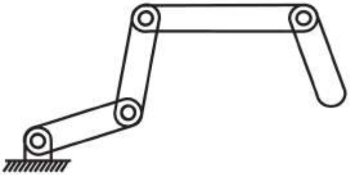
- The Stewart-Gough platform is a popular choice for car and airplane cockpit simulators since it moves with the full six degrees of freedom of motion of a rigid body.
- Its parallel structure means that each leg needs to support only a fraction of the weight of the payload.



Stewart-Gough platform

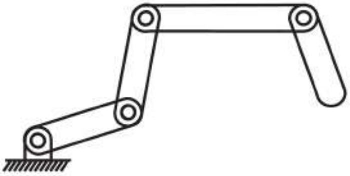
Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$



Degree of Freedom (DoF):

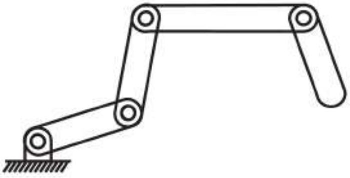
Grübler's Formula (Examples) DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$

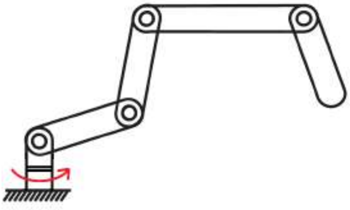


$$m = 3$$
$$N = 5 \text{ links}$$
$$J = 4 \text{ joints}$$
$$\text{DoF} = 3(5-1-4)+4$$
$$\text{DoF} = 4$$

Degree of Freedom (DoF):

Grübler's Formula (Examples)   DoF $= m(N-1-J) + \sum_{i=1}^{J} f_i$

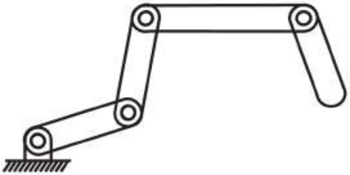




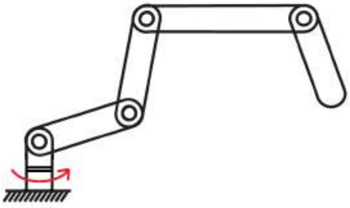
$$m = 3$$
$$N = 5 \text{ links}$$
$$J = 4 \text{ joints}$$
$$\text{DoF } = 3(5-1-4) + 4$$
$$\text{DoF } = 4$$

Degree of Freedom (DoF):

Grübler's Formula (Examples) DoF $= m(N - 1 - J) + \sum_{i=1}^{J} f_i$



$m = 3$
$N = 5$ links
$J = 4$ joints
DoF $= 3(5 - 1 - 4) + 4$
DoF $= 4$

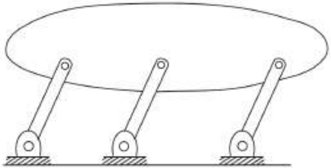


$m = 6$
$N = 6$ links
$J = 5$ joints
DoF $= 6(6 - 1 - 5) + 5$
DoF $= 5$

Degree of Freedom (DoF):

Exception to Grübler's Formula DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$

- Using Grüebler's equation, this linkage has zero degrees of freedom: DoF $= 3(5-1-6)+6(1)=0$

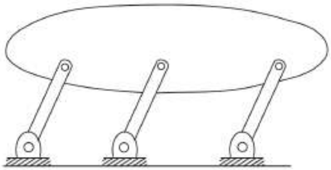


A parallelogram linkage
$N=5, \quad J=6R$

Degree of Freedom (DoF):

Exception to Grübler's Formula DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$

- Using Grüebler's equation, this linkage has zero degrees of freedom: DoF $= 3(5-1-6)+6(1)=0$
- This indicates that the mechanism is **locked** (No motion). This is true **if all pivoted links are not identical**.

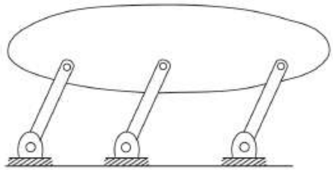


A parallelogram linkage
$N=5, \quad J=6R$

Degree of Freedom (DoF):

Exception to Grübler's Formula DoF $= m(N-1-J)+\sum_{i=1}^{J} f_i$

- Using Grüebler's equation, this linkage has zero degrees of freedom: DoF $= 3(5-1-6)+6(1)=0$
- This indicates that the mechanism is **locked** (No motion). This is true **if all pivoted links are not identical**.
- If all pivoted links were the same size and the distance between the joints on the frame and coupler were identical, this mechanism is capable of motion, with a **single degree of freedom**.
- The center link is **redundant** and because it is identical in length to the other two links attached to the frame, it can be removed and, DoF $= 3(4-1-4)+4(1)=1$



A parallelogram linkage
$N=5, \quad J=6R$

Table of Contents

Task Space and Workspace:

Task space

- The task space is a space in which the robot's task can be naturally expressed.
- The decision of how to define the task space is driven by the task, independently of the robot.

Drawing task space: $\mathbb{R}^2$

Peg-in-hole task space: $\mathbb{R}^5$

Task Space and Workspace:

Workspace

- **Reachable workspace:** is a specification of the configurations that the robot end-effector **can reach**.

Task Space and Workspace:

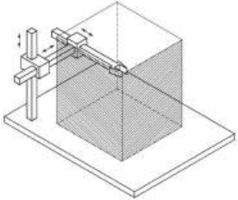
Workspace

- **Reachable workspace:** is a specification of the configurations that the robot end-effector **can reach**.
- **Dexterous workspace:** is a specification of the configurations that the robot end-effector **can reach with arbitrary orientation**.

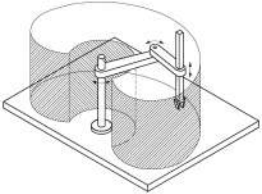
Task Space and Workspace:

Workspace

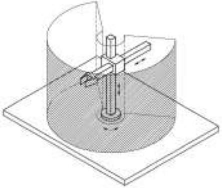
- **Reachable workspace:** is a specification of the configurations that the robot end-effector **can reach**.
- **Dexterous workspace:** is a specification of the configurations that the robot end-effector **can reach with arbitrary orientation**.
- Robot's workspace depends on: the kinematic configuration, the links' dimension, the joints' range of motion.



Cartesian Manipulator



SCARA Manipulator



Cylindrical Manipulator

KUKA YouBot ?

Table of Contents

Common Kinematic Arrangements:

[1] Articulated Manipulator (RRR):

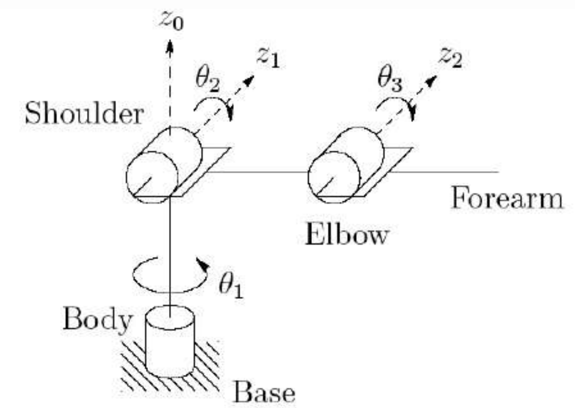
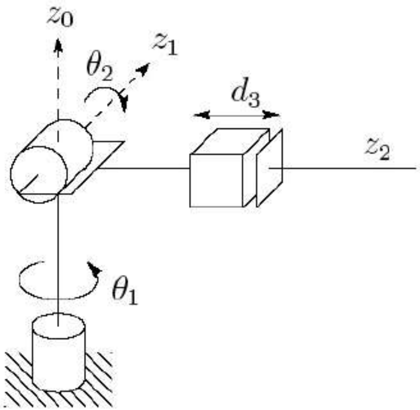


ABB IRB1400 Anthropomorphic Robot

Common Kinematic Arrangements:

[2] Spherical Manipulator (RRP):

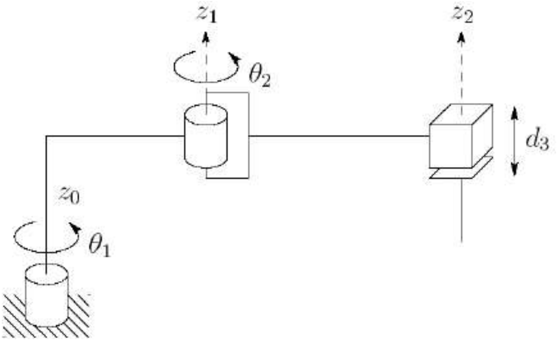


Stanford Arm

Common Kinematic Arrangements:

[3] SCARA Manipulator (RRP):

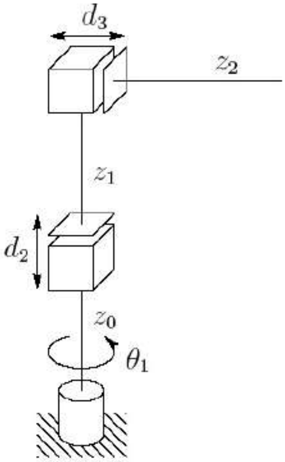
Selective **C**ompliant **A**rticulated **R**obot for **A**ssembly:

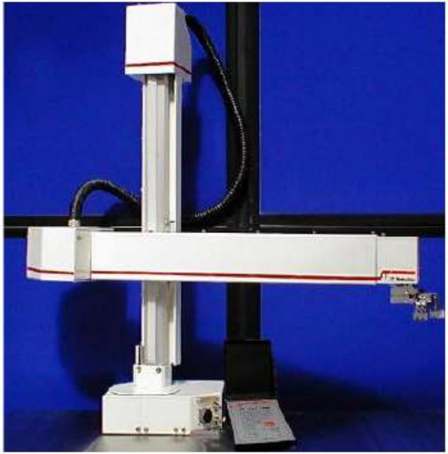


Adept Cobra i600

Common Kinematic Arrangements:

[4] Cylindrical Manipulator (RPP):

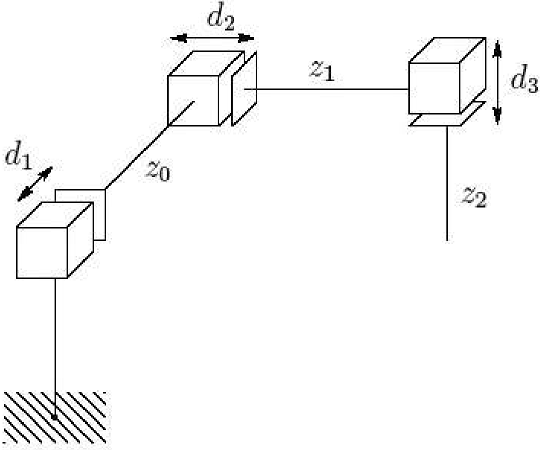




Seiko RT3300 Robot

Common Kinematic Arrangements:

[5] Cartesian Manipulator (PPP):

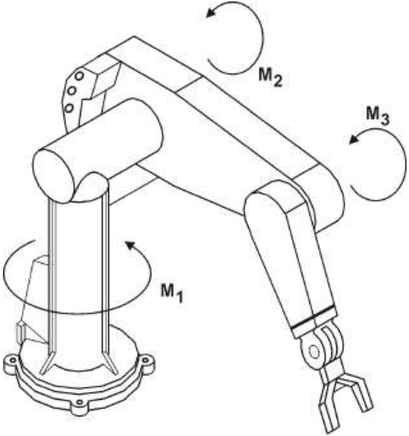


Epson Cartesian Robot

Common Kinematic Arrangements:

[6] PUMA Manipulator (RRR):

Programmable **U**niversal **M**achine for **A**ssembly:

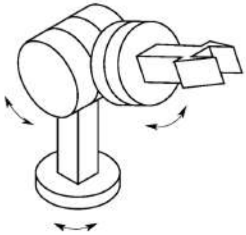


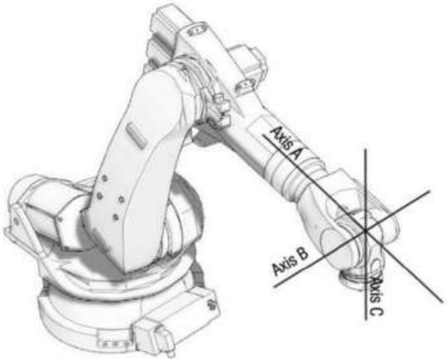
PUMA Robot

Common Kinematic Arrangements:

[7] Spherical Wrist (RRR):

- It is common to attach a spherical wrist to the manipulator end to **allow the orientation of the end-effector**.
- In spherical wrist the axes of the three joints **are intersecting** at the wrist center point.





"Robots are becoming more human, and humans are becoming more robotic"

Bob Metcalfe (1946-), Ethernet inventor.

Questions?

haitham.elhussieny@feng.bu.edu.eg