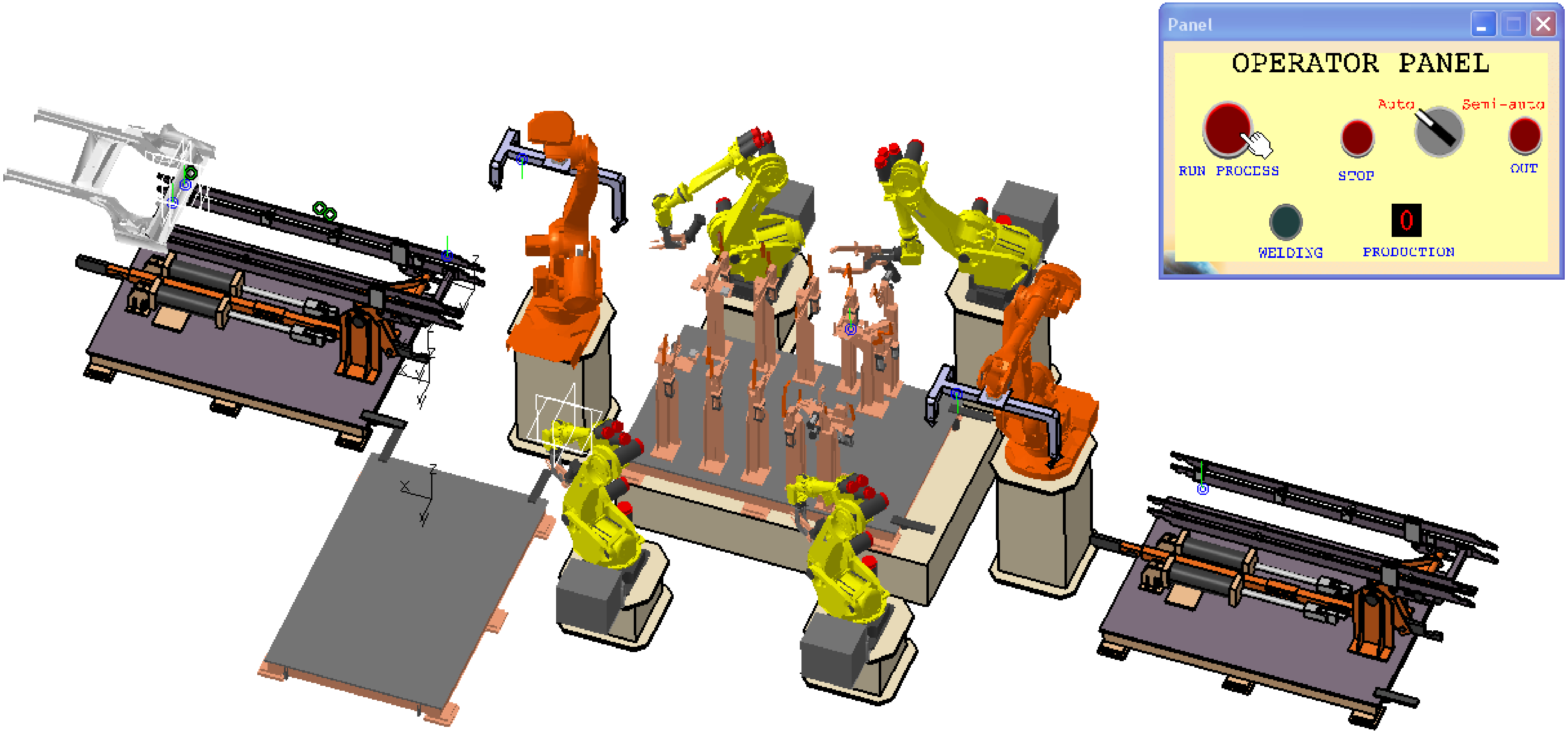
جلسه نهم و دهم: کاربرد رباتیک در اتوماسیون


Panel
OPERATOR PANEL
Auto
Semi-auto
RUN PROCESS
STOP
OUT
WELDING
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PRODUCTION

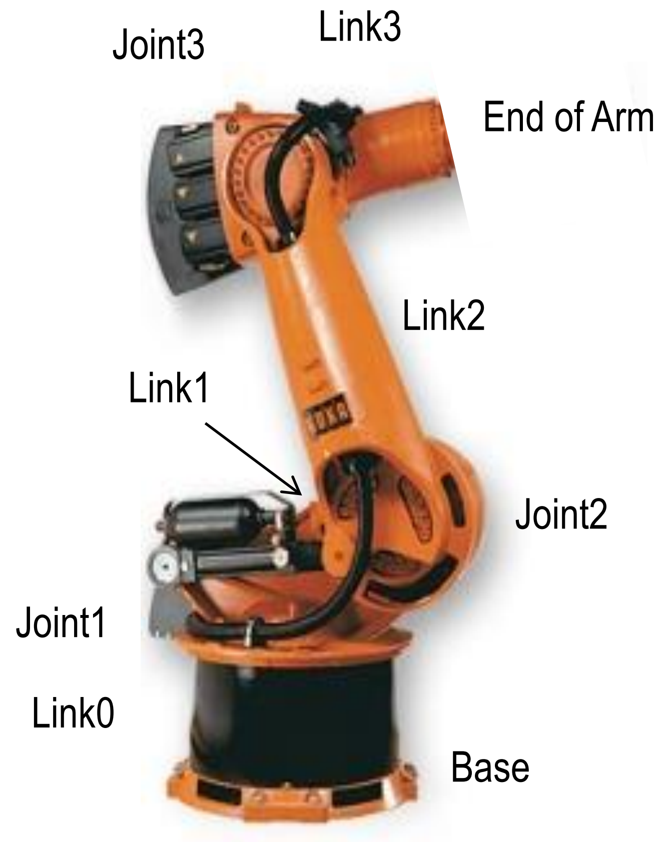
Industrial Robot Defined

Definition: A general-purpose, programmable machine possessing certain anthropomorphic characteristics

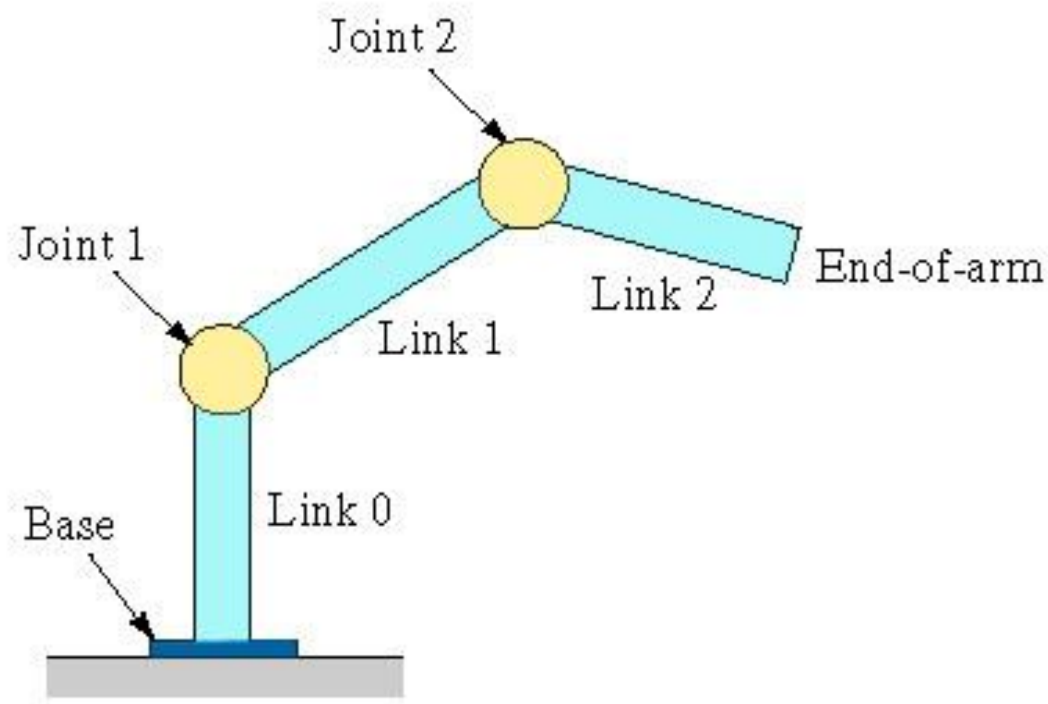
- Why industrial robots are important:
  - Robots can substitute for humans in hazardous work environments
  - Consistency and accuracy not attainable by humans
  - Can be reprogrammed
  - Most robots are controlled by computers and can therefore be interfaced to other computer systems

Robot Anatomy

- Manipulator consists of **joints** and **links**
  - Joints provide relative motion
  - Links are rigid members between joints
  - Various joint types: linear and rotary
  - Each joint provides a “degree-of-freedom”
  - Most robots possess five or six degrees-of-freedom
- **Robot manipulator consists of two sections**:
  - Body-and-arm – for positioning of objects in the robot's work volume
  - Wrist assembly – for orientation of objects



Robot Anatomy



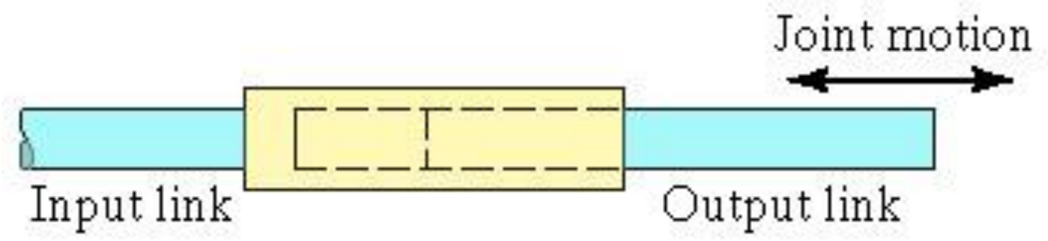
Robot manipulator - a series of joint-link combinations

Types of Manipulator Joints

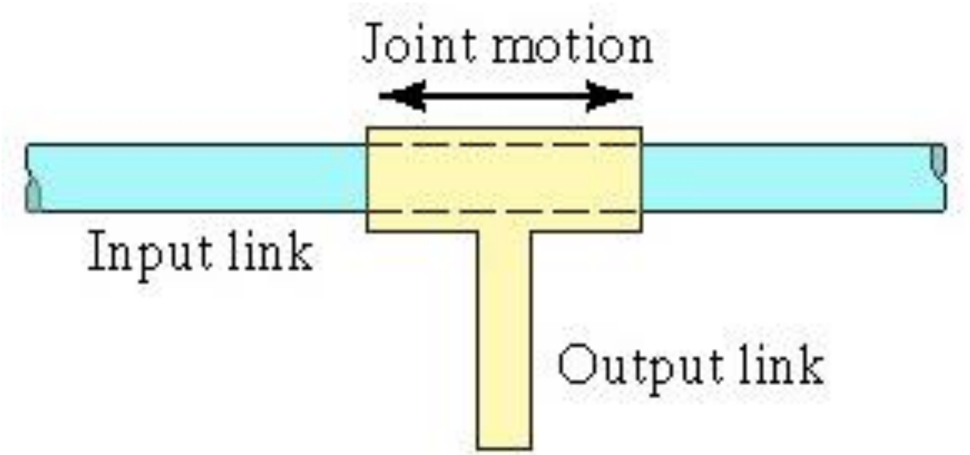
- Translational motion
  - Linear joint (type L)
  - Orthogonal joint (type O)
- Rotary motion
  - Rotational joint (type R)
  - Twisting joint (type T)
  - Revolving joint (type V)

Translational Motion Joints

Linear joint
(type L)

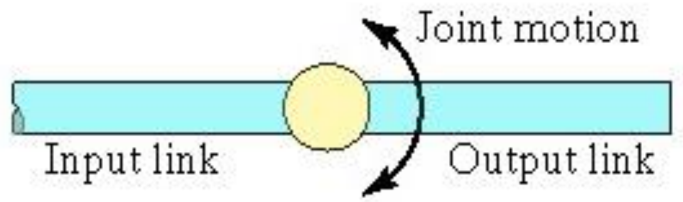


Orthogonal joint
(type O)

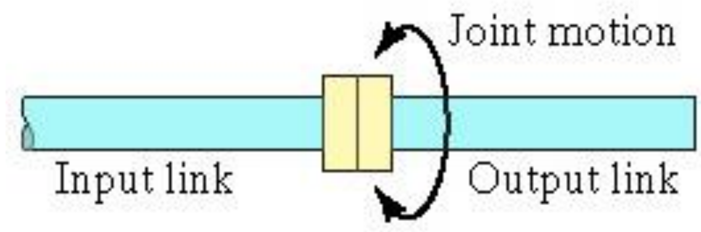


Rotary Motion Joints

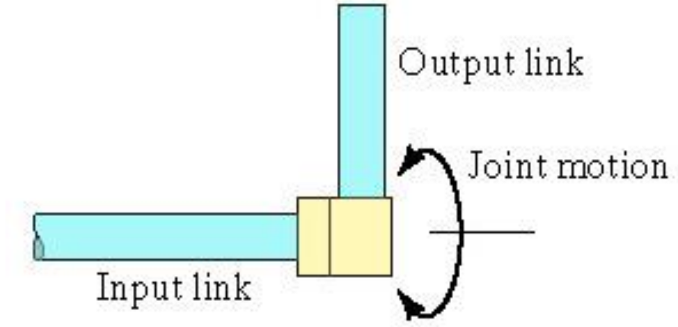
Rotational joint
(type R)



Twisting joint
(type T)



Revolving joint
(type V)



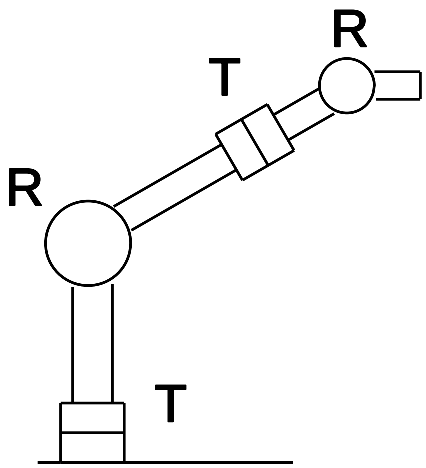
Joint Notation Scheme

- Uses the joint symbols (L, O, R, T, V) to designate joint types used to construct robot manipulator
- Separates body-and-arm assembly from wrist assembly using a colon (:)
- Example: TLR : TR

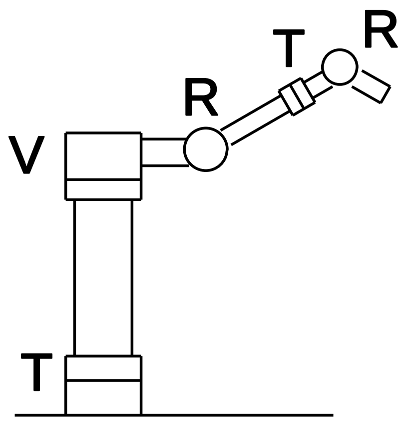
Example

- Sketch following manipulator configurations
- (a) TRT:R, (b) TVR:TR, (c) RR:T.

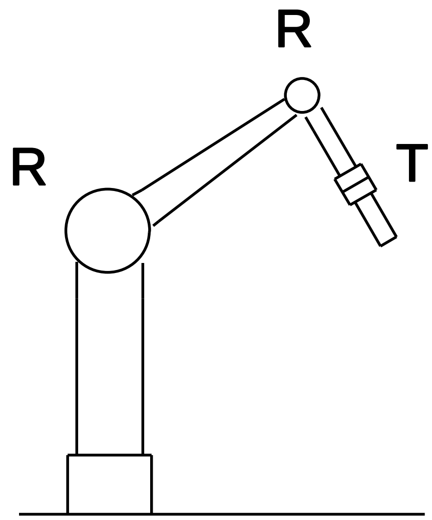
Solution:



(a) TRT:R



(b) TVR:TR



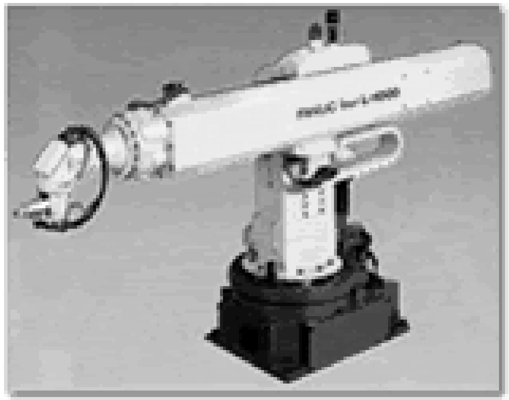
(c) RR:T

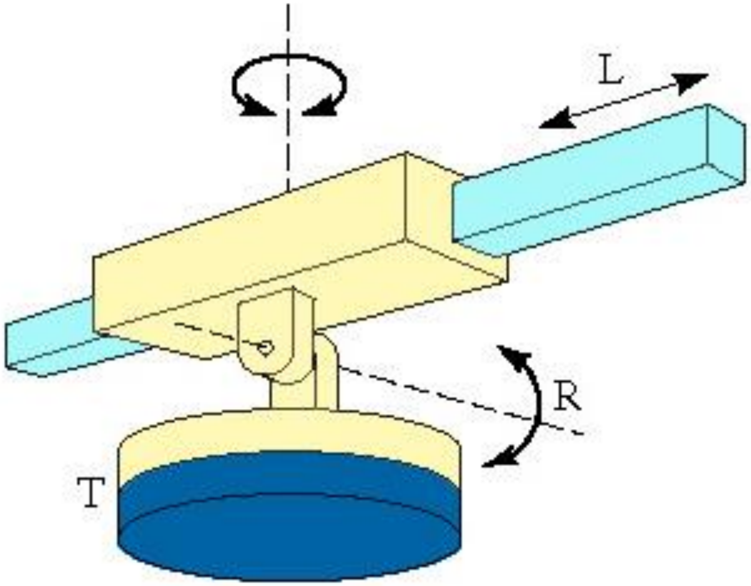
Robot Body-and-Arm Configurations

- Five common body-and-arm configurations for industrial robots:
  1. Polar coordinate body-and-arm assembly
  2. Cylindrical body-and-arm assembly
  3. Cartesian coordinate body-and-arm assembly
  4. Jointed-arm body-and-arm assembly
  5. Selective Compliance Assembly Robot Arm (SCARA)
- Function of body-and-arm assembly is to position an end effector (e.g., gripper, tool) in space

Polar Coordinate Body-and-Arm Assembly

- Notation TRL:

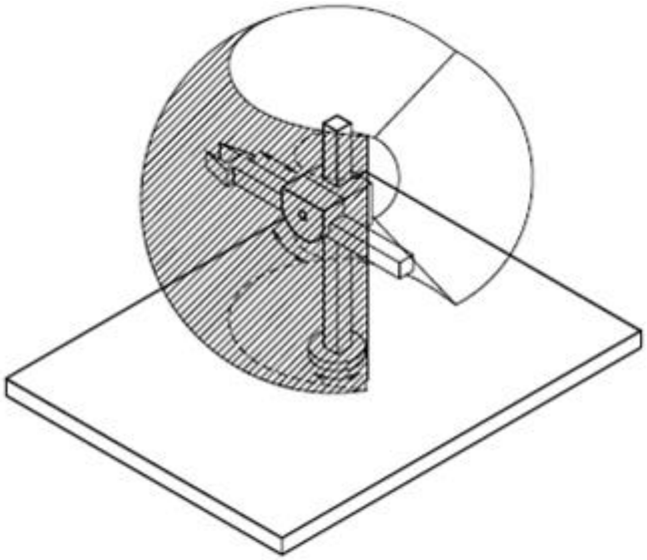




- Consists of a sliding arm (L joint) actuated relative to the body, which can rotate about both a vertical axis (T joint) and horizontal axis (R joint)

Polar or Spherical Manipulator

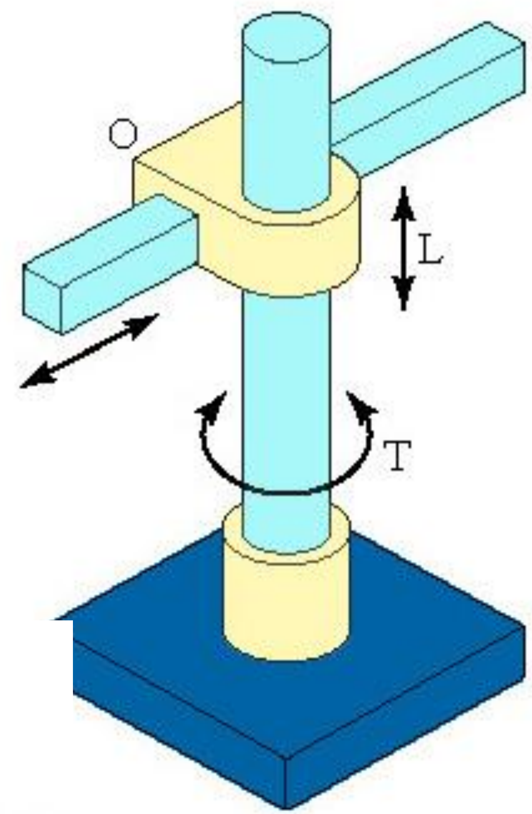
- rotation about the base
- Rotation about an axis in the vertical plane to raise and lower it.
- reaches in and out.



Spherical manipulator and its workspace

Cylindrical Body-and-Arm Assembly

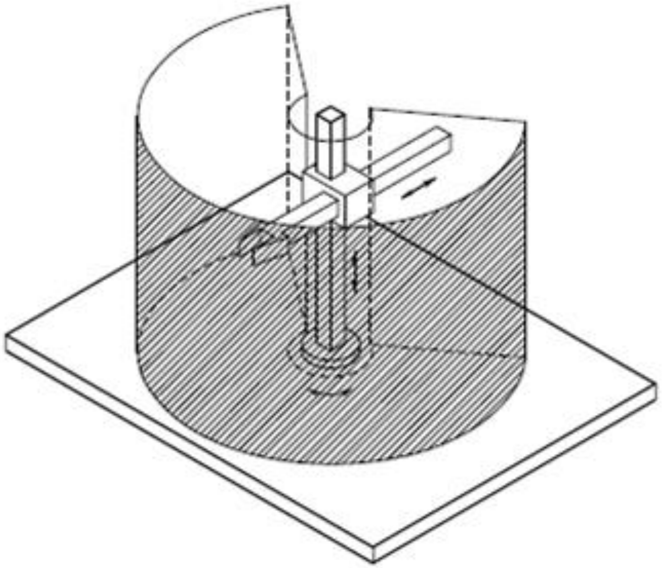
- Notation TLO:



- Consists of a vertical column, relative to which an arm assembly is moved up or down
- The arm can be moved in or out relative to the column

Cylindrical Manipulator

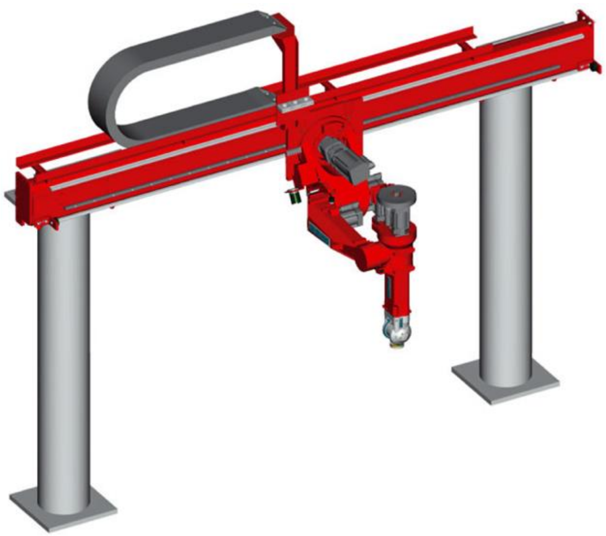
- Rotation about the base or shoulder. (θ)
- up and down (z)
- in and out (R)

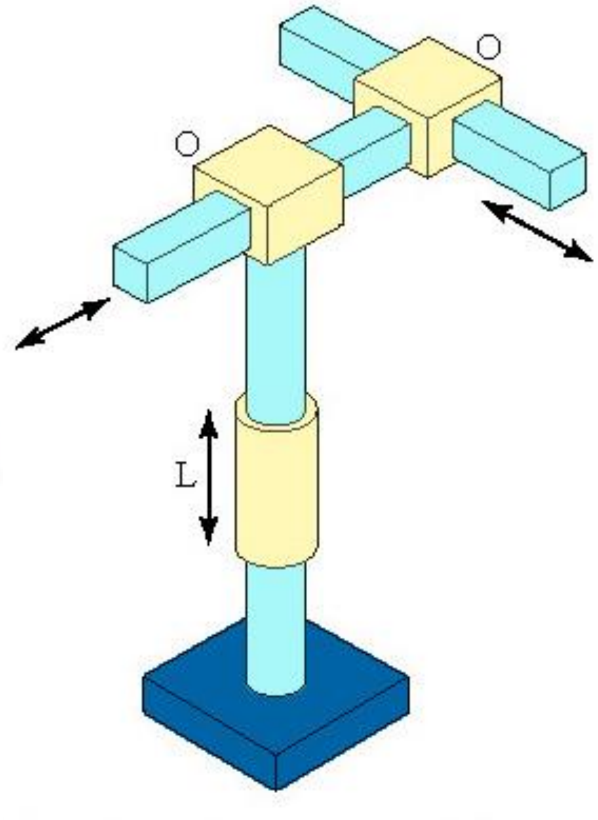


Cartesian Coordinate Body-and-Arm Assembly

- Notation LOO:

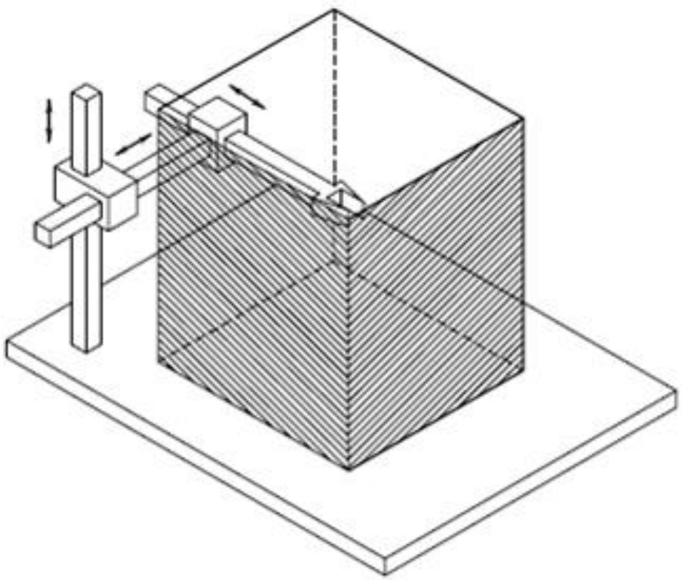
- Consists of three sliding joints, two of which are orthogonal
- Other names include rectilinear robot and x-y-z robot





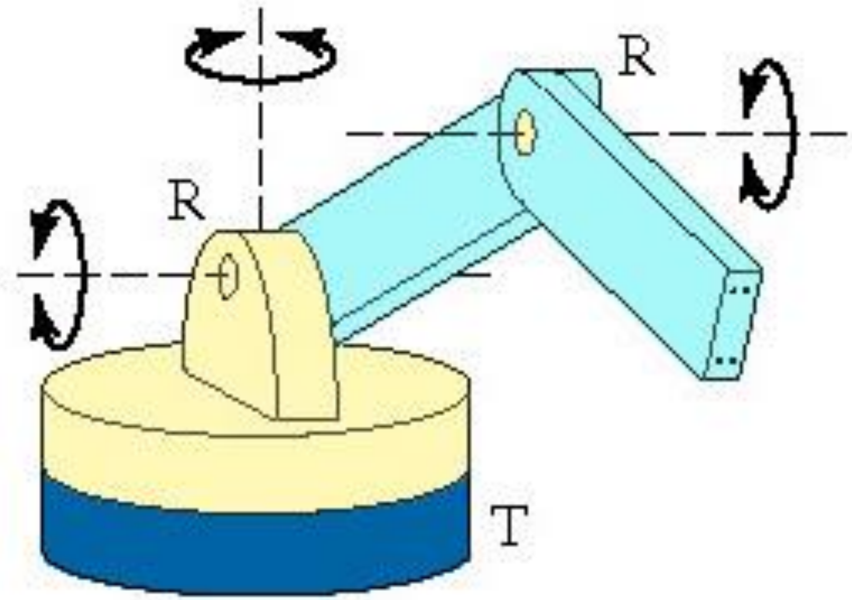
Cartesian/Rectangular Manipulator

- straight, or linear motion along three axes:
  - in and out, (x)
  - back and forth (y)
  - up and down (z)



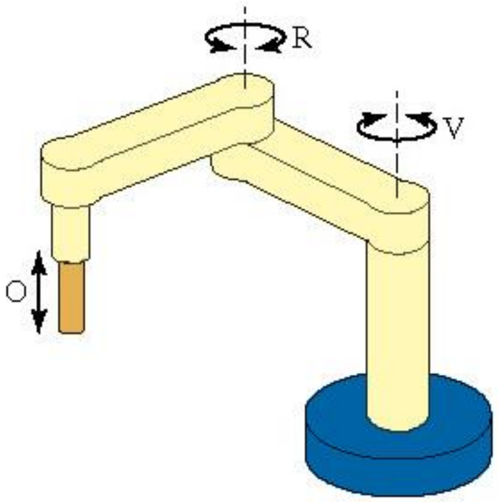
Jointed-Arm Robot

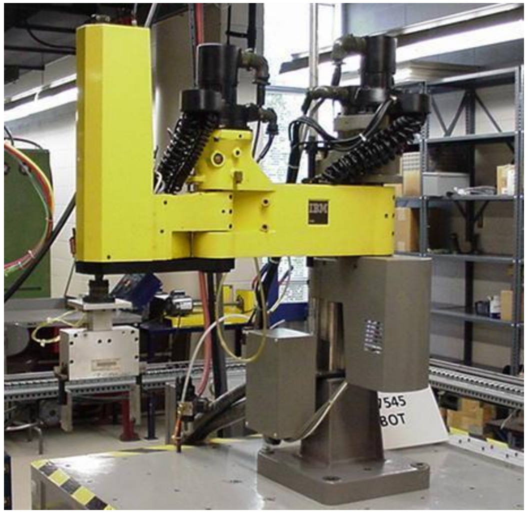
- Notation TRR:



SCARA Robot

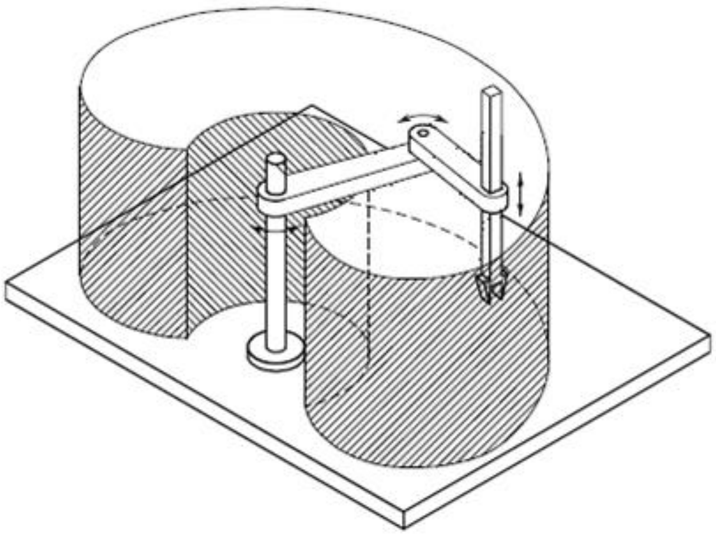
- Notation VRO
- SCARA stands for Selectively Compliant Assembly Robot Arm
- Similar to jointed-arm robot except that vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction for vertical insertion tasks





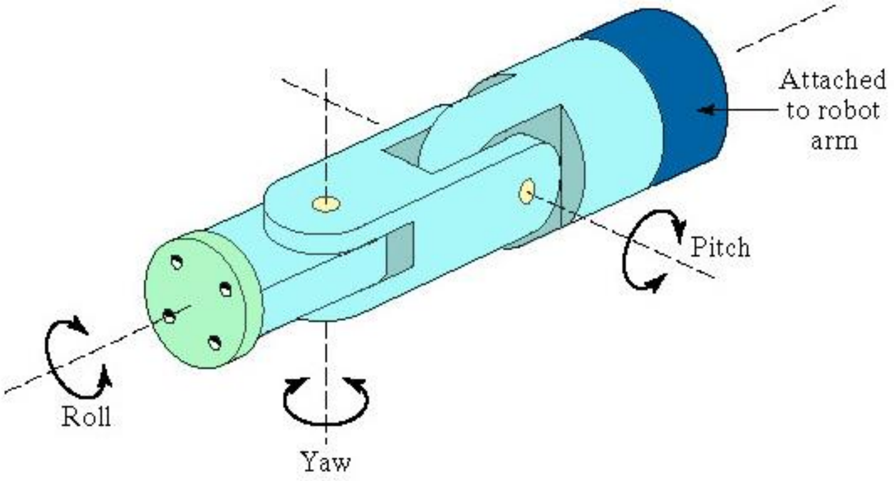
SCARA Robot

- Selective Compliance Assembly Robot Arm
  - the same work area as a cylindrical-coordinates robot.
  - the reach axis includes a rotational joint in a plane parallel to the floor.



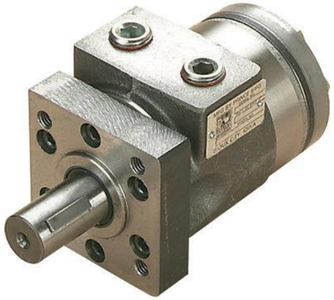
Wrist Configurations

- Wrist assembly is attached to end-of-arm
- End effector is attached to wrist assembly
- Function of wrist assembly is to orient end effector
  - Body-and-arm determines global position of end effector
- Two or three degrees of freedom:
  - Roll
  - Pitch
  - Yaw
- Notation :RRT



Joint Drive Systems

- Electric
  - Uses electric motors to actuate individual joints
  - Preferred drive system in today's robots
- Hydraulic
  - Uses hydraulic pistons and rotary vane actuators
  - Noted for their high power and lift capacity
- Pneumatic
  - Typically limited to smaller robots and simple material transfer applications



Robot Control Systems

- **Limited sequence control** – pick-and-place operations using mechanical stops to set positions
- **Playback with point-to-point control** – records work cycle as a sequence of points, then plays back the sequence during program execution
- **Playback with continuous path control** – greater memory capacity and/or interpolation capability to execute paths (in addition to points)
- **Intelligent control** – exhibits behavior that makes it seem intelligent, e.g., responds to sensor inputs, makes decisions, communicates with humans

Point to point control

Point-To-Point: These robots are most common and can move from one specified point to another but cannot stop at arbitrary points not previously designated.

- All Axes start and end simultaneously
- All Geometry is computed for targets and relevant Joint changes which are then forced to be followed during program execution
- Only the end points are programmed, the path used to connect the end points are computed by the controller
- user can control velocity, and may permit linear or piece wise linear motion
- Feedback control is used during motion to ascertain that individual joints have achieved desired location
- Often used hydraulic drives, recent trend towards servomotors
- loads up to 500lb and large reach

Applications

- pick and place type operations
- palletizing
- machine loading

Continuous path control

Continuous Path:

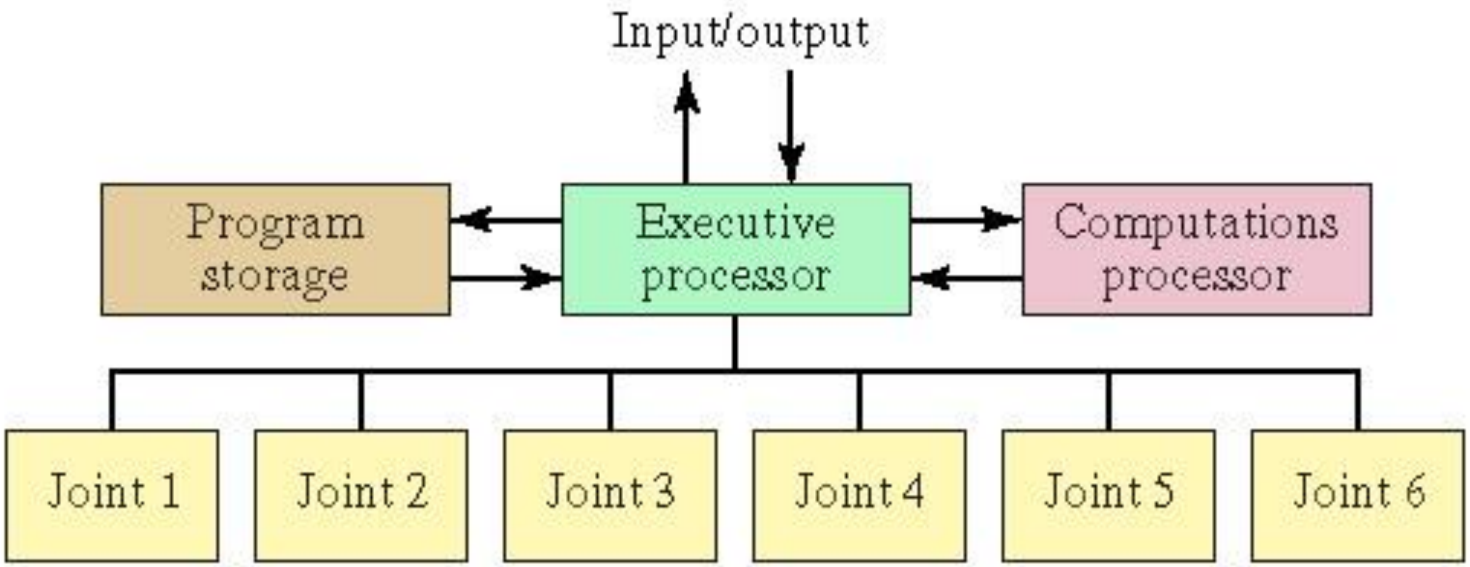
- It is an extension of the point-to-point method. this involves the utilization of more points and its path can be arc, a circle, or a straight line.
- Because of the large number of points, the robot is capable of producing smooth movements that give the appearance of continuous or contour movement.
- In addition to the control over the endpoints, the path taken by the end effector can be controlled
- Path is controlled by manipulating the joints throughout the entire motion, via closed loop control.

Applications

- spray painting
- polishing
- grinding
- arc welding

Robot Control System

Hierarchical control structure of a robot microcomputer controller



End Effectors

- The special tooling for a robot that enables it to perform a specific task
- Two types:
  - Grippers – to grasp and manipulate objects (e.g., parts) during work cycle
  - Tools – to perform a process, e.g., spot welding, spray painting

Gripper Types

mechanical grippers: consisting of two or more fingers that can be actuated by the robot controller to open and dose to grasp the workpart.

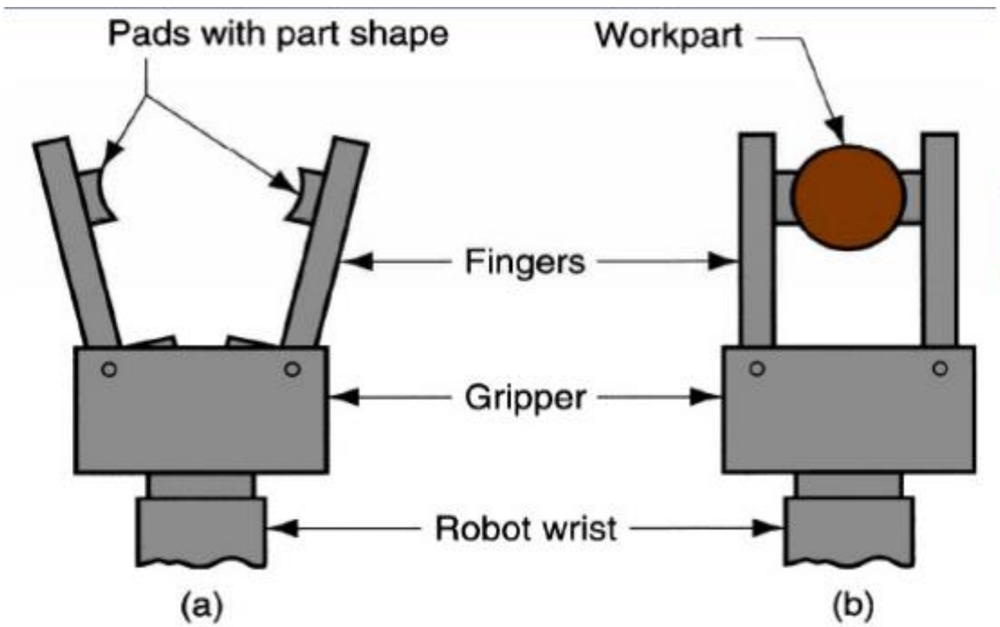
vacuum grippers: in which suction cups are used to hold flat objects

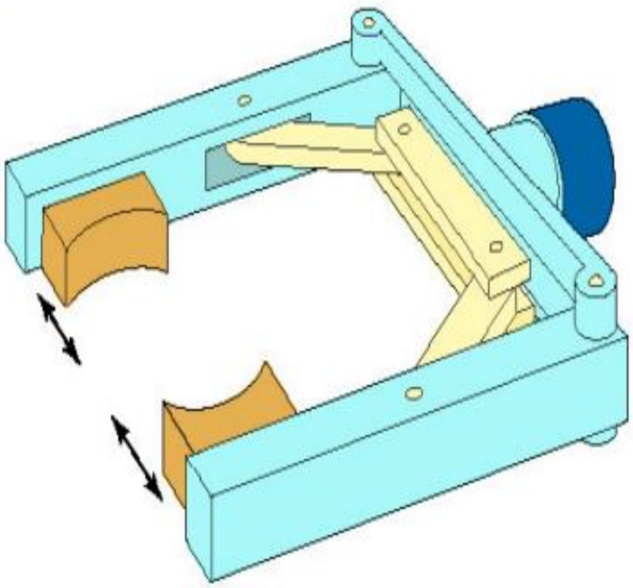
magnetized devices: for holding ferrous parts

adhesive devices: where an adhesive substance is used to hold a flexible material such as a fabric.

simple mechanical devices such as hooks and scoops.

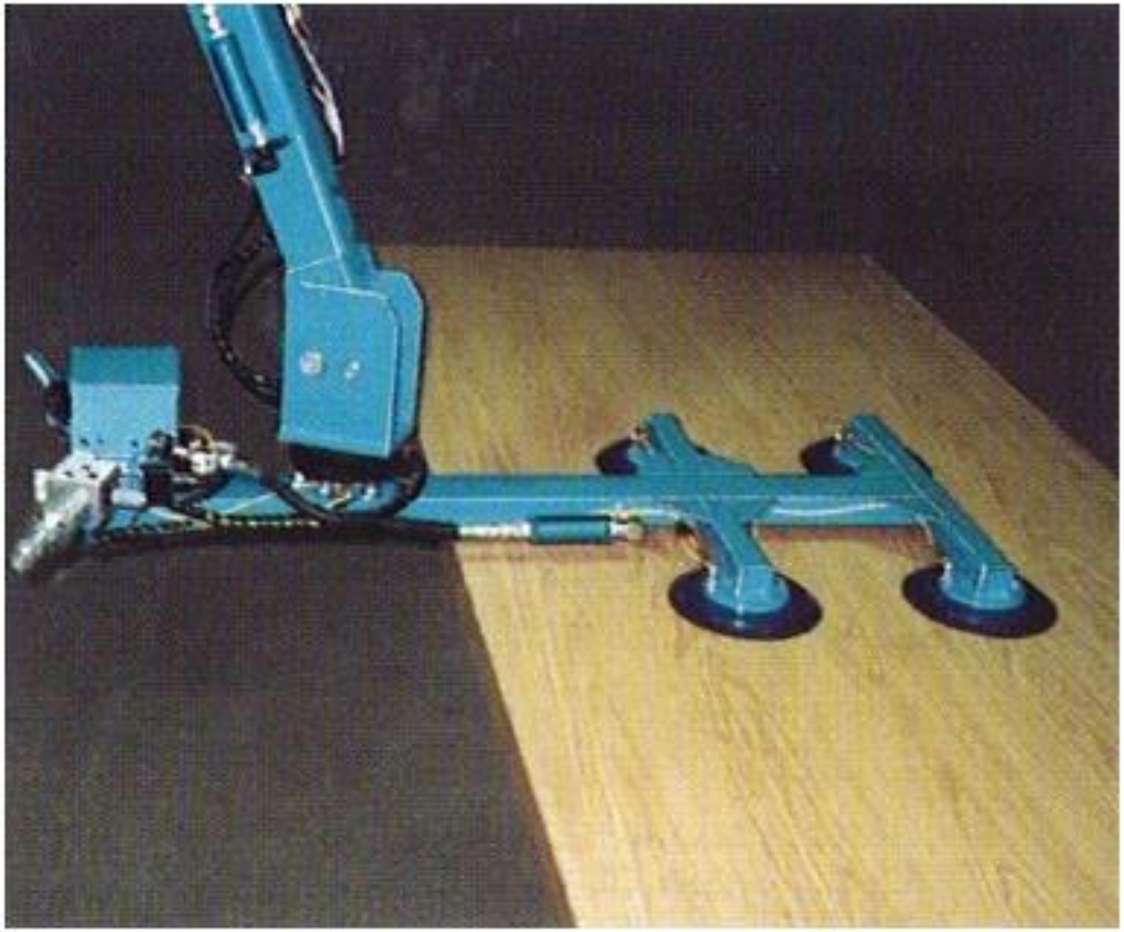
Robot Mechanical Gripper



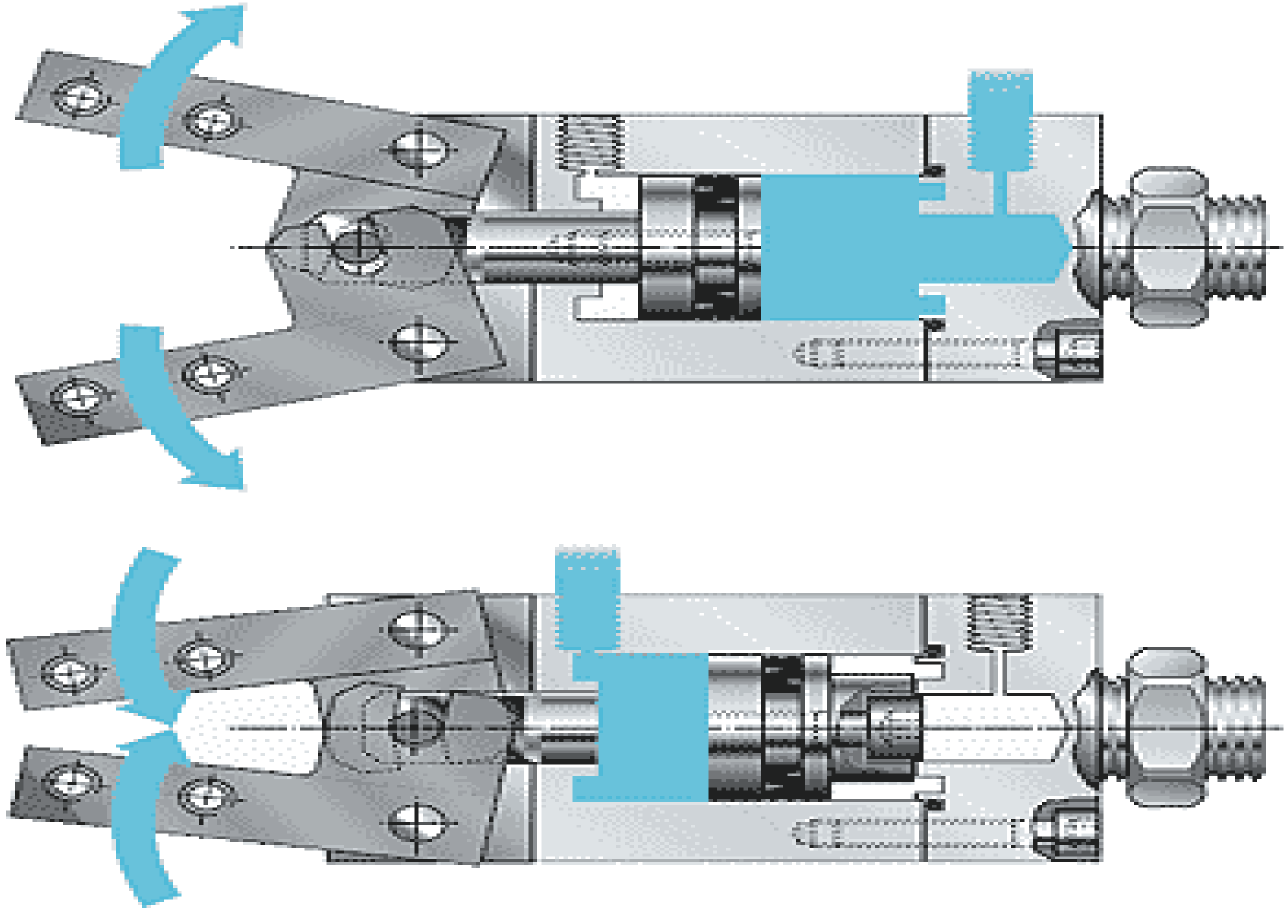


- A two-finger mechanical gripper for grasping rotational parts

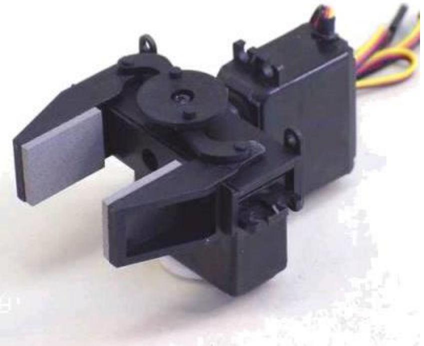
Vacuum Gripper

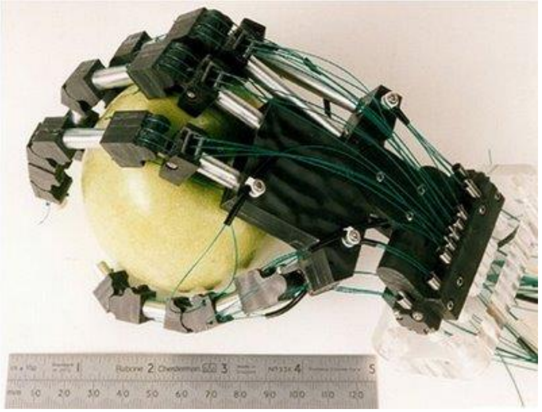


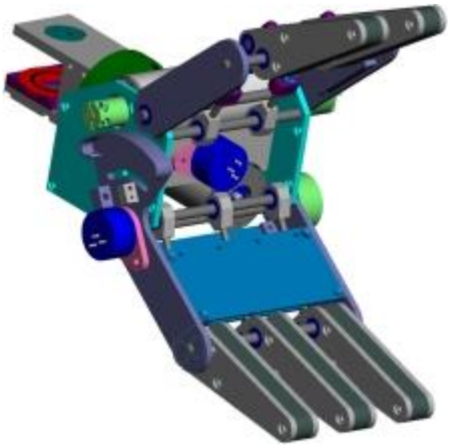
Pneumatic gripper



Grippers and Tools







Requirements for an effective gripper

- Parts or items must be grasped and held without damage
- Parts must be positioned firmly or rigidly while being operated on.
- Hands or grippers must accommodate parts of differing sizes or even of varying sizes
- Self-aligning jaws are required to ensure that the load stays centered in the jaws
- Grippers or end effectors must not damage the part being handled.
- Jaws or grippers must make contact at a minimum of two points to ensure that the part doesn’t rotate while being positioned.

Advances in Mechanical Grippers

- Dual grippers
- Interchangeable fingers
- Sensory feedback
  - To sense presence of object
  - To apply a specified force on the object
- Multiple fingered gripper (similar to human hand)
- Standard gripper products to reduce the amount of custom design required

Why do Robots need sensors?

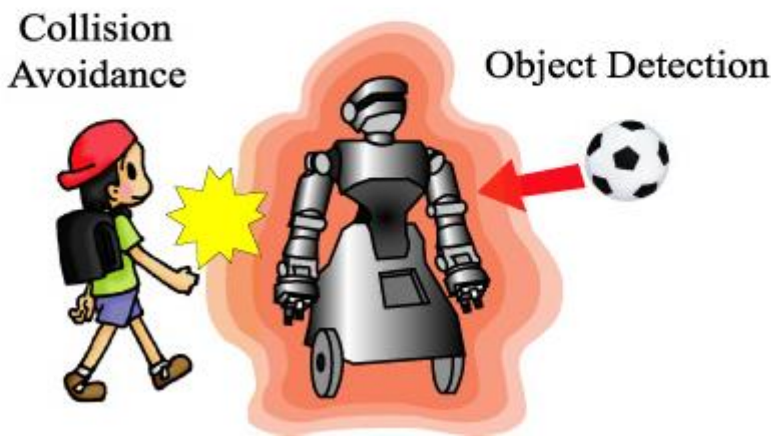
- Provides "awareness" of surroundings
  - What's ahead, around, "out there"?
- Allows interaction with environment
  - Robot lawn mower can "see" cut grass
- Protection & Self-Preservation
  - Safety, Damage Prevention, Stairwell sensor
- Gives the robot capability to goal-seek
  - Find colorful objects, seek goals
- Makes robots "interesting"

Sensors in Robotics

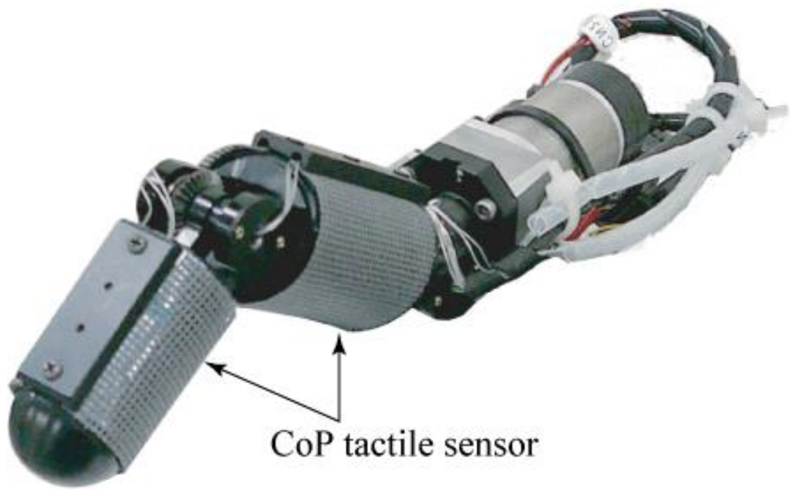
Two basic categories of sensors used in industrial robots:

1. Internal - used to control position and velocity of the manipulator joints
2. External - used to coordinate the operation of the robot with other equipment in the work cell
   - Tactile - touch sensors and force sensors
   - Proximity - when an object is close to the sensor
   - Optical -
   - Machine vision
   - Other sensors - temperature, voltage, etc.

Sensors in Robotics



Proximity Sensor



Tactile Sensor

Robot Application Characteristics

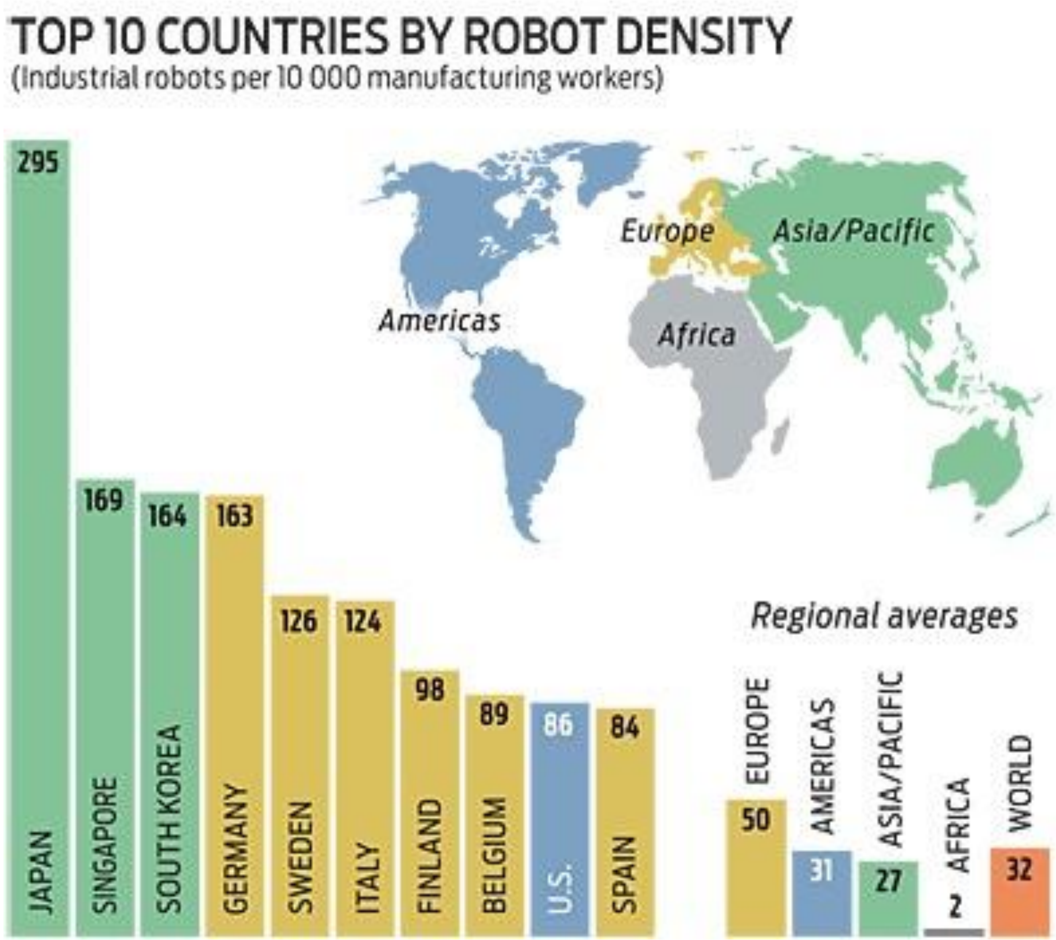
General characteristics of industrial work situations that promote the use of industrial robots

1. Hazardous work environment for humans
2. Repetitive work cycle
3. Difficult handling task for humans
4. Multishift operations
5. Infrequent changeovers
6. Part position and orientation are established in the work cell

Industrial Applicability Checklist

Characteristics of the Work Situation	NO (Characteristic Does Not Apply)	YES (Characteristic Applies)
1. Hazardous work environment for humans		
2. Repetitive work cycle		
3. Difficult handling for humans		
4. Multishift operation		
5. Infrequent changeovers		
6. Part position and orientation are established in the work cell		
Total check marks in each column		

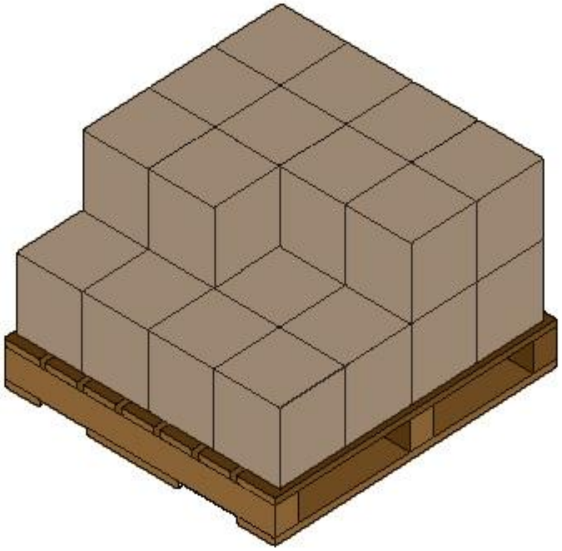
Industrial Robot Applications



Industrial Robot Applications

1. Material handling applications
   - Material transfer – pick-and-place, palletizing
   - Machine loading and/or unloading
2. Processing operations
   - Spot welding and continuous arc welding
   - Spray coating
   - Other – waterjet cutting, laser cutting, grinding
3. Assembly and inspection

1. Material handling applications



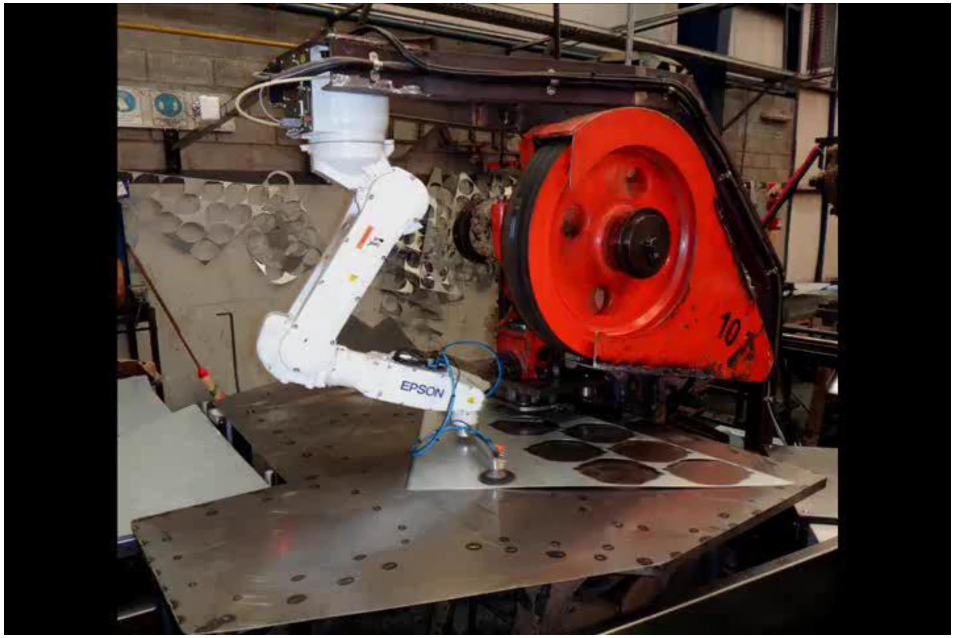
Arrangement of Cartons on Pallet

Loading and unloading Applications

Machine loading and/or unloading

1. robot loads parts into a production machine, but the parts are unloaded by some other means.

- ***Example:*** a press working operation, where the robot feeds sheet blanks into the press, but the finished parts drop out of the press by gravity.

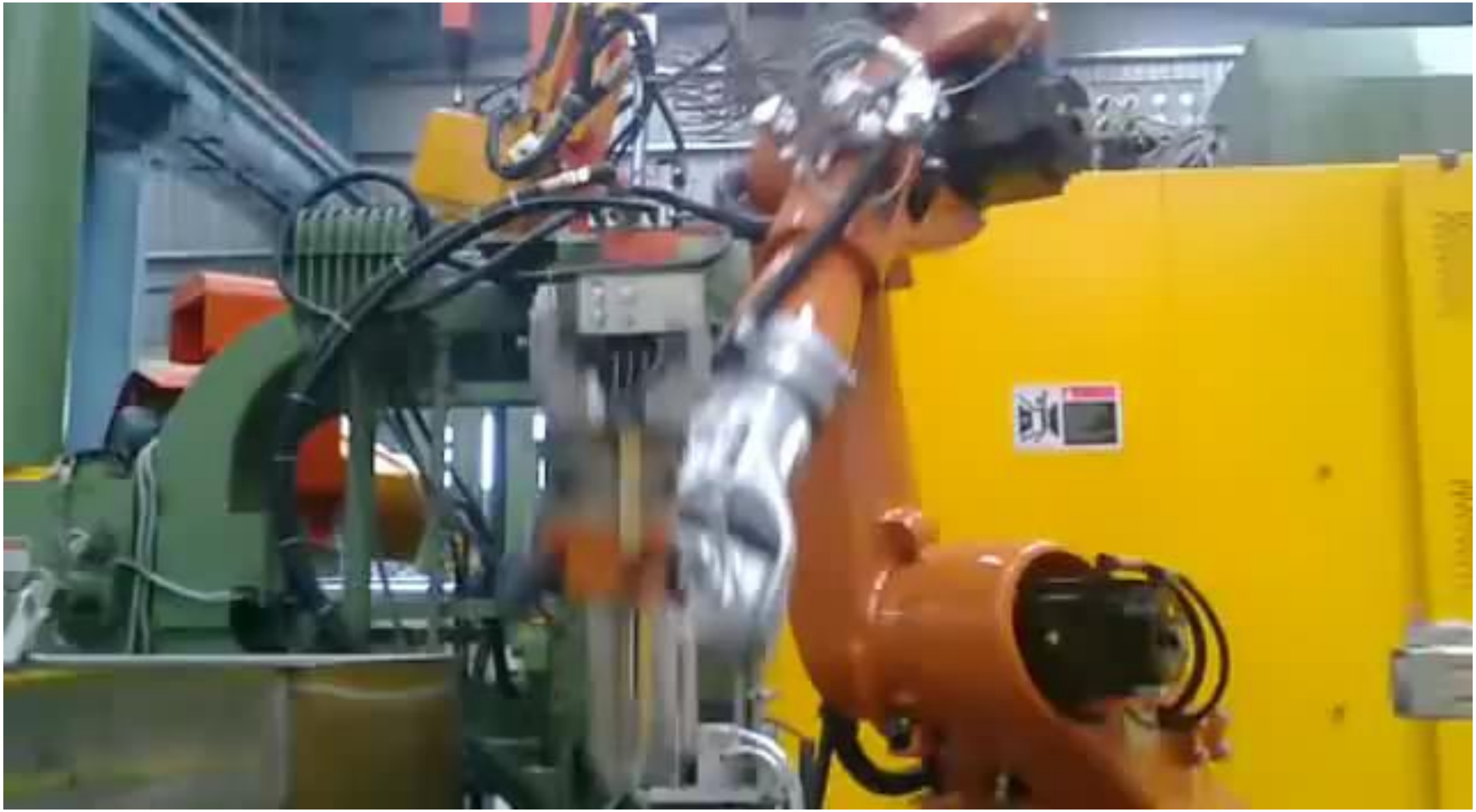


Machine loading and/or unloading

2. raw materials are fed into the machine without robot assistance. The robot unloads the part from the machine assisted by vision or no vision.

- ***Example:*** bin picking, die casting, and plastic injection moulding.

Robot in Die Casting



Machine loading and/or unloading

3. Machine loading and unloading that involves both loading and unloading of the work parts by the robot. The robot loads a raw work part into the process ad unloads a finished part.

Example: machining Operations

Loading and un loading of parts in hot forging

Processing operations

- Robot performs a processing procedure on the part.
- The robot is equipped with some type of process tooling as its end effector.
- Manipulates the tooling relative to the working part during the cycle.
- Industrial robot applications in the processing operations include:

Spot welding

Continuous arc welding

Spray painting

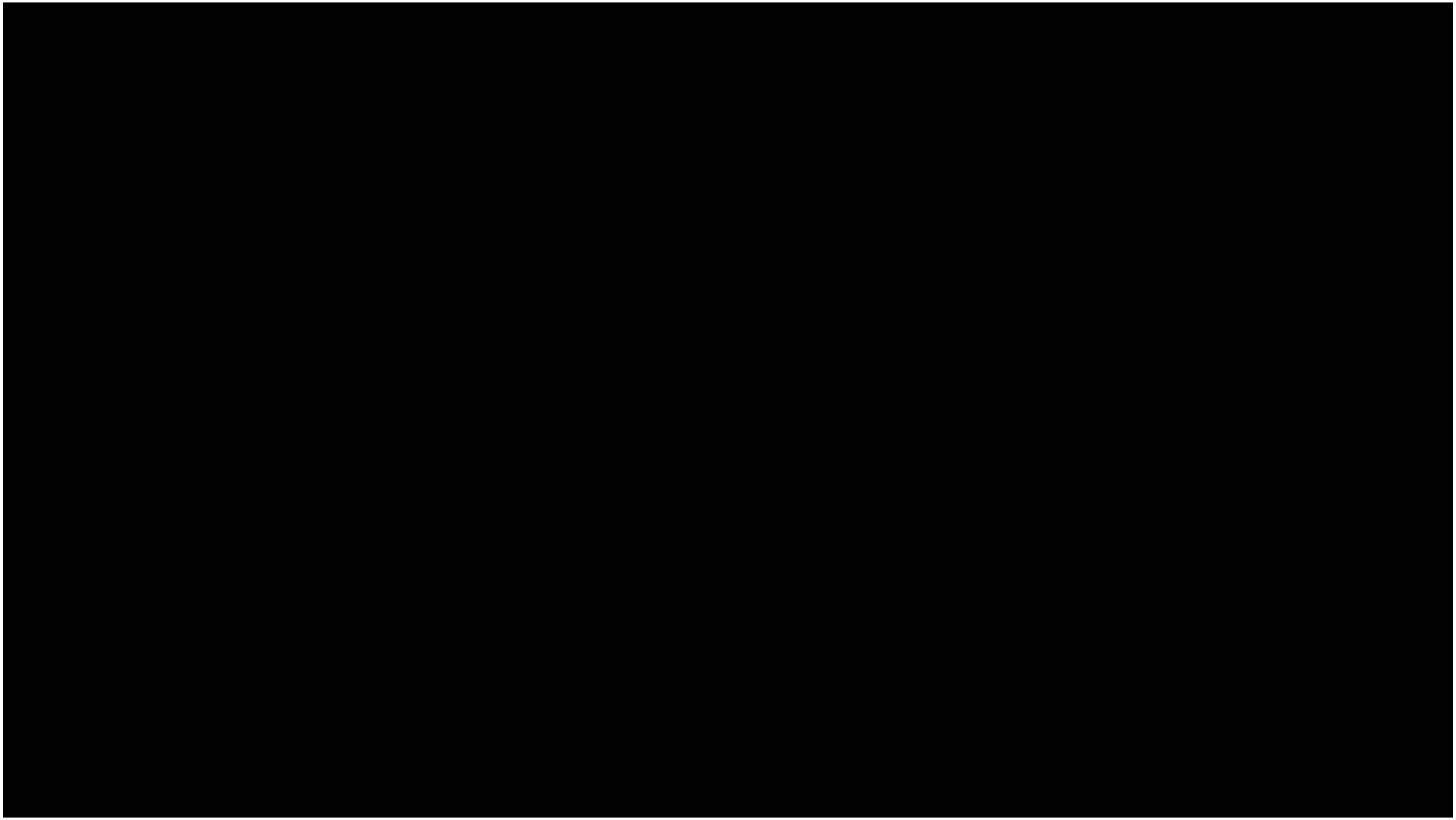
Metal cutting and deburring operations

Various machining operations like drilling, grinding, laser and water jet cutting, and riveting.

Rotating and spindle operations

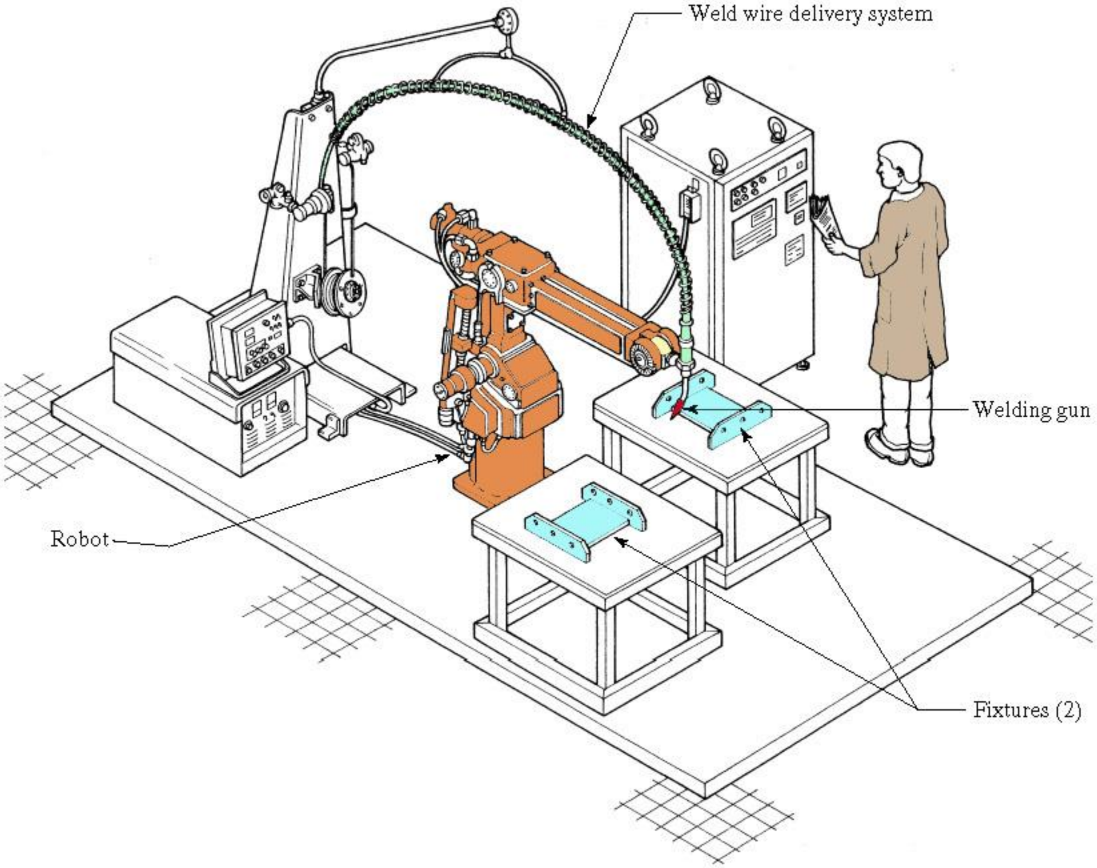
Adhesives and sealant dispensing

Spot Welding

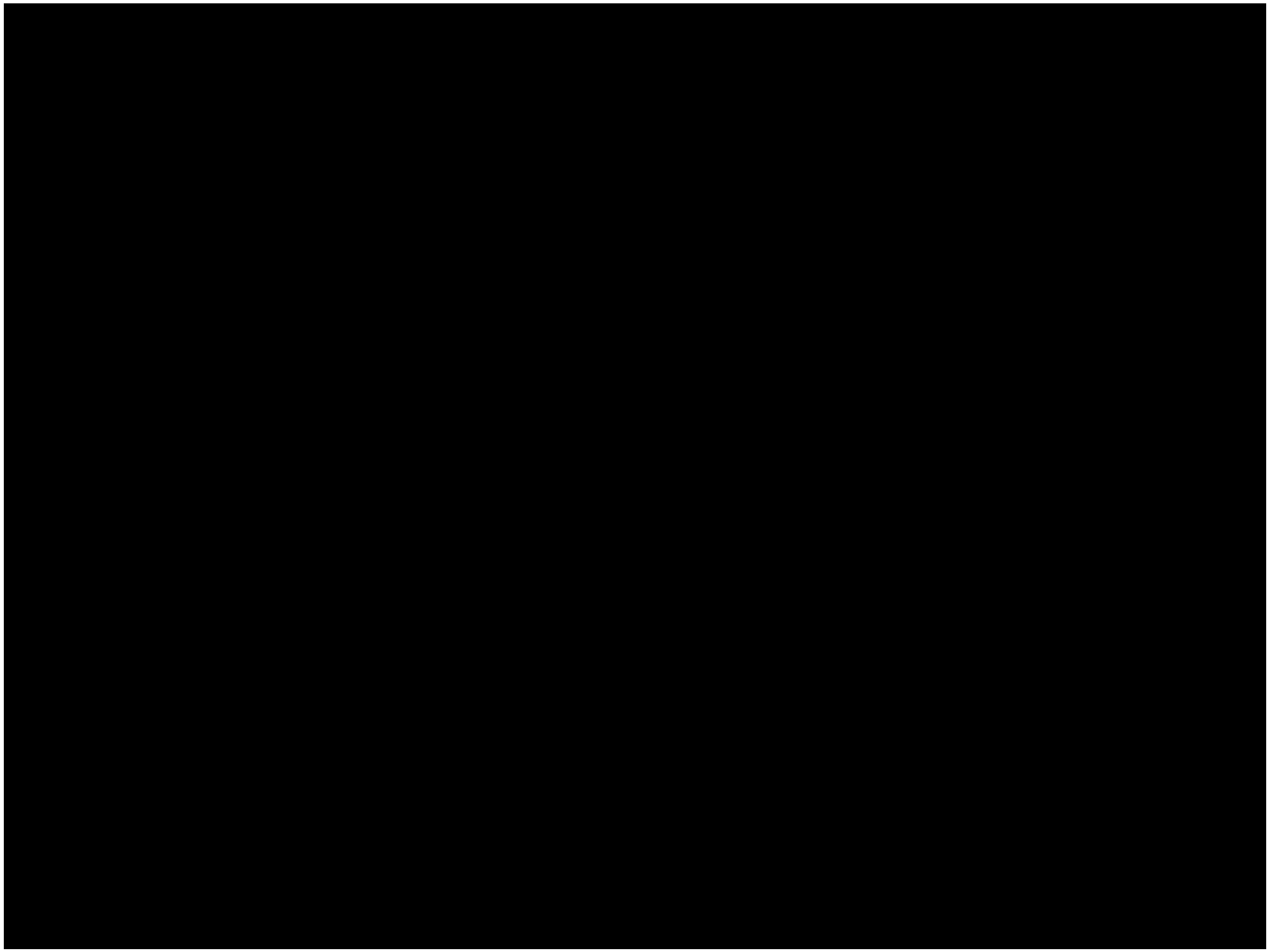


Robotic Arc-Welding Cell

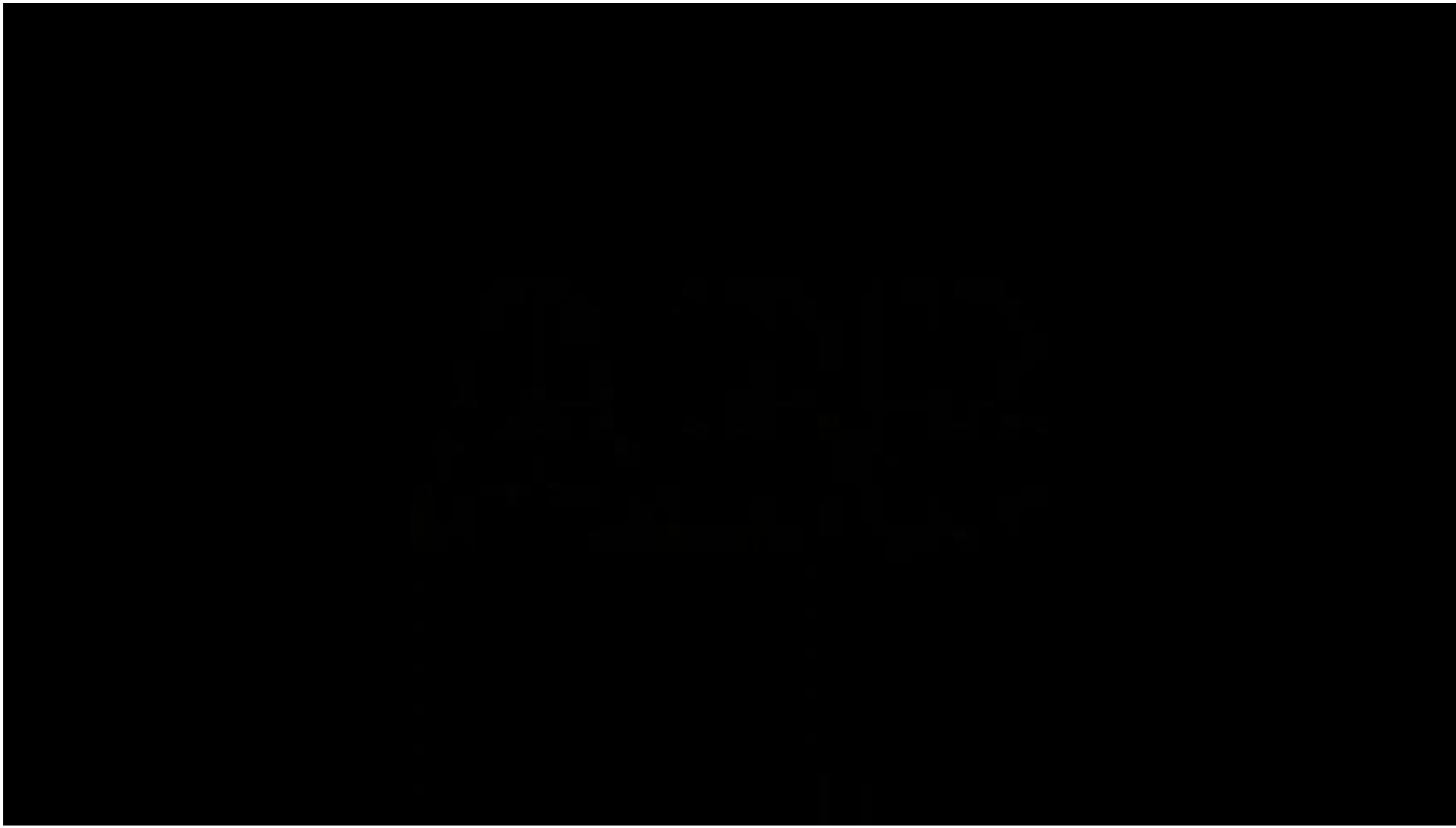
- Robot performs arc welding operation at one workstation while fitter changes parts at the other workstation.



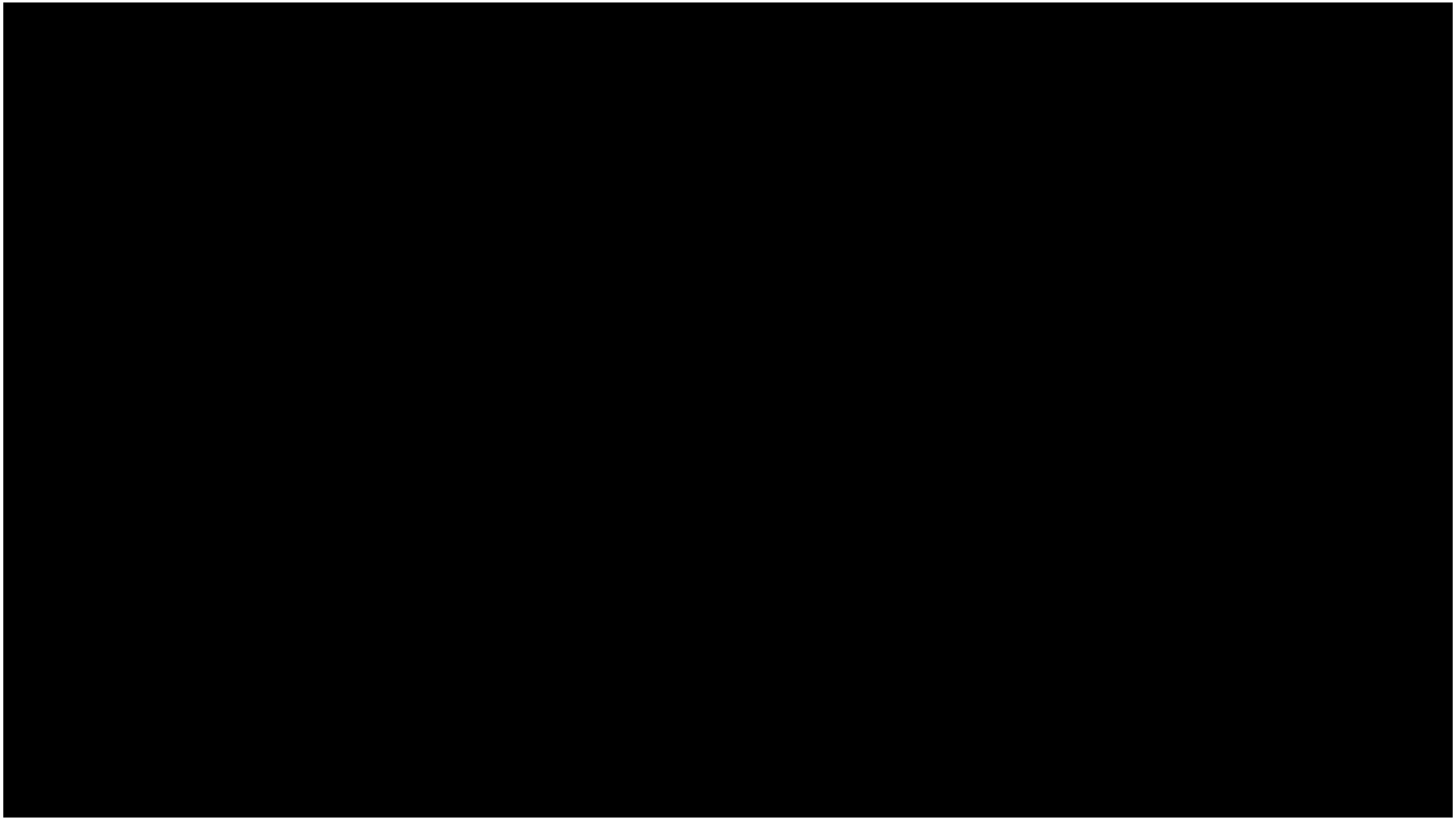
Arc welding robot



Spray painting



Robots application in assembly



Inspection by Robots

(1) making sure that a given process has been completed.
(2) ensuring that parts have been added in assembly
(3) identifying flaws in raw materials and finished parts.

Inspection by Robots

Robot Programming

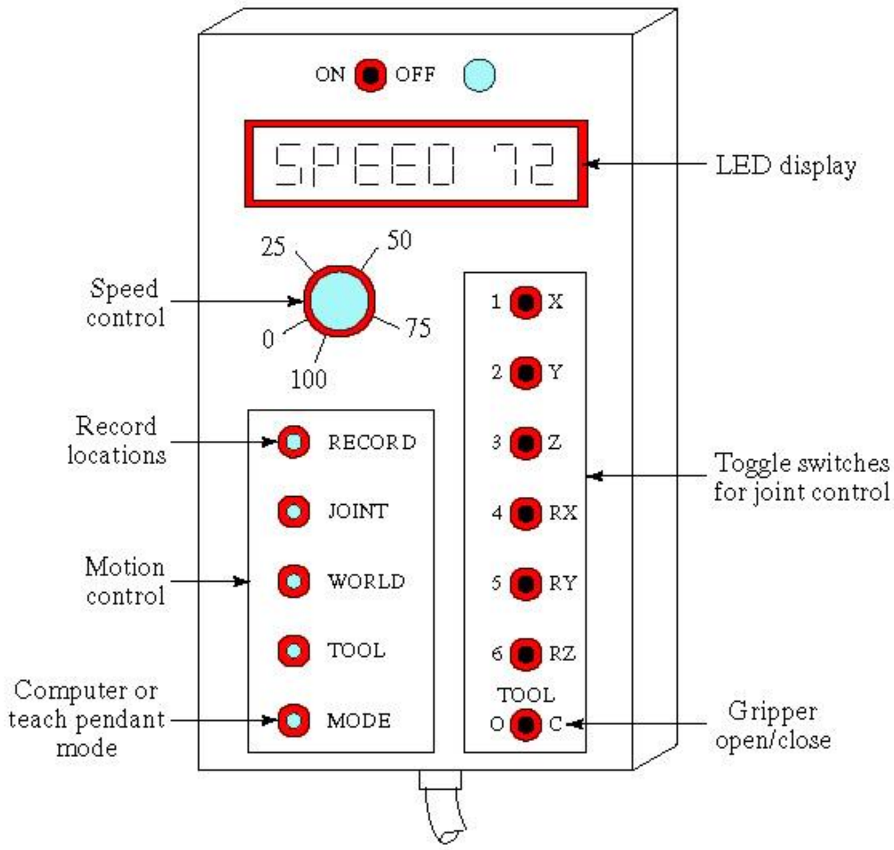
- Leadthrough programming
  - Work cycle is taught to robot by moving the manipulator through the required motion cycle and simultaneously entering the program into controller memory for later playback
- Robot programming languages
  - Textual programming language to enter commands into robot controller
- Simulation and off-line programming
  - Program is prepared at a remote computer terminal and downloaded to robot controller for execution without need for leadthrough methods

Leadthrough Programming

Two types:

1. Powered leadthrough
    - Common for point-to-point robots
    - Uses teach pendant to move joints to desired position and record that position into memory
2. Manual leadthrough
    - Convenient for continuous path control robots
    - Human programmer physical moves manipulator through motion cycle and records cycle into memory

Teach Pendant for Powered Leadthrough Programming



Leadthrough Programming Advantages

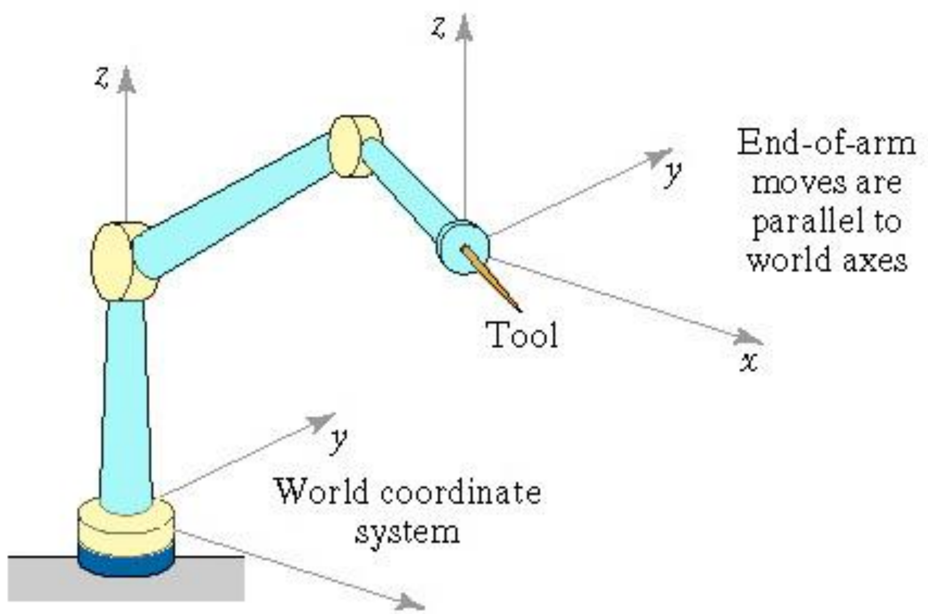
- Advantages:
  - Can readily be learned by shop personnel
  - A logical way to teach a robot
  - Does not required knowledge of computer programming
- Disadvantages:
  - Downtime - Regular production must be interrupted to program the robot
  - Limited programming logic capability
  - Not readily compatible with modern computer-based technologies

Robot Programming Languages

Textural programming languages provide the opportunity to perform the following functions that leadthrough programming cannot readily accomplish:

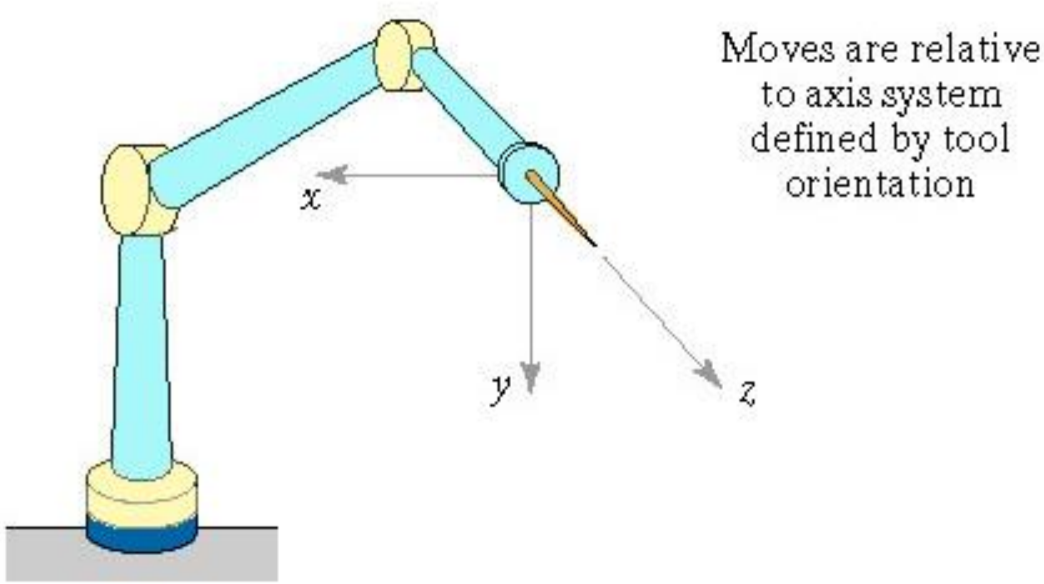
- Enhanced sensor capabilities
- Improved output capabilities to control external equipment
- Program logic not provided by leadthrough methods
- Computations and data processing similar to computer programming languages
- Communications with other computer systems

World Coordinate System



- Origin and axes of robot manipulator are defined relative to the robot base

Tool Coordinate System



- Alignment of the axis system is defined relative to the orientation of the wrist faceplate (to which the end effector is attached)

Motion Programming Commands

MOVE P1

HERE P1 - used during leadthrough of manipulator

MOVES P1

DMOVE(4, 125)

APPROACH P1, 40 MM

DEPART 40 MM

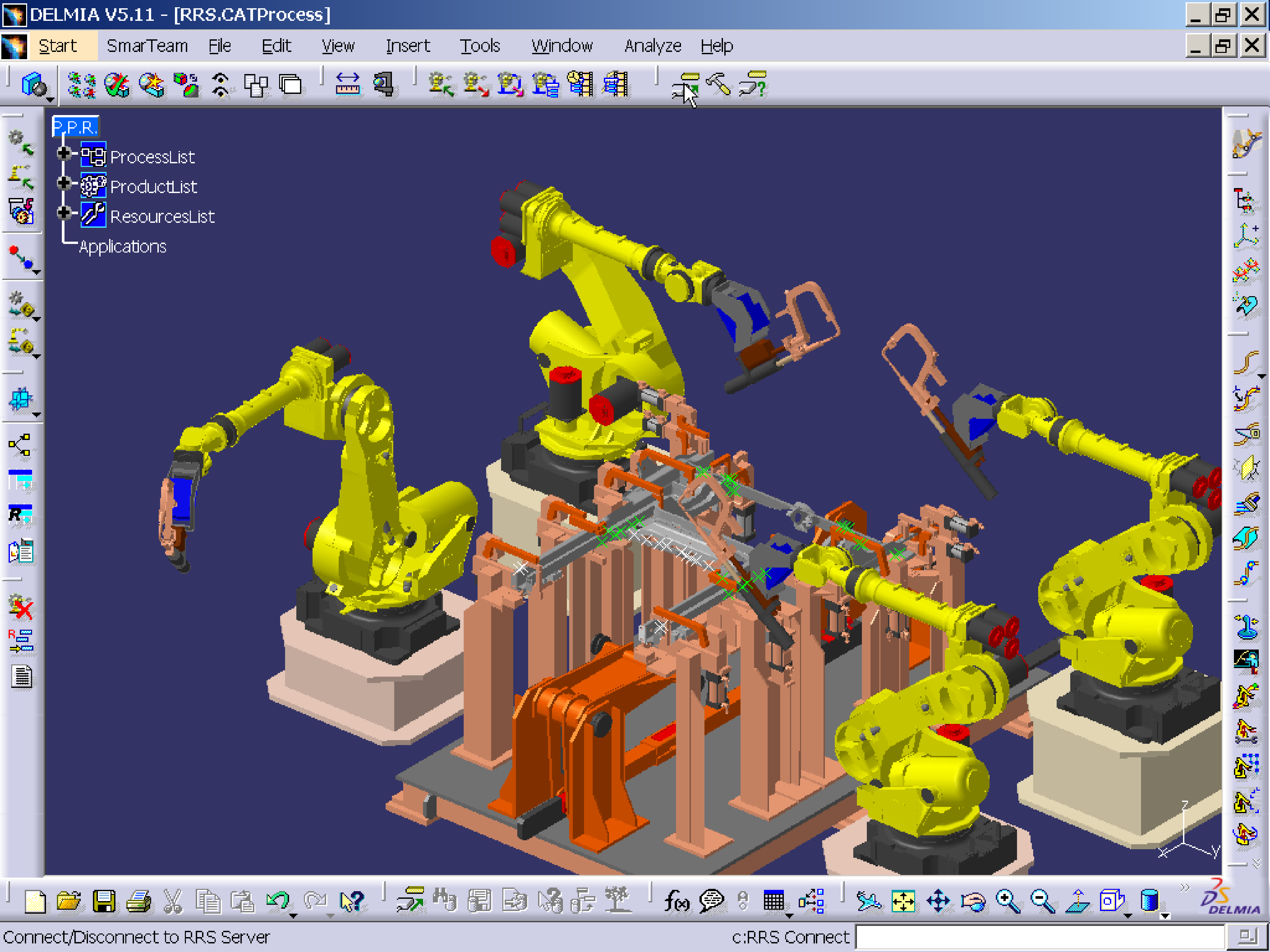
DEFINE PATH123 = PATH(P1, P2, P3)

MOVE PATH123

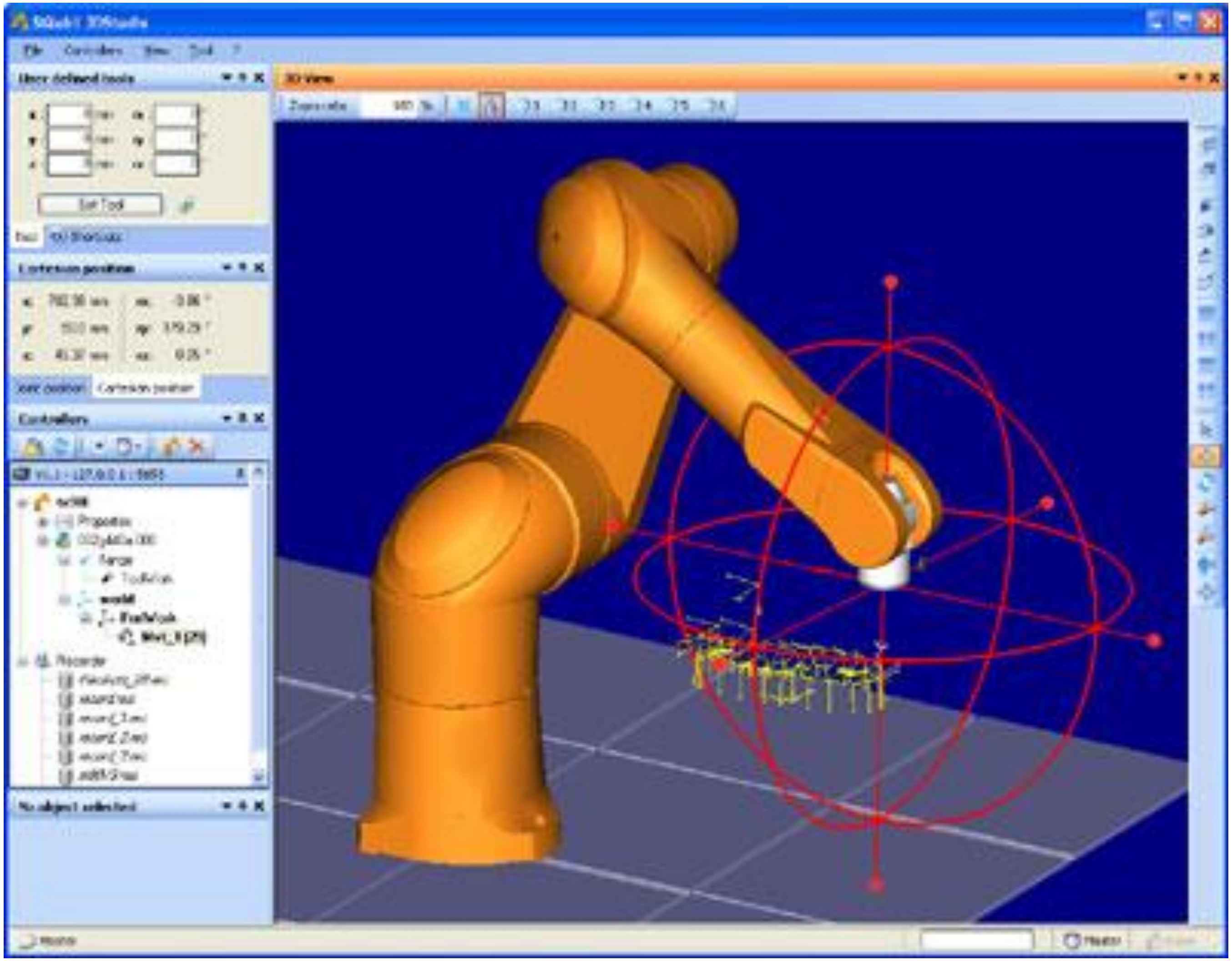
SPEED 75

Simulation and Off-Line Programming

- In conventional usage, robot programming languages still require some production time to be lost in order to define points in the workspace that are referenced in the program
  - They therefore involve on-line/off-line programming
- Advantage of true off-line programming is that the program can be prepared beforehand and downloaded to the controller with no lost production time
  - Graphical simulation is used to construct a 3-D model of the robot cell in which locations of the equipment in the cell have been defined previously


DELMIA V5.11 - [RRS.CATProcess]
Start
SmarTeam
File
Edit
View
Insert
Tools
Window
Analyze
Help
P.P.R.
ProcessList
ProductList
ResourcesList
Applications
Connect/Disconnect to RRS Server
c:RRS Connect

Simulation and Off-Line Programming



Example

A robot performs a loading and unloading operation for a machine tool as follows:

- Robot pick up part from conveyor and loads into machine (Time=5.5 sec)
- Machining cycle (automatic). (Time=33.0 sec)
- Robot retrieves part from machine and deposits to outgoing conveyor. (Time=4.8 sec)
- Robot moves back to pickup position. (Time=1.7 sec)

Every 30 work parts, the cutting tools in the machine are changed which takes 3.0 minutes. The uptime efficiency of the robot is 97%; and the uptime efficiency of the machine tool is 98% which rarely overlap.

Determine the hourly production rate.

Solution

T_c = 5.5 + 33.0 + 4.8 + 1.7 = 45 sec/cycle

Tool change time T_{tc} = 180 sec/30 pc = 6 sec/pc

Robot uptime E_R = 0.97, lost time = 0.03.

Machine tool uptime E_M = 0.98, lost time = 0.02.

Total time = T_c + T_{tc}/30 = 45 + 6 = 51 sec = 0.85 min/pc

R_c = 60/0.85 = 70.59 pc/hr

Accounting for uptime efficiencies,

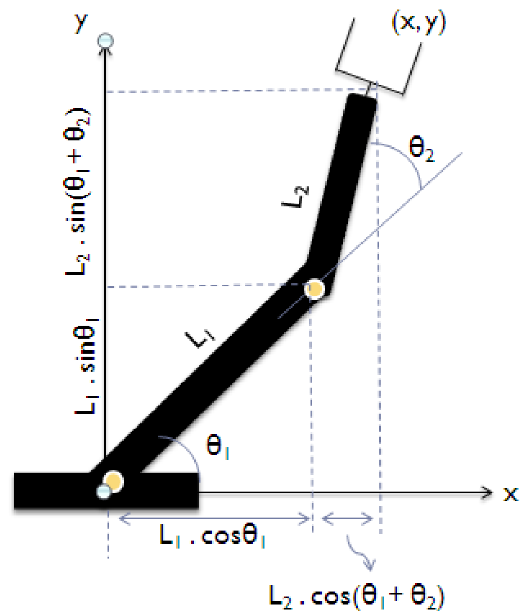
R_p = 70.59(1.0 - 0.03 - 0.02) = 67.06 pc/hr

Forward Kinematics (angles to position)

- What you are given:
  - The length of each link
  - The angle of each joint
- What you can find:
  - The position of any point (i.e. it's (x, y, z) coordinates
- Forward Kinematics of 2 link manipulator

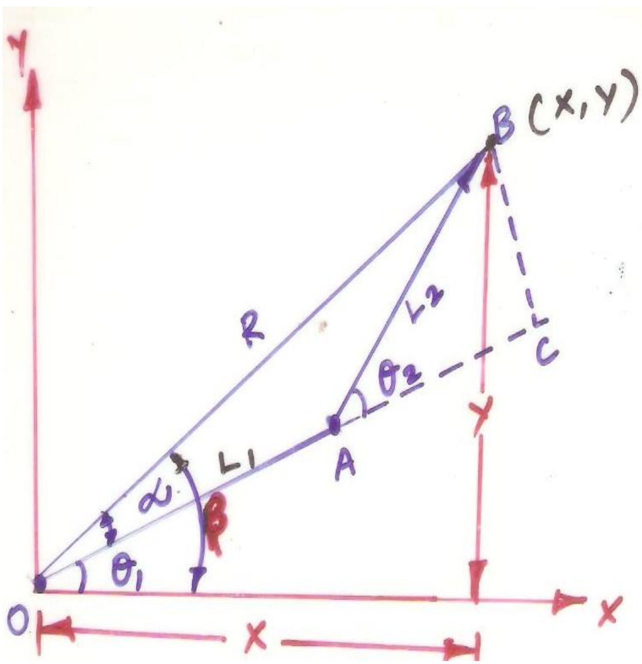
$$x = L_1 . \cos\theta_1 + L_2 . \cos(\theta_1 + \theta_2)$$

$$y = L_1 . \sin\theta_1 + L_2 . \sin(\theta_1 + \theta_2)$$



Inverse Kinematics (position to angles)

- What you are given:
  - The length of each link
  - The angle of each joint
- What you can find:
  - The angles of each joint needed to obtain that position
- Inverse kinematics of 2 link manipulator



$$BC = L_2 \sin\theta_2$$
$$AC = L_2 \cos\theta_2$$

$$\tan\alpha = \frac{L_2 \sin\theta_2}{L_1 + L_2\cos\theta_2} \quad (1)$$

$$\tan\beta = \frac{Y}{X} \quad (2)$$

$$X = [L_1\cos\theta_1 + L_2\cos(\theta_1+\theta_2)] \quad - (3)$$
$$Y = [L_1\sin\theta_1 + L_2\sin(\theta_1+\theta_2)] \quad - (4)$$

Squaring on both sides and adding

$$x^2 + y^2 = L_1^2 + L_2^2 + 2L_1L_2\cos\theta_2$$

or

$$\boxed{\cos\theta_2 = \frac{x^2 + y^2 - L_1^2 - L_2^2}{2L_1L_2}}$$

$$\beta - \alpha = \theta_1$$
$$\tan(\beta - \alpha) = \tan\theta_1$$
$$\frac{\tan\beta - \tan\alpha}{1 + \tan\beta\tan\alpha} = \tan\theta_1$$

$$\tan\theta_1 = \frac{Y[L_1 + L_2\cos\theta_2] - X L_2\sin\theta_2}{X[L_1 + L_2\cos\theta_2] + Y L_2\sin\theta_2}$$

Robot Accuracy and Repeatability

Three terms used to define precision in robotics, similar to numerical control precision:

1. Control resolution - capability of robot's positioning system to divide the motion range of each joint into closely spaced points
2. Accuracy - capability to position the robot's wrist at a desired location in the work space, given the limits of the robot's control resolution
3. Repeatability - capability to position the wrist at a previously taught point in the work space

Precision in Positioning

- Three critical measures of precision in positioning:
  1. Control resolution
  2. Accuracy
  3. Repeatability

Control Resolution (CR)

Defined as the distance between two adjacent control points in the axis movement

- Control points are locations along the axis to which the worktable can be directed to go
- CR depends on:
  - Electromechanical components of positioning system
  - Number of bits used by controller to define axis coordinate location

Statistical Distribution of Mechanical Errors

- When a positioning system is directed to move to a given control point, the movement to that point is limited by mechanical errors
  - Errors are due to various inaccuracies and imperfections, such as gear backlash, play between leadscrew and worktable, and machine deflection
  - Errors are assumed to form a normal distribution with mean = 0 and constant standard deviation over axis range

Accuracy in a Positioning System

Maximum possible error that can occur between desired target point and actual position taken by system

- For one axis:

$$\text{Accuracy} = 0.5\, CR + 3\sigma$$

where CR = control resolution; and σ = standard deviation of the error distribution

Repeatability

Capability of a positioning system to return to a given control point that has been previously programmed

- Repeatability of any given axis of a positioning system can be defined as the range of mechanical errors associated with the axis

$$\text{Repeatability} = \pm 3\sigma$$

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