IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

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WEEK 2: ROBOTICS

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Topic 1: Introduction to Robots and Robotics

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Resolution, Accuracy and Repeatability

Resolution

It is defined as the smallest allowable position increment of a robot

Resolution

Programming resolution

Smallest allowable position increment in robot programme

Basic Resolution Unit

BRU = 0.01 inch/0.1degree

Control resolution

Smallest change in position that the feedback device can measure say 0.36 degrees per pulse

Accuracy (mm)

It is the precision with which a computed point can be reached

Repeatability (mm)

It is defined as the precision with which a robot re-position itself to a previous taught point

Applications of Robots

In Manufacturing Units

Advantages of Robots

- Robots can work in hazardous and dirty environment
- Can increase productivity after maintaining improved quality
- Direct labour cost will be reduced
- Material cost will be reduced
- Repetitive tasks can be handled more efficiently

Application Areas

- Arc Welding
- Spot Welding
- Spray Painting
- Pick and Place Operation
- Grinding
- Drilling
- Milling

Under-Water Applications

Purposes

- To explore various resources
- To study under-water environment
- To carry out drilling, pipe-line survey, inspection and repair of ships

Notes

- Robots are developed in the form of ROV (Remotely Operated Vehicle) and AUV (Autonomous Under-water Vehicle)
- Robots are equipped with navigational sensors, propellers/ thrusters, on-board softwares, and others

Medical Applications

- Telesurgery
- Micro-capsule multi-legged robots
- Prosthetic devices

Space Applications

- For carrying out on-orbit services, assembly job and interplanetary missions
- Spacecraft deployment and retrieval, survey of outside space shuttle; assembly, testing, maintenance of space stations; transport of astronauts to various locations
- Robo-nauts
- Free-flying robots
- Planetary exploration rovers

In Agriculture

- For spraying pesticides
- For spraying fertilizers in liquid form
- Cleaning weeds
- Sowing seeds
- Inspection of plants

Some Other Applications

- Replacement of maid-servant
- Garbage collection
- Underground Coal mining
- Sewage-line cleaning
- Fire-fighting etc.

Robot End-Effectors

An end-effector is a device attached to the wrist of a manipulator for the purpose of holding materials, parts, tools to perform a specific task

End Effectors

Grippers

End-effectors used to grasp and hold objects

Tools

End-effectors designed to perform some specific tasks
Ex: Spot welding electrode, Spray gun

Classification of Grippers

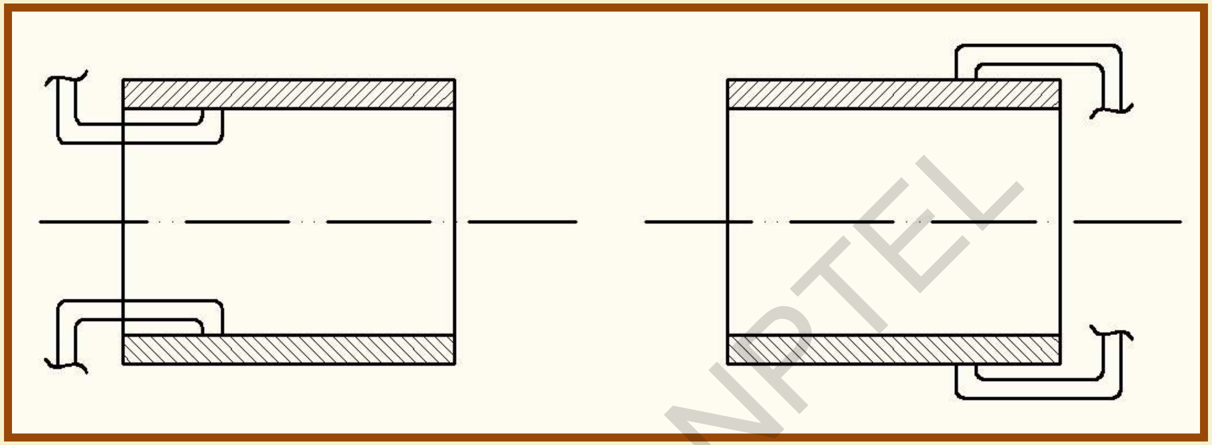
1. Single gripper and double gripper

- **Single gripper:** Only one gripping device is mounted on the wrist

- **Double gripper:** Two independent gripping devices are attached to the wrist

Example: Two separate grippers mounted on the wrist for loading and unloading applications

2. Internal gripper vs. External gripper

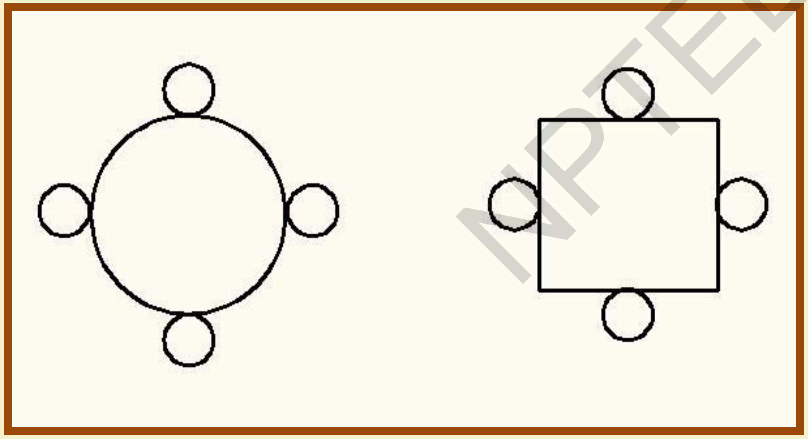


Internal gripper **External gripper**

3. Soft gripper vs. Hard gripper

Hard gripper: Point contact between the finger and object

Soft gripper: Area (surface) contact between the finger and object



4. Active Gripper and Passive Gripper

- **Active gripper: Gripper equipped with sensor**
- **Passive gripper: Gripper without sensor**

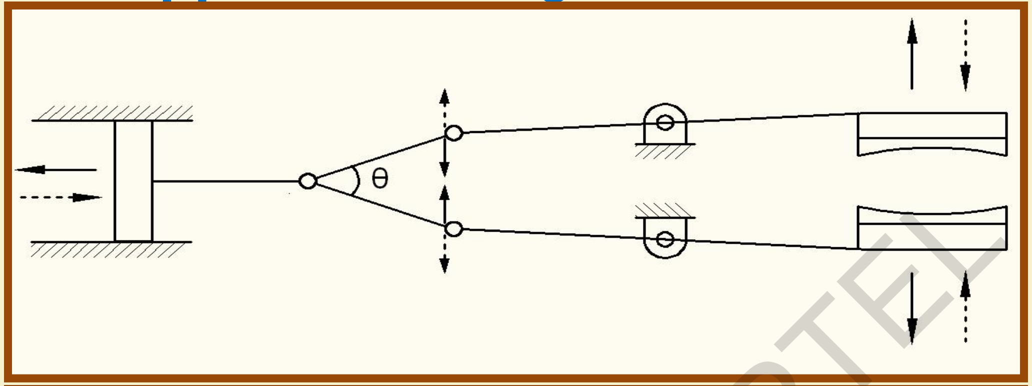
A Few Robot Grippers

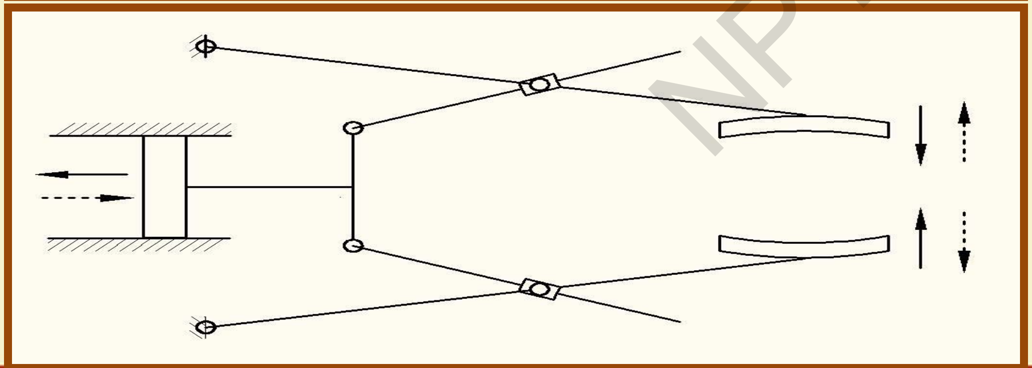
1. Mechanical Grippers

- Use mechanical fingers (jaws) actuated by some mechanisms
- Less versatile, less flexible and less costly

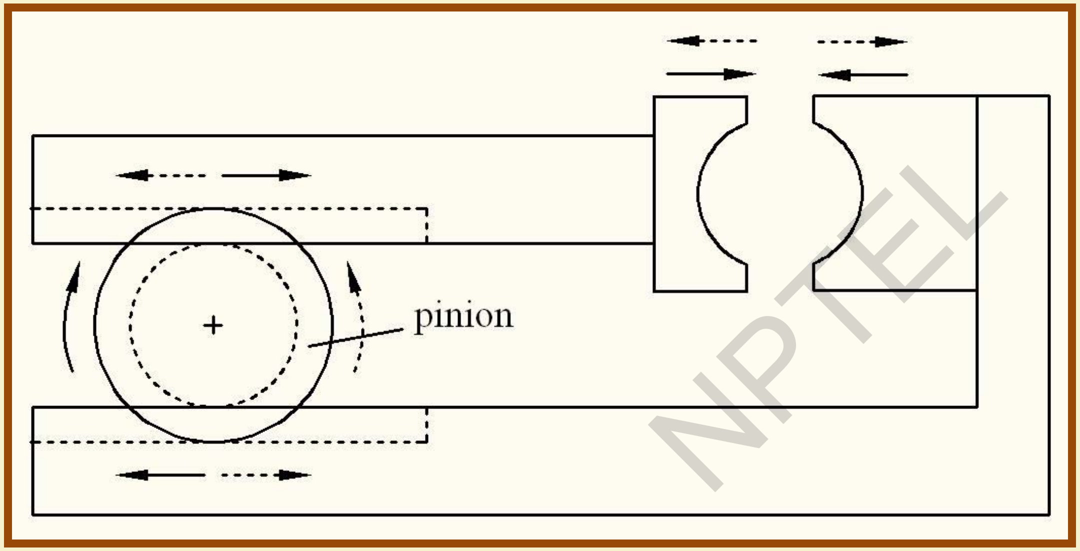
Examples

i. Gripper with linkage actuation

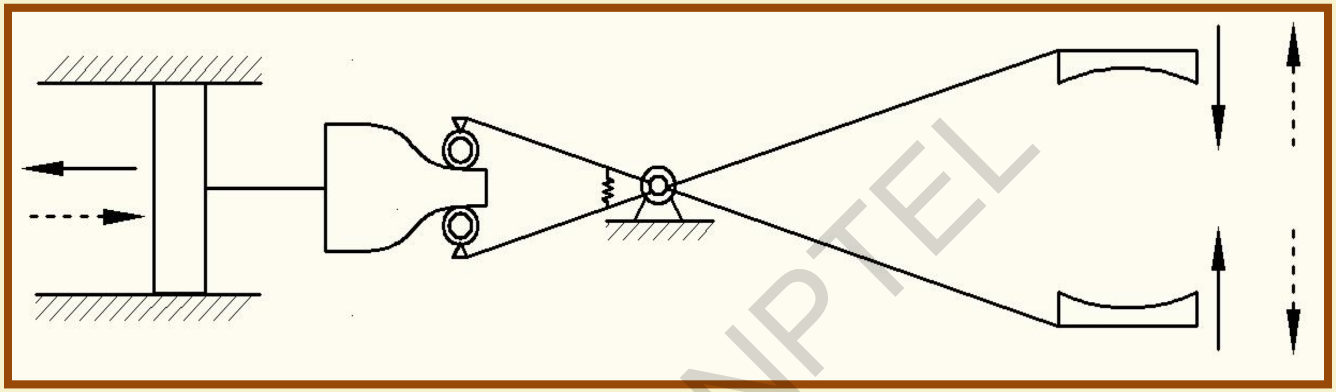




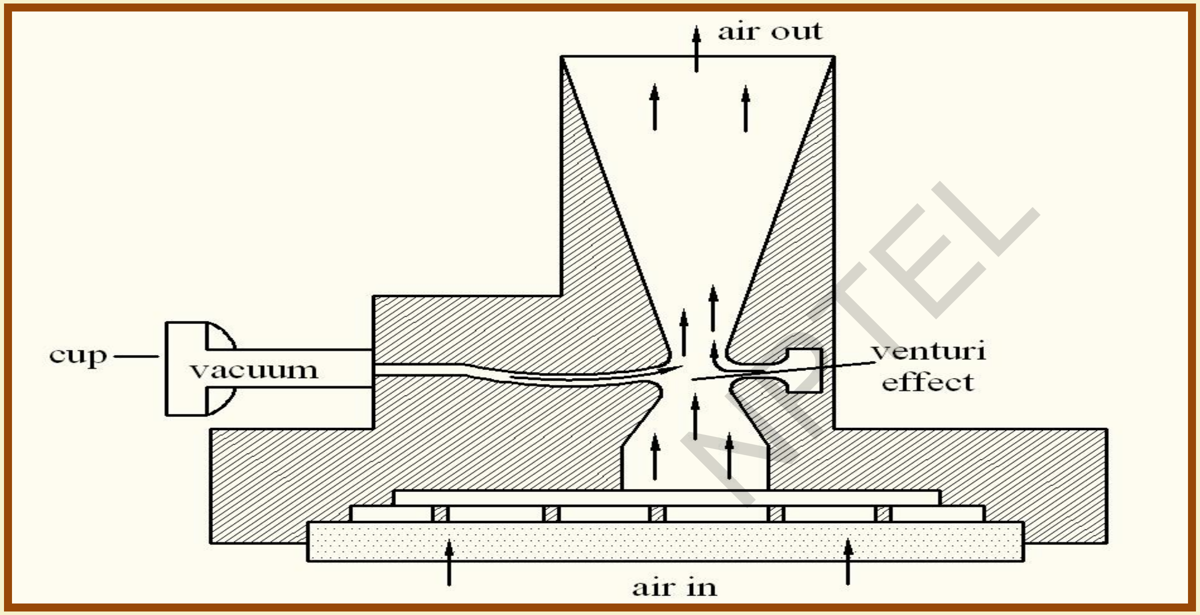
ii. Gripper with rotary actuation

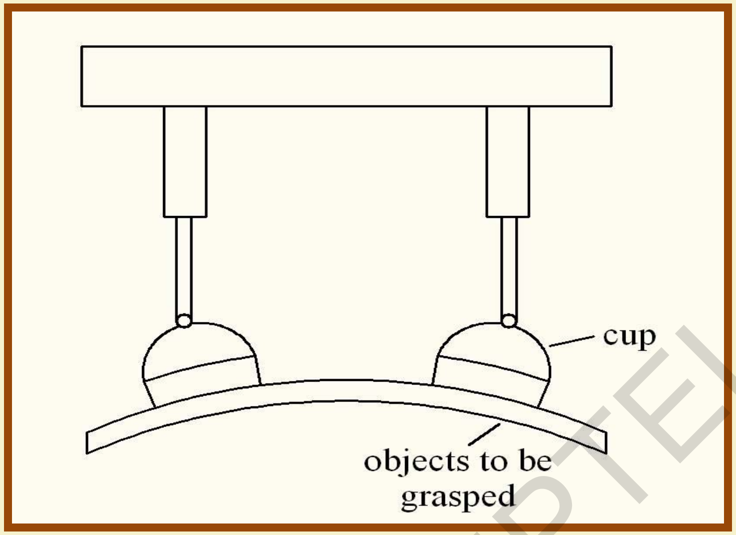


iii. Gripper with cam actuation



2. Vacuum Gripper (used for thin parts)



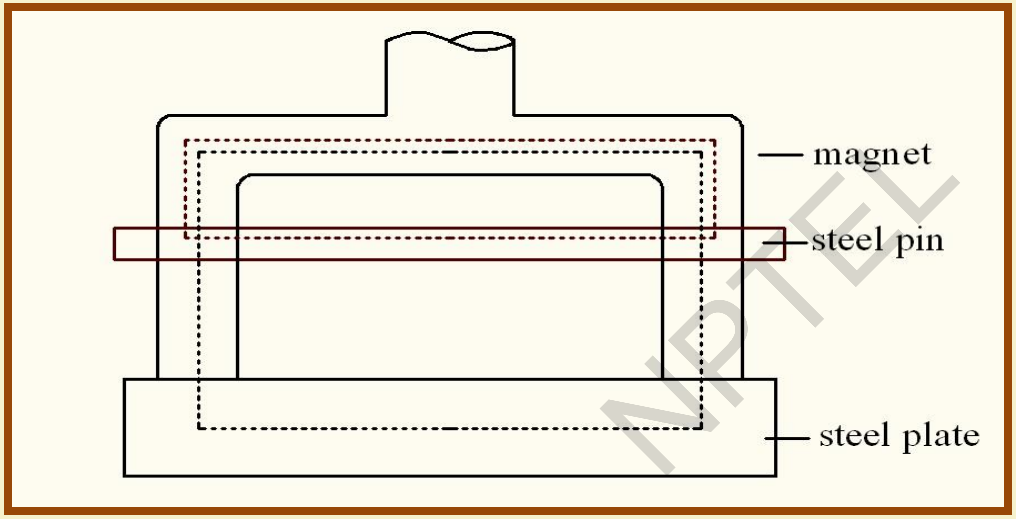


- Suction cup is made of elastic material like rubber or soft plastic
- When the object to be handled is soft, the cup should be made of hard substance
- Two devices can be used: Either Vacuum pump or venturi

3. Magnetic Gripper (for magnetic materials only. For example: various steels but not stainless steel)

- Can use either electro-magnets or permanent magnets
- Pick up time is less
- Can grip parts of various sizes
- Disadvantage: residual magnetism
- Stripping device: for separating the part from the permanent magnet
- For separating the part from electro-magnet, reverse the polarity

Magnetic Gripper



4. Adhesive Gripper

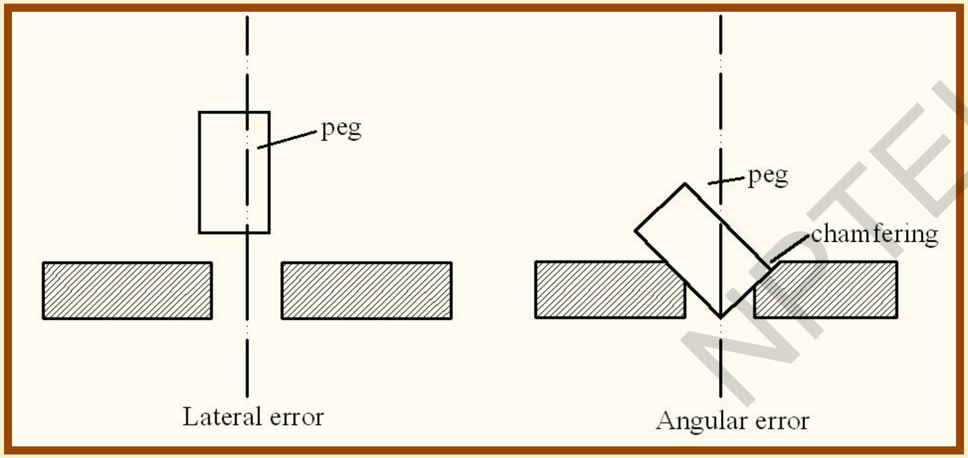
- Grasping action using adhesive substance
- To handle lightweight materials

5. Universal Gripper

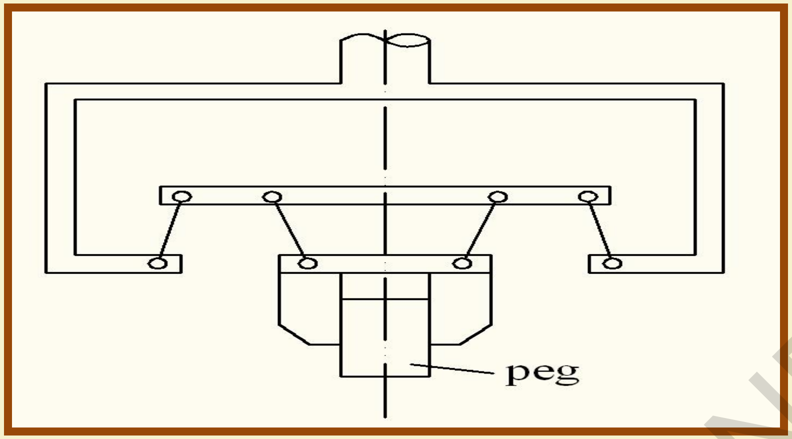
Example: Human gripper

Passive Gripper

Task: To insert a peg into a hole



Solution: Use Remote Center Compliance (RCC)



RCC is inappropriate for assembly of pegs in horizontal direction

Insertion angle must be less than 45 degrees

Cannot be used in chamferless insertion tasks

Robot Teaching

❖ To provide necessary instructions to the robot

Teaching Methods

- **Online Methods**
  - **Manual teaching** (point to point task)
    - Control handle / Joystick
    - Push buttons
    - Teach-pendant
  - **Lead-through Teaching** (continuous path task)
    - Robot simulator
- **Off-line Methods** (Programming language)

Off-line Method

VAL Programming for PUMA

Task: Pick and place operation

VAL program

APPRO PART, 100
MOVES PART
CLOSEI
DEPARTS 200
APPROS BIN, 300
MOVE BIN
OPENI
DEPART 100

Other VAL commands

SPEED 40
EXECUTE
ABORT
EDIT filename
LISTF
STORE
DELETE
LOAD filename

Specification of a Robot

- Control type
- Drive system
- Coordinate system
- Teaching/Programming methods
- Accuracy, Repeatability, Resolution
- Pay-load capacity
- Weight of the manipulator
- Applications
- Range and speed of arms and wrist
- Sensors used
- End-effector/ gripper used

Economic Analysis

- Let F: Capital investment to purchase a robot which includes its purchasing cost and installation cost
- B: Savings in terms of material and labour cost
- C: Operating and maintenance cost
- D: Depreciation of the robot
- A: Net savings

$$A = B - C - D$$

G: Tax to be paid on the net savings

Pay-back period, E = (Capital investment, F)/ (B-C-G)

Economic Analysis

- Let I: **Modified net savings after the payment of tax**
- Rate of return on investment

$$H = (I/F) \times 100\%$$

A company decides to purchase the robot, if

- **pay-back period < techno-economic life**
- **rate of return on investment > rate of bank interest**

Numerical Example

The costs and savings associated with a robot installation are given below.

Costs of a robot including accessories : Rs. 12,00,000

Installation cost : Rs. 3,00,000

Maintenance and operating cost : Rs. 20 per hour

Labour saving : Rs. 100 per hour

Material saving : Rs. 15 per hour

The shop runs 24 hours in a day (in 3 shifts) and the effective workdays in a year are 200. The tax rate of the company is 30% and techno-economic life of the robot is expected to be equal to six years.

Determine (a) pay-back period of the robot and (b) rate of return on investment

Solution

Capital investment $F = cost\ of\ the\ robot\ including\ accessories + Installation\ cost = Rs.\,15,00,000$

Total hours of running of the robot per year $= 24 \times 200 = 4800$

Saving per year $B = Labour\ saving + Material\ saving$

$$= 100 \times 4800 + 15 \times 4800 = Rs.\,5,52,000$$

Maintenance and operating cost per year $C = 20 \times 4800 = Rs.\,96,000$

Techno-economic life of the robot $= 6\ years$

Solution (Cont.)

Constant depreciation per year $= \frac{12{,}00{,}000}{6} = Rs.\,2{,}00{,}000$

Net savings $A = Savings - Operating\ cost - Depreciation$

$= 5{,}52{,}000 - 96{,}000 - 2{,}00{,}000$

$= Rs.\,2{,}56{,}000$

Tax to be paid to the government by the company $G = 30\%\ of\ A$

$= Rs.\,76{,}800$

Pay-back period of the robot

$E = \frac{F}{B-C-G} = 3.9\ years <$ techno-economic life

Solution (Cont.)

Net savings after the payment of tax

$$I = 0.7 \times 2,56,000$$
$$= Rs.\,1,79,200$$

Rate of return on investment

$$H = \frac{I}{F} \times 100\% = 11.95\% > \textit{rate of bank interest}$$

Therefore, the purchase of the robot is justified by taking loan from the bank.

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Topic 2: Robot Kinematics

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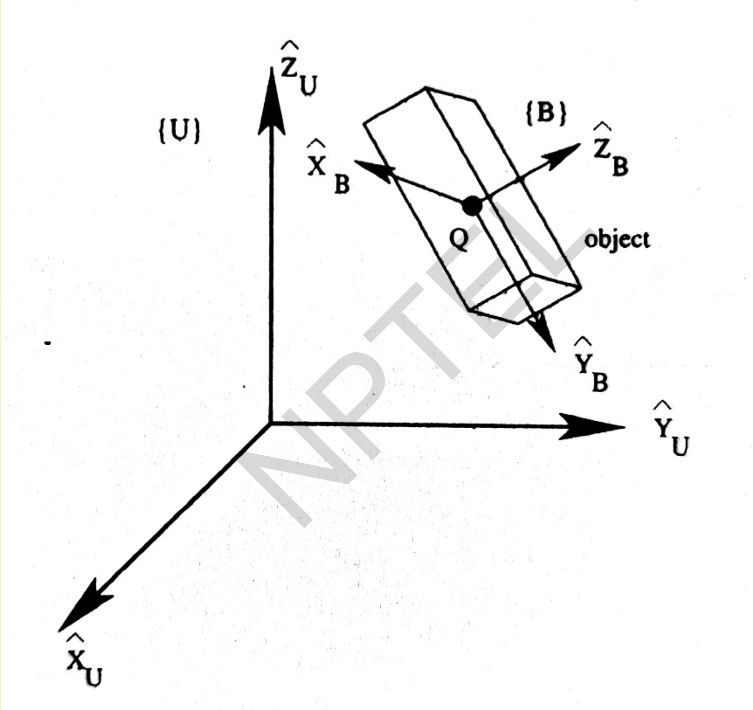
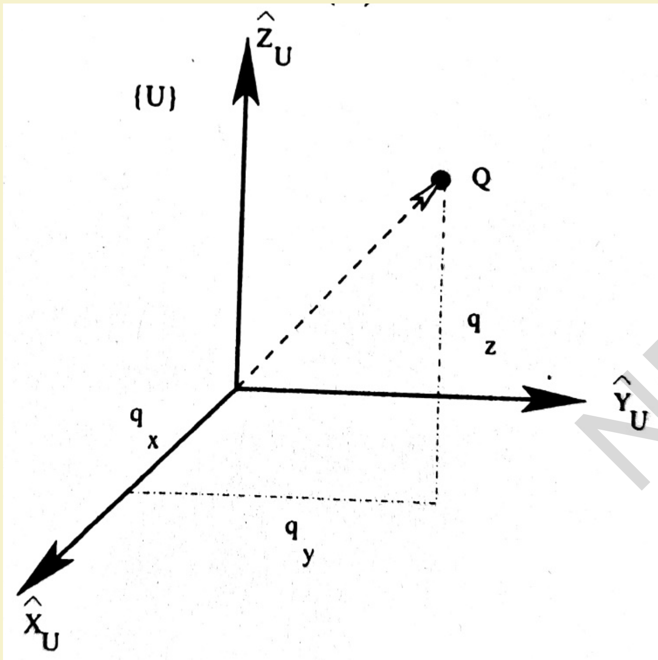
Representation of an Object in 3-D Space

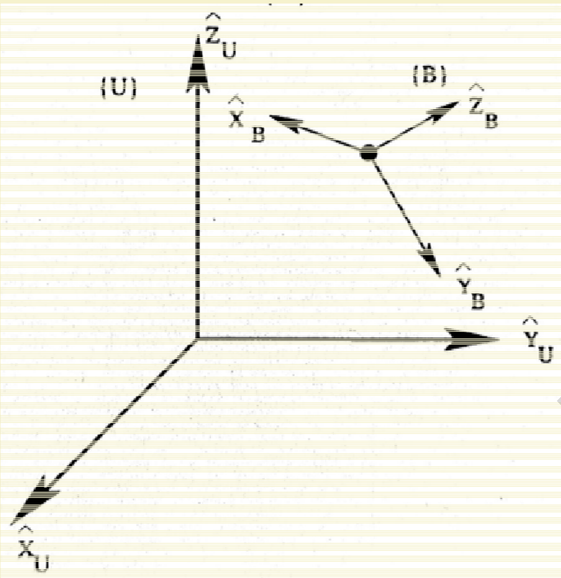


Representation of the Position



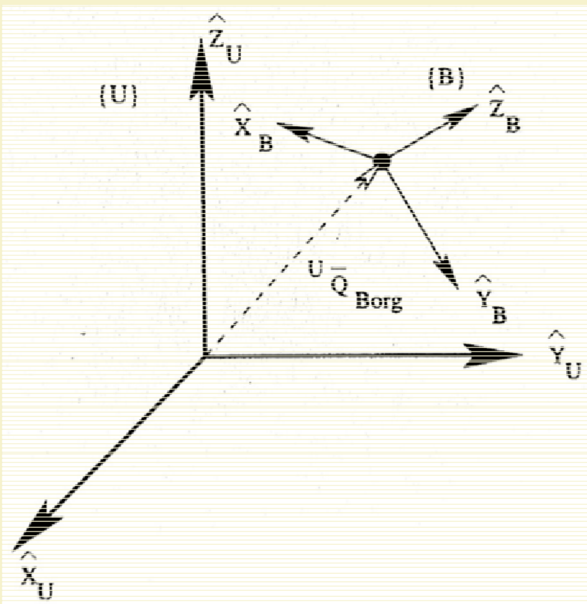
$$ {}^{U}\overline{Q} = \begin{bmatrix} q_x \\ q_y \\ q_z \end{bmatrix} $$ **; 3x1 matrix**

Representation of the Orientation



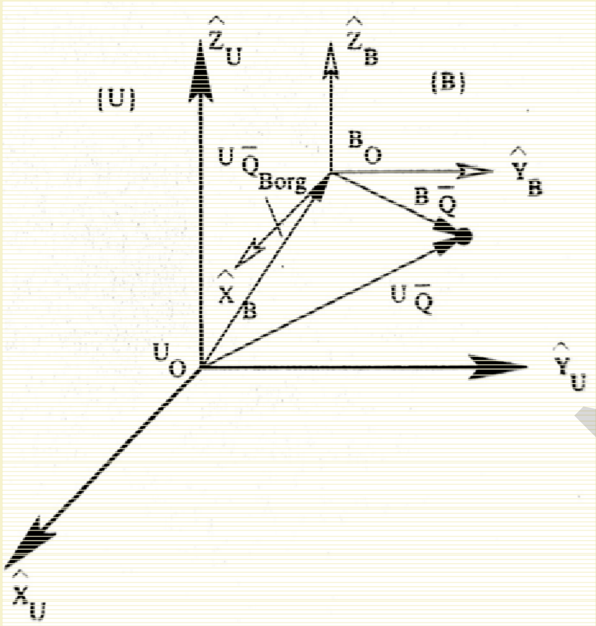
$${}^{U}_{B}R = [\,{}^{U}\hat{X}_{B} \;\; {}^{U}\hat{Y}_{B} \;\; {}^{U}\hat{Z}_{B}\,]_{\text{3x3 matrix}}$$

Frame Transformations



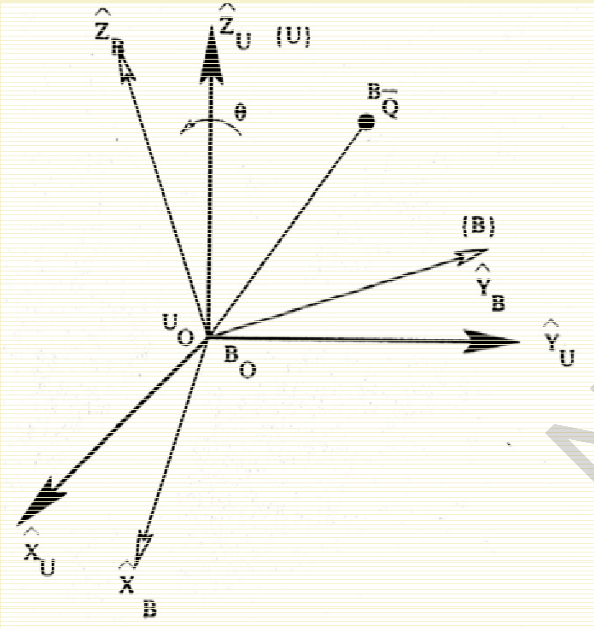
Frame: **A set of four vectors carrying position and orientation information**

Translation of a Frame



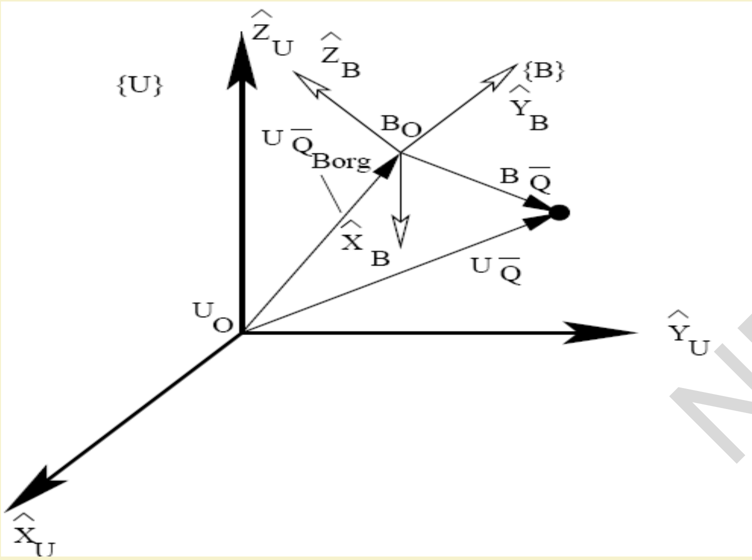
$$^{U}\overline{Q} = {}^{U}\overline{Q}_{Borg} + {}^{B}\overline{Q}$$

Rotation of a Frame



$$ {}^U\overline{Q} = {}^U_B R \, {}^B\overline{Q} $$

Translation and Rotation of a Frame



$$^U\overline{Q} = {}^U_BR\,{}^B\overline{Q} + {}^U\overline{Q}_{Borg}$$

$$^U\overline{Q} = {}^U_BR\,{}^B\overline{Q} + {}^U\overline{Q}_{Borg}$$

$$\Rightarrow {}^U\overline{Q} = {}^U_BT\,{}^B\overline{Q}$$

where T: transformation

$$\Rightarrow \begin{bmatrix} {}^{U}\overline{Q}(3X1) \\ ---- \\ \; \end{bmatrix} = \left[\begin{array}{c|c} {}^{U}_{B}R(3X3) & {}^{U}\overline{Q}_{Borg}(3X1) \\ ---- & ---- \\ & \end{array}\right] \begin{bmatrix} {}^{B}\overline{Q}(3X1) \\ ---- \\ \; \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} {}^{U}\overline{Q}(3X1) \\ ---- \\ 1 \end{bmatrix} = \left[\begin{array}{c|c} {}^{U}_{B}R(3X3) & {}^{U}\overline{Q}_{Borg}(3X1) \\ ---- & ---- \\ 0 \quad 0 \quad 0 & 1 \end{array}\right] \begin{bmatrix} {}^{B}\overline{Q}(3X1) \\ ---- \\ 1 \end{bmatrix}$$

Let $[\mathrm{T}]$: Homogeneous transformation matrix

$$[\mathrm{T}] = \begin{bmatrix} {}^{U}_{B}\mathrm{R}(3x3) & | & {}^{U}\overline{Q}_{\mathrm{Borg}}(3x1) \\ ----- & | & ---- \\ 0 \quad 0 \quad 0 & | & 1 \end{bmatrix}$$

Say

$$[T] = \begin{bmatrix} r_{11} & r_{12} & r_{13} & q_x \\ r_{21} & r_{22} & r_{23} & q_y \\ r_{31} & r_{32} & r_{33} & q_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Translation Operator

Trans $(\hat{X}, q)$: Translation of q units along x-direction

Trans $(\hat{X}, q)$ = $$\begin{bmatrix} 1 & 0 & 0 & q \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Note: Trans operators are commutative in nature

$$Trans(\hat{X}, q_x)Trans(\hat{Y}, q_y) = Trans(\hat{Y}, q_y)Trans(\hat{X}, q_x)$$