MITMECHE

Introduction to Mechanism Design and Robotics

Workshop

TiM

THE BEAVER

Department of Mechanical Engineering
Massachusetts Institute of Technology

Outline

- Mechanism Design
  - Showcase of various types of mechanism
  - Basic mechanism introduction (Linkage and Gear)
- Robotic Arm Design
  - Example robots
  - Kinematics
- Actuator Overview
  - Types of actuators
  - DC brushed motor working mechanism
- Robotic Gripper Assembly

Mechanism Design

- Definition: A mechanism is a device for transferring motion and/or force from a source to an output. In a mechanism, at least one link has been grounded, or attached to the frame of reference (which itself may be in motion)
- Mechanism are everywhere in our daily life
  - Transmission in cars
  - Crane
  - Door with latch
  - Airplane landing gear
  - Etc.
- Mechanical engineers design smart mechanisms to solve complex problems

Vehicle Transmission

Crane

MITMECHE

AsiaUS Business Connection

Workshop TiM THE BEAVER

Door Latch

Airplane Landing Mechanism

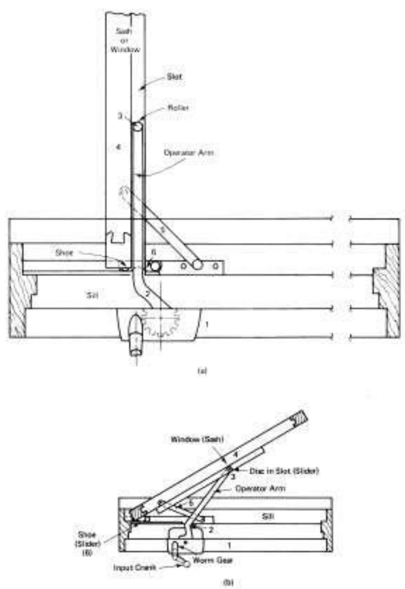
MITMECHE

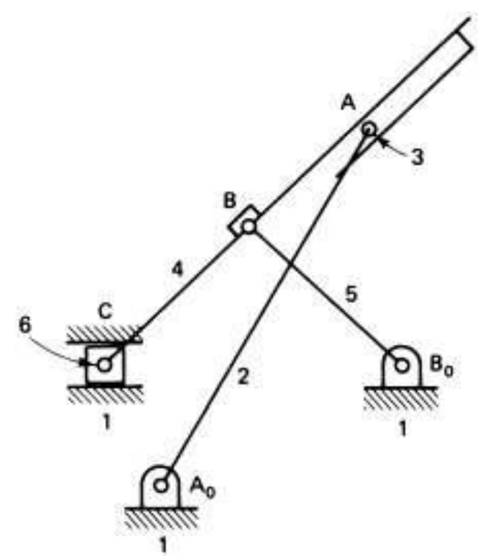
AsiaUS Business Connection

Workshop TIM THE BEAVER

Kinematic Diagrams

- We draw kinematic diagrams to reduce mechanisms into a simpler form so we can analyze them.

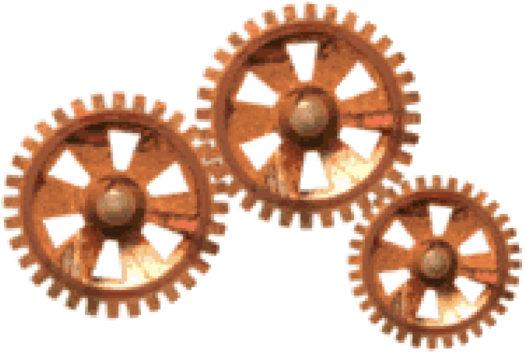




Department of Mechanical Engineering
Massachusetts Institute of Technology

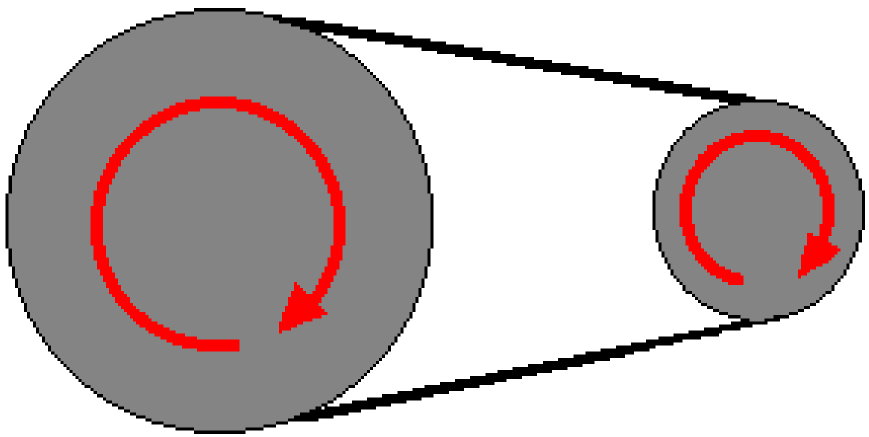
Gear

- Transmit rotation (reversed direction between pair)



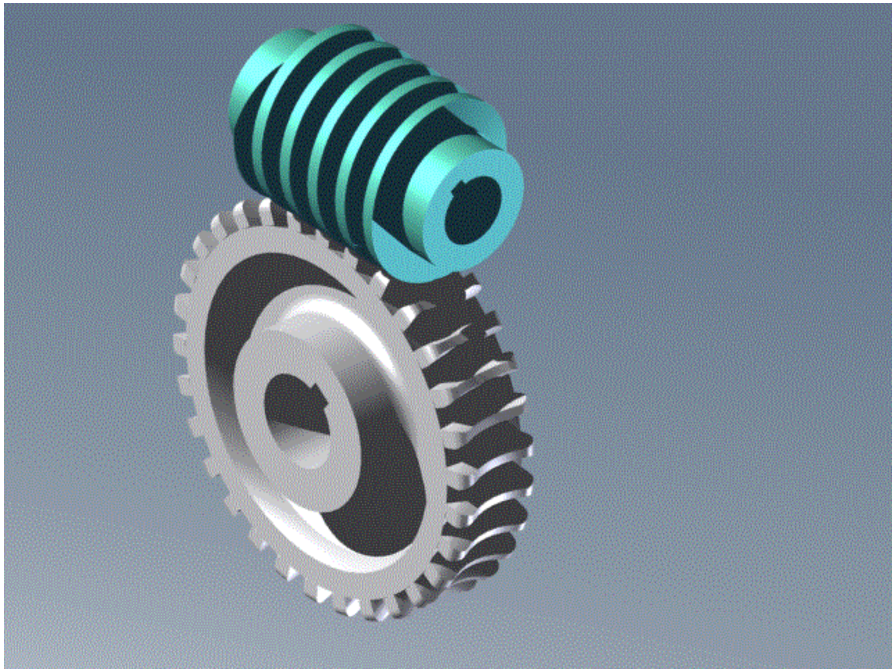
Pulley and Belt

- Transmit rotation (same direction)



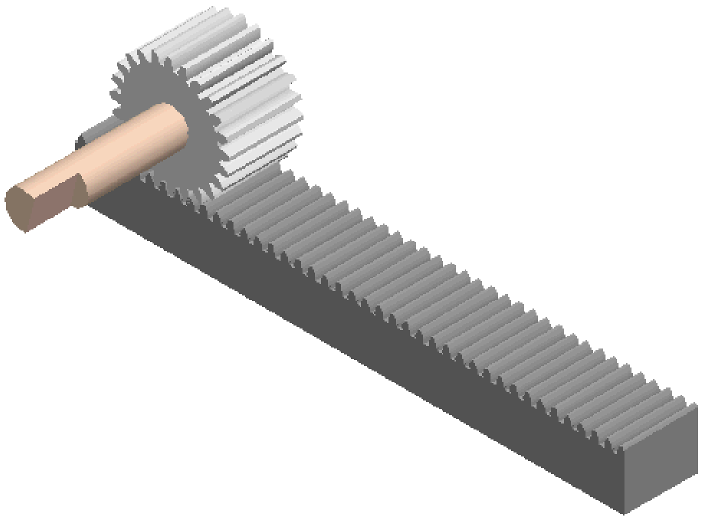
Worm Gear

- Transmit rotation with self locking (90 degree shaft orientation)



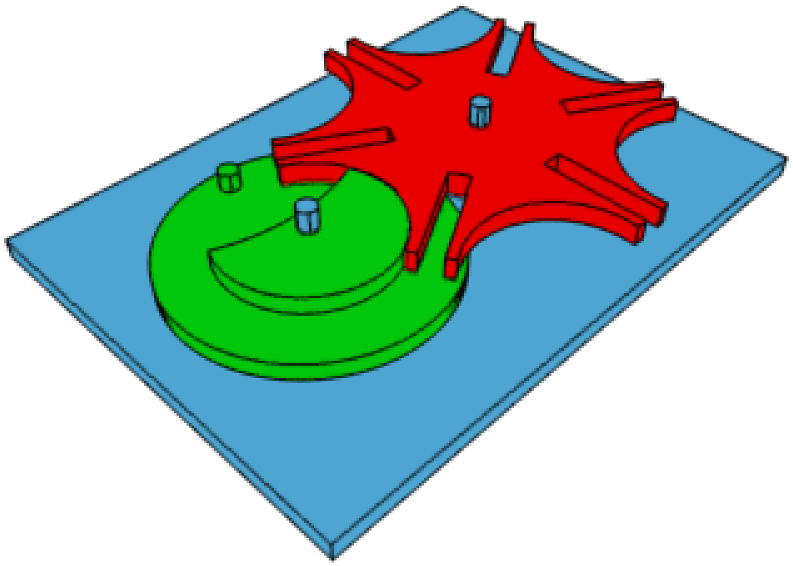
Rack and Pinion

- Translates rotation to linear motion (vise versa)



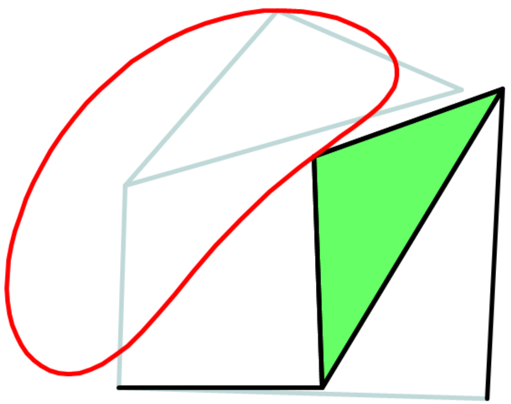
Geneva Drive

- Translates a continuous rotation into an intermittent rotation



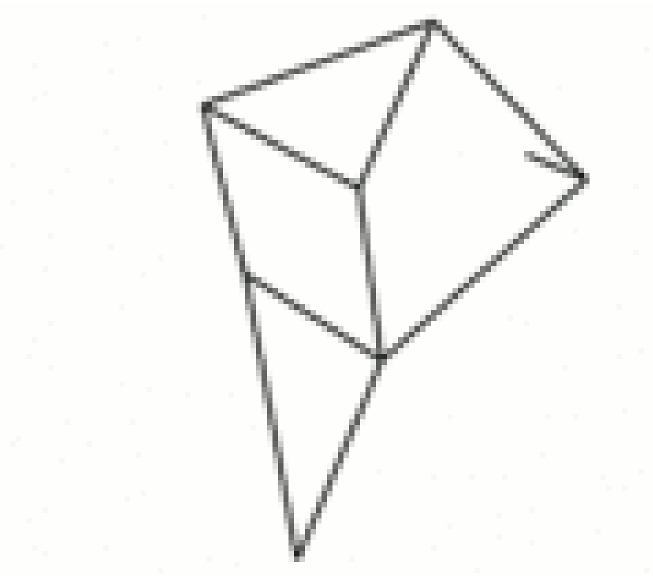
Linkage System

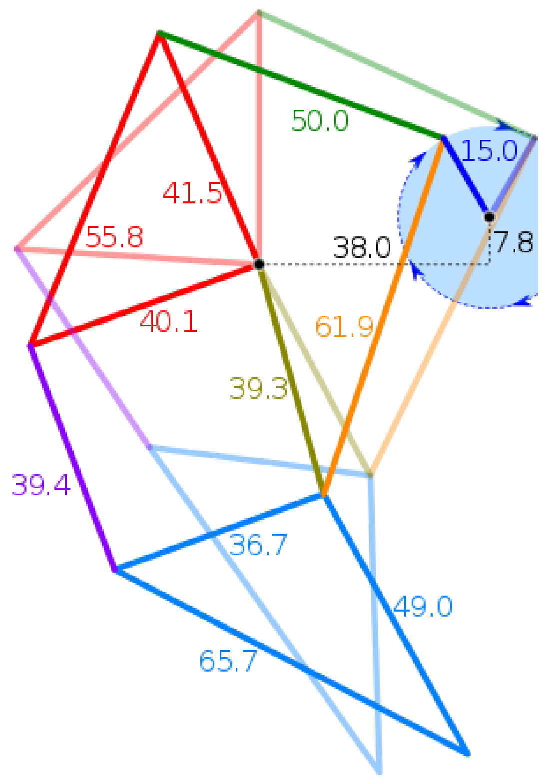
- Translate rotation to contour motion



Jansen's Linkage

- Translates a continuous rotation into an intermittent rotation

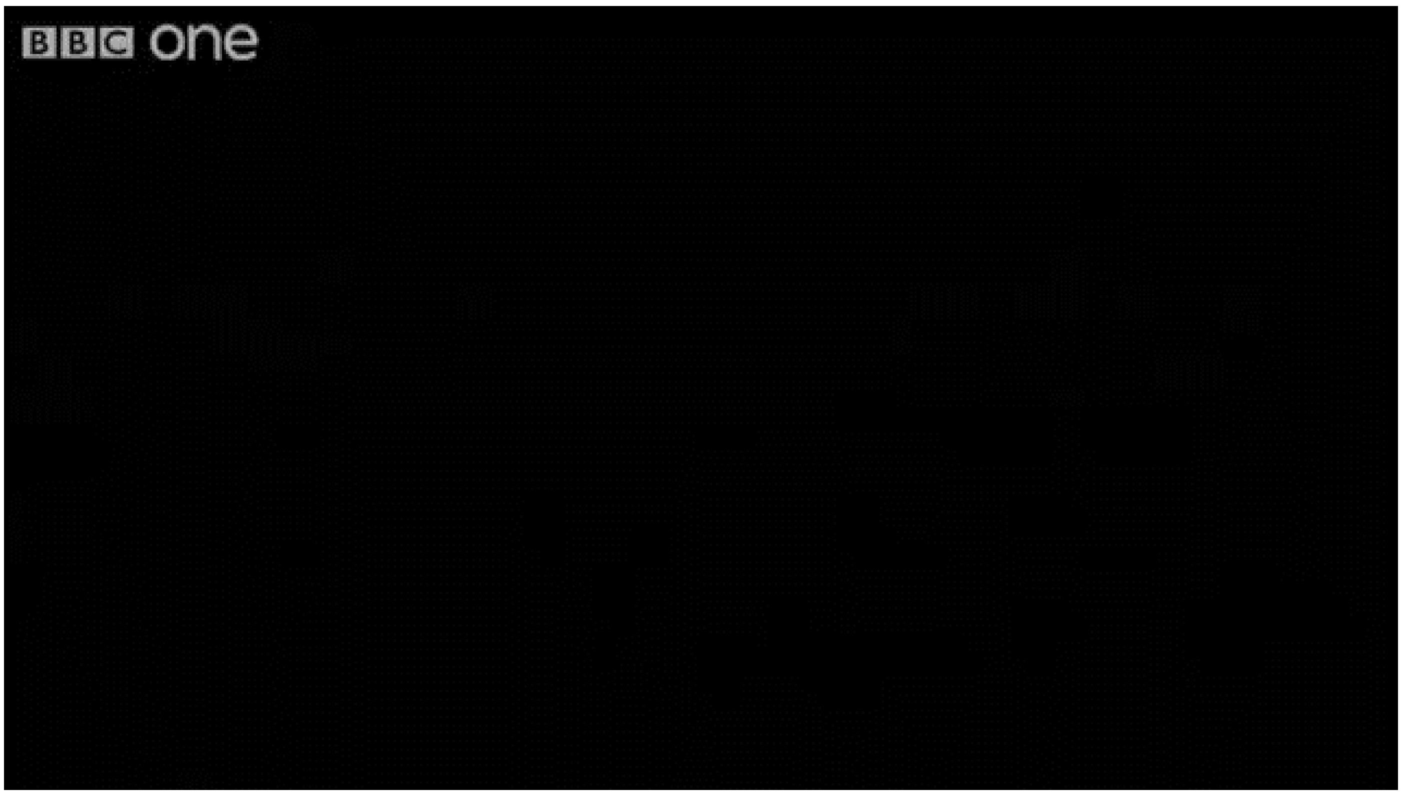




MITMECHE

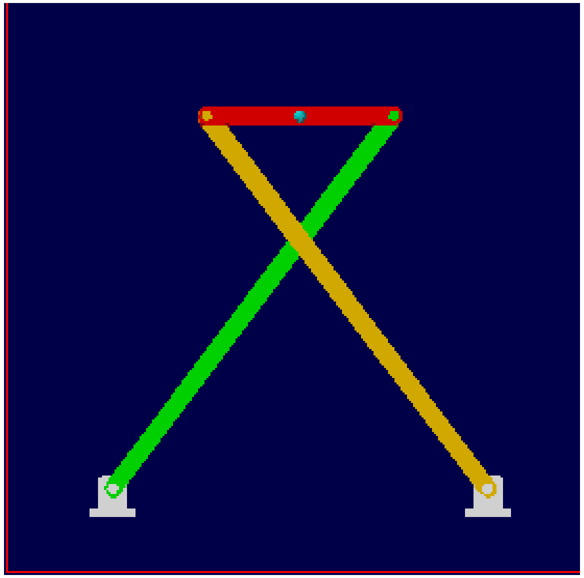
AsiaUS Business Connection

Jansen's Linkage

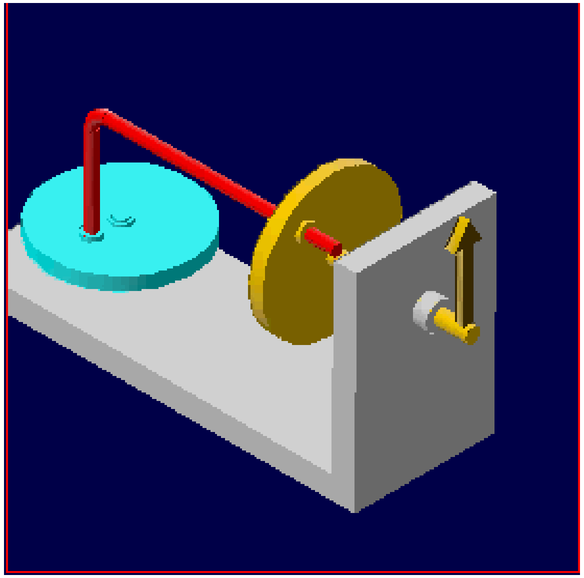


Planar vs. Spatial Mechanisms

Planar (2-D): Links move in parallel planes throughout the motion cycle.

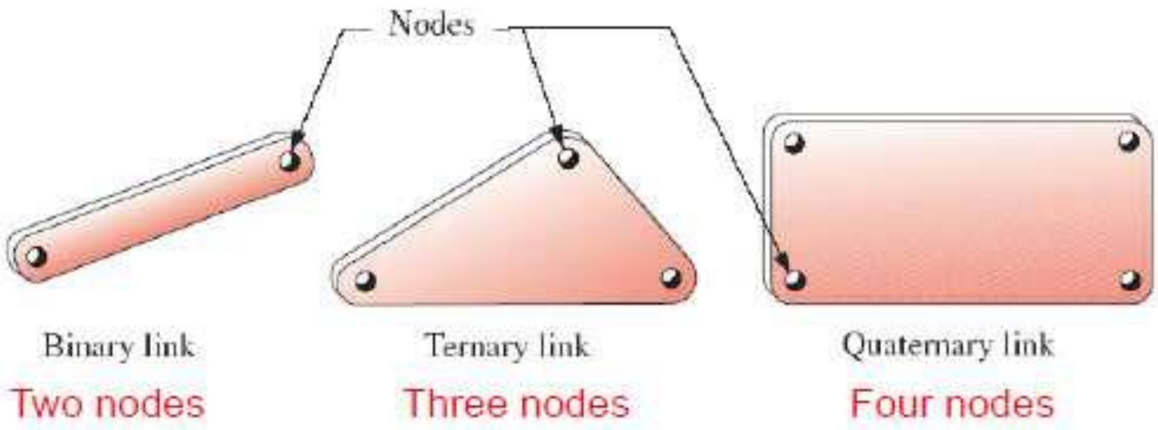


Spatial (3-D): At least one link does not move parallel to a single plane.

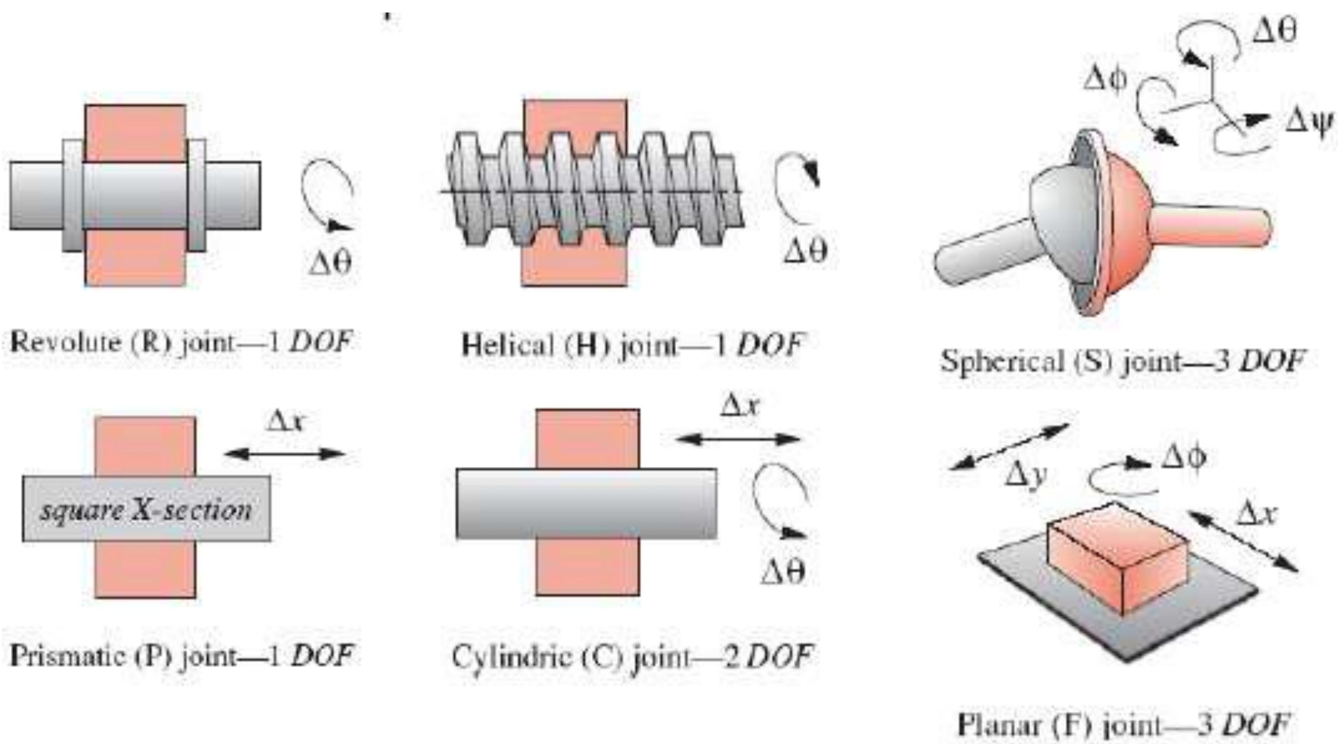


Linkage Definition

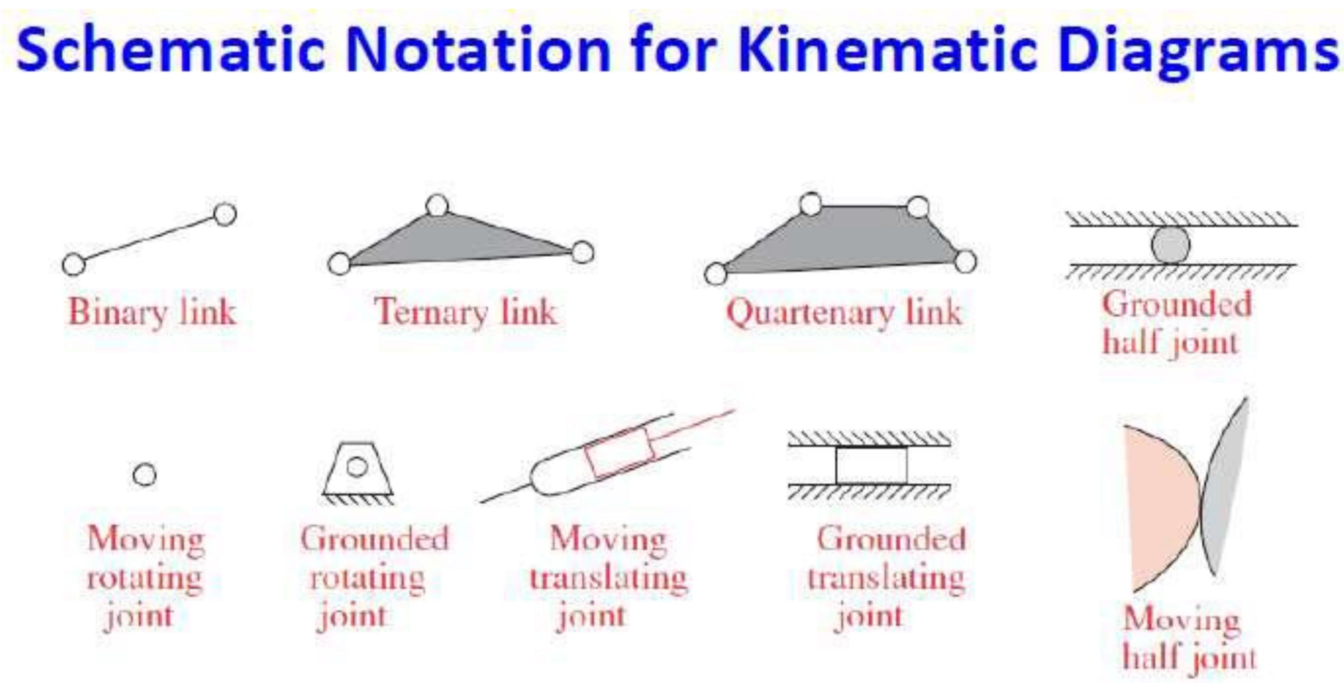
- **Linkage:** the basic building block of all mechanisms
- **Link**: a rigid body with at least two nodes
- **Node**: the point of attachment to other links
- **Joint**: the connection between two links



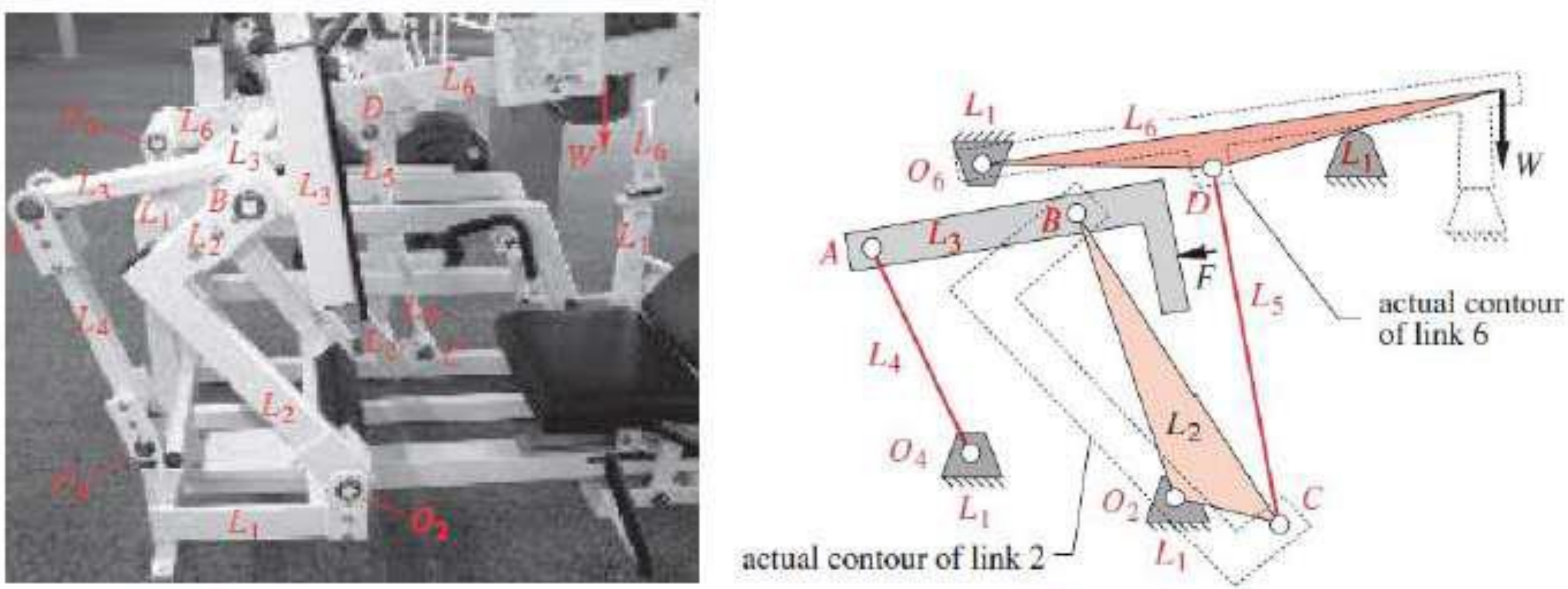
Types of Joints



Notation


Schematic Notation for Kinematic Diagrams
Binary link
Ternary link
Quartenary link
Grounded half joint
Moving rotating joint
Grounded rotating joint
Moving translating joint
Grounded translating joint
Moving half joint

Represent Linkage with Kinematic Diagrams



(a) Weight-training mechanism

(b) Kinematic diagram

Degrees of Freedom Calculation

$$M = 3(L - 1) - 2\,J_1 - J_2$$

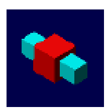
- M (mobility) is the number of independent inputs required to completely specify the geometric configuration of a mechanism
- L is the number of links
- J1 is the number of joints with one DOF
- J2 is the number of joints with two DOF

Examples of Joints

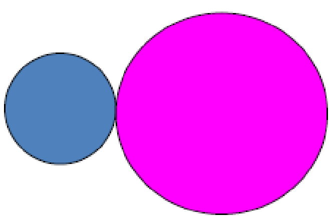
J_1 joints:

- Revolute (pin) joints

- Prismatic (slider) joints

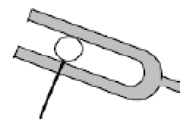


- Pure rolling contact

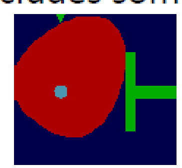


J_2 joints (half joints):

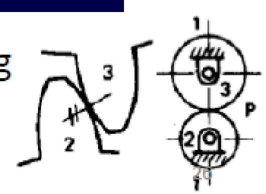
- Pin-in-slot

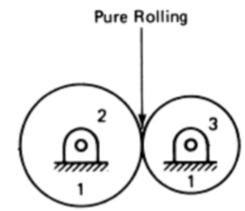


- Joints that allow rotation and sliding between the two links (includes some cam joints).



- 2 gears meshing





$L = 3$

$J_1 = 3$ (2 pin joints, & pure rolling)

$J_2 = 0$

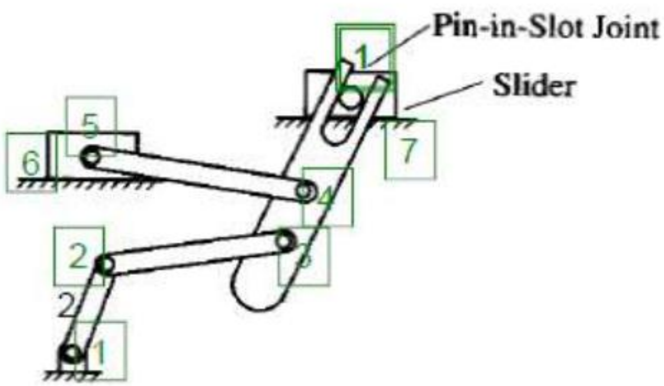
$M = 3(L\text{-}1) - 2\,J_1 - J_2$

$= 3(3\text{-}1) - 2\,(3) - 0$

$= 0$ according to Gruebler.

BUT it can actually move due to the special geometrical configuration. (Exact spacing of rollers and ground pivots.)

Example Calculation

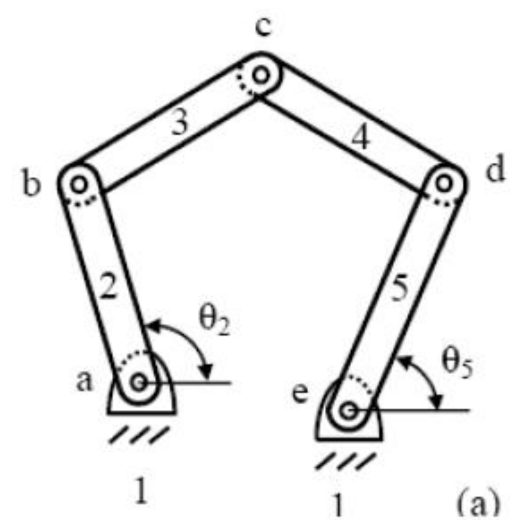


$L = 7$

$J_1 = 7$

$J_2 = 1$

$M = 3(7\text{-}1)\text{-}2*7\text{-}1*1 = 3$



M = ?

$M = 3(L - 1) - 2\,J_1 - J_2 = 2$

Gear Transmission Ratio

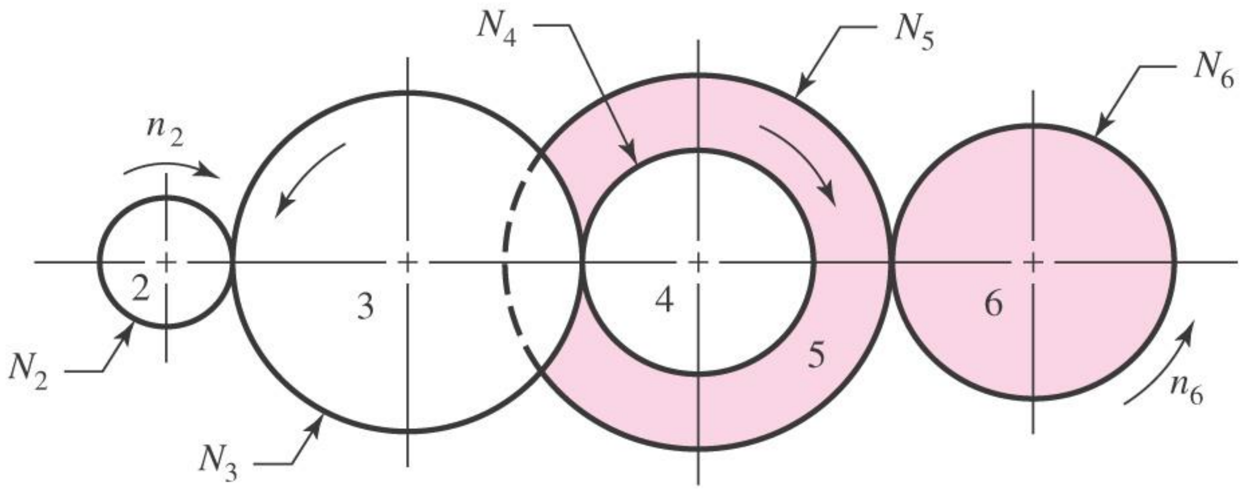
- The two gears must have the same velocity at the contact point.
- The contact point between the gears is on the pitch circle.

$$V = r_o\ \omega_o = r_i\omega_i\ ;\ o = \text{output},\ i = \text{input},$$

$$r = \text{gear pitch radius}$$

$$\omega_o/\omega_i = r_i/r_o = n_t\ ;\ n_t \text{ is Transmission Ratio}$$

Gear Transmission Ratio Example



$$n_6 = -\frac{N_2}{N_3}\frac{N_3}{N_4}\frac{N_5}{N_6}n_2$$

MITMECHE

AsiaUS Business Connection

Workshop TIM THE BEAVER

Introduction to Robotics

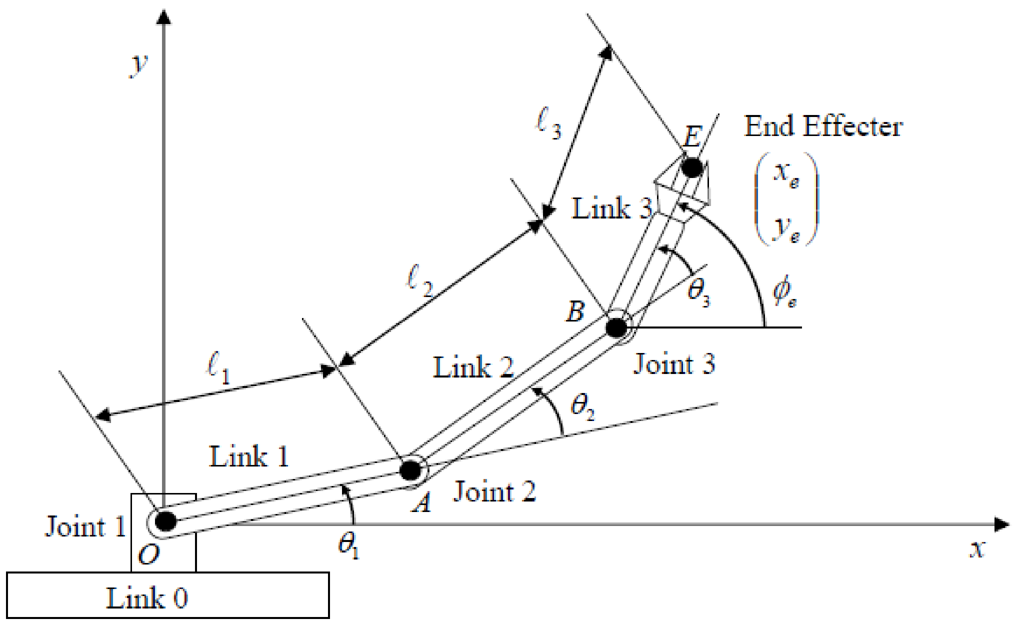
MITMECHE

AsiaUS Business Connection

Workshop TiM THE BEAVER

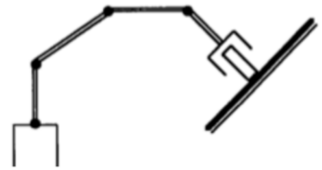
Introduction to Robotics

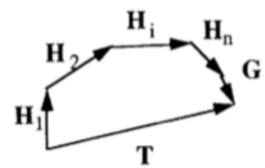
Kinematics of Robotic Arm



$$x_e = \ell_1 \cos\theta_1 + \ell_2 \cos(\theta_1 + \theta_2) + \ell_3 \cos(\theta_1 + \theta_2 + \theta_3)$$
$$y_e = \ell_1 \sin\theta_1 + \ell_2 \sin(\theta_1 + \theta_2) + \ell_3 \sin(\theta_1 + \theta_2 + \theta_3)$$

Homogenous Transformation Matrix

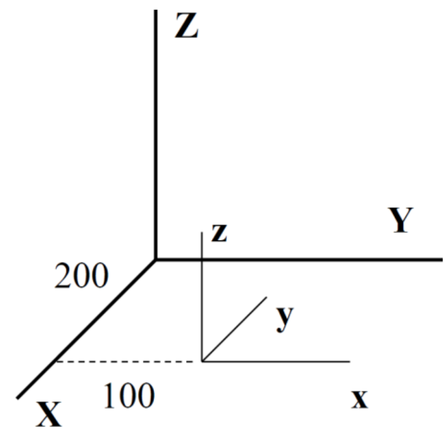




$$T = {}^{1}H_{0}\,{}^{2}H_{1}\ldots G$$

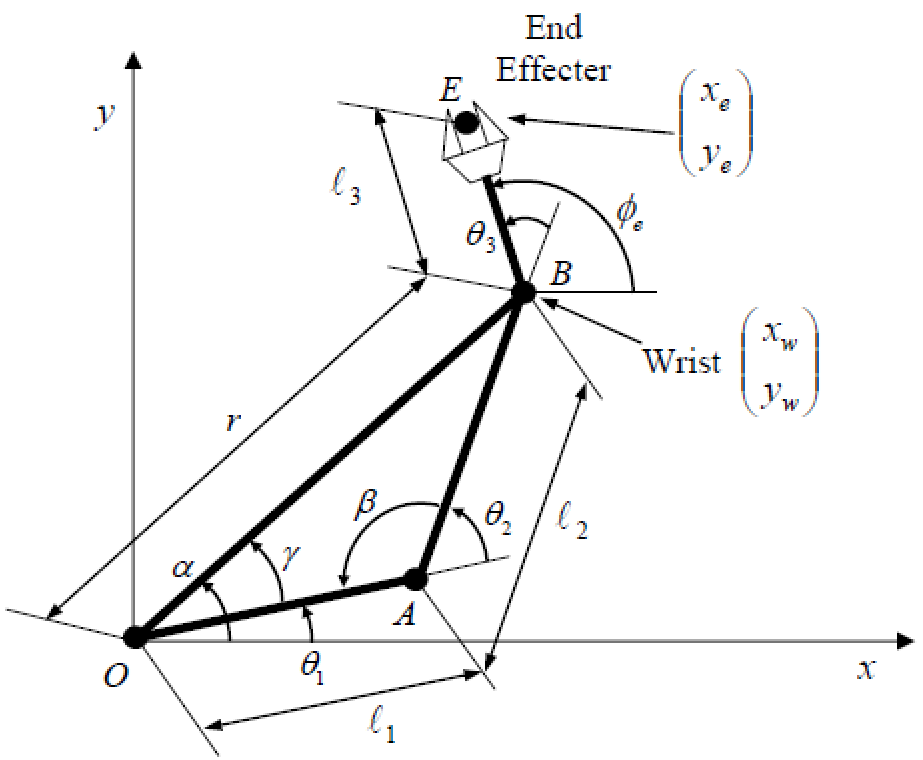
$${}^{n}H_{n+1} = \left[\begin{array}{c|c} \mathbf{R}^{n}_{n+1} & p^{n}_{n+1} \\ \hline \mathbf{0}_{1\times 3} & 1 \end{array}\right]$$

$$\begin{aligned}
R_1^0 &= R_{z,\phi}R_{y,\theta}R_{x,\psi} \\
&= \begin{bmatrix} c_\phi & -s_\phi & 0 \\ s_\phi & c_\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_\theta & 0 & s_\theta \\ 0 & 1 & 0 \\ -s_\theta & 0 & c_\theta \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_\psi & -s_\psi \\ 0 & s_\psi & c_\psi \end{bmatrix} \\
&= \begin{bmatrix} c_\phi c_\theta & -s_\phi c_\psi + c_\phi s_\theta s_\psi & s_\phi s_\psi + c_\phi s_\theta c_\psi \\ s_\phi c_\theta & c_\phi c_\psi + s_\phi s_\theta s_\psi & -c_\phi s_\psi + s_\phi s_\theta c_\psi \\ -s_\theta & c_\theta s_\psi & c_\theta c_\psi \end{bmatrix}.
\end{aligned}$$



$$\begin{bmatrix} 0 & -1 & 0 & 200 \\ 1 & 0 & 0 & 100 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Inverse Kinematics



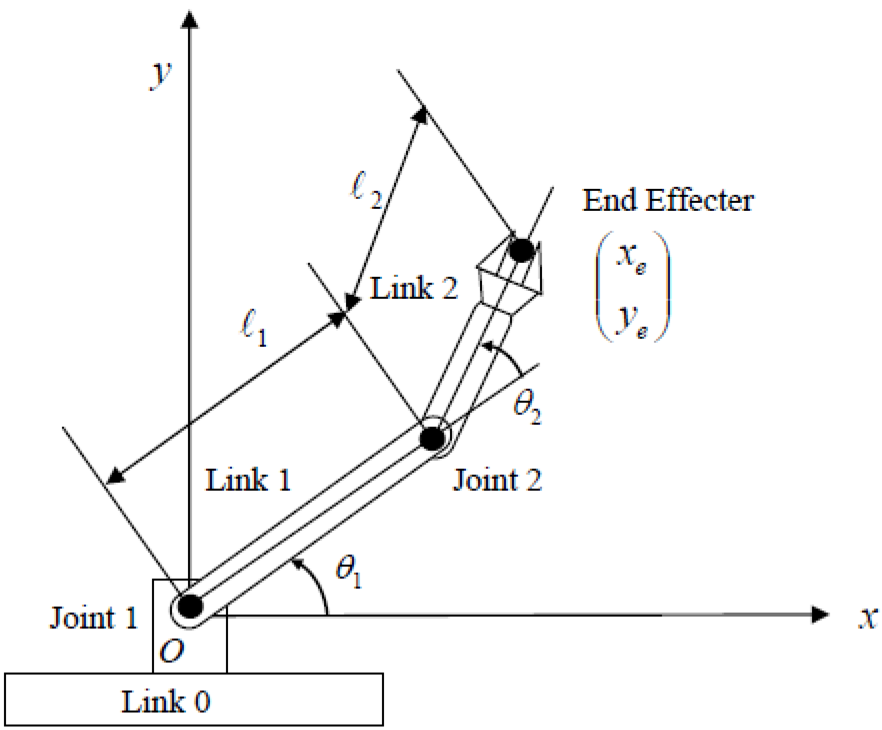
$$x_w = x_e - \ell_3 \cos\phi_e$$
$$y_w = y_e - \ell_3 \sin\phi_e$$

$$\theta_1 = \alpha - \gamma = \tan^{-1}\frac{y_w}{x_w} - \cos^{-1}\frac{x_w^2 + y_w^2 + \ell_1^2 - \ell_2^2}{2\ell_1\sqrt{x_w^2 + y_w^2}}$$

$$\theta_2 = \pi - \beta = \pi - \cos^{-1}\frac{\ell_1 + \ell_2 - x_w - y_w}{2\ell_1\ell_2}$$

$$\theta_3 = \phi_e - \theta_1 - \theta_2$$

Differential Motion



$$x_e(\theta_1, \theta_2) = \ell_1 \cos\theta_1 + \ell_2 \cos(\theta_1 + \theta_2)$$

$$y_e(\theta_1, \theta_2) = \ell_1 \sin\theta_1 + \ell_2 \sin(\theta_1 + \theta_2)$$

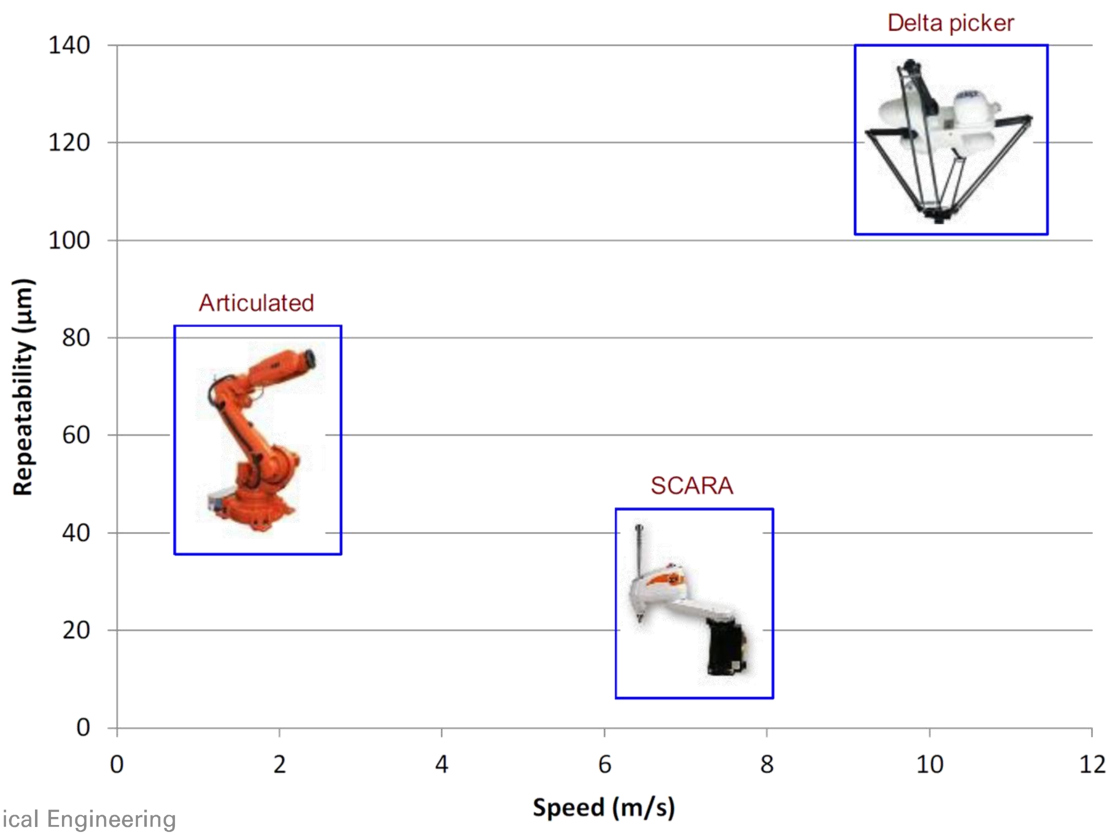
$$dx_e = \frac{\partial x_e(\theta_1, \theta_2)}{\partial \theta_1} d\theta_1 + \frac{\partial x_e(\theta_1, \theta_2)}{\partial \theta_2} d\theta_2$$

$$dy_e = \frac{\partial y_e(\theta_1, \theta_2)}{\partial \theta_1} d\theta_1 + \frac{\partial y_e(\theta_1, \theta_2)}{\partial \theta_2} d\theta_2$$

$$\mathbf{J} = \begin{pmatrix} -\ell_1 \sin\theta_1 - \ell_2 \sin(\theta_1 + \theta_2) & -\ell_2 \sin(\theta_1 + \theta_2) \\ \ell_1 \cos\theta_1 + \ell_2 \cos(\theta_1 + \theta_2) & \ell_2 \cos(\theta_1 + \theta_2) \end{pmatrix}$$

$$\mathbf{v}_e = \mathbf{J} \cdot \dot{\mathbf{q}}$$

Speed VS Repeatability

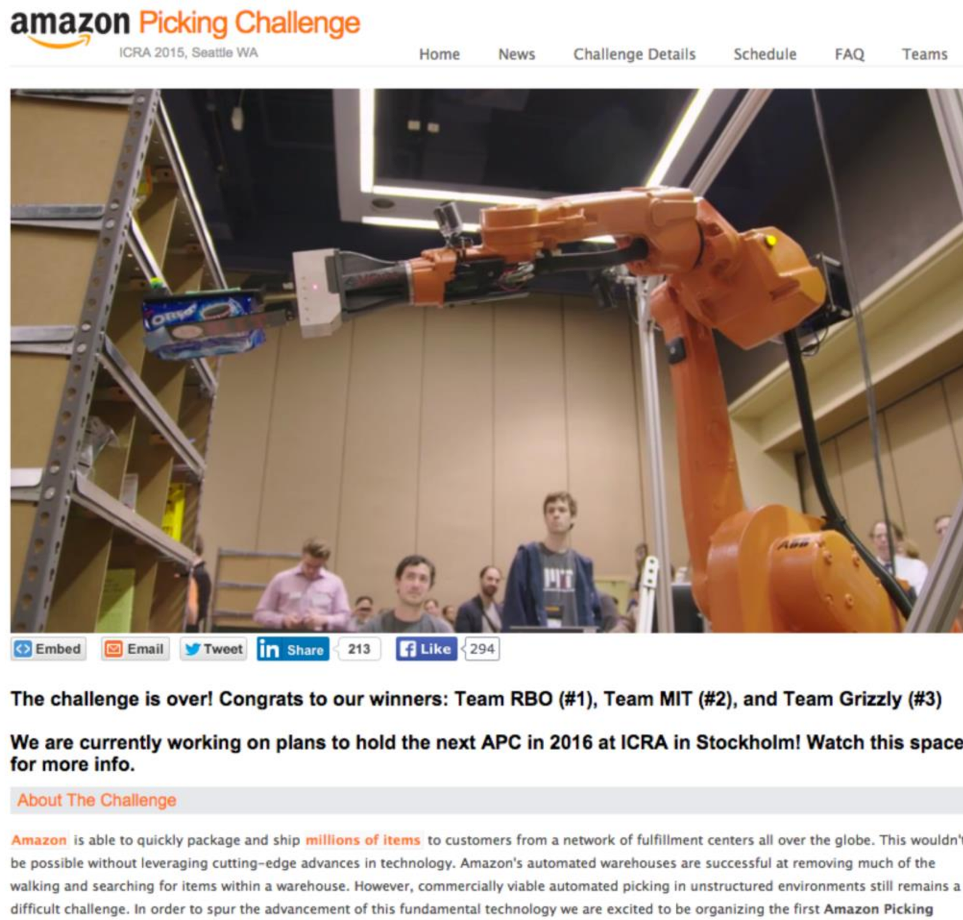


MITMECHE

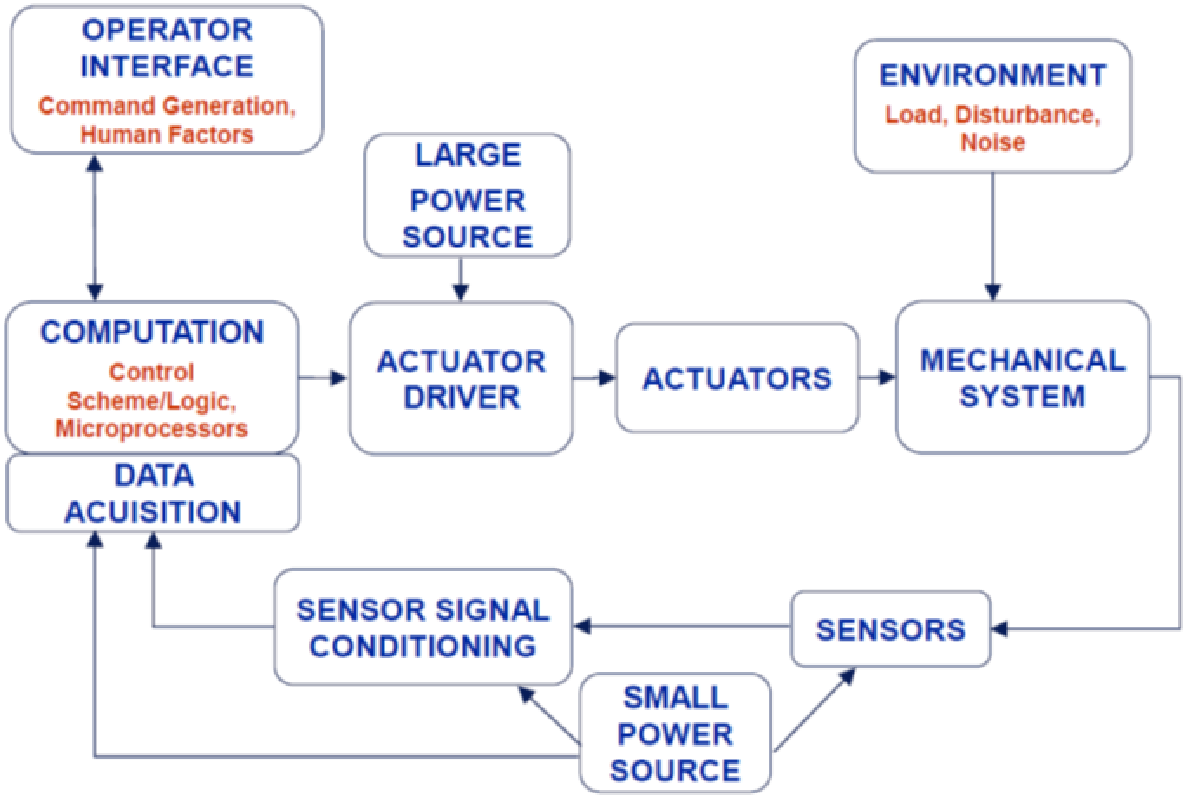
AsiaUS Business Connection

Workshop TIM THE BEAVER

Things to Do or Not Do with Your Robot

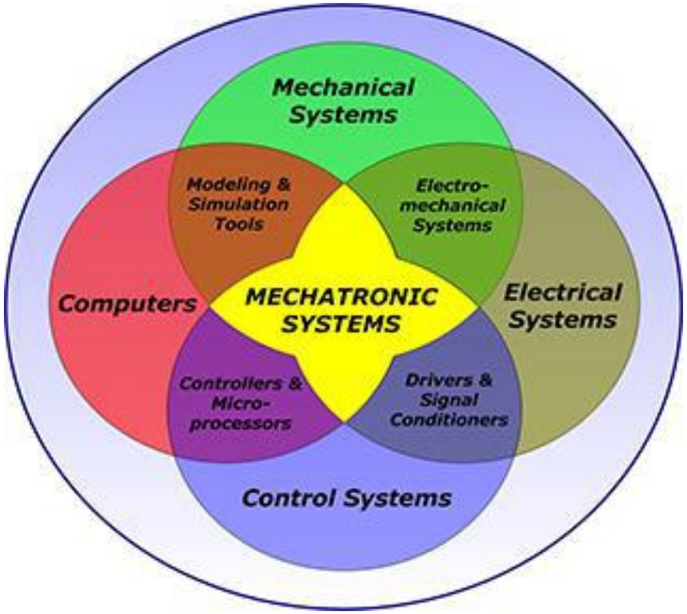


Robot as Mechatronic Systems



What is Mechatronics

- Mechatronics is the synergetic integration of mechanical disciplines, electronics, controls, and computers in the design of high performance systems.



Methods of Actuation

Hydraulic

Pneumatic

Electric

MITMECHE

AsiaUS Business Connection

Workshop TIM THE BEAVER

Types of Motion

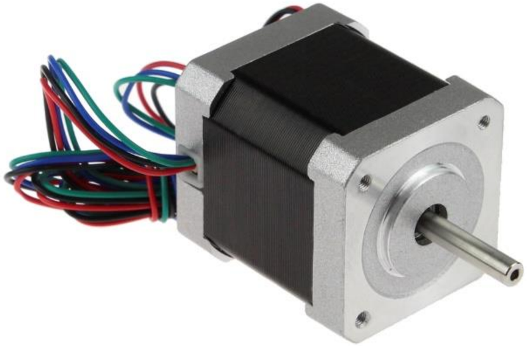
Linear

Rotational

Department of Mechanical Engineering
Massachusetts Institute of Technology

Types of Electric Rotational Acuators

Servo Motor

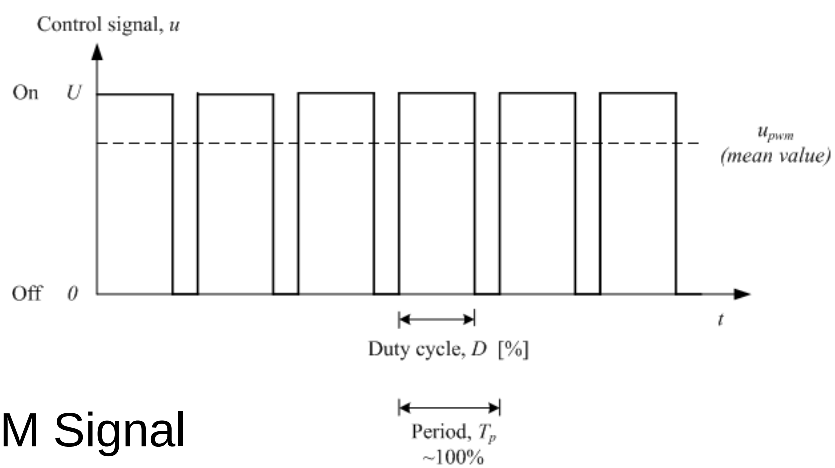


Stepper

DC Brushed

Servo Motors

- 0-180 degree range of motion
- Controlled by Pulse Width Modulation (PWM) signal
- Built in circuitry for angle control
- Ideal for move and hold application

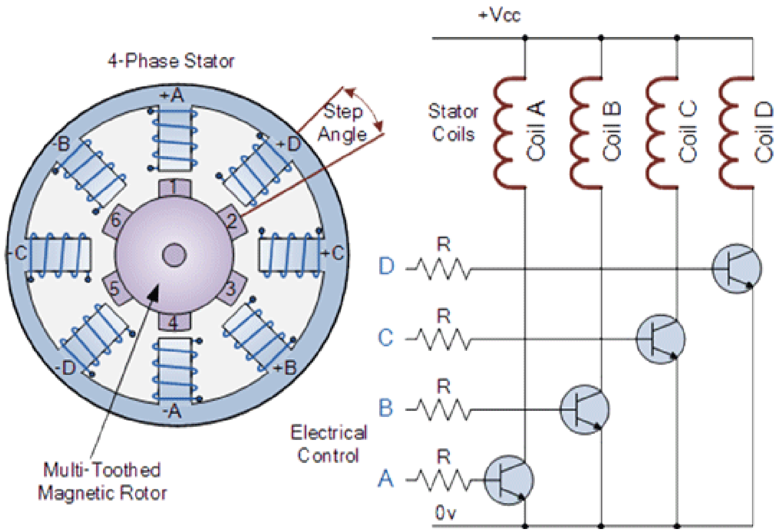


PWM Signal

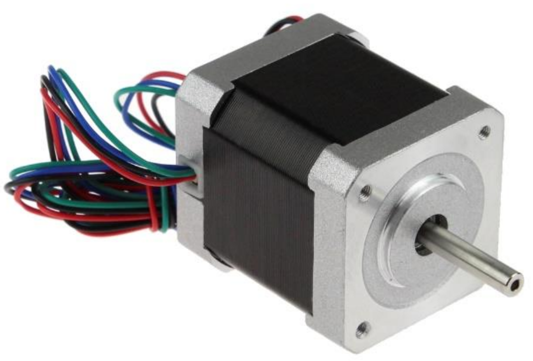
Servo Motor

Stepper Motors

- Step by step accurate motion control (1.8 degree usually)
- Actuated by rotor magnet aligning with stator coil



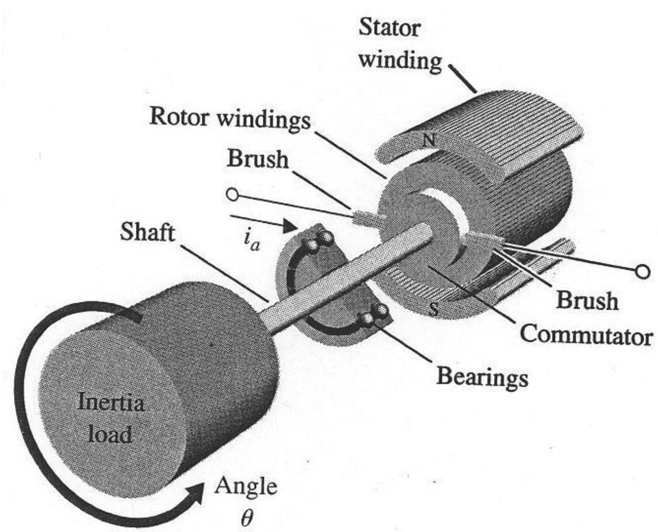
Functional Diagram



Stepper Motor

DC Brushed Motors

- Common motor for continuous rotational application

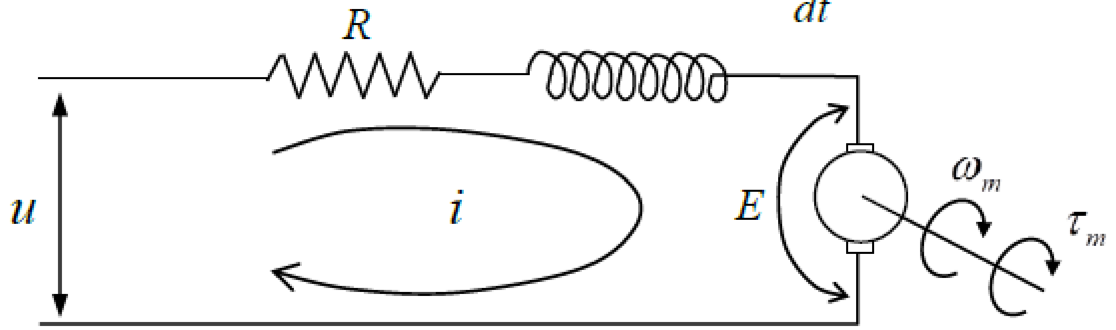


Functional Diagram

DC Brushed Motor

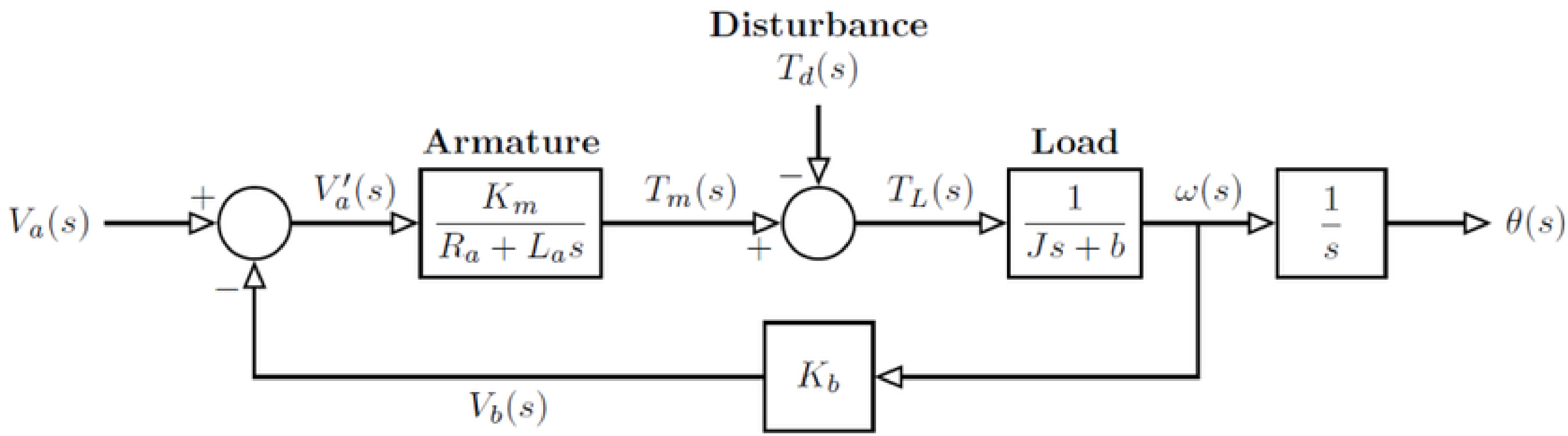
DC Brushed Motor Equations

- Current is proportional to torque $\tau_m = K_t \cdot i$
- Assume power is conserved $P_{in} = E \cdot i = \tau_m \cdot \omega_m$
- Voltage is proportional to speed $E = K_t \omega_m$
- From the model of motor circuit $u = R \cdot i + L\dfrac{di}{dt} + E$



- Obtain governing equation: $\dfrac{K_t}{R}u = \tau_m + T_e\dfrac{d\tau_m}{dt} + \dfrac{K_t^{\,2}}{R}\omega_m$
- Where the reactance is defined: $T_e = \dfrac{L}{R}$

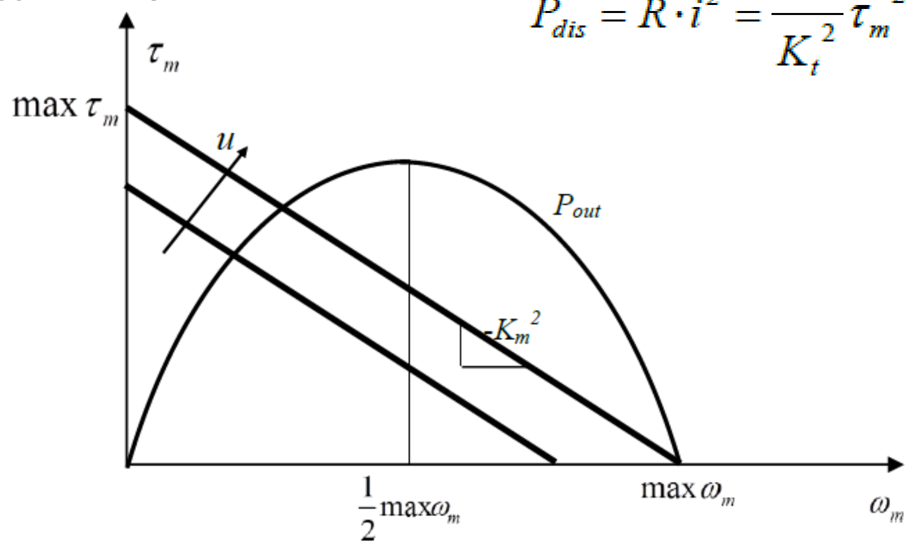
DC Motor Block Diagram



Department of Mechanical Engineering
Massachusetts Institute of Technology

DC Brushed Motor Equations

- Since motor reactance is often negligible to get $\tau_m = \frac{K_t}{R}u - \frac{K_t^{\,2}}{R}\omega_m$
- The result can be plotted as shown
- With the definition of power being $P_{out} = \tau_m \cdot \omega_m = (\frac{K_t}{R}u - K_m^{\,2}\omega_m)\,\omega_m$
- The energy dissipated from loss $P_{dis} = R \cdot i^2 = \frac{R}{K_t^{\,2}}\tau_m^{\,2}$



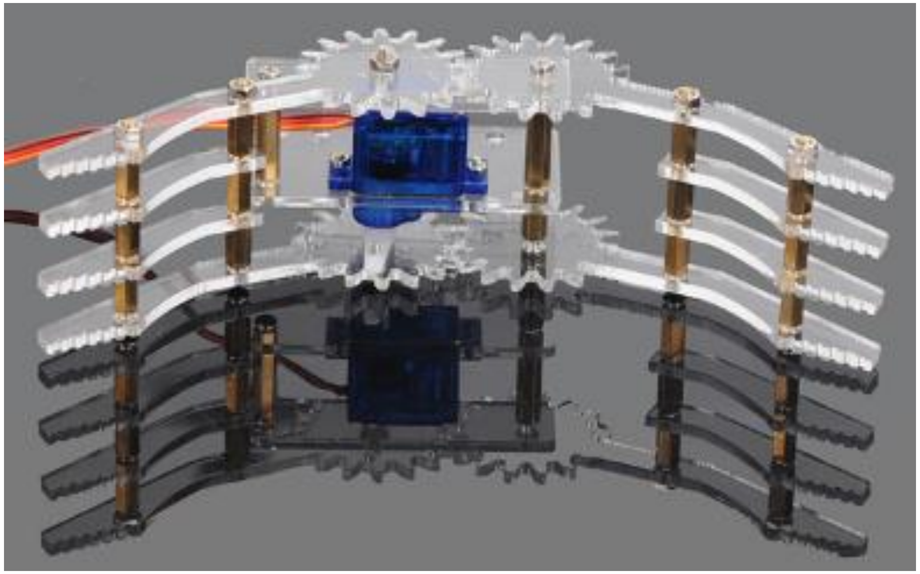
MITMECHE

AsiaUS Business Connection

Workshop TIM THE BEAVER

Robotic Gripper

- 1 degree of freedom geared mechanism
- Actuated by servo motor



Gripper Assembly

Homework

- CAD mechanism design of 1 DOF index finger
- CAD mechanism design of 2 DOF thumb finger
- 3 minutes presentation from each group

MITMECHE

Thank You!