Introduction to Robotics

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Robot

- **Robot** is an automatically operated machine that replaces human effort with/without any resemblance to human.
  $\rightarrow$ They are usually programmable through a computer and can carry our a complex series of tasks automatically.
- **Industrial Robot** are used for manufacturing in the Industry and are capable of movement on three or more axes.
- With various attachments to its end-effector it has a potential to be used for all *Dull, Dirty, Dangerous, Difficult* and *Dear* tasks.

Figure: FANUC $M - 2000iA$, Payload: $2300kg$
Repeatability: $0.18mm$, Reach: $3734mm$

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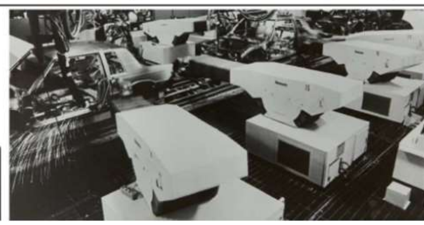
Timeline of Industrial Robot and its Evolution

- The first stationary industrial robot was the programmable *Unimate*.
- Invented in 1954 by the American engineer George Devol.
- Developed by *Unimation Inc.*, a company founded in 1956 by American engineer Joseph Engelberger.
- First prototype was introduced in 1959 at General Motors Corporation at its die-casting factory in Trenton, New Jersey.
- World's first production-line *serial robot* was delivered to GM factory in 1961 by *Condec Corporation* (an acquisition of Unimation).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Applications of Industrial Robots

Video tour of various industrial applications

- Material Handling: pick and place, palletizing, packaging, etc.
- Processing: Welding (spot or arc), Surface finishing (polishing, buffing, grinding, deburring), painting, spray coating, metal cutting, gluing, adhesive sealing, machining, drilling, etc.
- Assembling: Collaborative tasks, needs Compliance.
- Machine Tending
- PCB manufacturing
- **Others**: Medical, Space, Underwater, Defense, Agriculture, Movie making, Amusement, etc.

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Anatomy of the Robot Arm

Video demonstration

1. Robot Manipulator: Serial/Parallel Arm
2. Connecting Cables: Power, Sensing, Pneumatics and Actuators
3. Controller Hardware and Software
4. Teach Pendant for Programming
5. End-Effector Tools: Gripper, Painting gun, Welding attachment, Grinding or polishing attachment, etc.
6. Software for controller, GUI and I/O's.
7. Optional Accessories: Camera, External Axes, Sensors, etc.

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Anatomy of the Controller Hardware

1. Controller IPC
→ RT-OS, VxWorks, WinCE, Proprietary Embedded OS, etc.
2. Servo Drives
3. Backup Battery
4. Input/Output Modules
→ For grippers, sensors, etc.
5. Safety Circuits
6. Power Systems
7. Cable connectors
8. Data communication wires
→ Profinet, DeviceNet, Profibus, EtherCAT, etc.

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Payload of a Robot

- **Payload**: is the maximum weight a robot can lift in all possible configurations within the specified workspace.
- It includes the weight of the end-effector tool and the weight of the object it is carrying.
- Industrial robots are certified for the various performance parameters, like repeatability, maximum velocity, etc. by considering this weight.

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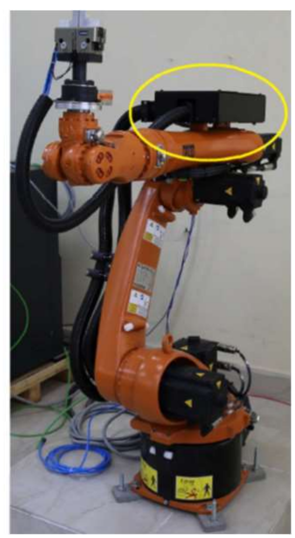
- **Supplementary Loads**: It is an additional load apart from the robot's payload that it can carry on the one of its moving link.
- The maximum dimensions and possible positions of the installation can be found in the datasheet.



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- **Number of Axes**: Normally this is the number of Degrees-of-Freedom for a typical industrial serial robot.
  → E.g: SCARA Robot - 4 Axis, FANUC R-2000iC/210F - 6 Axis, KUKA iiwa - 7 Axis

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- **Mounting Flange**: Normally all standard media flanges have a hole pattern conforming to ISO 9409.
  → This supports interchangeability of various end-effector tool attachments with different industrial standards.

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- **Pose Repeatability** quantify the differences which occur between a command and attained pose, and the fluctuations in the attained poses for a series of repeat visits to a command pose.
- Geometrically it is the radius of the smallest sphere that encompasses all the positions reached for the same commanded position.
- ISO 9283 refers to the standard that defines repeatability and its measurement procedures.
- It is measured with the specified payload and maximum velocity under standard operating conditions as prescribed by the manufacturer.
- For industrial robots it varies from ± 0.05 to $\pm 0.1 mm$.
- **Others**: Drift, Overshoot, Accuracy, Stabilization time,
  Velocity, Compliance, Cornering deviation, etc.

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- **Mounting Position**: Floor, Ceiling, Wall, Inclined

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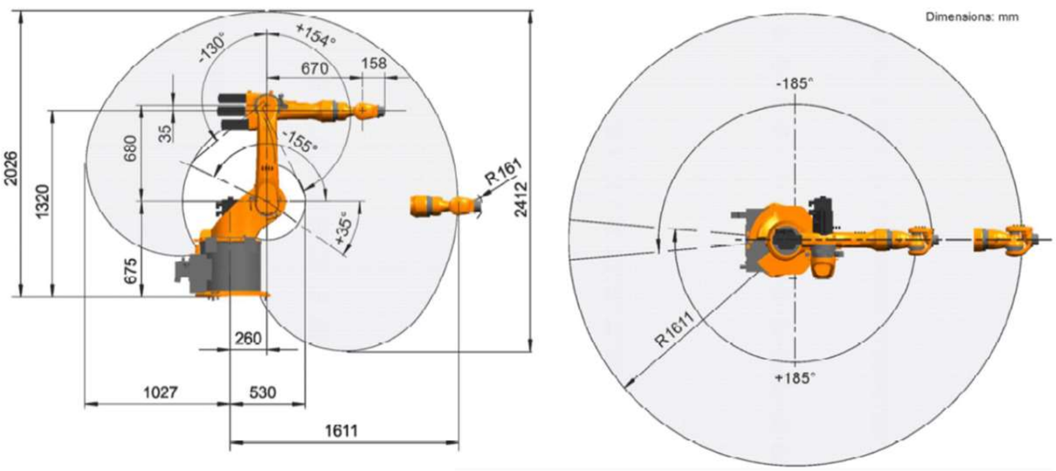
- **Working envelope**: Cylindrical, Cartesian, Spherical, Articulated (Complex 3D shape involving convex and concave circular arcs), 3D or 2D, etc.



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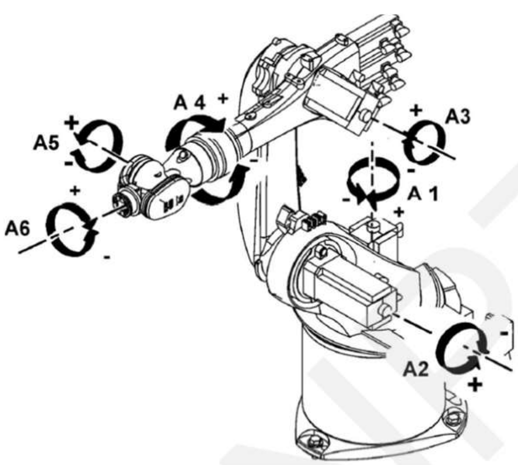

- Specifies the extents and shape of the working envelope.
- Defines the positive direction of rotation: Useful in programming.
- Useful in identifying safe zone from link collisions by setting software limits.

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Classification of Robots

1. Existing Internationally approved classifications (JIRA and AFR).
2. Classifications based on:
   - Power Source
   - Workspace Geometry
   - Degrees of Freedom
   - Kinematic Structure
   - Movement and
   - Type of Applications

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Classification by Japanese Industrial Robot Association (JIRA)

- **Class 1: Manual Handling device** - A device with multiple degrees of freedom that is actuated by an operator.
- **Class 2: Fixed-sequence robot** - A device that performs the successive stages of a task according to a predetermined, unchanging method and is hard to modify.
- **Class 3: Variable-sequence robot** - A device that performs the successive stages of a task according to a predetermined, unchanging method and is easily reprogrammed.
- **Class 4: Playback robot** - A human operator performs the task manually by leading the robot, which records the motions for later playback. The robot repeats the same motions according to the recorded information.
- **Class 5: Numerical Control robot** - The operator supplies the robot with a movement program rather than teaching it the task manually.
- **Class 6: Intelligent robot** - A robot with the means to understand its environment and the ability to successfully complete a task despite changes in the surrounding conditions under which it is to be performed.

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Classification by Association Francaise de Robotique (AFR)

French Association of Industrial Robotics

- **Type A**: Handling device with manual control to telerobotics. (class 1)
- **Type B**: Automatic handling devices with predetermined cycles. (classes 2-4)
- **Type C**: Programmable, servo controlled robots with continuous or point-to-point trajectories. (class 5)
- **Type D**: Programmable, servo controlled robots equipped with sensing systems and capable of adapting to changes in surrounding conditions. (class 6)

Note:

Type A = Telerobotic
Type B = Sequencing robots
Type C = CNC robots - Not a CNC Machine owing to mechanism or tasks.
Type D = Intelligent robots

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Based on Power Source: As in ISO 9946

Electrical, Hydraulic, Pneumatic, Non-conventional sources

1. **Electrical**: AC/DC
   DC: Higher torque, More parts and maintenance
   → BLDC, Brushed geared motors, Steppers, etc.
   → Used in Mobile, Aerial, and Underwater robots.
   → AC Servo: Large capacity industrial robots
   → Mostly with synchronous servo motors.

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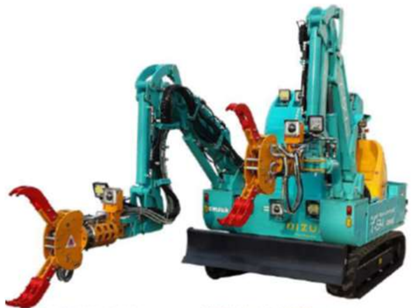

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   → Problems - noise, leak, fire hazard, maintenance, etc.

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   → Problems - noise, leak, fire hazard, maintenance, etc.
3. **Pneumatic**: High speed robots.
   → Issues of compressibility of gas - lack of precision, drifting, etc.
4. **Non-conventional sources**: Nuclear - Submarines, Deep Space explorations, Solar - Space robots, etc.
   → Mostly runs electrical actuators.

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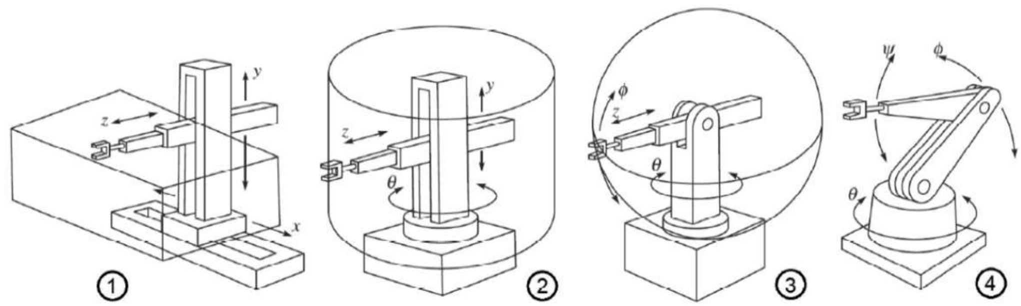
Based on Workspace Geometry: Mechanical Structure (ISO 9946) [1]

1. **Cartesian (PPP)**: For heavy loads in Industry - Simple, Easy to use and program.
2. **Cylindrical (RPP)**: More reachable, large payload, rigid structure.
3. **Spherical/Polar (RRP)**: Large range.
4. **Articulated Arm**: Most common in Industry.



Joint type: Prismatic (Linear Actuators - P) or Revolute (Rotary Actuators - R).

[1] An extended discussion shall be made while covering kinematics.

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Cartesian Robot

Cartesian/Rectangular Gantry(3P): These Robots have 3-Linear joints that position the end-effector, which are usually followed by additional revolute joints for controlling orientation.

Makers: *Gudel AG, Martin Lord, Fibro, IAI, PROMOT, MOTEC, BOSCH Rexroth, KUKA, Nordson EFD, Cincinnati Milacron, Parker, Festo Diactic, Mazak, Lucas.*

Applications: CMM, Inspection, Laser Cutting, Pick-and-place, Loaders, etc.

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Cylindrical Robot

Cylindrical Robot (R2P or RPP): These Robots have a rotary joint and 2-Linear joints that position the end-effector, and are usually followed by additional revolute joints for controlling orientation.

Makers: (Very Few and Old) *Seiko, Hudson, ST Robotics.*

Applications: Limited operations in hotel industry, tool loaders, pick-and-place, etc.

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Spherical Robot

Spherical Robot (2RP): These Robots have 2-rotary joints and a prismatic joint that position the end-effector, and may have an additional revolute joint for controlling orientation.

Makers: (Obsolete) *Unimate-Kawasaki.*

Applications: (Limited) Lack of vertical axis motion, used as tool loaders and specific pick-and-place.

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Articulated Robot

Articulated Arms (6R or Combination): These are serial chained robots that normally have 6-rotary or in combination with prismatic joints that position the end-effector that can position and orient in 3D space.

Makers: *Yaskawa, Fanuc, KUKA, ABB, and many others.*
Applications: Almost all industrial jobs that includes pick-and-place, surface finishing, welding, painting, collaborative tasks, assembly, etc.

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Based on Degrees of Freedom (DoF)/ Number of Axis[2]

1. Planar - 2/3 DoF
2. Spatial: 3 DoF pure translating/rotating robot
3. 6-DoF: 3 Translation and 3 Rotation
4. Redundant robots
5. Limited DoF: 4 or 5 for special purposes

[2]Degrees of Freedom (DoF) is the number of independent parameters that define the configuration or state of a mechanical system.

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Based on Kinematic Structure

1. Open loop: Serial Robot

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Based on Kinematic Structure

1. Open loop: Serial Robot
2. Closed loop: Parallel structure

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Based on Kinematic Structure

1. Open loop: Serial Robot
2. Closed loop: Parallel structure
3. Hybrid or Tree type systems

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Based on Movement

1. Fixed Robots

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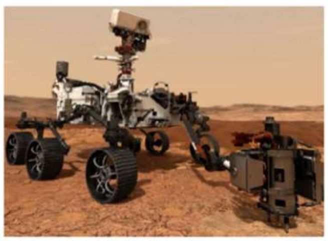
Based on Movement

1. Fixed Robots
2. Mobile robots:
   → Wheeled, Omni wheels, Legged, etc.



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Based on Movement

1. Fixed Robots
2. Mobile robots:
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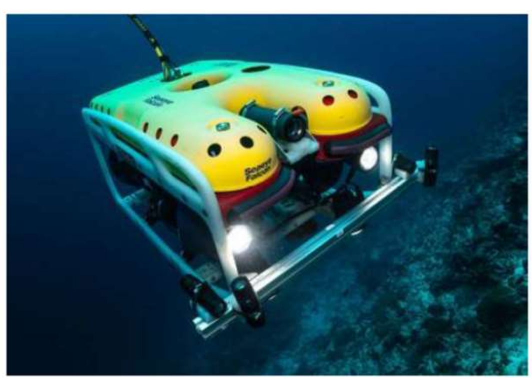
3. Swimming robots and Underwater robots.



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3. Swimming robots and Underwater robots.
4. Aerial or Flying robot.

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Other Classifications: Based on applications (Industrial/Domestic).

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Broad categories of Articulated and Parallel Robot

Based on Majority of Application

Selective Compliance Articulated Robot Arm (SCARA): 4 DoF, Fast
Used in: Electronics industry, pick-and-place.

Delta: 3/4 DoF, Extremely Fast
Used in: Food, Beverage, Agro industries.

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Serial Robots: Cartesian Motion of End-effector

- Most widely used class of robot
- Simple and easy to program
- Balance: Reach ↔ Payload
- Video: Motion in *Base Frame*
  → Cartesian translation
  → and Rotations along X, Y, Z
- These facilitate:
  → Point-to-Point (PTP): pick and place tasks
  → Combination of primitives: CIRC, LIN, etc.
  → Interpolated spline trajectory: welding, painting, etc.
  → Compliant motions using Force/Torque sensors.

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Serial Robots: Joint space trajectories

- Each joint motion would create a segment of circular arc in space
- Difficult to estimate the tool path
- Requires proficiency in robot programming skills
- Configuring axis-specific workspaces: limiting joint motions.
- This restricts the robot entering into the probable areas of collision with the surrounding objects $\rightarrow$ Also applicable for Cartesian motion restriction.
- Program for path that passes near to the robot's **singularity**

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Popular Industrial Serial Vs Complex Parallel Architectures

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Brief History of Parallel Robot

- 1928: First motion platform - Oxymoron "Motion Base", Patent by James E. Gwinnett.
  ⇒ A spherical parallel robot! (near to the first motion picture in color)
  ⇒ No reporting on any hardware being developed on that.
  ⇒ **Industry was not ready for the complexity of his invention**
- 1934: Willard Pollard Jr. filed a patent for a spray painting parallel manipulator.
  ⇒ Unfortunately again: No machine was ever built!
- **1954**: Dr. Eric Gough (Automotive engineer at Dunlop Rubber Co., Birmingham) built the "first hexapod"
  ⇒ Used for Tire testing machine.
- 1965: Mr. Stewart describes a 6-DOF motion platform for use as a flight simulator
  ⇒ Followed by chain of publication by Mr. Stewart!

Note: **1954**: George Devol applied for the first industrial robot arm patent (granted in 1961)
1956: First Industrial robot was built by Unimation Inc.
A company by G. Devol and Joseph F. Engelberger.

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Parallel Robots: Cartesian Motion of End-effector

- Popular variant: 3-DoF Delta robot
- Applications: Pick-and-place tasks, 3D Printing, Medical.
- Demo: 6-DoF Parallel robot in 6-RSS Zamanov configuration
- More power/weight ratio, Extremely fast and Precise.
- Complex mechanisms
- High end controllers: perplexed kinematic/dynamic solutions, workspace singularities exists.
- All the capabilities of a serial robot in *relatively small workspace*.
- Joint trajectory planning is far too complex to be used even by any expert programmer.

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Parallel Robots in the Industry

- Simulators: Flight, Naval, Automobile (Mining or Just Trucks)
- Moving Giant Telescopes, Solar panels!!
- Pick-and-Place in Food, Packaging, and Agro industries: Mainly 3-DoF Delta
- Medical robot for surgeries
- 3D Printing, Milling (5D Printing!!)
- Micro-manipulators
- Most of the applications where a serial robot can go with some exception in workspace and reach requirements.

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Advantages and Disadvantages: Serial and Parallel

As compared to serial robot of similar payload capacities

Advantages of parallel manipulators:

- High stiffness: load is shared by multiple legs
- High accuracy: joint manufacturing and/or assembly errors will be even out rather than accumulated at the end effector.
- High speed of movements: low moment of inertia of moving links !!!
- High payload-to-self weight ratio
- High natural frequencies: Why is it fruitful?
- High power/weight ratio.

Disadvantages:

- Limited workspace: Not an issue
- Singularities: ???
- Non-linearity: Even Serial robots are highly non-linear!

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