ROBOTICS

Industrial Robots Definition

A robot is a programmable arm simulator

"A robot is a re-programmable, multifunction manipulator designed to move material, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks"

Robot Institute of America

Main Components of Industrial Robots

– Arm or Manipulator

– End effectors

– Drive Mechanism

– Controller

– Custom features: e.g. sensors and transducers

The Advent of Industrial Robots

Motivation for using robots to perform task which would otherwise be performed by humans.

- Safety
- Efficiency
- Reliability
- Worker Redeployment
- Cost reduction

Main Components of Industrial Robots

- Arm or Manipulator
- End effectors
- Drive Mechanism
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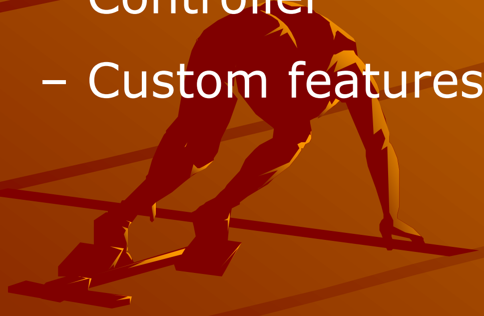
- Custom features: e.g. sensors and transducers

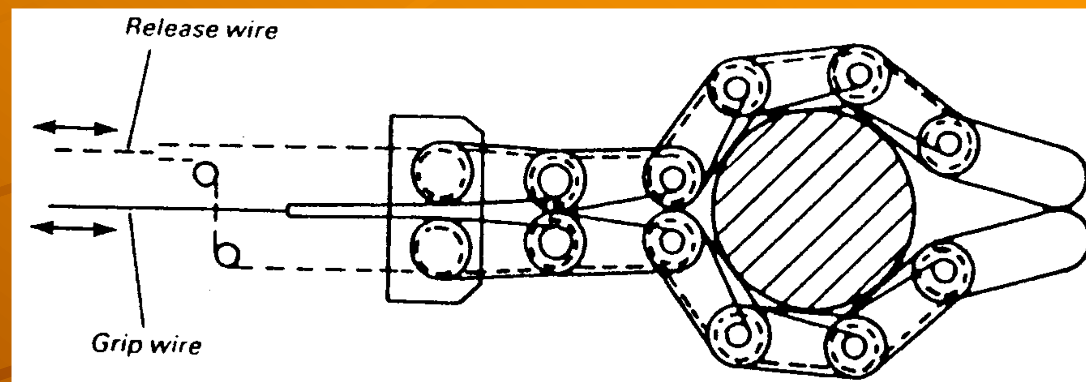


Arm or Manipulator

- The main anthropomorphic element of a robot.
- In most cases the degrees of freedom depends on the arm
- The work volume or reach mostly depends on the functionality of the Arm

End Effectors

Device attached to the robot's wrist to perform a specific task



Grippers

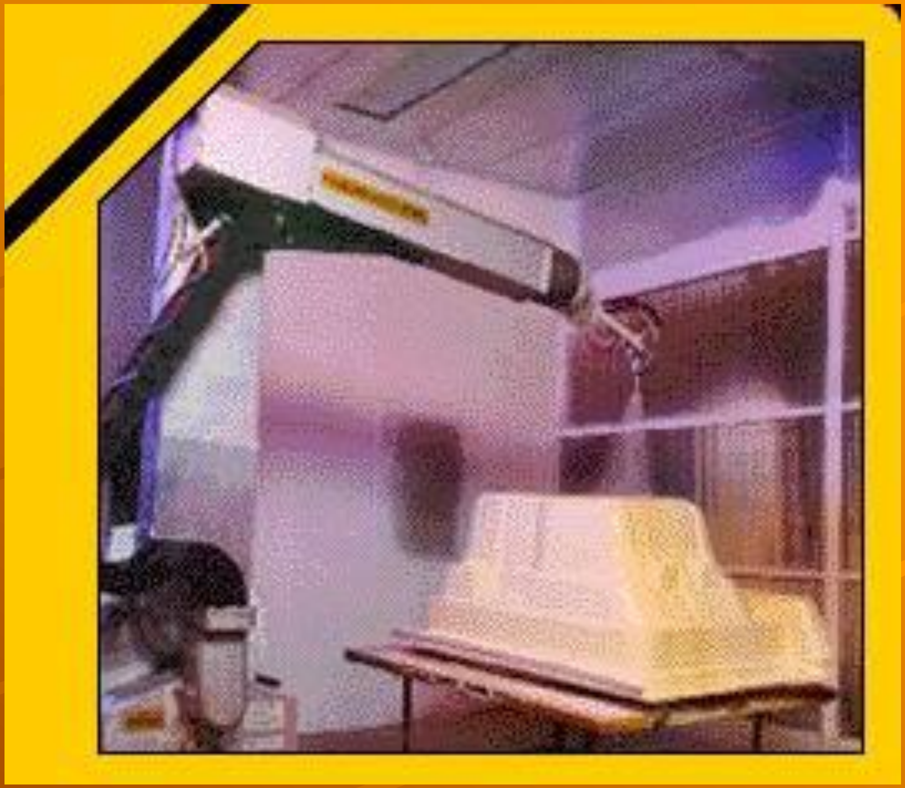
- Mechanical Grippers
- Suction cups or vacuum cups
- Magnetized grippers
- Hooks
- Scoops (to carry fluids)

End Effectors

Device attached to the robot's wrist to perform a specific task

Tools

- Spot Welding gun
- Arc Welding tools
- Spray painting gun
- Drilling Spindle
- Grinders, Wire brushes
- Heating torches



Sensors in robotics

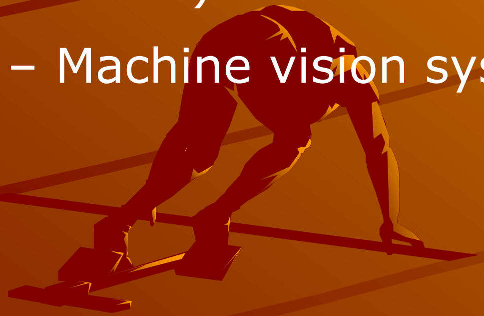
Types of sensors :

– Tactile sensors (touch sensors, force sensors, tactile array sensors)

– Proximity and range sensors (optical sensors, acoustical sensors, electromagnetic sensors)

– Miscellaneous sensors (transducers and sensors which sense variables such temperature, pressure, fluid flow, thermocouples, voice sensors)

– Machine vision systems



Sensors in robotics

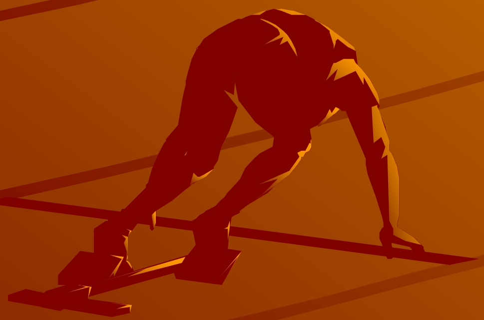
Uses of sensors:

– Safety monitoring

– Interlocks in work cell control

– Part inspection for quality control

– Determining positions and related information about objects



Sensors in robotics

Desirable features of sensors:

Accuracy

Operation range

Speed of response

Calibration

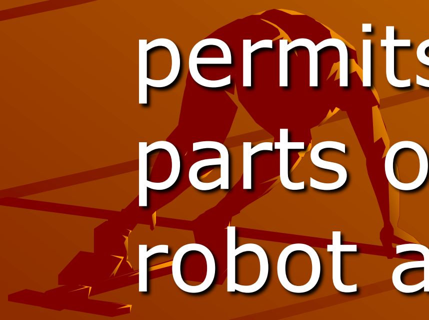
Reliability

Cost and ease of operation

Robotics Terminology

Link: A rigid piece of material connecting joints in a robot.

Joint: The device which allows relative motion between two adjoining links in a robot.



A robot joint is a mechanism that permits relative movement between parts of a robot arm. The joints of a robot are designed to enable the robot to move its end-effectors along a path from one position to another as desired.

The Robotic Movements

The basic movements required for a desired motion of most industrial robots are:

- ***Rotational movement:*** This enables the robot to place its arm in any direction on a horizontal plane.
- ***Radial movement:*** This enables the robot to move its end-effectors radially to reach distant points.
- ***Vertical movement:*** This enables the robot to take its end-effector to different heights.

The Robotic Joints

A robot joint

Types of JOINTS

1) Linear Joint (L) 2) Rotational Joint (R)
3) Twisting Joint (T) 4) Revolving Joint (V)

1) Linear Joints are also known as sliding as well as ***Prismatic joints*** (L)

They are called ***prismatic*** because the cross section of the joint is considered as a generalized prism. They permit links to move in a linear relationship.

Revolute joints permit only angular motion between links. Their variations include:

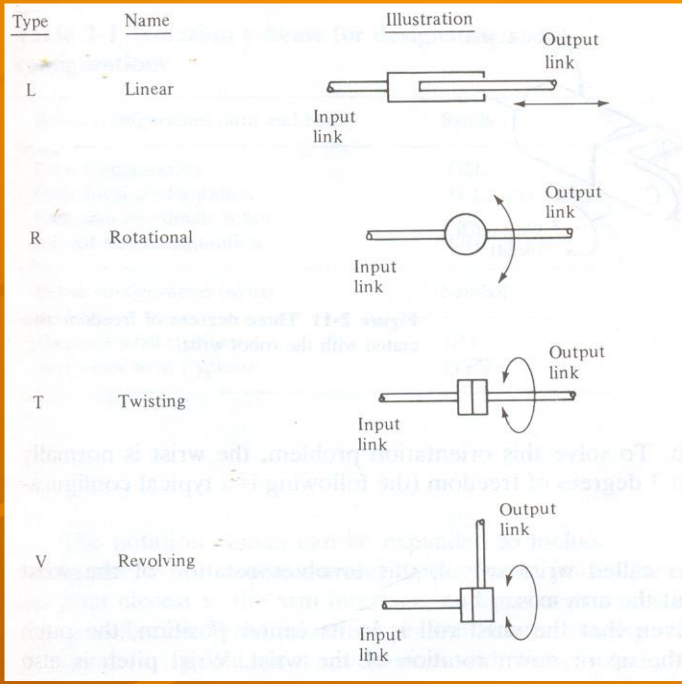
Rotational joint (R)
Twisting joint (T)
Revolving joint (V)

A ***rotational joint*** (R)

is identified by its motion, rotation about an axis perpendicular to the adjoining links.

A ***twisting joint*** (T)

is also a rotational joint, where the rotation takes place about an axis that is parallel to both adjoining links.



A ***revolving joint*** (V)

is another rotational joint, where the rotation takes place perpendicular to one another at this kind of joint. The rotation involves revolution of one link about another.

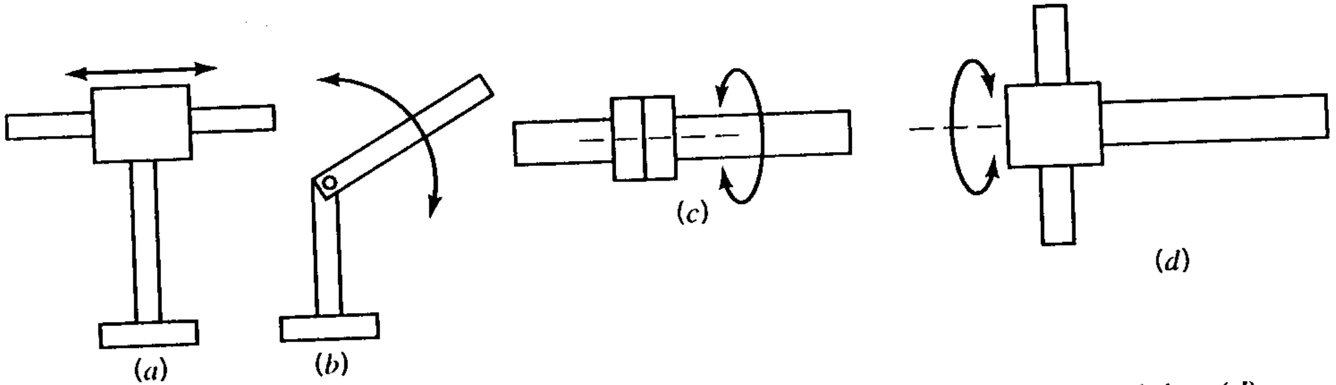


FIGURE 8.3 Types of joints: (*a*) linear joint; (*b*) rotational joint; (*c*) twisting joint; (*d*) revolving joint.

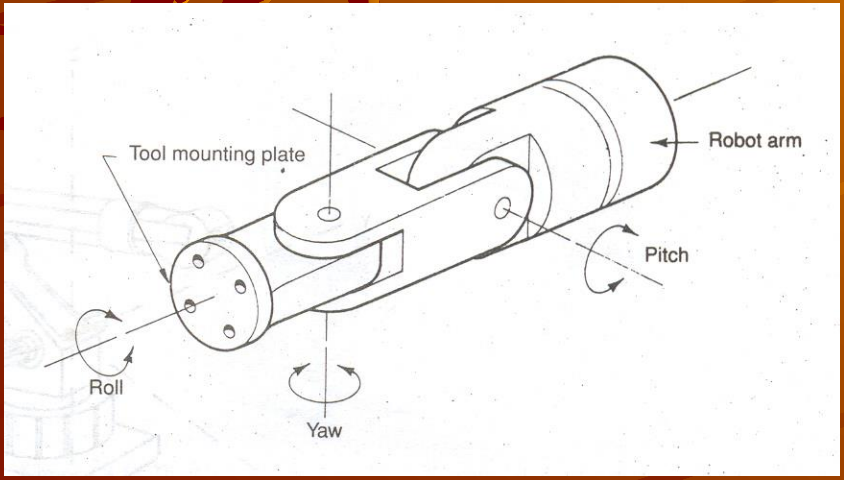
Wrist Movement

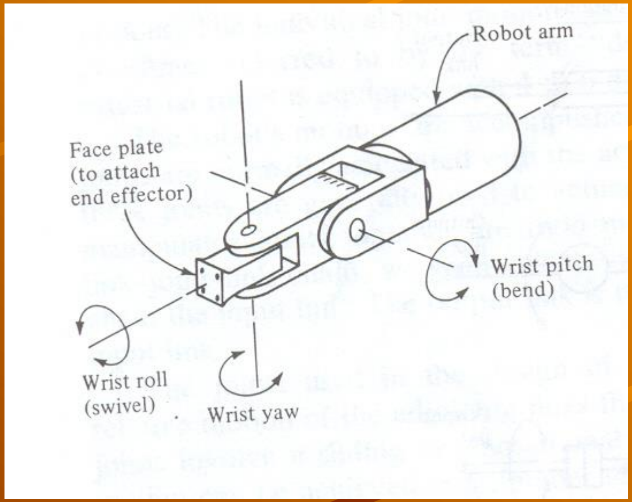
The Wrist movement is designed to enable the robot to orient the end effector properly with respect to the task to be performed.

Eg. Human hand

To solve the orientation problem, the wrist is normally provided with upto 3 DOF.

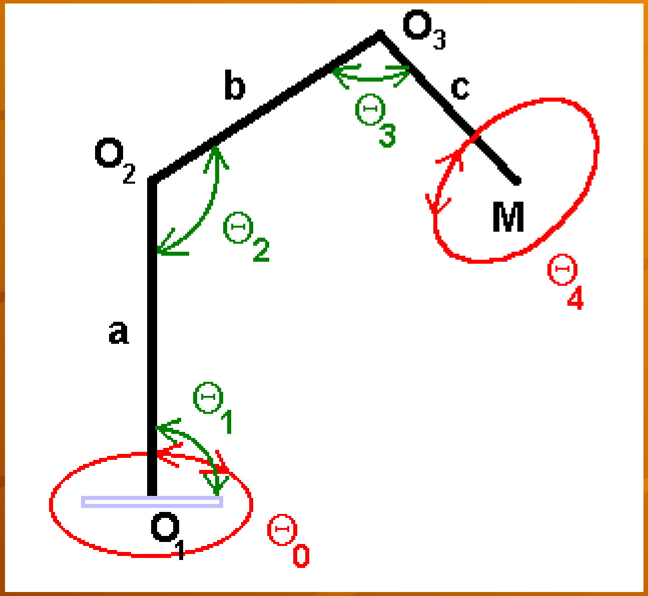
1) Wrist Roll- which involves rotation of the wrist mechanism about the arm axis. Also called as wrist swivel.
2) Wrist Pitch- If the wrist roll is in its center position , the pitch would involve the up and down rotation of the wrist. Also called as wrist bend.
3) Wrist Yaw- If the wrist roll is in its center position of its range, wrist yaw would involve the right or left rotation of the wrist.





Robotics Terminology

***DOF degrees-of-freedom*: can be defined as the number of independent motions a device can make. (Also called *mobility*)**



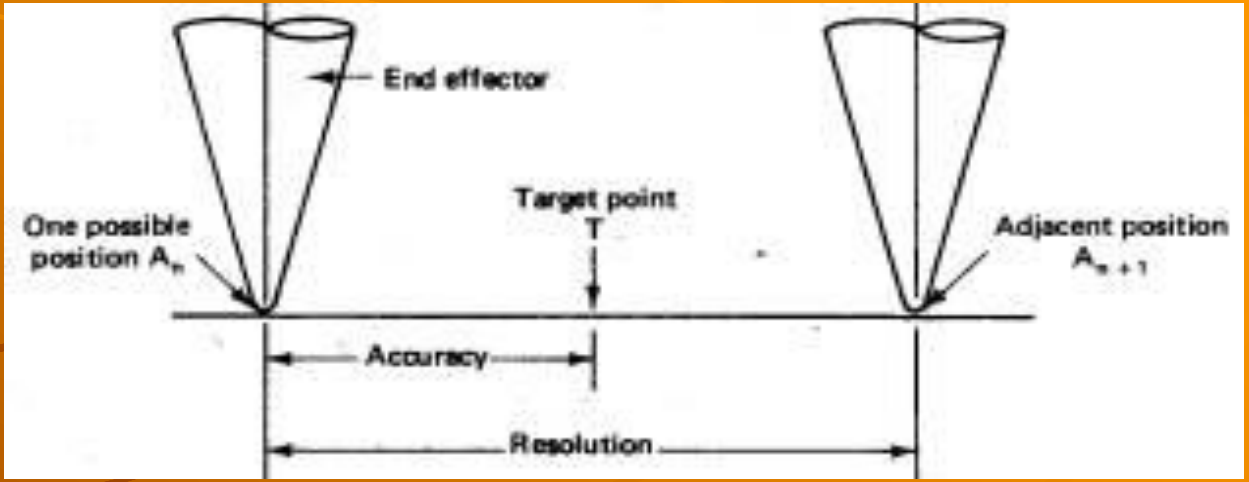
five degrees of freedom

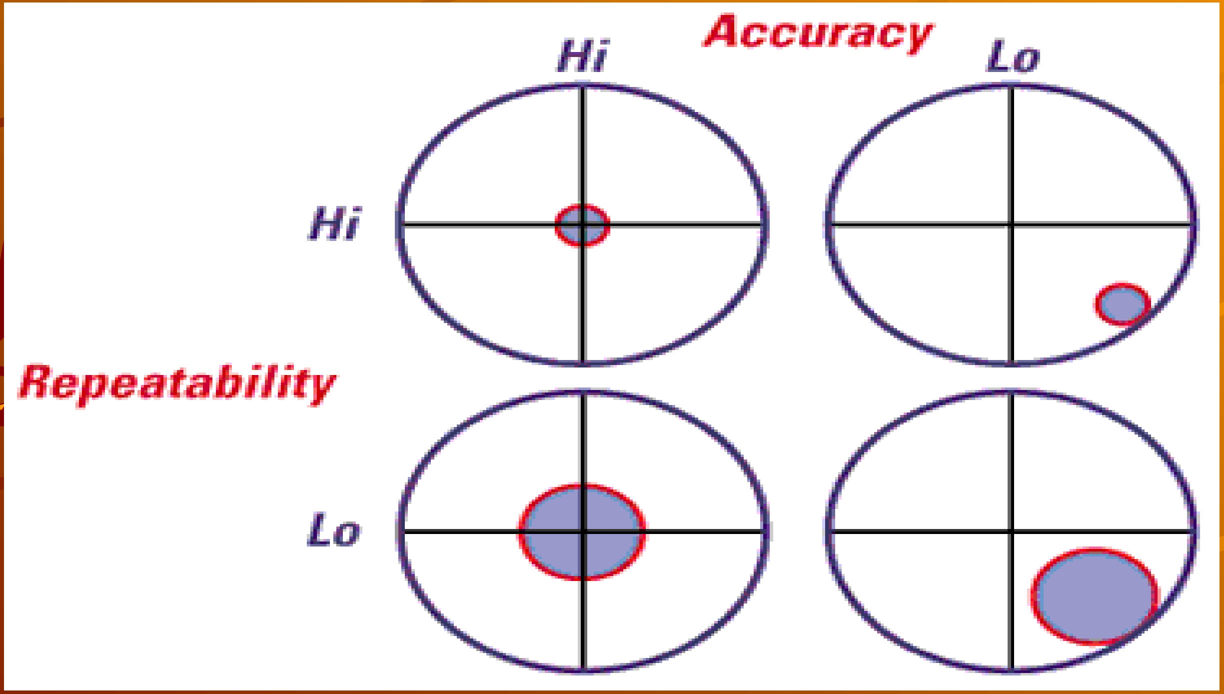
Accuracy

- The ability of a robot to go to the specified position without making a mistake.
- It is impossible to position a machine exactly.
- Accuracy is therefore defined as the ability of the robot to position itself to the desired location with the minimal error (usually 25 μm).

Repeatability

- The ability of a robot to repeatedly position itself when asked to perform a task multiple times.
- Accuracy is an absolute concept, repeatability is relative.
- A robot that is repeatable may not be very accurate, visa versa.


End effector
Target point
T
One possible
position A_n
Adjacent position
A_{n+1}
Accuracy
Resolution


Accuracy
Hi
Lo
Hi
Repeatability
Lo

Joint Notation Scheme

Physical configuration of the robot manipulator can be described by means of a joint notation scheme .

Considering the arm and body joints first, the letters can be used to designate the particular robot configuration starting with the joint closest to the base and proceeding to the joint configuration that connects to the wrist.

Robot configuration	Symbol
Polar configuration	TRL
Cylindrical configuration	TLL,LTL,LVL
Cartesian configuration	LLL
Joint arm configuration	TRR, VVR

ROBOT CLASSIFICATION

1) Depending on Configuration

2) Depending on type of control system

3) Fixed or variable sequence robot

4) Depending upon generation

5) Servo / nonservo robots

6) Point to Point or continuous controlling robots

ROBOT CLASSIFICATION

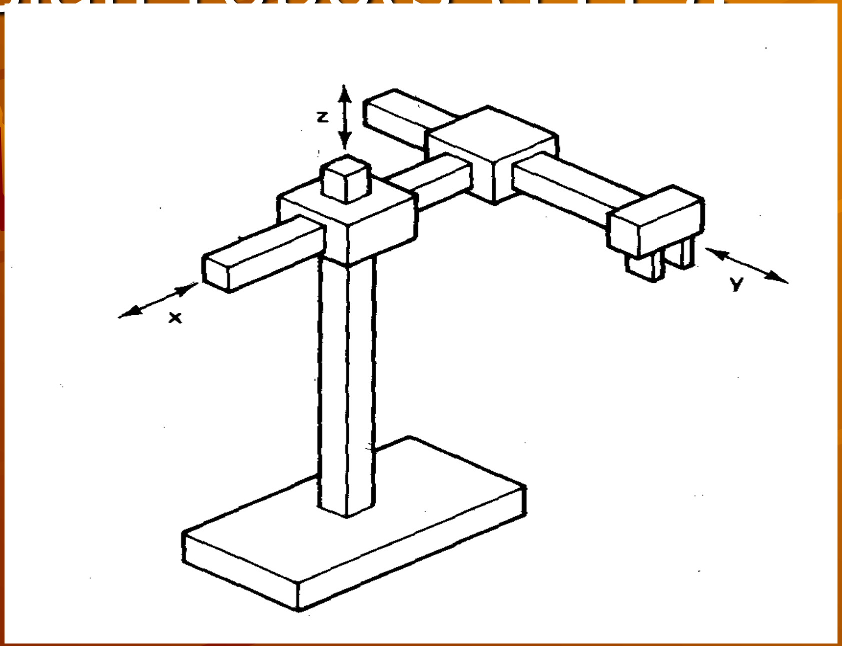
Classification Based on Physical Configuration:

1. Cartesian configuration
2. Cylindrical configuration
3. Polar configuration
4. Joint-arm configuration
5. SCARA

ROBOT CLASSIFICATION

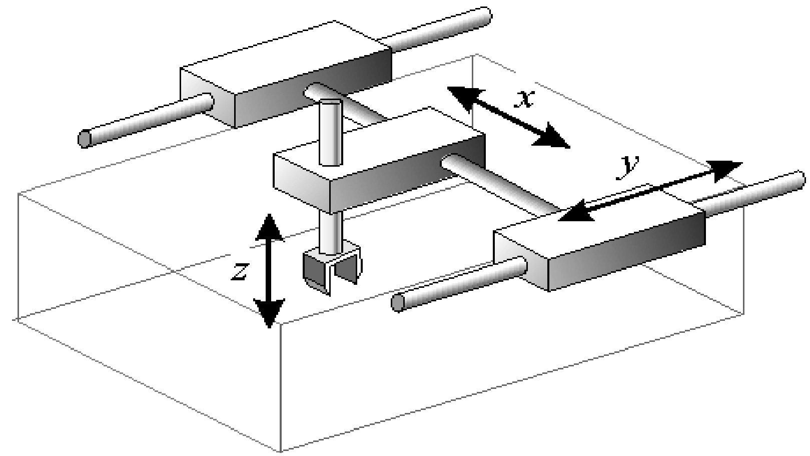
Cartesian Configuration:

- Robots with Cartesian configurations consists of links connected by linear joints (L). Gantry robots are Cartesian robots (LLL).



Cartesian Robots

A robot with 3 prismatic joints – the axes consistent with a Cartesian coordinate system.



Commonly used for:

- pick and place work
- assembly operations
- handling machine tools
- arc welding

Cartesian Robots

Advantages:

- ability to do straight line insertions into furnaces.
- easy computation and programming.
- most rigid structure for given length.

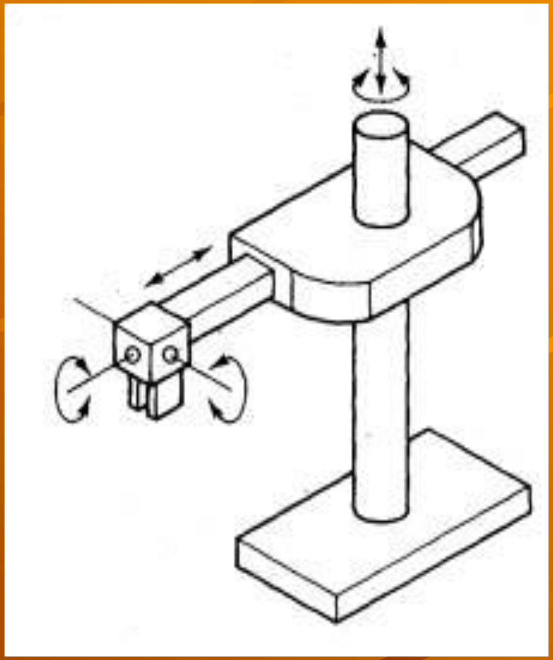
Disadvantages:

- requires large operating volume.
- exposed guiding surfaces require covering in corrosive or dusty environments.
- can only reach front of itself
- axes hard to seal

ROBOT CLASSIFICATION

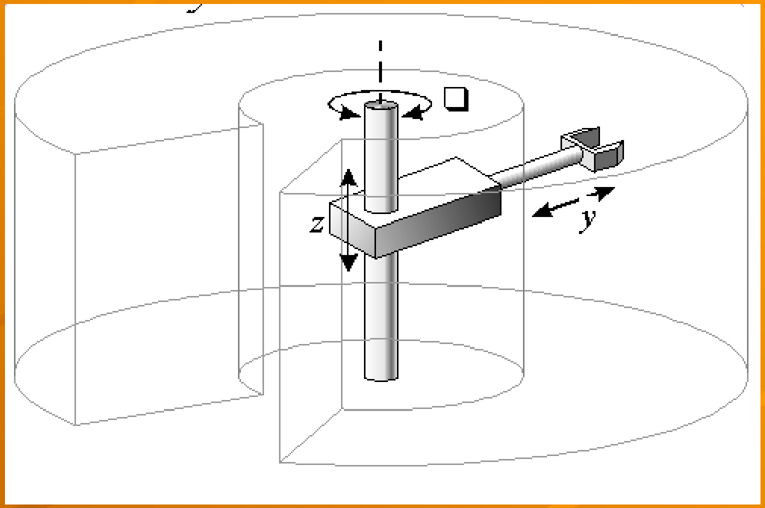
Cylindrical Configuration:

- Robots with cylindrical configuration have one rotary (R) joint at the base and linear (L) joints succeeded to connect the links.



Cylindrical Robots

A robot with 2 prismatic joints and a rotary joint – the axes consistent with a cylindrical coordinate system.



Commonly used for:
•handling at die-casting machines
•assembly operations
•handling machine tools
•spot welding

Cylindrical Robots

Advantages:

- can reach all around itself
- rotational axis easy to seal
- relatively easy programming
- rigid enough to handle heavy loads through large working space
- good access into cavities and machine openings

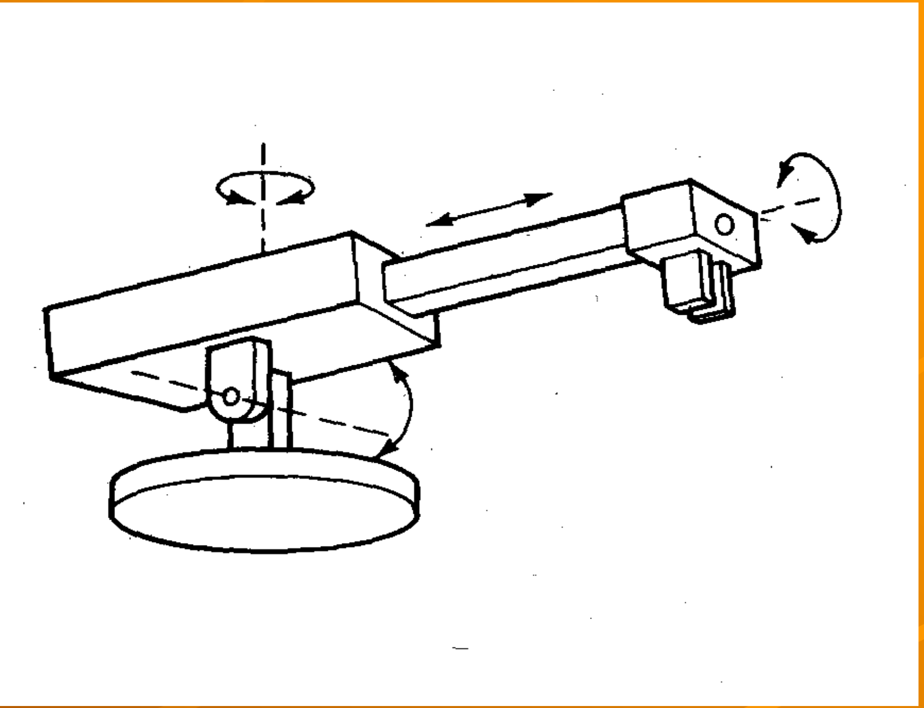
Disadvantages:

- can't reach above itself
- linear axes is hard to seal
- won't reach around obstacles
- exposed drives are difficult to cover from dust and liquids

ROBOT CLASSIFICATION

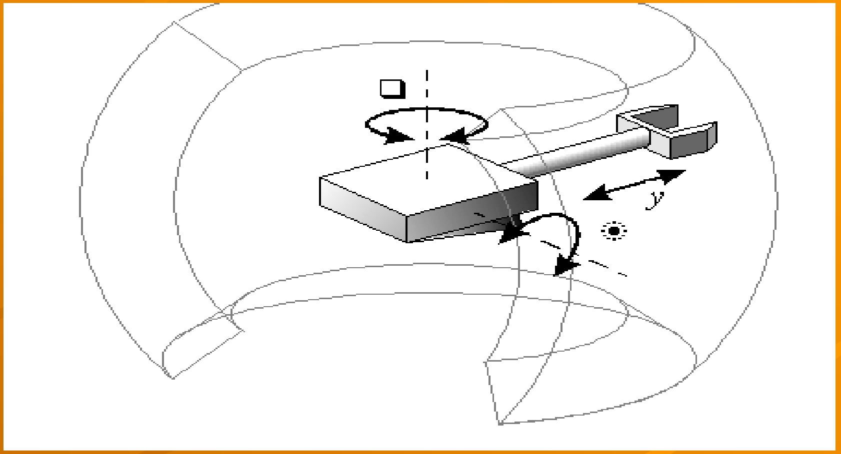
Polar Configuration:

- Polar robots have a work space of **spherical shape**. Generally, the arm is connected to the base with a twisting (T) joint and rotatory (R) and linear (L) joints follow.



Spherical/Polar Robots

A robot with 1 prismatic joint and 2 rotary joints – the axes consistent with a polar coordinate system.



Commonly used for:
•handling at die casting or fettling machines
•handling machine tools
•arc/spot welding

Spherical/Polar Robots

Advantages:

- large working envelope.
- two rotary drives are easily sealed against liquids/dust.

Disadvantages:

- complex coordinates more difficult to visualize, control, and program.
- exposed linear drive.
- low accuracy.

ROBOT CLASSIFICATION

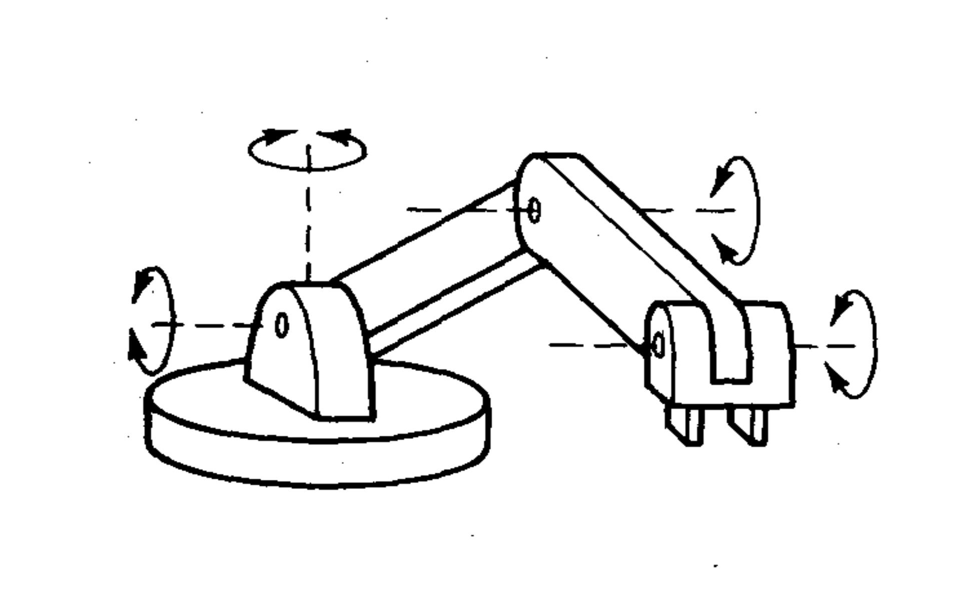
- The designation of the arm for this configuration can be TRL or TRR.
- Robots with the designation TRL are also called **spherical robots**. Those with the designation TRR are also called **articulated robots**. An articulated robot more closely resembles the human arm.

ROBOT CLASSIFICATION

Joint-arm Configuration:

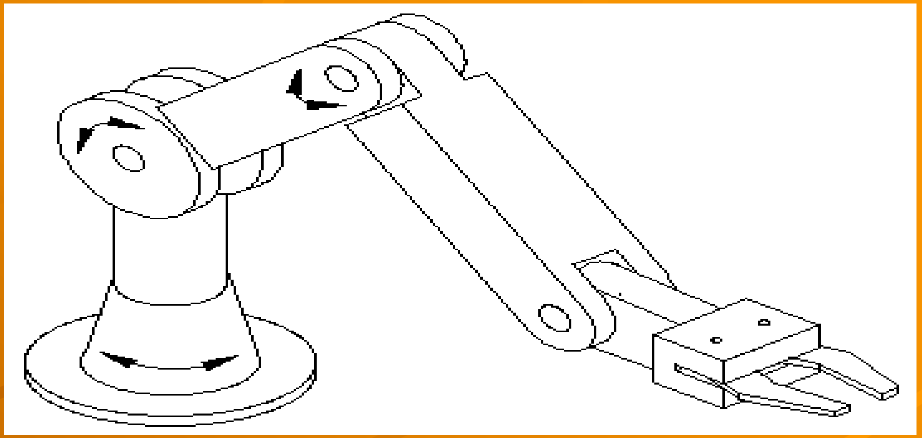
- The jointed-arm is a combination of cylindrical and articulated configurations. The arm of the robot is connected to the base with a twisting joint. The links in the arm are connected by rotatory joints. Many commercially available robots have this configuration.

ROBOT CLASSIFICATION



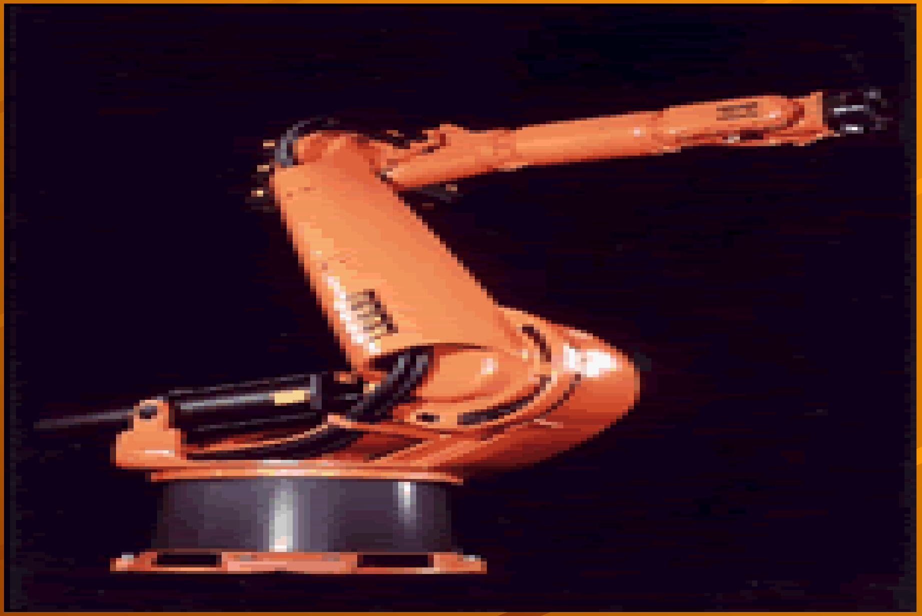
Articulated Robots

A robot with at least 3 rotary joints.



Commonly used for:

- assembly operations
- welding
- weld sealing
- spray painting
- handling at die casting or fettling machines



Articulated Robots

Advantages:

- all rotary joints allows for maximum flexibility
- any point in total volume can be reached.
- all joints can be sealed from the environment.

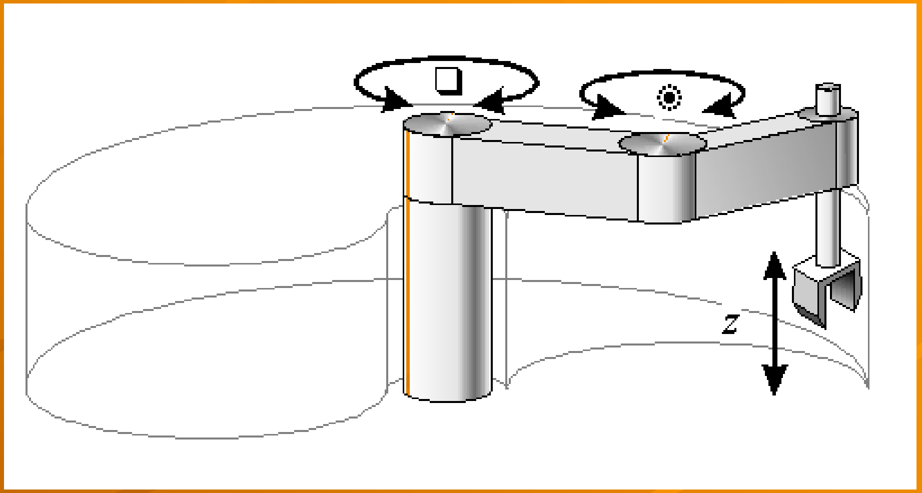
Disadvantages:

- extremely difficult to visualize, control, and program.
- restricted volume coverage.
- low accuracy

SCARA (*S*elective *C*ompliance *A*rticulated *R*obot *A*rm) Robots

A robot with at least 2 parallel rotary joints.

Commonly used for:
•pick and place work
•assembly operations



SCARA (Selective Compliance Articulated Robot Arm) Robots

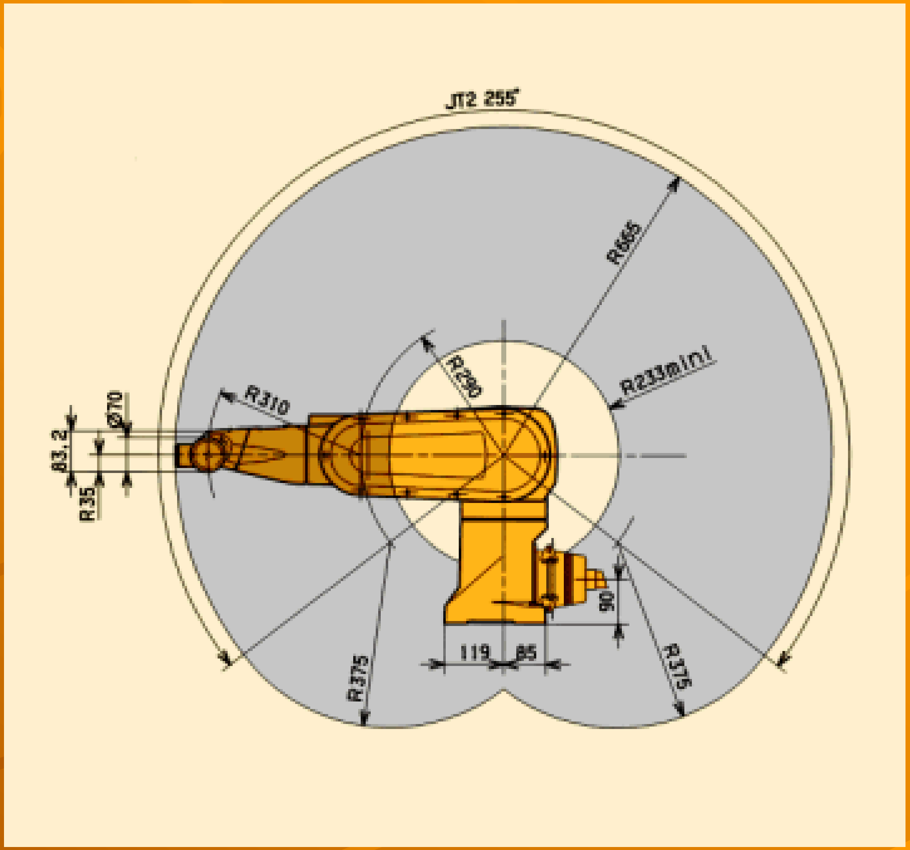
Advantages:

- high speed.
- height axis is rigid
- large work area for floor space
- moderately easy to program.

Disadvantages:

- limited applications.
- 2 ways to reach point
- difficult to program off-line
- highly complex arm

Work Volume



Spatial region within which the end of the robot's wrist can be manipulated

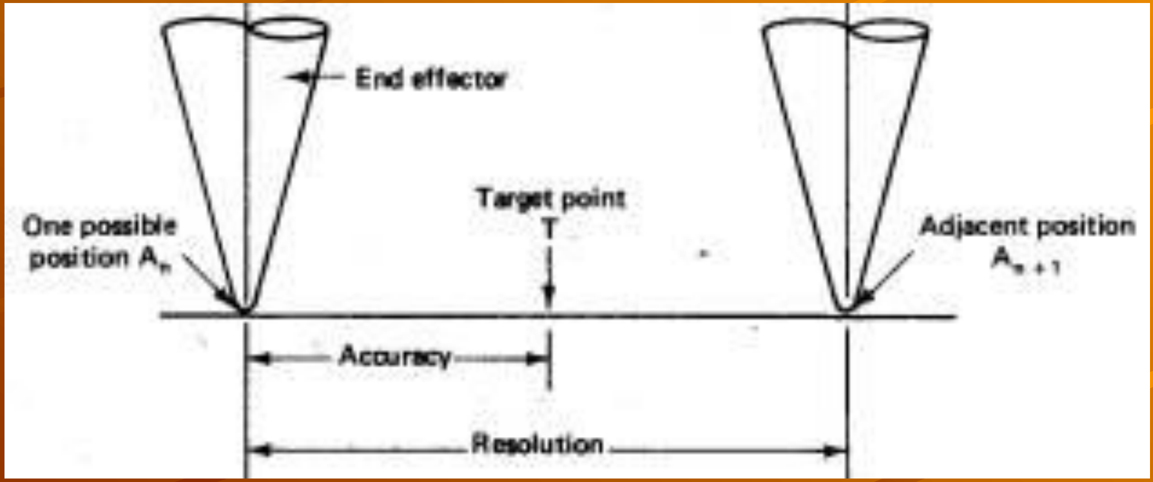
Determined by

- Physical configurations
- Size
- Number of axes
- The robot mounted position (overhead gantry, wall-mounted, floor mounted, on tracks)
- Limits of arm and joint configurations
- The addition of an end-effector can move or offset the entire work volume

Spatial Resolution

Smallest increment of motion at the wrist end that can be controlled by the robot

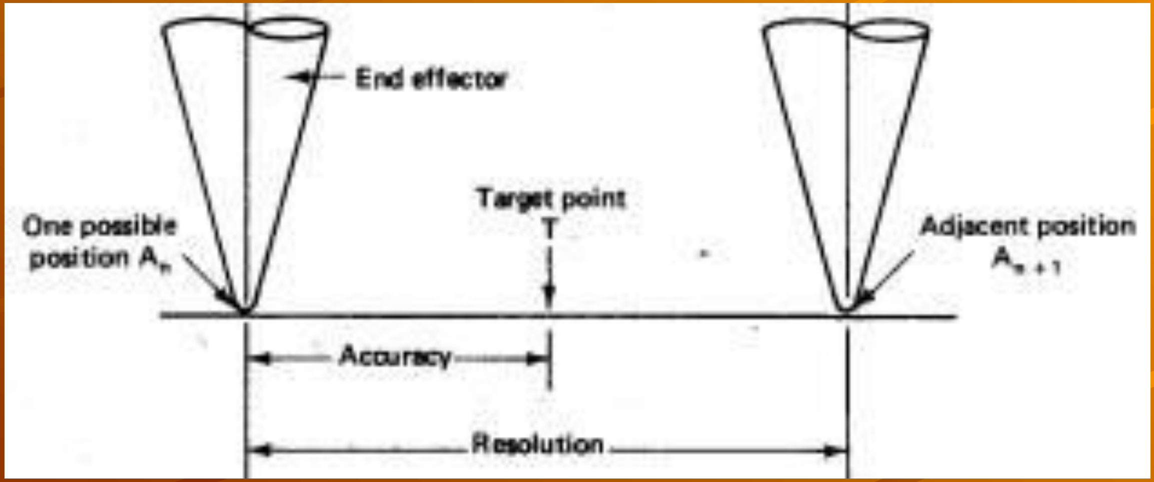
Depends on the position control system, feedback measurement, and mechanical accuracy



Accuracy

Capability to position the wrist at a target point in the work volume

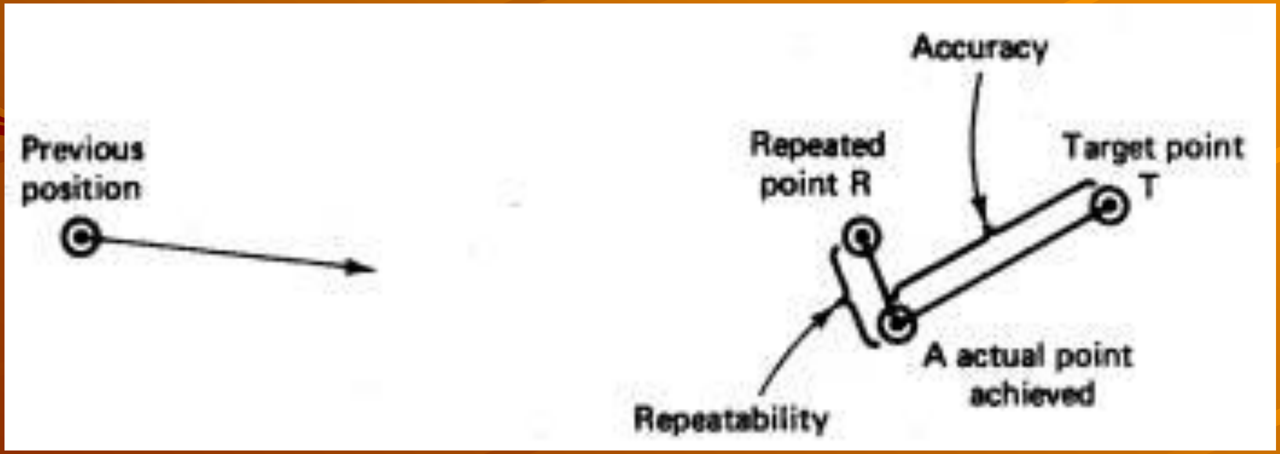
- One half of the distance between two adjacent resolution points
- Affected by mechanical Inaccuracies
- Manufacturers don't provide the accuracy (hard to control)



Repeatability

Ability to position back to a point that was previously taught

- Repeatability errors form a random variable.
- Mechanical inaccuracies in arm, wrist components
- Larger robots have less precise repeatability values



Weight Carrying Capacity

- The lifting capability provided by manufacturer doesn’t include the weight of the end effector
- Usual Range 2.5lb-2000lb
- Condition to be satisfied:

Load Capability > Total Wt. of workpiece +Wt. of end effector + Safety range

Speed of Movement

Speed with which the robot can manipulate the end effector

- Acceleration/deceleration times are crucial for cycle time.
- Determined by
  - Weight of the object
  - Distance moved
  - Precision with which object must be positioned

ROBOT CLASSIFICATION

Classification Based on Control Systems:

- 1. Point-to-point (PTP) control robot
- 2. Continuous-path (CP) control robot
- 3. Controlled-path robot

Point to Point Control Robot (PTP):

- The PTP robot is capable of moving from one point to another point.
- The locations are recorded in the control memory. PTP robots do not control the path to get from one point to the next point.
- Common applications include:
  - component insertion
  - spot welding
  - hole drilling
  - machine loading and unloading
  - assembly operations

Continuous-Path Control Robot (CP):

- The CP robot is capable of performing movements along the controlled path. With CP from one control, the robot can stop at any specified point along the controlled path.
- All the points along the path must be stored explicitly in the robot's control memory. Applications Straight-line motion is the simplest example for this type of robot. Some continuous-path controlled robots also have the capability to follow a smooth curve path that has been defined by the programmer. In such cases the programmer manually moves the robot arm through the desired path and the controller unit stores a large number of individual point locations along the path in memory (***teach-in***).

Continuous-Path Control Robot (CP):

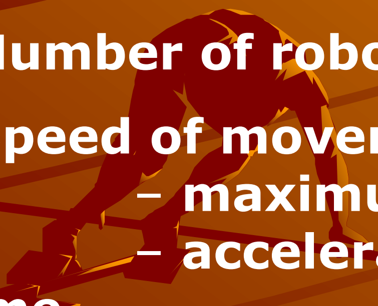
Typical applications include:

- spray painting
- finishing
- gluing
- arc welding operations

Controlled-Path Robot:

- In controlled-path robots, the control equipment can generate paths of different geometry such as straight lines, circles, and interpolated curves with a high degree of accuracy. Good accuracy can be obtained at any point along the specified path.
- Only the start and finish points and the path definition function must be stored in the robot's control memory. It is important to mention that all controlled-path robots have a servo capability to correct their path.

Performance Specifications of Industrial Robots



- Size of the working envelope
- Precision of movement
  - Control resolution
  - Accuracy
  - Repeatability
- Lifting capability
- Number of robot axes
- Speed of movement
  - maximum speed
  - acceleration/deceleration time
- Motion control
  - path control
  - velocity control
- Types of drive motors
  - hydraulic
  - electric
  - pneumatic

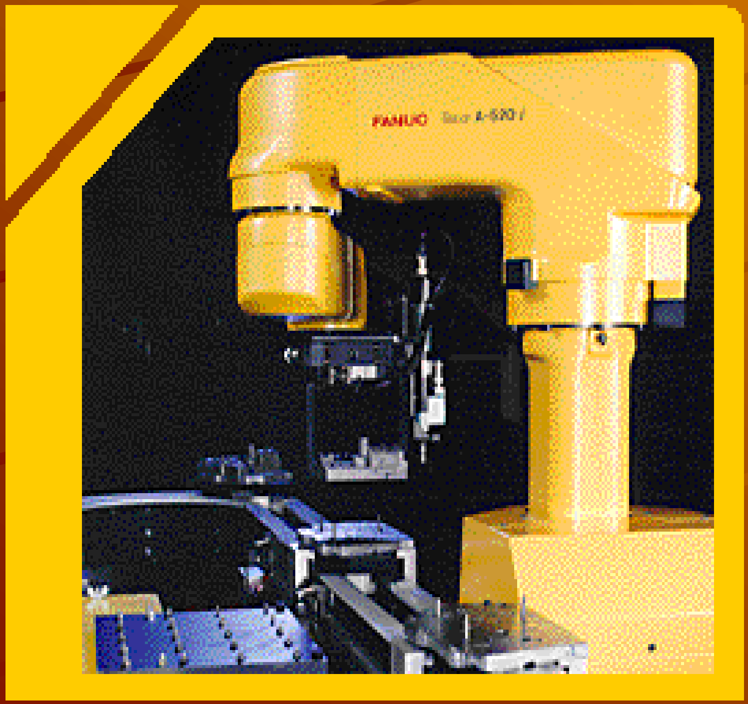
Robot Specifications

Characteristics	Units
No of Axes	Numbers(eg 1,2)
Max speed/cycle time	mm/sec
Load carrying capacity (pay load)	Kg
Reach & stroke	mm
Total orientation	Degrees
Repeatability	--
Precision & Accuracy	mm

Robot Applications (Configurations/Characteristics)

SCARA Robot

(Selective Compliance Assembly Robot Arm)



Characteristics:

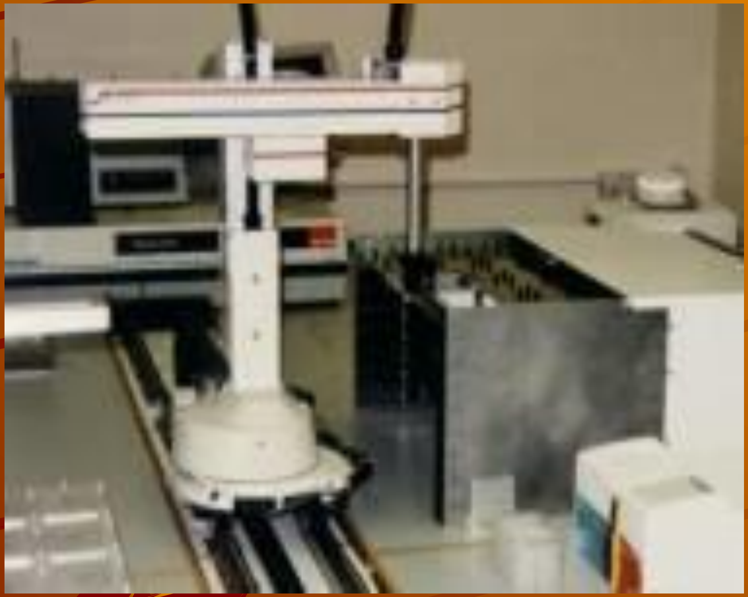
- Repeatability: < 0.025mm (high)
- No. of axes: min 4 axes
- Vertical motions smoother, quicker, precise (due to dedicated vertical axis)
- Good vertical rigidity, high compliance in the horizontal plane.
- Working envelope: range < 1000mm
- Payload:10-100 kg
- Speed: fast 1000-5000mm/s

Applications:

- Precision, high-speed, light assembly

Robot Applications (Configurations/Characteristics)

Cylindrical Coordinate Robot



Characteristics:

- Wide range of sizes
- Repeatability: vary 0.1-0.5mm
- No. of axes: min 3 arm axes (2 linear)
- Working envelope: typically large (vertical stroke as long as radial stroke)
- The structure is not compact.
- Payload: 5 - 250kg
- Speed: 1000mm/s, average
- Cost: inexpensive for their size and payload

Applications:

- Small robots: precision small assembly tasks
- Large robots: material handling, machine loading/unloading.

Robot Applications (Configurations/Characteristics)

Vertical Articulated Arm Robot

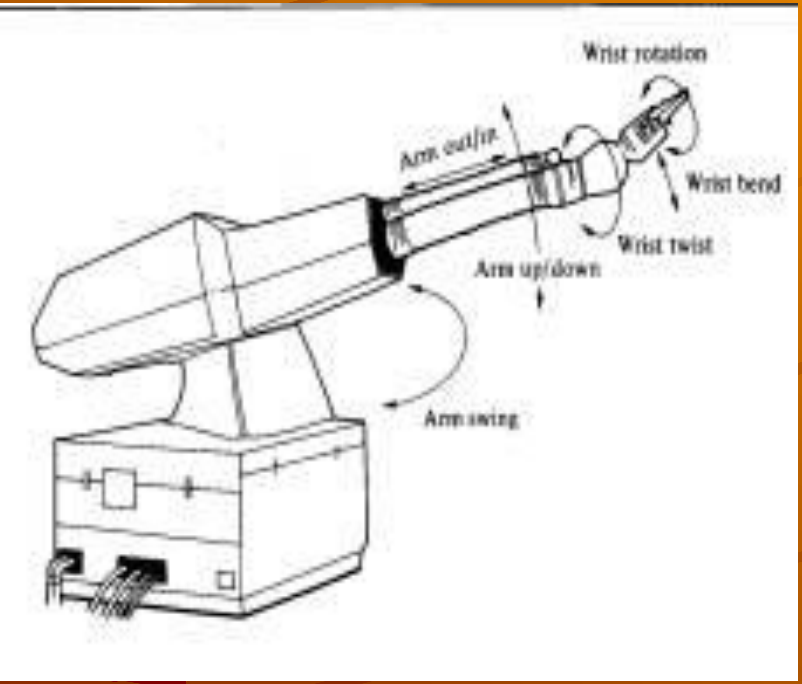
Characteristics:

- Repeatability: 0.1-0.5mm (large sizes not adequate for precision assembly)
- No. of axes: 3 rotary arm-axes, 2-3 additional wrist axis (excellent wrist articulation)
- Working envelope: large relative to the size, Structure compact, but not so rigid
- Payload: 5-130kg
- Tool tip speed: fast 2000mm/s

Applications: Welding, painting, sealing, deburring, and material handling

Robot Applications (Configurations/Characteristics)

Spherical Coordinate Robot



Characteristics:

- Repeatability: poor 0.5-1mm
- No. of axes: 3 arm-axes (1 linear radial), 1-2 additional wrist-axes.
- Working envelope: large vertical envelope relative to the unit size
- Payload: 5-100 kg
- Speed: low (linear motions are not smooth and accurate- require coordination of multiple axes)

Applications: Material handling, spot welding, machine loading

Robot Applications (Configurations/Characteristics)

Cartesian Coordinate Robot

Characteristics:

- Repeatability: high (0.015-0.1)
- No. of axes: 3 linear arm-axis,
- Working envelope:relative large
- Payload:5- 100kg
- Speed: fast

Applications: Precise assembly, arc welding, gluing, material handling

Robot Applications (Configurations/Characteristics)

Gantry Robot

Characteristics:

- Repeatability: 0.1-1mm
- No. of axes: 3 linear traverse-axes, 1-3 additional wrist axes
- Working envelope: very large
- Payload: vary function of size, support very heavy 10-1000kg
- Speed: low for large masses

Applications:

Handling very large parts, moving material on long distances, welding, gluing.

Programming Robots

- **Manual**

  Cams, stops etc
- **Walkthrough (Lead-through)**

  Manually move the arm, record to memory
- **Manual teaching**

  Teach pendant

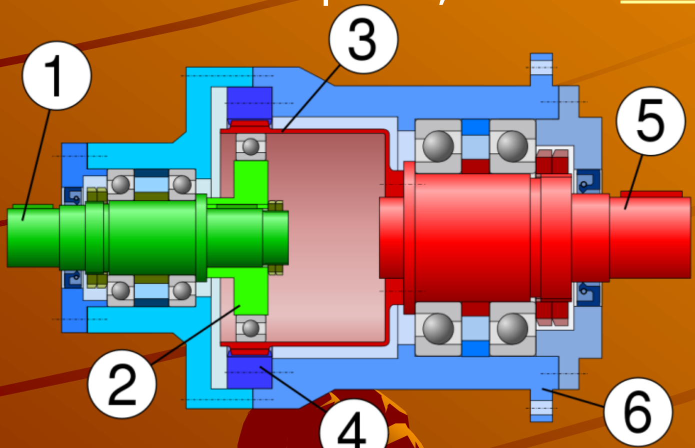
- **Off-line programming**

  Similar to NC part programming

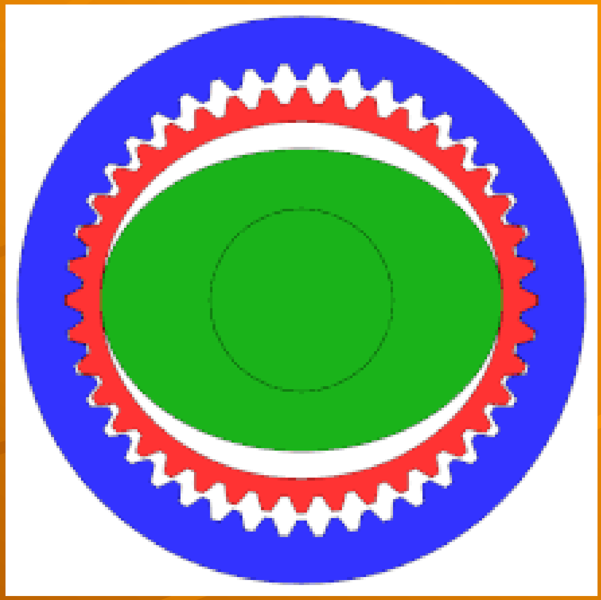
  VAL, RAPT

Harmonic drive

Harmonic Drive is the brand name of strain wave gear trademarked by the Harmonic Drive company, and invented in 1957 by C.W. Musser. It is very commonly implemented in robotics today and used in aerospace as well, for gear reduction but may also be used to increase rotational speed, or for differential gearing.



Cross section of a harmonic gear.
1-input shaft
2-wave generator
3-flexspline
4-circular spline
5-output shaft
6-housing



Blue (outer circle): circular spline (fixed)
Red (middle flexible circle): flex spline (attached to output shaft, which is not shown)
Green (inner oval): wave generator (attached to input shaft; inner ball bearing and shaft are not shown)