Introduction to Robotics, class notes (UG level)

Research · June 2015

1 author:

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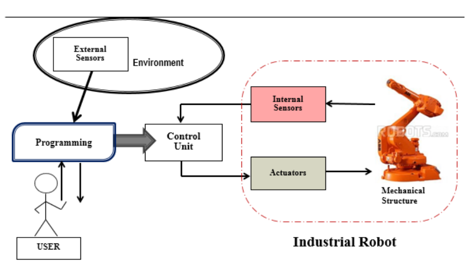
College of Electronic Technology / Bani Walid

Control System Department

Subject Name: **Introduction to Robotics**

Class Notes (Part One)

BY: Yousef Moh. Abueejela



Course Info

Lecture Hours: 14 weeks x 2.5 hours = 35 hours/semester

Tutorial Hours: 10 weeks x 2 hour = 20 hours/semester

Self-Readings: 14 weeks x 4 hours = 56 hours/semester

Attendance: > 75 % "it means you must attend at least 10 weeks "

Grading

Midterm Exam (Exam 1, Exam 2) ………………………………..……….. 25 %

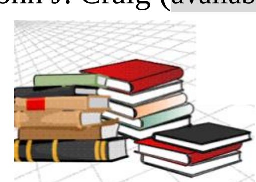
Quiz "total "……………………………………..…………5 %

Assignments & H.ws…………………………………….….. 10 %

Final Exam ……………………………………………..…… 60 %

Text Books and References

- Introduction to Robotics: analysis, systems, applications, by Saeed B. Niku (available in college library CNT 291).
- Introduction to Robotics: mechanics and control 2nd edition, by John J. Craig (available in college library CNT 254/4).
- Fundamentals of robotics by Ming xie (Copies will be given).
- This Class Notes and hard copy materials



Contacts

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Schedule of Lectures for Spring 2014/2015

week	Lecture	Topic	Date
1	1	Introduction to Robot and Robotics, Three laws of robotics, History, Issues of industrial robot usage, Robot Types, limitations, Architecture ,**Videos Media**	
	2	Robot Applications ,Robot Configuration, Classification, Robot Repeatability and Accuracy, **Videos Media**	
2	3	Robot Applications, Robot component, Degree of freedom, Drive Technologies,**Videos Media**	
	4	2D Vectors ,Point Representation in 3D, Vectors in Space 3D, Unit Vector, 2,3D Vectors Rotations and Translation.	
3	5	Rules to finding H.T.M, 3D Rotation and Translation in Space,	
	6	Examples 3D vectors, Issues, Relative Frames, Homogeneous Transformation H.T.M,	
4	7	Coordinate Systems, three related frames, Rotational about fixed frames (x,y,z). Transformation of Coordinate Frame	
	8	Rotational , Translation about fixed frames (θ,α,γ).	
5	9	Forward Kinematics Basics, Orientations, Translation of rigid body	
	10	3D System " Camera, Robot and an Object" designing and solution.	
6	11	Forward Kinematics Examples for Camera object Robot Systems.	
	12	Mid Term Examination (***postponed by the student 2 times***)	
7	13	Denavit-Hertanberg representation, D-H algorithm of tow axis robot	
	14	Forward Kinematics Solutions For 2 Dof Robots, Examples.	
8	15	Forward Kinematics Solution For 3 Dof Robot, Examples.	
	16	Forward Kinematics Solution For 4 Dof Robots, Examples.	
9	17	Forward Kinematics Solutions For 5 Dof Robots, Examples.	
	18	Forward Kinematics Solution For 6 Dof Robots, Mitsubishi	
10	19	problem of inverse kinematics , Inverse Kinematics solutions	
	20	Inverse Kinematics Examples and review	
11	21	Wheeled mobile robot, structure, types, modelling	
	22	Wheeled mobile robot speed and position calculation	
12	23	Paper exam revision and solutions	
	24	Last exams Solutions	
Quiz's (4/5)………………..…….. Homework's (3/10) …………………………….. Mid term(1/25)			

What Is a Robot?

Robots today are being utilized in a wide variety of *industrial application*. The most majority of industrial robots are mechanical arms attached to a fixed base, with some form of programmable control for automatic execution of motion.

There are a variety of definitions of an industrial robot, ***two of which are as follows***:

A robot is a re programmable multi-function manipulator designed to move material parts, tools or specialised devices, through variable programmed motions for the performance of a variety of tasks. ***(Robotic Institute of America, 1979)***

An industrial robot is a re-programmable device designed to both manipulate and transport parts, tools or specialised manufacturing implements through variable programmed motions for the performance of specific manufacturing tasks.

(British Robots Association)

Robotics is the engineering science and technology of robots, and their design, manufacture, application, and structural disposition. It requires a working knowledge of electronics, mechanics, and software.

The word 'robot' first appeared in 1921 but was not a technical term. It was used by a Czech playwright called Karel Capek in a satirical play called 'Rossums Universal Robots' to describe slave labourers who had their souls removed to make them work harder. In, 1942 Isaac Asimov wrote a short science fiction story in which the word 'robotics' was first used and presented **3 laws of robotics**.

1. Robots ***must not*** injure humans
2. Robots ***must*** obey orders
3. Robots ***must*** protect their own existence

Issues of industrial robot usage!

How to tackle the issues of industrial relation?!!!

RIA (Robotics Industries Association) has put up the following promise for the Opponents of robot usage in the industry:

- **Not** to replace workers, **only** replace equipment.
- Use only for (hazardous, boring, demoralizing, and repetitive tasks).
- Only if it can result in shorter work week, higher pay, and better working conditions for human.

Classes of Robot

Most of physical robots fall into one of the three categories:

- ***Manipulators/robotic arms*** which are anchored to their workplace and built usually from sets of rigid links connected by joints.
- ***Mobile robots*** which can move in their environment using wheels, legs, etc.
- ***Hybrid robots*** which include humanoid robots are mobile robots equipped with manipulators.

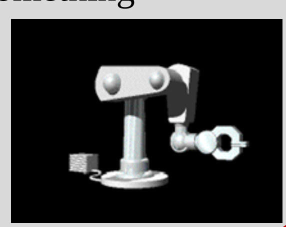
To qualify as a robot, a machine must be able to:

1) Sensing and perception: get information from its surroundings.

2) Carry out different tasks: Locomotion or manipulation, do something Physical–such as move or manipulate objects

3) Re-programmable: can do different things

4) Function autonomously and/or interact with human beings



Why Use Robots?!!!

There are many different reasons for using a robot but the **central reasons** are:

Application 4D environments	**4A tasks**
Dangerous (***exploring inside a volcano***)	Automation
Dirty	Augmentation
Dull (***such as domestic cleaning***)	Assistance
Difficult ***(cleaning the inside of a long pipe and space missions)***	Autonomous

Most robots today are used to do ***repetitive*** (***boring and dull***) actions or jobs considered too ***dangerous*** and ***difficult*** for humans. They are also used in factories to build things like cars and electronics. Some robots are even designed to explore underwater and on other planets!

Another reason we use robot is because it is cheaper, easier and sometimes the only way we can get things done! Robots can explore inside gas tanks, volcanoes, Mars and other places too dangerous for humans to go! Robots also can do one thing over and over again without getting bored – is that something you could do? Think about it – standing in one place doing the same thing all day and night would get pretty boring! **Another reason to use robots is because they never get sick; don't need to take a day off, and best of all they don't ever complain!**

There are four major reasons why **Nissan Corporation** uses automation and in particular industrial robots.

- Quality improvement.
- Better cost effectiveness.

- Flexibility to change.
- Improvement of working environment

Limitations of Robotics

- Are not creative or innovative
- Can not think independently
- Can not make complicated decisions
- Can not learn from mistakes
- Can not adapt quickly to changes in their surroundings

History of Automation/Robotics

Date	Development
mid- 1 700s	J. de Vaucanson built several human-sized mechanical dolls that played music.
1801	J. Jacquard invented the Jacquard loom, a programmable machine for weaving threads or yarn into cloth.
1830	Christopher Spencer (American) designs a cam operated lathe
1892	Seward Babbit (American) designs a motorized crane with gripper to remove ingots from a furnace.
1921	The first reference to the word robot appears in a play opening in London. The play, written by Czechoslovakian Karel Capek, introduces the word robot from the Czech robota, which means a serf or one in subservient labor.
1938	Willard Pollard and Harold Roselund (Americans) design a programmable paint-spraying mechanism for the DeVilbiss Company.
1946	J. Presper Eckert and John Mauchly build the first large electronic computer called the Eniac at M.I.T.
1948	Norbert Wiener (professor at M.I.T.) publishes Cybernetics, a book which describes the concept of communications and control in electronic, mechanical, and biological systems.
1954	1954 The first programmable robot is designed by George Devol, who coins the term Universal Automation. He later shortens this to Unimation, which becomes the name of the first robot company.
1960	Unimation is purchased by Condec Corporation and development of Unimate Robot Systems begins.
1964	Artificial intelligence research laboratories are opened at M.I.T., Stanford Research Institute (SRI), Stanford University, and the University of Edinburgh.
1970	At Standford University a robot arm is developed which becomes a standard for research projects. The arm is electrically powered and becomes known as the Stanford Arm.
1973	The first commercially available mini computer controlled industrial robot is developed by Richard Hohn for Cincinnati Milacron.
1978	The Puma (Programmable Universal Machine for Assembly) robot is developed by Unimation from Vicarm techniques and with support from General Motors.
1980	The robot industry starts its rapid growth, with a new robot or company entering the market every month.

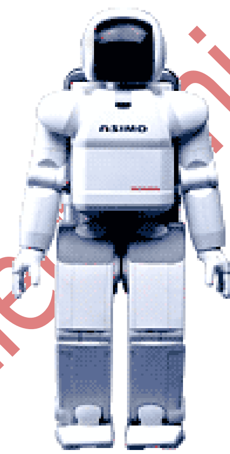
Types of Robots (some examples)

☐ ***Robot Manipulators***


☐ ***Mobile Manipulators***


☐ ***Aerial Robots***

☐ **Humanoid**



☐ ***Legged***

☐ ***Underwater robots***

☐ ***Wheeled mobile robots***

Hilare

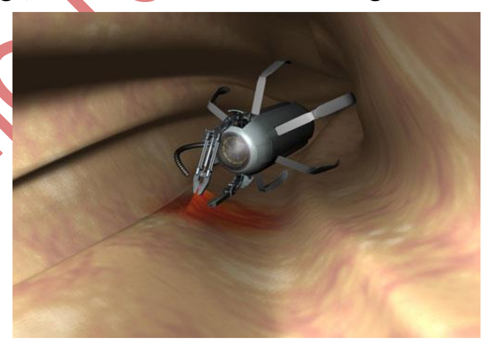
Sojourner

NASA and JPL, Mars

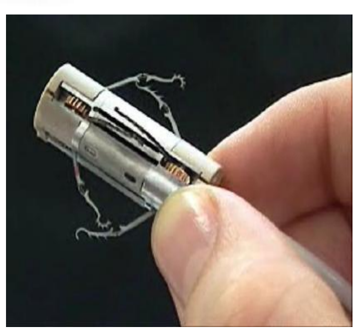
Mobile robot examples

2001: Capsule endoscopy

VECTOR-Versatile Endoscopic Capsule for gastrointestinal TumOr Recognition



Tele-operated Endoscopic Capsule with Active Locomotion Scuola Superiore Sant'Anna, Italy (research project)



Industrial Robot Applications

Historically, there have been two main streams for the development of robotics. ***One application area*** is the traditional industrial robot, employed for assembly line tasks such as welding, painting, and materials handling. ***The other application area*** is teleportation for hazardous environments, such as handling nuclear materials. More recently, the domain of application for robotics has expanded. Here are the most 10 industrial robot applications:

1) **Material Handling (see slide 12).**
2) **Polishing (see slide 12).**
3) **Punching (see slide 13).**
4) **Welding (see slide 13).**
5) **Palletizing.**
6) **Assembly.**
7) **Laser Cutting.**
8) **Spray Painting.**
9) **Inspection.**
10) **Deburring.**

See "industrial robot Videos" slide 14

Percentages of industrial robot uses in worldwide are **(60**% welding and painting ,20% pick and place and 20% others).

Advantages &Benefits of Industrial Robots

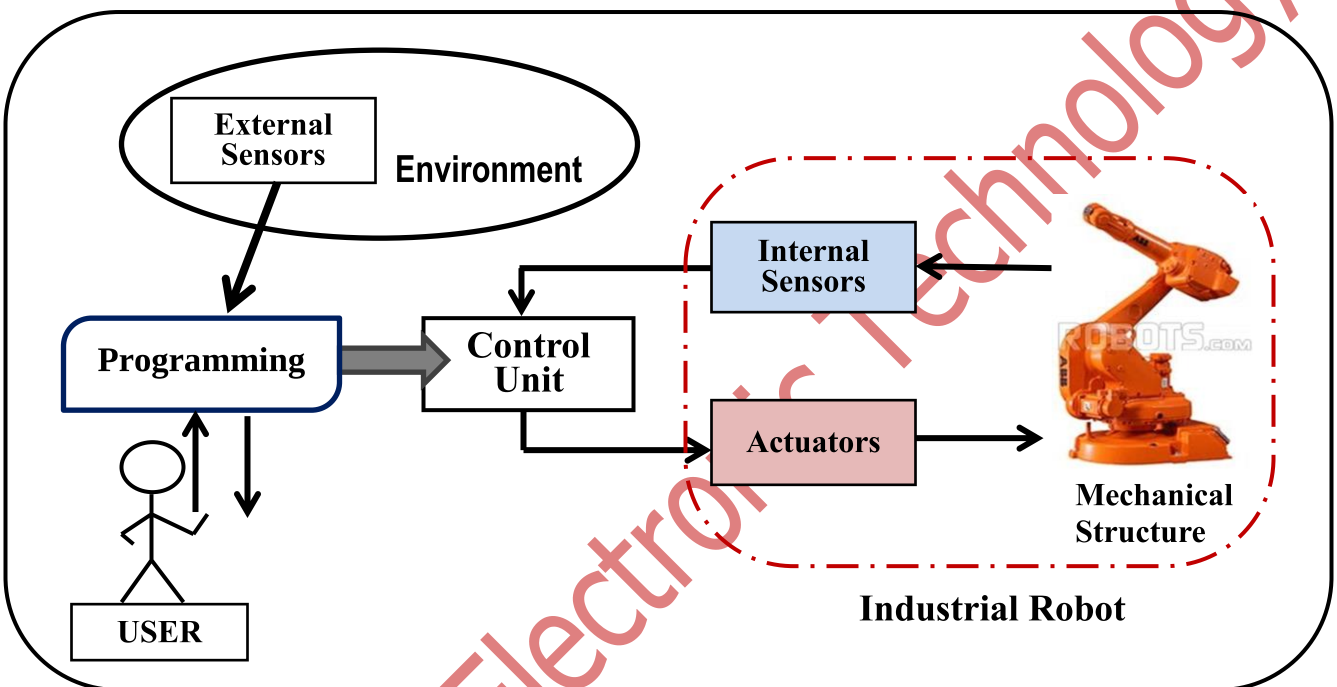
1. Increased output rates.
2. Improved product quality
3. Reduced material wastage.
4. Accident reduction.
5. Reduced labor turnover.
6. Greater flexibilityandre-programmability.

Dis-advantages of Industrial Robot

1) Replacement of human labor.
2) Robots are an expensive initial cost.
3) Can only do what it is instructed to do; nothing more, nothing les
4) Greater unemployment

Architecture of Robotic Systems

An industrial robot contains several electrical and mechanical components acting together as a system. The controller contains an operating system and software that dictates how the system operates and communicates. Sensors work together for gathering information (Localization and positioning).



- **Actuators:**
  Electrical, Hydraulic, Pneumatic, Artificial Muscle

- **Sensors:**
  Camera, Encoder, Photo Electronic, GPS, Compass, Gyroscope, Inertial navigation, Laser Range Scanners, Pressure

Configuration of Industrial Robot

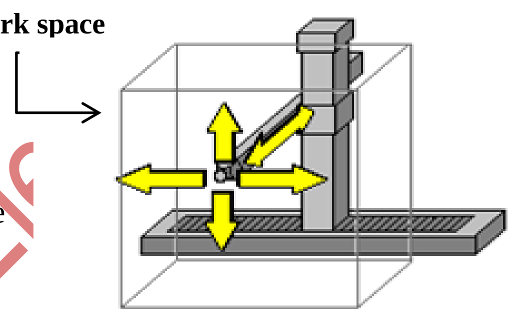
Over the years robot manufacturers have developed many types of robots of differing configurations and mechanical design, to give a variety of spatial arrangements and working volumes. The majority of these manipulators fall into one of these six configurations: **Cartesian** (PPP), **Cylindrical** (RPP), **Spherical** (RRP), **SCARA** (RRP), **Articulate/Revolute** (RRR) and **robot.** The work envelope or work volume is defined as the space within which the robot cans manipulator the end of its wrist. The shape of work volume is determined by the type of robot configuration.

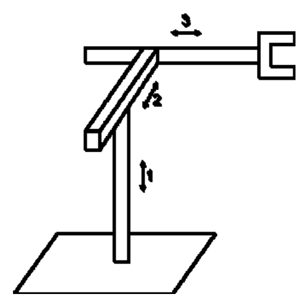
1- Cartesian Type Configuration (PPP),(X Y Z)

It is form by ***3 prismatic joints***, whose axes are coincident with the X, Y and Z planes. These robots move in three directions, in translation, at right angles to each other. Cartesian manipulator is useful for table-top assembly applications and, as gantry robots for transfer of material and cargo.

Advantages:

- 3 linear axes
- Easy to visualize
- Rigid structure
- Easy to program off-line





Disadvantage:

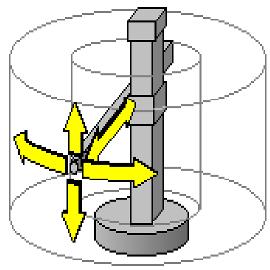
- Can only reach in front of itself
- Requires large floor space for size of work envelop
- Axes hard to seal

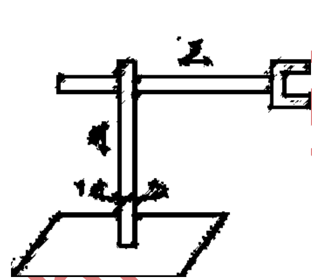
2- Cylindrical Type Configuration (RPP), (θ, r, z)

For cylindrical type manipulator, its first joint is revolute which produces a rotation about the based, while its second and third joints are prismatic. The robot arm is attached to the slide so that it can be moved radially with respect to the column.

Advantages:

- 2 linear axes, 1 rotating axis
- Can reach all around itself
- Reach and height axes rigid





Disadvantage:

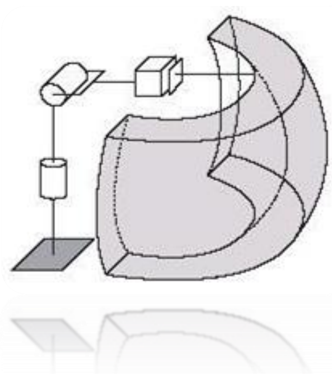
- Cannot reach above itself
- Base rotation axis is less rigid than a linear axis
- Will not reach around obstacles

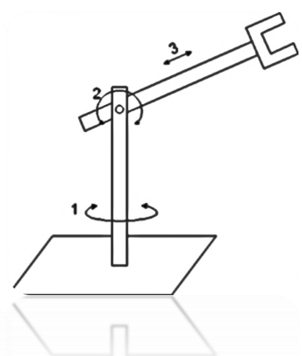
3- Spherical Type Configuration (RRP), (θ, β, z)

The first two joints of this type of manipulators are revolute, while its third Joint is prismatic. It used for a small number of vertical actions and is adequate for loading and unloading of a punch.

Advantages:

- 1 linear axis, 2 rotating axes
- Long horizontal reach





Disadvantage:

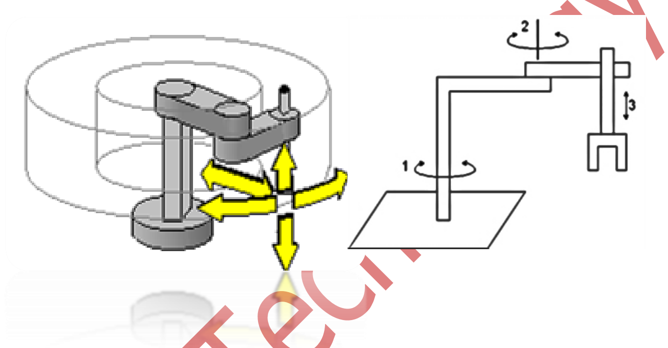
- Cannot reach around obstacles
- Generally has short vertical reach

4- Scara Type Configuration (RRP or PRR), (θ, φ, z)

The word SCARA stands for Selective Compliant Articulated Robot for Assembly. There are two type of SCARA robot configuration: either the first two joints are revolute with the third joint as prismatic, or the first joint is revolute with the second and third Joints as prismatic. Although some of the SCARA robots have the RRP structure.

Advantages:

- 1 linear axis, 2 rotating axes
- Height axis is rigid
- Large work area floor space
- Can reach around obstacles
- Two ways to reach a point



Disadvantage:

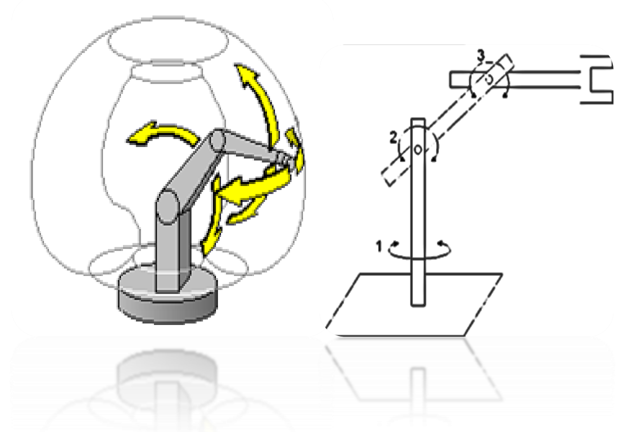
- Difficult to program off-line
- Highly complex arm

5- Revolute Type Configuration (RRR), (θ, β, α)

Also called articulated manipulator that looks like an arm with at least ***three rotary joints***. They are used in welding and painting; gantry and conveyor systems move parts in factories.

Advantages:

- 3 rotating axes
- Can reach above or below obstacles
- Largest work area for least work space
- Two or four ways to reach a point



Disadvantage:

- Difficult to program off-line
- The most complex manipulator

6- Parallel Type Configuration (RRR), (θ, β, α)

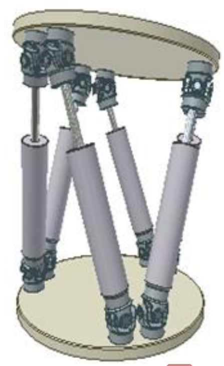
It is a complex mechanism which is constituted by two or more kinematics chains between, the base and the platform where the end-effectors are located.

Advantages:

- Motors can be proximal:
- higher bandwidth,
- easier to control

Disadvantage:

- Generally less motion
- kinematics can be challenging

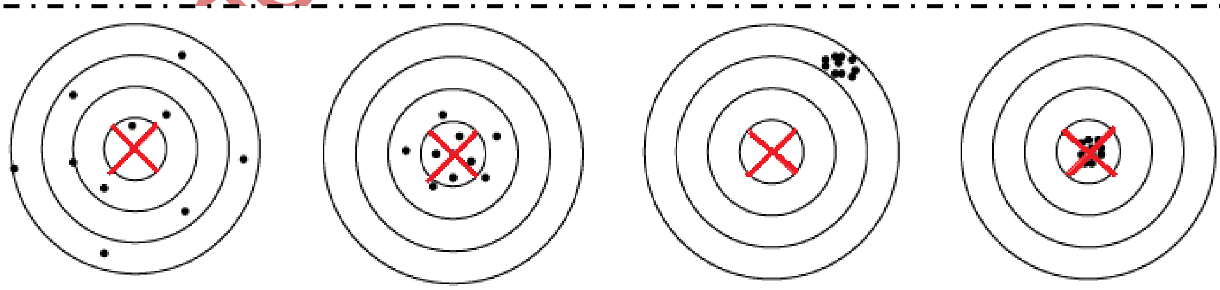


Workspace : is the volume of space reachable by the end-effector, Everywhere a robot reaches must be within this space.Tool orientation and size also important.

Repeatability and Accuracy of an Industrial Robot

Accuracy: Accuracy refers to a robot's ability to position its wrist end at a desired target point within the work volume.

Repeatability: Repeatability describes how a points are repeated at the same place or target.



Bad Accuracy
Bad Repeatability

Good Accuracy
Bad Repeatability

Bad Accuracy
Good Repeatability

Good Accuracy
Good Repeatability

Robot Classification

- **Arm Configuration:**
  - Cartesian Coordinate.
  - Cylindrical Coordinate.
  - Spherical Coordinate.
  - Scara Coordinate.
  - Revolute Coordinate.

- **Drive System:**
  - Electrical.
  - Hydraulic.
  - Pneumatic.

- **Drive Gear System:**
  - Direct Drive Robots.
  - Geared Robots.

- **Level of Technology:**
  - Low Technology: (material handling, using simple assemble 2-4 axes of movement, stop at extremes).
  - Medium Technology: (pick & place, material handling, 4-6 axes).
  - High Technology: (material handling, pick and place, loading, painting and welding, 6-9 axes).

- **Field of Applications:**
  - Industrial Robot.
  - Medical Robot.
  - Space Robot.
  - Military Robot.
  - Aerial Robot.
  - Etcetra ………..

- **Tooling Applications:**
  - Painting robot.
  - Welding robot.
  - Gluing robot.
  - Deburring robot.
  - Etcetra ………..

Motors and Actuators Technologies

Actuators and Motors are devices that make robot move “robot muscle “. For most industrial robots, the actuators are coupled to the respective robot link through a, gear train. The effect of the gear reduction is largely to decoupled the system by reducing the coupling among the joints. However, the present of gears introduces friction, backlash and drive train compliance. **The commonly used actuators are:**

Pneumatic:
- Energy efficient
- Hard for feedback control

Electric:
- clean
- choice of today

Hydraulic:
- can deliver large forces
- bulky, leakage problems

Electrical Drive

Small and medium size robots are usually powered by electric drives via gear trains using servomotors and stepper motors. Most commonly used are dc motors, although for larger robots, ac motors may be utilised. *A new design based on direct drives (without gear trains) is being developed*.

Advantages:

- Better accuracy & repeatability
- Require less floor space
- More towards precise work such as assembly applications

Disadvantage:

- Generally not as speedy and powerful as hydraulic robots
- Expensive for large and powerful robots, can become fire hazard

Hydraulic Drive

Larger robots are usually powered by hydraulic drives . Hydraulic drive system can provide rotational motion (rotary vane actuators) and linear motion (hydraulic pistons).

Advantages:

- More strength-to-weight ratio
- Can also actuate at a higher speed

Disadvantage:

- Require large floor space
- Tendency to oil leakage

Pneumatic Drive

Generally used For smaller robots that possess fewer degrees of freedom (2- 4 joint motions). They are limited to pick-and-place tasks with fast cycles. Pneumatic drive system can be applied to the actuation of piston devices to provide linear motions. Rotational motions can be achieved by rotary actuators

Advantages:

- Cheaper & lower technology options for control of speed.
- Safe to use and Light in weight

Disadvantage:

- Require large floor space
- Tendency to oil leakage