Automation &
Robot Economics

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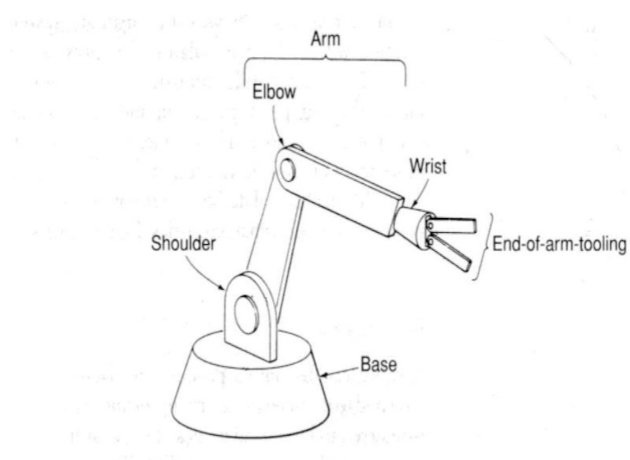

Figure :Parts of a manipulator : The industrial robot manipulator has a body, arm, and wrist. names match those of the corresponding human parts

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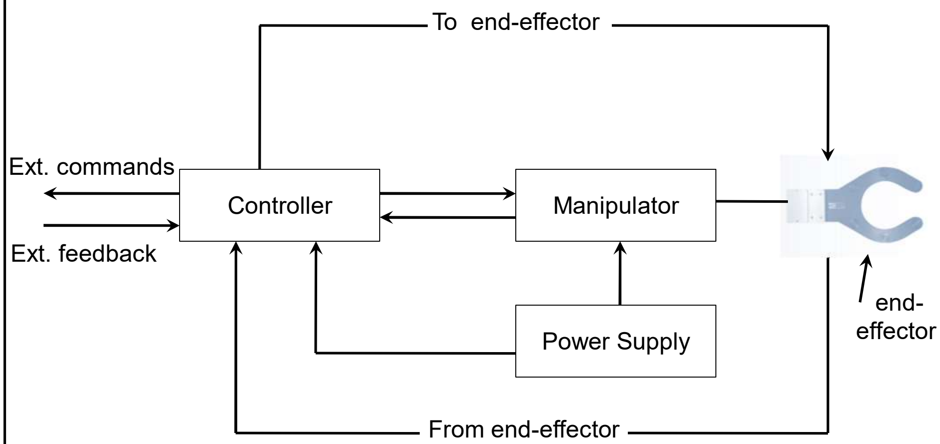

Figure : Basic components of an industrial robot

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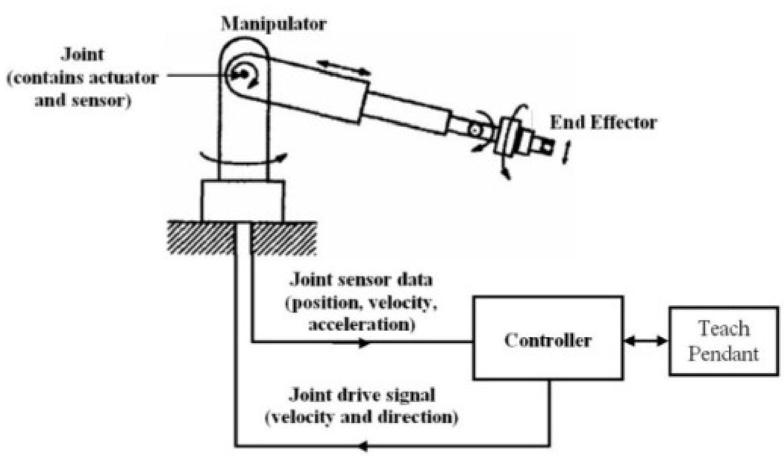

Figure : Basic components of an Industrial robots

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Robotics Industrial Association (RIA)

- An industrial robot is a :
  - » Reprogrammable;
  - » Multifunctional

↓

Manipulator

↓

Designed to move ✓Materials, ✓Parts ✓Tools ✓Special devices

↓

Through variable programmed motions for the performance of variety of tasks.

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International Standard Organisation (ISO)

- A machine formed by a mechanism, including several degrees of freedom, often having the appearance of one or several arms ending in a wrist capable of holding a :

  ✓Tools,

  ✓Workpiece or

  ✓An inspection device

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International Standard Organisation (ISO)

- In particular, its CONTROL UNIT must be used as a MEMORIZING DEVICE and it may sometimes use SENSING OR ADAPTIVE APPLIANCES

to take into account

↓

environment and circumstances.

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International Standard Organisation (ISO)

- These multipurpose machines are generally designed to carry out
  - A repetitive function and
  - Can be adapted to other functions

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Robot application areas as a percentage of total robot population

Spot welding	:29%
Material handling	:27%
Coating	:20%
Arc welding	:12%
Material removal	:4%
Dispensing	:4%
Assembly	:4%

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Reasons of using Robots

Ranking	Potential Benefits
1	Reduce labour costs
2	Eliminate dangerous jobs
3	Increase output rate
4	Improve product quality
5	Increase product flexibility
6	Reduce material waste
7	Reduce labour turnover
8	Reduce capital cost

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Reasons of using Robots

1. The primary purpose of the robot
   as a machine is ⇨ Controlled Motion.
   If it does not move ⇨ it is not a robot
2. Two reasons for selecting a robot to operate in a production line
   i. To reduce labour costs
   ii. To perform repetitive work that is
      - Boring or
      - Unpleasant or
      - Hazardous for human beings

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Reasons of using Robots (Contd.)

3. Rule of thumb applications for robots are the four D's.
   i. Dull
   ii. Dirty
   iii. Dangerous
   iv. Difficult

   & four H's
   i. Hot
   ii. Heavy
   iii. Hazardous
   iv. Humble

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Robot and Automation

- Automation and Robotics are two closely related technologies.

- Both are concerned with the USE and CONTROL of PRODUCTION OPERATIONS.

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Robot and Automation

- ROBOTICS (study of robots) is a form of Industrial automation, which is of three types :
- Fixed automation :
  - Used for high production volume and utilizes expensive special equipment to process only one product.
- Flexible automation :
  - Used for medium production volume and utilizes a central computer to control the process of different products at the same time.
- Programmable automation :
  - Used for low production volume operated under control of program.
  - It processes one batch of similar products at a time.
  - When one batch is completed, the equipment is reprogrammed to process the next batch.

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Robot and Automation

- Robots are <u>examples</u> of <u>Programmable automation</u>.

  however they are often used in <u>Flexible</u> or <u>even fixed automation</u>.
- Robot technology is an Applied Science

  ⇩

  Referred to as

  ⇩

  Combination of machine tools & computer applications.
- It includes diverse fields as Machine Design, Control Theory, Microelectronics, Computer Programming, Artificial Intelligence, Machine Learning, Human factors & Production Theory.

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Robot Economics

- If robots can not be justified economically they should not be used in production lines.

$$Y = \frac{(P + A + I) - C}{(L + M - O)H(1 - TR) + D(TR)}$$

Where,

Y = number of years to breakeven

P = price of the robot

A = cost of tooling and fixturing

I = installation Cost

C = investment tax credit (Assume at 10%)

$[\,(P + A + I) - C\,]$ is the total investment.

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Robot Economics

$$Y = \frac{(P + A + I) - C}{(L + M - O)H(1 - TR) + D(TR)}$$

Where,

L = hourly cost of labour including fringe benefits

M = hourly savings in cost of material

O = cost of running & maintaining the robot system

H = number of hours per year per shift

D = annual depreciation

TR = corporate tax rate

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Robot Economics

Example 1:

Y = number of years to breakeven

P = price of the robot=Rs.27,50,000/-

A = cost of tooling and fixturing=Rs. 15,00,000/-

I = installation Cost=Rs.7,50,000/-

C = investment tax credit (Assume at 10%)=Rs. 5,00,000/-

L = hourly cost of labour including fringe benefits=Rs.850/-

M = hourly savings in cost of material=Rs.50/-

O = cost of running & maintaining the robot system=Rs.300/-

H = number of hours per year per shift=2000

D = annual depreciation.

Using 8 year tax life, the straight line method and a salvage value of Rs. 5,00,000/-

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Robot Economics

D = Annual Depreciation

$$D = \frac{50{,}00{,}000 - 5{,}00{,}000}{8}$$

$$D = 5{,}62{,}500 \text{ Rs./year}$$

TR = corporate tax rate (assume 40%)= 0.4

- Payback period Y can be calculated as,

$$Y = \frac{(P + A + I) - C}{(L + M - O)H(1 - TR) + D(TR)}$$

$$Y = \frac{[\,(27{,}50{,}000 + 15{,}00{,}000 + 7{,}50{,}000) - 5{,}00{,}000\,]}{(850 + 50 - 300)2000(1 - 0.4) + 5{,}62{,}500(0.4)}$$

$Y = 4.7$ yrs for single shift

$Y = 2.7$ yrs for double shift

$Y = 1.9$ yrs for three shift

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Ex. 2.

The total investment of the robot is estimated to be Rs. 500,000. There is one shift operation of 2000 hours and 1 man replaced. Assuming labour rate inducing direct overheads to be Rs. 80 per hour, robot running cost including maintenance and depreciation to be rupees 1,00.000 and added value of increased output to be Rs. 1,20,000, determine the payback period.

$$payback\ period = \frac{5{,}00{,}000}{(80 \times 2000) + 1{,}20{,}000 - 1{,}00{,}000}$$

$$= 2.77\ years$$

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Return on Investment (ROI)

$$ROI = \frac{\text{total annual savings}}{\text{total investment}} \text{ x } 100\ \%$$

$$ROI = \frac{(L+M-O)H-D}{(P+A+I)-C} \text{ x } 100\ \%$$

- Economic measure do not take into consideration ECONOMIC BENEFITS that can be derived from a robot to produce a product that is of CONSISTENTLY HIGH QUALITY.

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Ex.3

The cost of Robot and accessories is Rs. 5,00,000 and yearly depreciation for robot with a life of 8 years is Rs. 62,500. The annual maintenance costs is Rs. 32,000 and Annual value of increased output is Rs. 1,20,000. The 1 man has been replaced, i.e. 1 shift of operation consider it be 2000 hours. The labour rate including direct overhead is Rs. 80/hr. Calculate Annual rate of return.

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- Solution:

$$Annual\ rate\ of\ return\ in\ \% = \frac{Net\ savings\ (or\ income) \times 100}{Total\ investment\ on\ robot}$$

$$Annual\ rate\ of\ return\ in\ \% = \frac{(Annual\ rate\ of\ increased\ labour) + (cost\ of\ labour\ savings) - (Annual\ depreciation) - (Annual\ maintenance\ cost)}{Total\ investment\ on\ robot}$$

$$= \frac{1{,}20{,}000 + (80 \times 2{,}000) - 62{,}500 - 32{,}000}{5{,}00{,}000} \times 100$$

$$= 37.1\%$$

- The rate of return is 37% which is quite good. Rate of return may be upto 50% or so. If the investor in this case borrows money with 20% annual interest, he will still get the benefit of net return on investment of about 17 %.
- If the robot is used for 2 shift operations, the annual rate of return

$$= \frac{2{,}40{,}000 + (80 \times 2{,}000) - 62{,}500 - 32{,}000}{5{,}00{,}000} \times 100$$

$$= 91.5\%$$

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Dynamic properties of robots

- Among the important properties of a robot that properly regulate its motions are

1. Stability
2. Control resolution
3. Spatial resolution
4. Accuracy
5. Repeatability
6. Compliance

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1. Stability

1. Variations in → INERTIAL / GRAVITATIONAL loads

↓

on individual joint servos

(as the arm's posture changes)

↓

makes the operation of robot

↓

prone to oscillations.

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1. Stability (Cont.)

2. STABILITY is associated with <u>oscillations</u> in the motion of the Robot Tool (End Effector).

Fewer oscillations imply → stable performance

3. Negative effects of oscillations include:

a) Additional wear → Mechanical/hydraulic and other parts of robot arm.

b) Tool will follow different Paths in space → During successive repetitions of the same movement.

.

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1. Stability (Cont.)

⇓

thus requiring more distance between the intended trajectory and surrounding objects.

c) Time required for tool to stop at a precise position. ⇒ will be increased

d) Tool may overshoot the intended stopping position ⇒ causing collision with some other objects in the system.

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1. Stability (Cont.)

4. Oscillations may be ⇒ Damped or Undamped
5. Damped(transient) oscillations will decay and cease with time.
6. Undamped (runaway) oscillations may <u>persist</u> or <u>grow</u> in <u>magnitude</u> and are most serious because of potential damage that may be caused to equipments.
7. Servos must operate over a wide range of position and velocity <u>error.</u>

   Despite the limitations imposed on velocity and acceleration by actuators used.

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1. Stability (Cont.)

e.g.1. when the load slips out of end effector,
⇓
causes a
⇓
step change in gravity loading
⇓
on one or more major joints
⇓
and can cause poorly designed arm
⇓
to undergo oscillations.

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1. Stability (Cont.)

e.g. 2) Motion of a joint can also exert
⇓
combination of
⇓
inertial, centrifugal and coriolis forces
⇓
on other joints.
⇓
The reaction of other joints to
⇓
these forces can exert
⇓
forces on original joint
⇓
causing oscillations.

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1. Stability (Cont.)

e.g. 3

The gain of controller

↓

determines

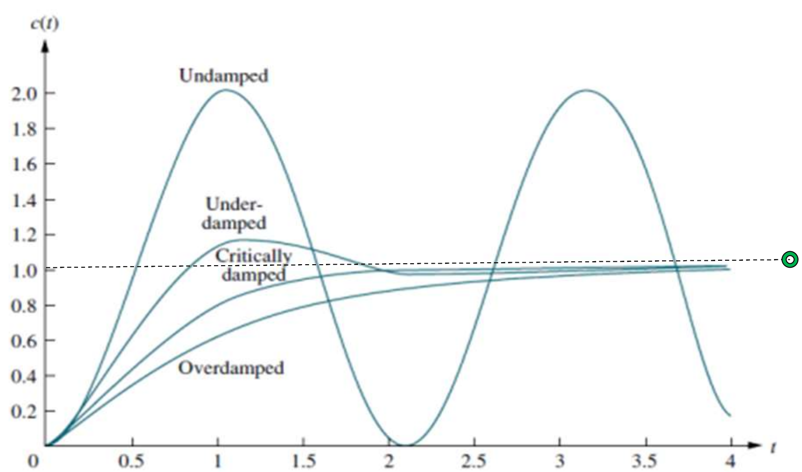
↓

control system response

↓

(speed of response)

As gain of controller increases, response changes in following order



1. Stability (Cont.)

9. Neither underdamped or overdamped response minimize the objective i.e. error.

10. Therefore optimum response is critically damped or slightly damped.

11. However good stability and fast response are competing objectives.

- Low damping gives fast response.
- High damping gives slow response.

Compromise between the two is needed.

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1. Stability (Cont.)

12. Solutions to eliminate oscillations

a)By having :

Joint servos operate continuously i.e. eliminating start and stop motions regardless of load carried.

a)By having:

Robot controller lock each joint independently the first time it reaches its set point.

When the joints are all locked (total coincidence) the arm is stationary and it can begin to move to next position.

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Control Resolution

1. Resolution specifies the Smallest Increment of Motion by which the robot can divide its work volume.
2. It is smallest increment of position

   ↓

   The control can

   ↓

   Command Or Measure
3. The Increment is referred as Addressable points.
4. Two manipulator positions that differ only by one Increment of a single Joint are called Adjacent.

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a) A unit change in position of a sliding joint will move the tool tip the same distance regardless of where it is in the work envelope.

b) But a unit change in the position of a rotary joint
   - Will move the tool tip through a distance that is proportional to the perpendicular distance from the joint axis to the tool tip.
   - Thus there is an angular position error on the final tool tip position that depends on how far the boom is extended.
   - The further the boom is extended the longer the distance that the tool tip will move when the rotary joint moves to an adjacent position.

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Spatial Resolution

1. Spatial resolution is control resolution “combined with”(+) mechanical inaccuracies.
2. Mechanical inaccuracies arise from:
   I. Elastic deflection in structural members
   II. Gear backlash
   III. Stretching of pulley cords
   IV. Leakages of hydraulic fluids
   V. Imperfection in the mechanical system

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Spatial Resolution(contd.)

3. These accuracies are also influenced by
   I. Load being handled
   II. Speed with which the arm is moving
   III. Condition/maintenance of robot
   IV. Other similar factors
4. Spatial Resolution can be improved by increasing bit capacity of control memory upto a limit as beyond point, mechanical inaccuracies become dominant a component for spatial resolution.

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Accuracy

1. Accuracy of Robot is the difference between,
   (desired control point – Actual control point)
2. Accuracy refers to ability of robot

⇩

To position & orient

⇩

End of its wrist

⇩

At a desired target point within its work envelope

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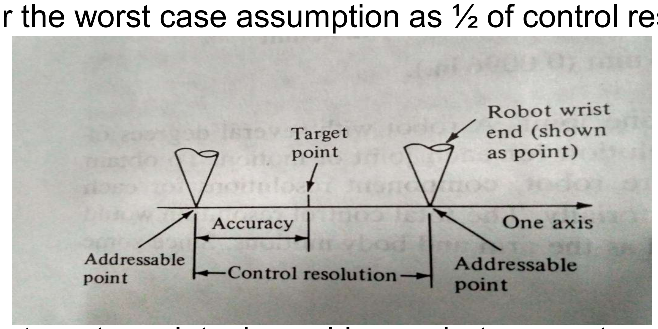
Accuracy (Contd.)

3. Accuracy is applied to worst case by ignoring mechanical inaccuracies.

We can define accuracy under the worst case assumption under the worst case assumption as ½ of control resolution.



Where target point is midway between two control (addressable) points.

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Accuracy (Contd.)

4. Accuracy is affected by following factors

a)Accuracy varies within work volume

Accuracy → Worse when arm is in outer range of work volume

(Because mechanical inaccuracies are magnified with Robot arm fully extended)

b)Accuracy → Improved if motion cycle is limited to a work range

(Mechanical errors tend to reduce when robot is exercised through restricted range of motions)

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Accuracy (Contd.)

c) Load carried by robot → Heavier workload cause greater deflection of mechanical links of robot resulting in lower accuracy.

5. The ability to divide the joint into increments depends upon the bit storage capacity of the CONTROL MEMORY.
6. The number of separate identifiable increments for a PARTICULAR AXIS is given as,

$$\text{Number of increments} = 2^n$$

Where n = no. of bits in the control memory

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Accuracy (Contd.)

Ex. Using a robot with 1 degree of freedom, assuming it has one sliding joint with a full range of 1.0 m and the control memory has 12 bit storage capacity, Find the control resolution of the axis for motion.

Sol: No. of increments = $2^n = 2^{12}$

= 4096

The total range of 1m (1000mm) is divided into 4096 increments

Thus each position will be separated by

1000/4096 = 0.244 mm

The control resolution is 0.244 mm.

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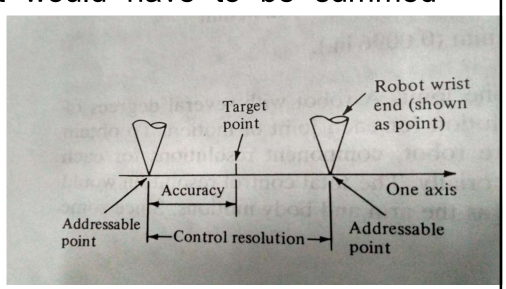
Accuracy (Contd.)

- This example deals with one joint, A Robot with several degree of freedom would have control resolution for each joint of motion.
- To obtain control resolution for entire robot component resolutions for each joint would have to be summed vectorially.
- The total Control

Resolution would depend on

I. Arm & body motion

II. Wrist motion



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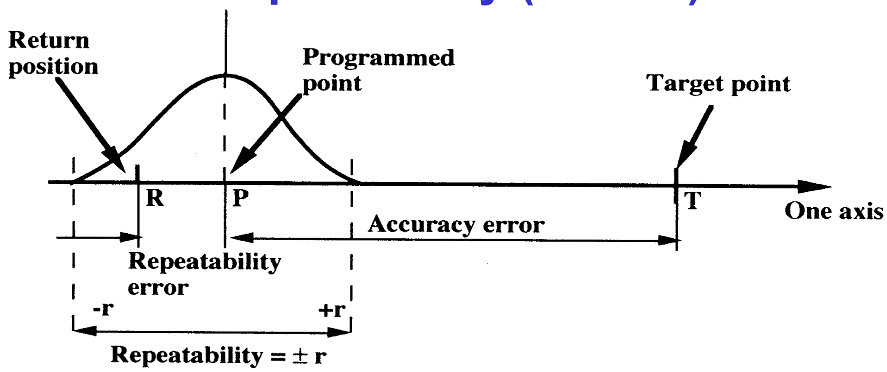
Accuracy (Contd.)

5. Local accuracy – Robot ability to reach a particular reference point within limited work space.
6. Global accuracy – Robot ability to reach a particular reference point within robots full work volume.

5. Repeatability

1. It is the ability of the robot to reposition itself to a position to which it was previously commanded or taught.
2. Repeatability is affected by control resolution and component inaccuracy.
3. Repeatability errors form a random variable and constitute statistically distributed region as shown in figure.
4. Mechanical inaccuracies are principally responsible for repeatability errors.

Repeatability (Contd.)



5.(a) Desired target point is T.

Point robot reaches P because of limitations in accuracy. i.e. programmed position "T" becomes "P".

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Repeatability (Cont.)

(b) Subsequently robot is instructed to return to P, it returns to position R.

(c) The difference between P and R is robots repeatability error.

(d)The robot will not always return to same position R on subsequent repetitions of motion cycle.

(e) Instead it will form cluster of points of both sides of "P".

Thus ,

repeatability = $\pm$r

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Repeatability (Contd.)

6. Important factors contributing to repeatability error are
   - Ambient conditions
   - Rigidity of structure
   - Precision of drive tranins and transmission devices
   - Kinematic equations used in ARM solution and BACK solution must accurately reflect the design of the manipulator.

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Repeatability (Contd.)

- Accuracy on these computations depend on the accuracy with which the following joint parameters are known:

  a) Joint extensions and rotations

  b) Link lengths

  c) Offset distances between successive joint axes and

  d) Angles between successive joint axes.

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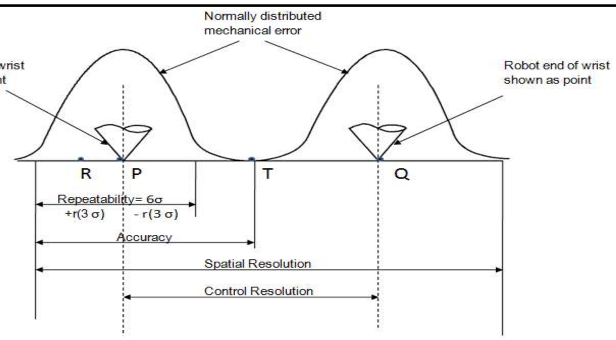

- P, Q – Programmed Points (Addressable Points)
- R – Return Position
- T –Target Point

$$\textit{Control Resolution} = \frac{\textit{Range of Movement}}{2^n}$$

Where, n is control bit memory storage capacity

$$\textit{Spatial Resolution} = 2 \times \textit{Accuracy}$$

$$= \textit{Control Resolution} + 6\sigma$$

$$\textit{Repeatability} = \pm r = \pm 3\sigma$$

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6. Compliance

1. Compliance is the quality that gives manipulator of a robot the ability to tolerate misalignments of mating parts.
2. It prevents jamming, wedging, galling of parts during assembly
3. High compliance means tool moves a lot response to small force.

   Manipulator is denotes as spongy or springy.
4. Low compliance means tool moves little.

   Manipulator is denoted as stiff.

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Compliance (Contd.)

5. Ideally for evaluating compliance relations

   a)Relation between disturbance and displacement should be linear i.e. displacement or rotation proportional to force or torque.

   b)Should be isotropic i. e. independent of direction of force applied.

   c)Should be diagonalized i.e. displacement and rotation occurring in direction of force

   d)Are constant with time

   e)Should be independent of tool position, orientation and velocity.

Compliance (Contd.)

6. In practice, robots compliance turns out to:

   a)Non linear

   b)Anisotropic tensor quantity that values with manipulator posture and motion.

- It is tensor because force in one direction can result in displacements in other directions and even rotations.
- A torque can result in rotation about any axis and displacement in any direction.
- Time can affect compliances through changes in temperature and subsequently viscosity of hydraulic fluid.

Compliance (Contd.)

- Compliance is found to be function of frequency of applied force or torque.

e.g. manipulator compliant at even 2 Hz frequency but very stiff in response to slower disturbance.

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