Introduction to Robotics
Rev II

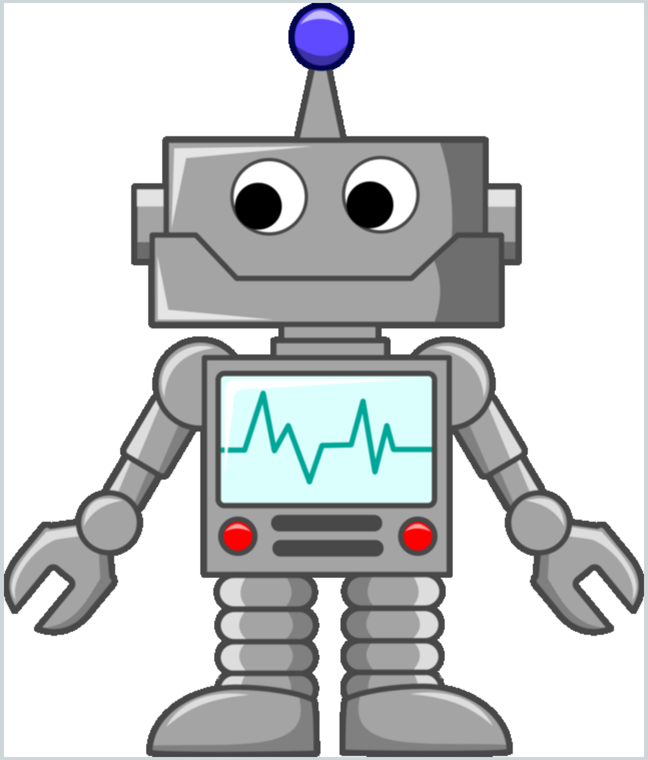
DR. TAREK A. TUTUNJI

MECHATRONICS ENGINEERING DEPARTMENT
PHILADELPHIA UNIVERSITY, JORDAN

2018

Outline

- Definition
- History
- Classification
  - Manipulators
  - Mobile
- Modeling, Planning, and Control
- Robotic Components
- Applications
- Conclusion



What is a Robot?

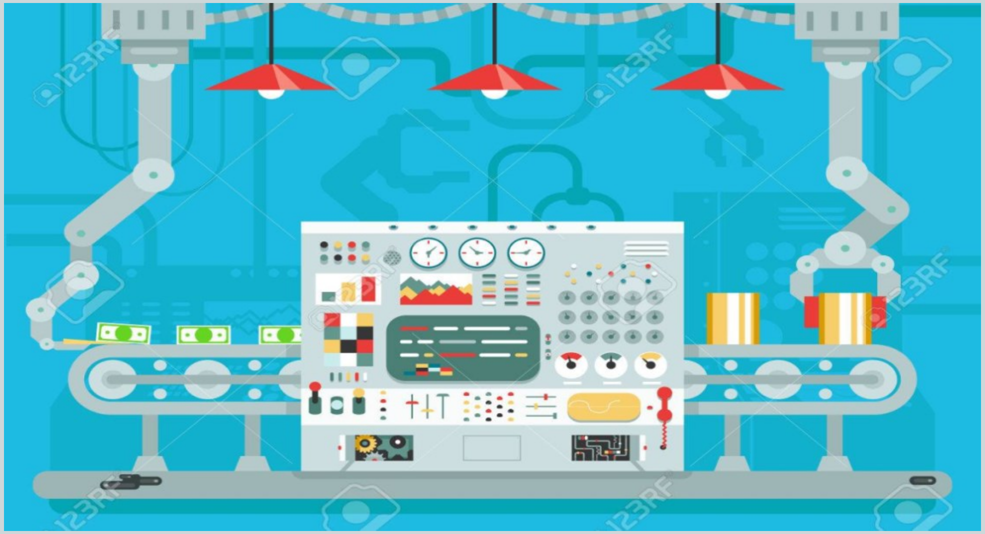
- *A machine capable of carrying out a complex series of actions automatically*. Webster Dictionary

- *Any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner*. Encyclopedia Britannica

- *An electric machine which has some ability to interact with physical objects and to be given electronic programming to do a specific task or to do a whole range of tasks or actions. It may also have some ability to perceive and absorb data on physical objects, or on its local physical environment, or to process data, or to respond to various stimuli*. General from Wikipedia

What is a Robot?

- ***A reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks*.** Robot Institute of America

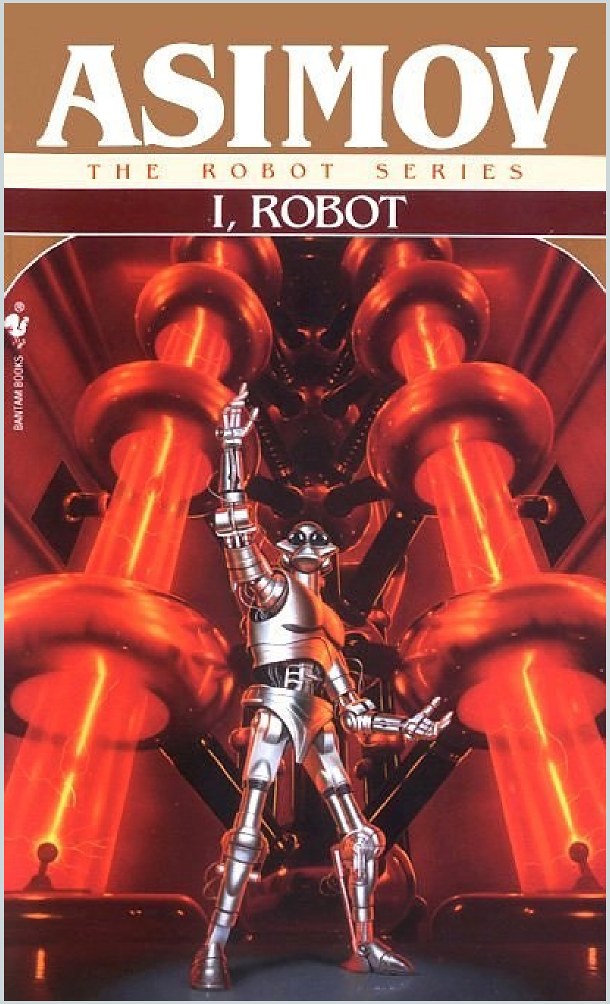


History

- Ancient Age: Pneumatica and Automatica (description of machines) by Heron.
- Middle Age: Early programmable automata (Musical Robot) by Al-Jazari
- 19th century: Japanese mechanical toys

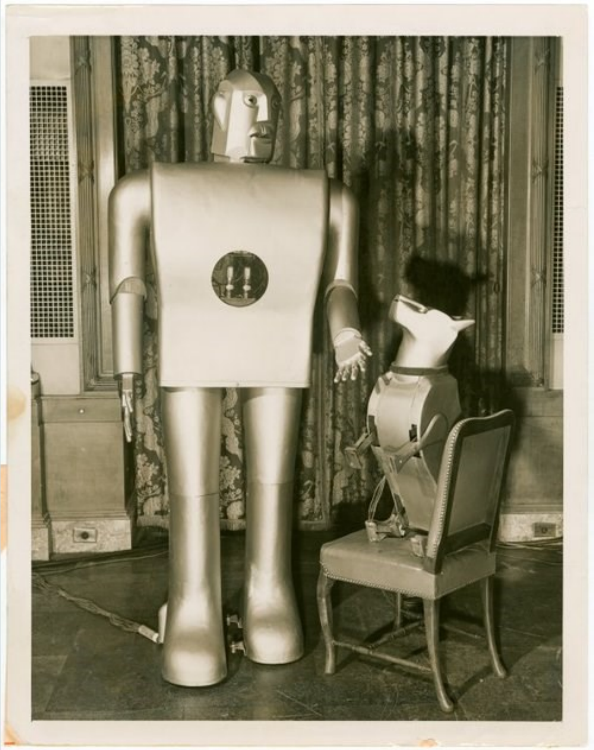
History

- 1920. The word ‘Robot’ appeared in a Czechoslovakian play.
- 1930. Isaac Asimov science fiction novels



History

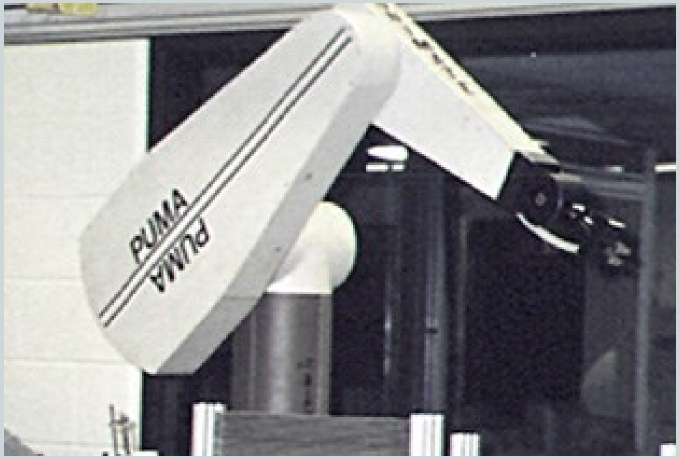
- 1940. Westinghouse Electric Company (Electra) develops walking robot using electrical actuators
- 1948 First Autonomous Robot (Elmer) used motor control by electric circuits and vacuum tubes
- 1954. First industrial/programmable Robot used in manufacturing T.V. tubes
- 1962. First Robot Company (Unimation) and First installed industrial robot



Electra

History

- 1968. Mobile Robot with Vision (Shaky) developed at Stanford Research Institute
- 1978. Programmable Universal Machine for Assembly (PUMA) developed at General Motors.



Puma

Shaky

History

- 1986. LEGO and MIT Media Labs collaborate on 1st LEGO educational kit.

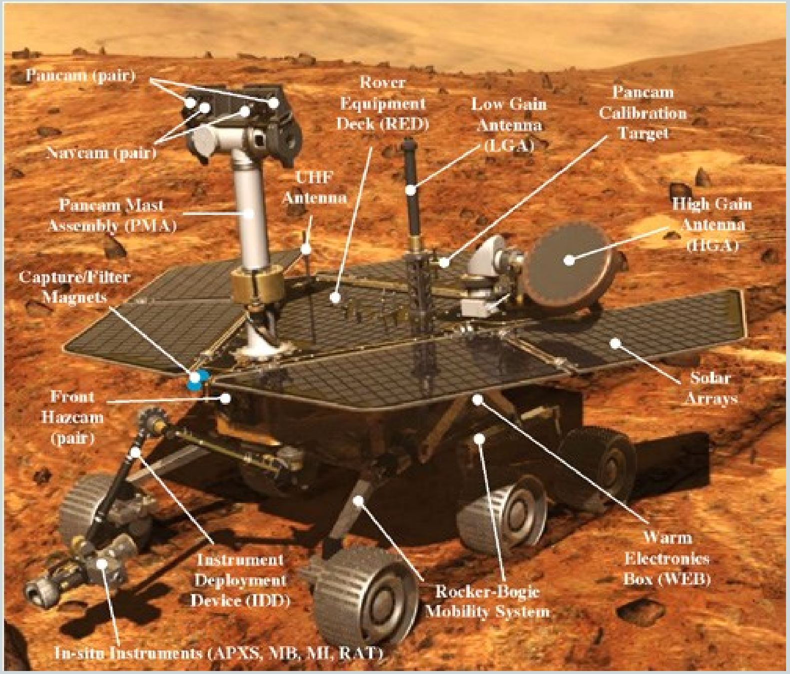
- 1994. Walking robot (Dante) to collect data from harsh environments

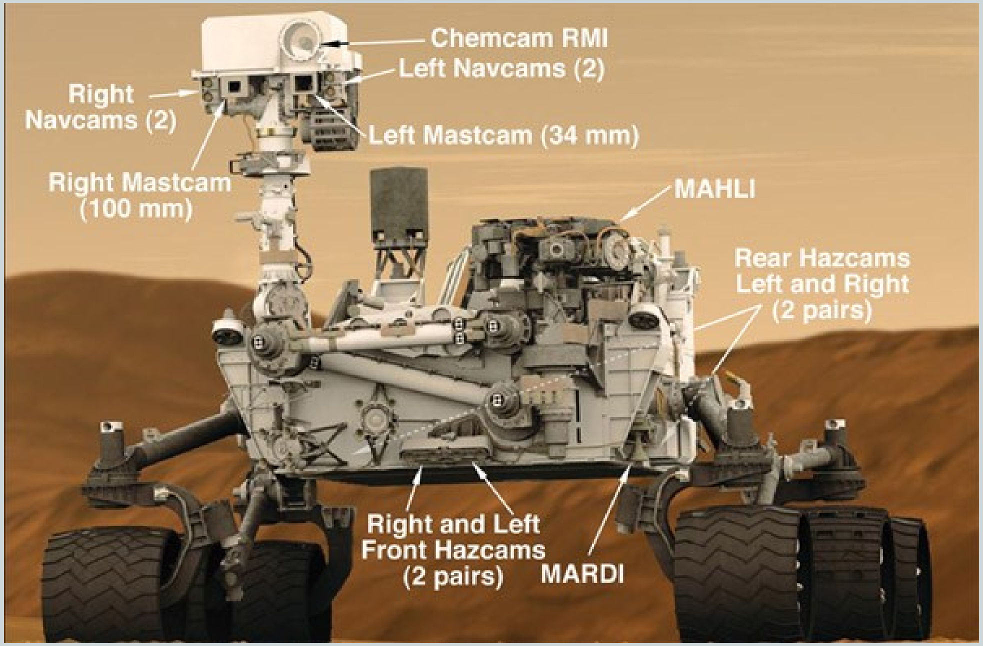
- 1998. Mindstorm LEGO Robotics

- 2000. Honda debuts humanoid robot (ASIMO)

History

- 1997-2012 NASA Mars explorations



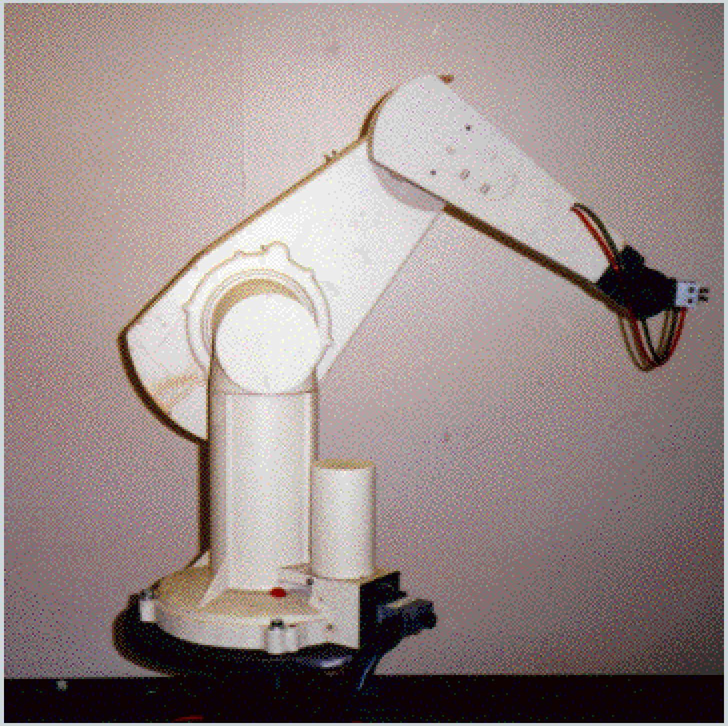


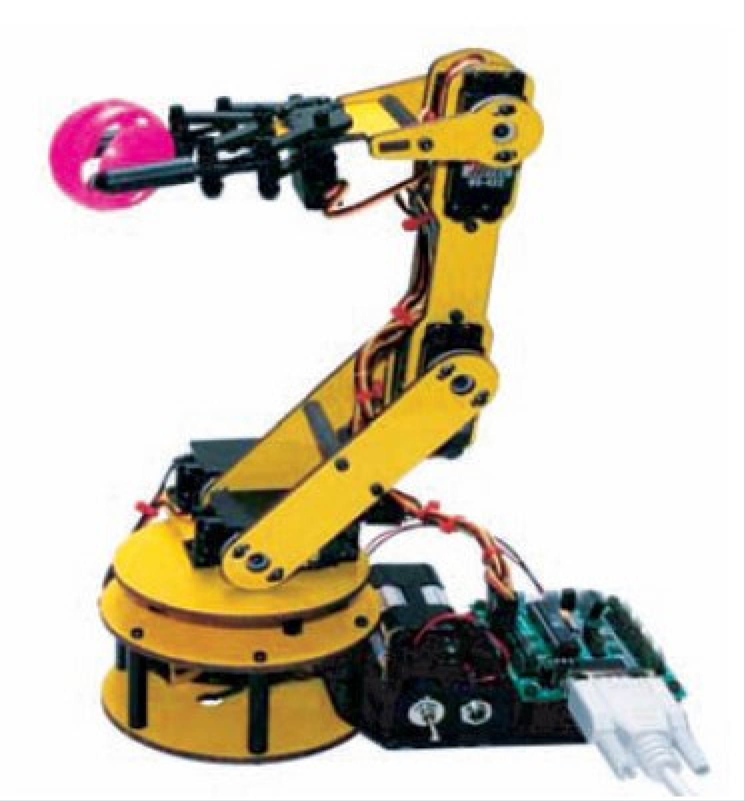
https://www.youtube.com/watch?v=liypQHa_dr8

Classifications

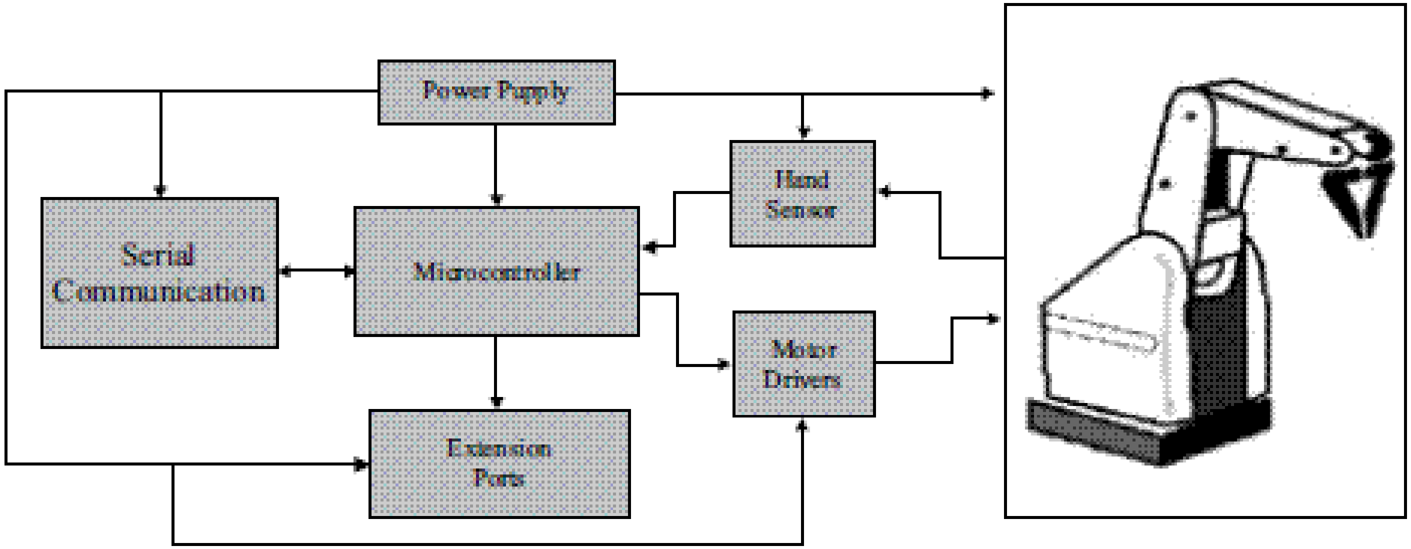
- **Fixed Robots**
  - Manipulator arms used mainly in industry
- **Mobile Robots**
  - Robots that navigate around a workspace. This requires sensors to see the workspace, avoid collisions, and accomplish the required target

Fixed Robots (Manipulators)



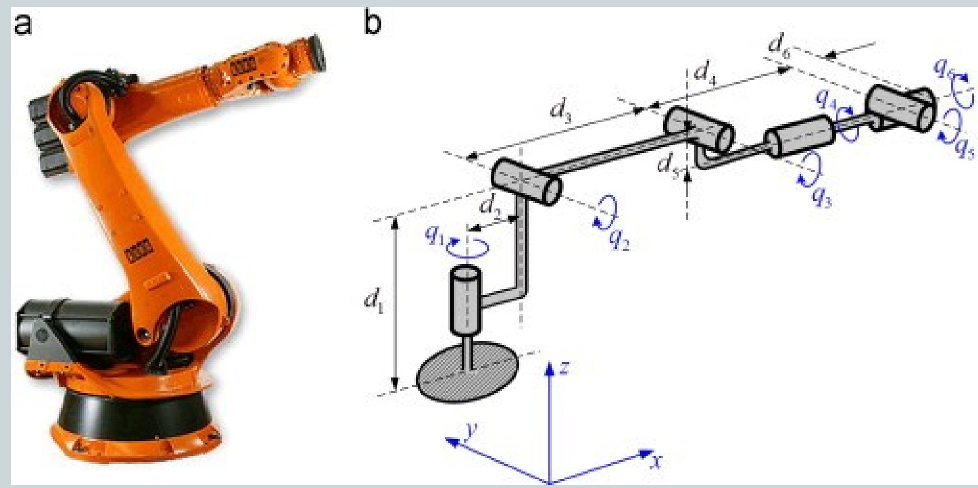


Fixed Robot: General Block Diagram



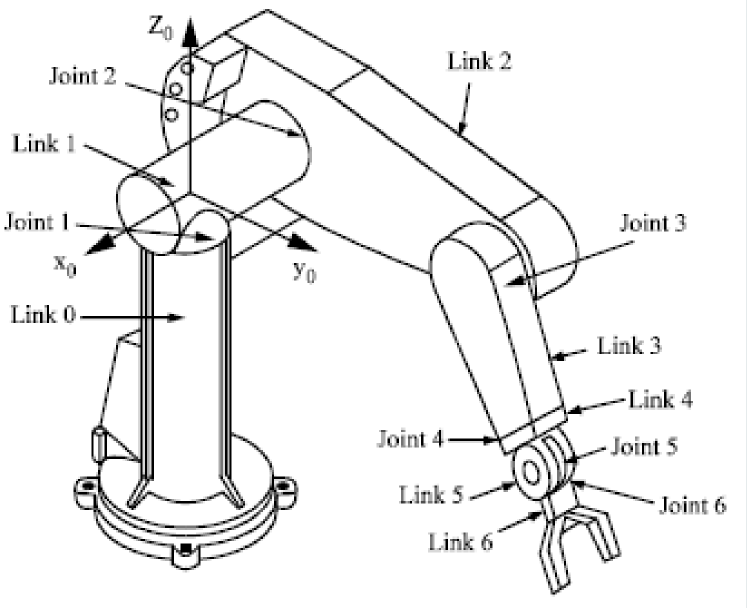
Kuka Robot Manipulator

KUKA

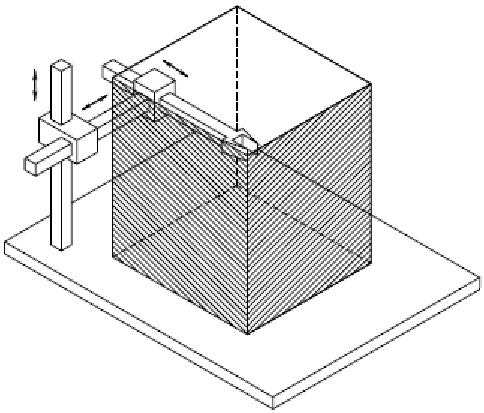


Six-axis robots in virtually all sizes with different payload capacities and reaches and a wide range of different variants

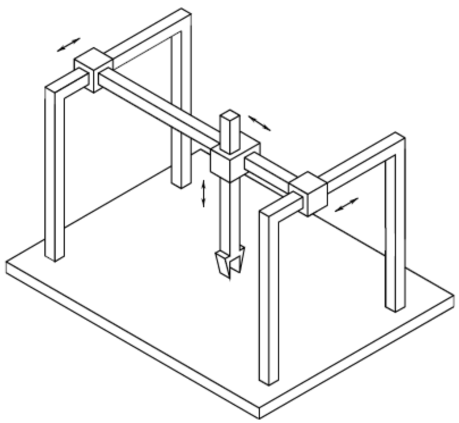
PUMA Robot Manipulator



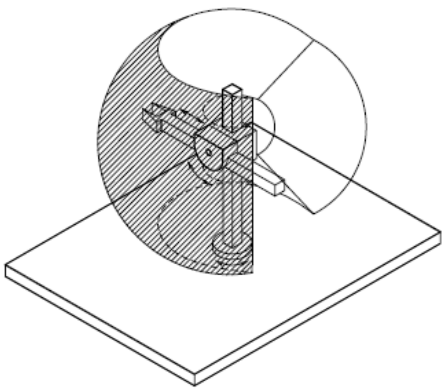
Robot Manipulators, Structures, and Workspace



Cartesian manipulator and its workspace



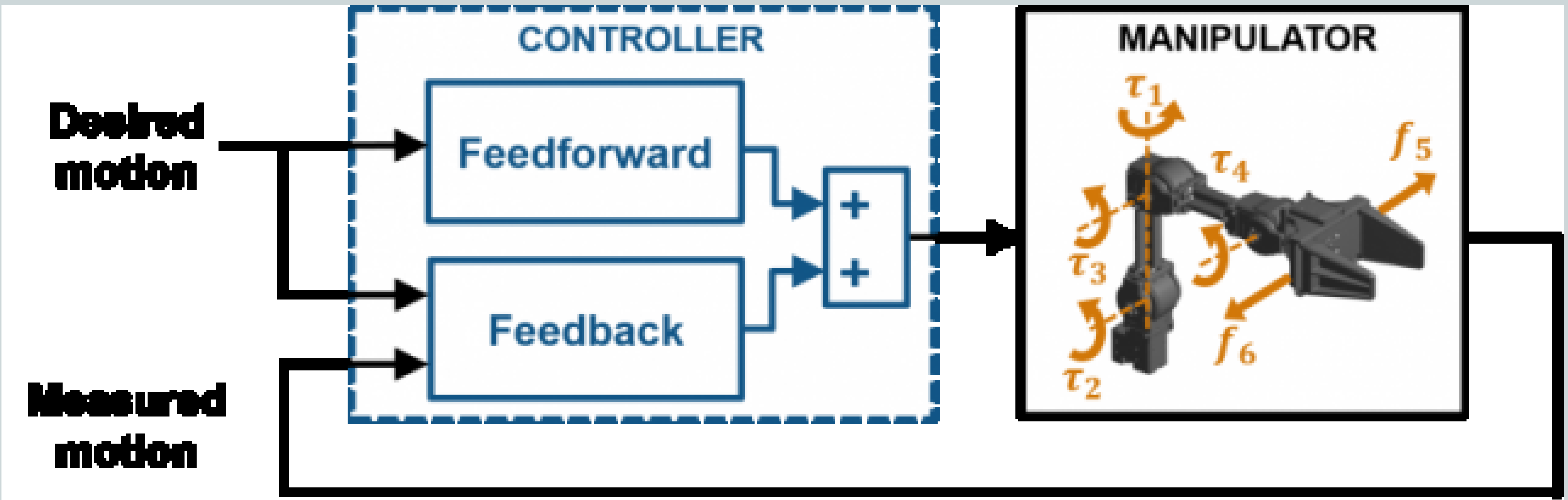
Gantry manipulator



Spherical manipulator and its workspace

https://www.youtube.com/watch?v=5tRT5j3jfsE

Robot Modeling, Planning, and Control



Robot Modeling, Planning, and Control

- **Robots** are required to execute certain **motions**.
- The **control system** provides the robot's actuators with commands to achieve the desired motion. This requires analysis of the mechanical structure's characteristics.
- **Mathematical models** describe the input/output relationship characterizing the robot and are necessary to design the motion control strategies.

Kinematic Modeling

- **Kinematics** are equations of the motion with respect to a fixed reference Cartesian frame (by ignoring the forces and moments that cause motion)

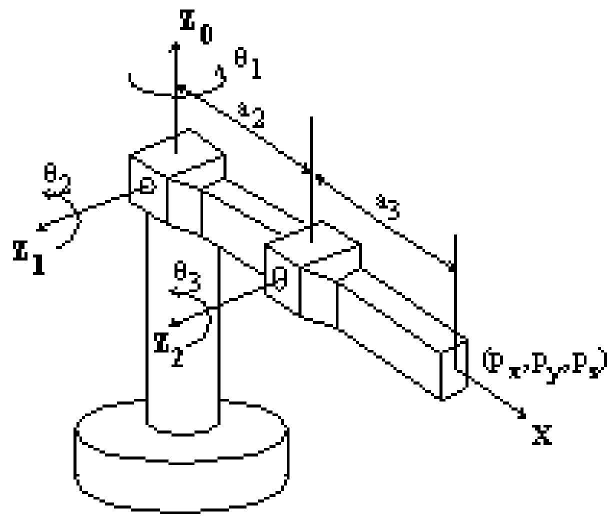
- Kinematics vs. differential kinematics
  - Kinematics describes the analytical relationship between the joint positions and the end-effector position and orientation.
  - Differential kinematics describes the analytical relationship between the joint motion and the end-effector motion in terms of velocities.

- Direct Kinematics and Inverse Kinematics

Kinematics

Table 1 Link parameter table.

link	variable	α	a	d
1	θ_1	90°	0	0
2	θ_2	0°	a_2	0
3	θ_3	0°	a_3	0



Denavit-Hartenburg Transformations

$$T_3 = A_1A_2A_3 = \left[\begin{array}{ccc|c} c_1c_{23} & -c_1s_{23} & s_1 & c_1(a_3c_{23} + a_2c_2) \\ s_1c_{23} & -s_1c_{23} & -c_1 & s_1(a_3c_{23} + a_2c_2) \\ s_{23} & c_{23} & 0 & a_3s_{23} + a_2s_2 \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

Dynamic Modeling

- **Dynamics** are equations of motion as a function of the forces and moments.
- Kinematic modeling forms the basis for dynamic modeling
- Dynamic model is important for the structure design, choice of actuators, determination of control strategies, and computer simulation of manipulator motion

Dynamics

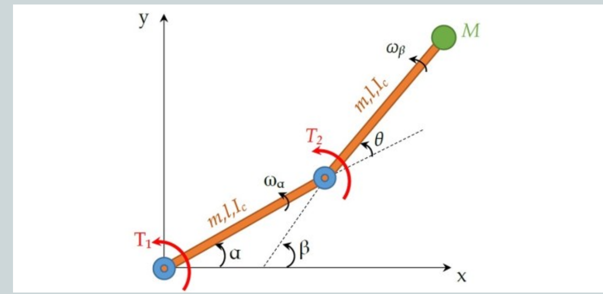
Dynamic Model of Two Link Arm w/point mass

$$
\begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} =
$$

$$
\begin{bmatrix} \frac{l_1^2 m_1 + l_2^2 m_2}{3} + l_1^2 m_2 + l_1 l_2 m_2 C_2 & \frac{l_2^2 m_2}{3} + \frac{l_1 l_2 m_2 C_2}{2} \\ l_2 m_2 \left(\frac{l_2}{3} + \frac{l_1}{2} C_2 \right) & \frac{m_2 l_2^2}{3} \end{bmatrix} \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{bmatrix}
$$

$$
+ \begin{bmatrix} -l_1 l_2 m_2 S_2 \dot{\theta}_1 \dot{\theta}_2 - \frac{l_1 l_2 m_2 S_2}{2} \dot{\theta}_2^2 \\ \frac{l_1}{2} m_2 S_2 \dot{\theta}_1^2 \end{bmatrix}
$$

$$
+ \begin{bmatrix} g \left(\frac{l_1}{2} C_1 m_1 + (l_1 C_1 + \frac{l_2}{2} C_{12}) m_2 \right) \\ g m_2 \frac{l_2}{2} C_{12} \end{bmatrix}
$$



Planning

- The robot motion can be planned using:
  - **Point-to-point** motion (example: material handling)
  - **Path motion** where the end-effector follows a desired trajectory (example: machining tasks)

- The goal of **trajectory planning** is to generate the timing laws for the relevant variables (joint or end-effector) starting from a concise description of the desired motion.

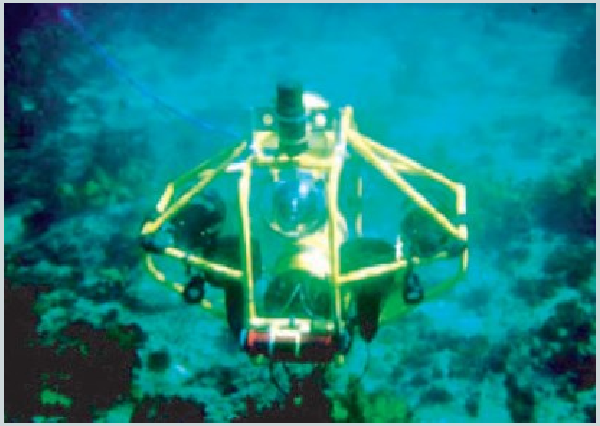
Control

- The **controller** calculates the required forces/torques and applies them to the joint actuators (through the drive system) in order to follow the desired trajectories.

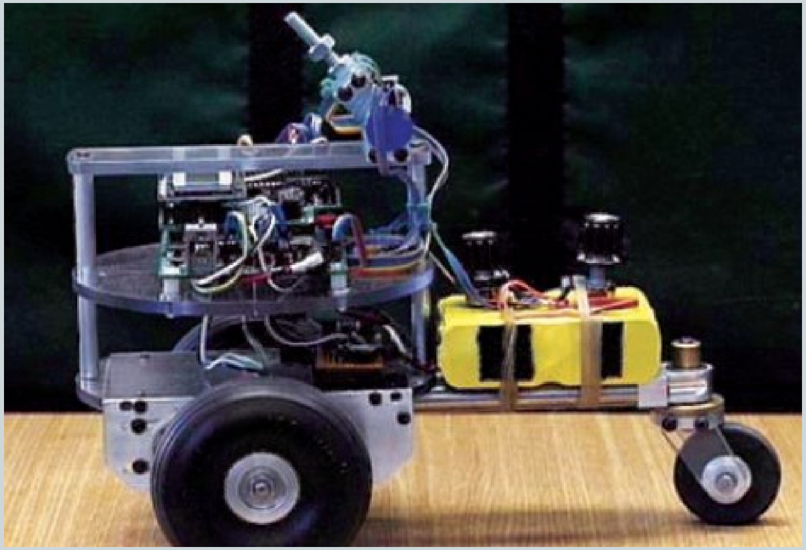
- This problem is quite complex because of nonlinearity and coupling effects

- **Manipulator control** uses feedback loops
  - by computing the deviation between the reference inputs and the data provided by the sensors, a feedback control system is capable of satisfying accuracy requirements on the execution of the prescribed trajectories.

Mobile Robots



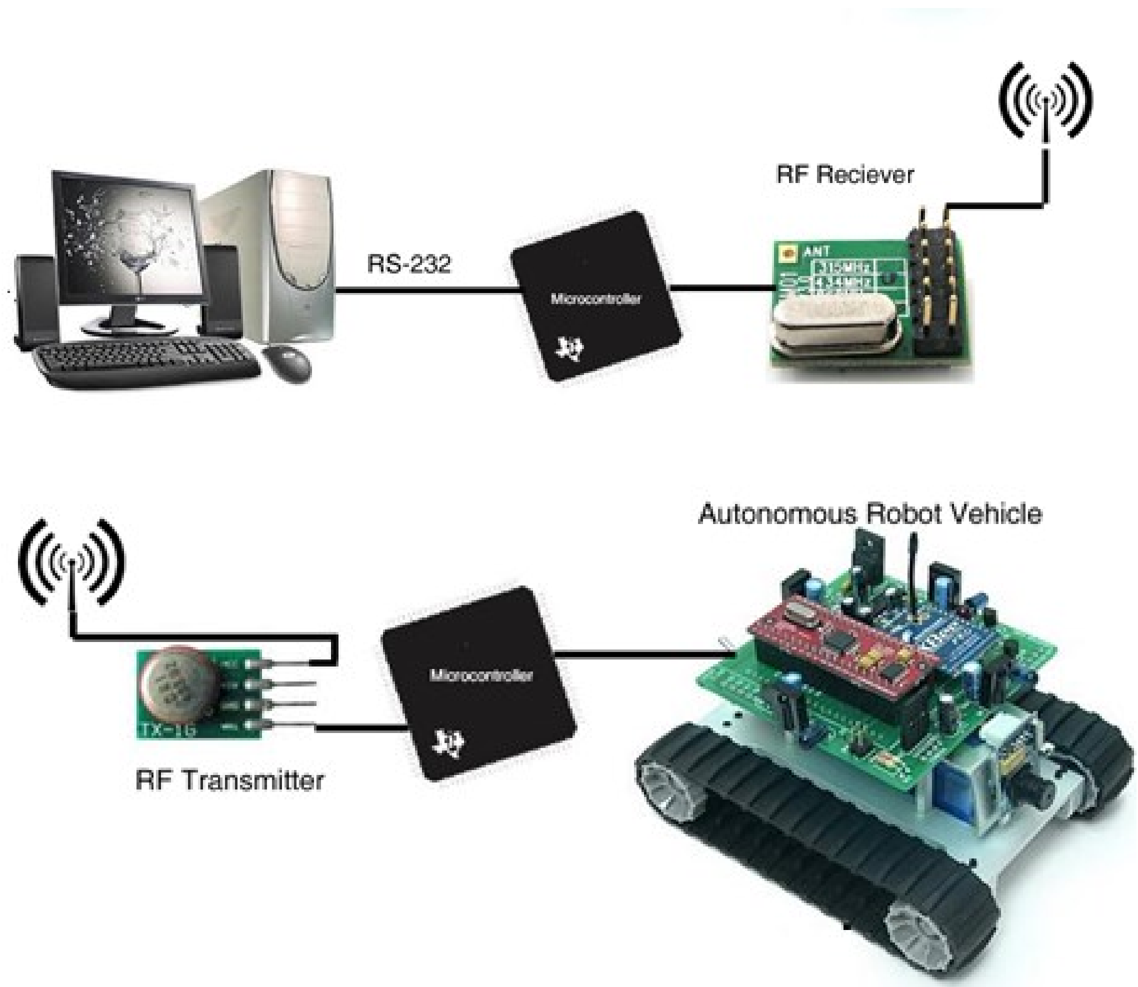
Undersea



Ground

Aerial

Mobile Robot: General Block Diagram



Mobile Robots: Modeling, Planning, and Control

- The ***kinematic model*** of a mobile robot is essentially the description of the admissible instantaneous motions in respect of the constraints.
- The ***dynamic model*** accounts for the reaction forces and describes the relationship between the above motions and the generalized forces acting on the robot.

Mobile Robots: Modeling, Planning, and Control

- The ***motion planning problem*** for a mobile robot concerns the generation of trajectories to take the vehicle from a given initial configuration to a desired final configuration.

- Such a problem is more complex than that of robot manipulators, since trajectories have to be generated in respect of the kinematic constraints imposed by the wheels.

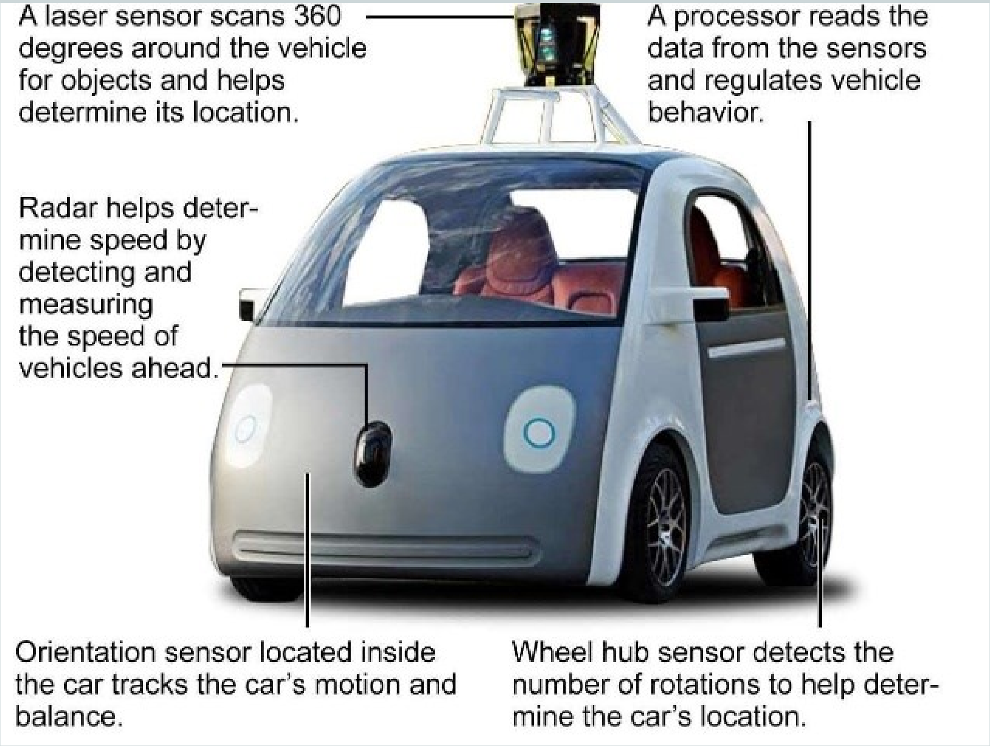
Mobile Robots: Modeling and Control

- ***Control of a mobile robot*** differs from the control of robot manipulators.

- Fewer control inputs are available with respect to the robot 's configuration variables. Therefore, the structure of a controller allowing a robot to follow a trajectory (**tracking problem**) is unavoidably different from that of a controller aimed at taking the robot to a given configuration (regulation problem).

- Mobile robot's proprioceptive sensors do not yield any data on the vehicle's configuration, it is necessary to develop ***localization and mapping methods*** for the robot.

Google Car



https://www.youtube.com/watch?v=ftouPdU1-Bo

Predators

https://www.youtube.com/watch?v=jrlxLEiYplE

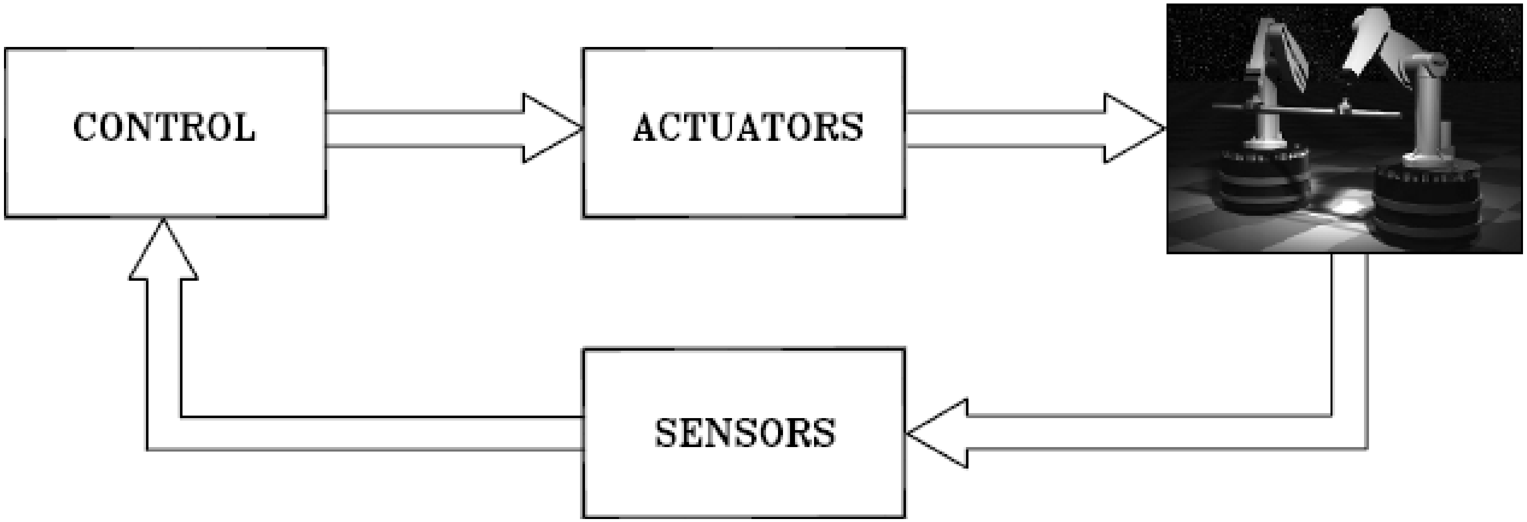
Robots: Humanoids

https://www.youtube.com/watch?v=fQ3EHtEl_NY

Boston Dynamics

https://www.youtube.com/watch?v=LikxFZZO2sk

Robotic Components

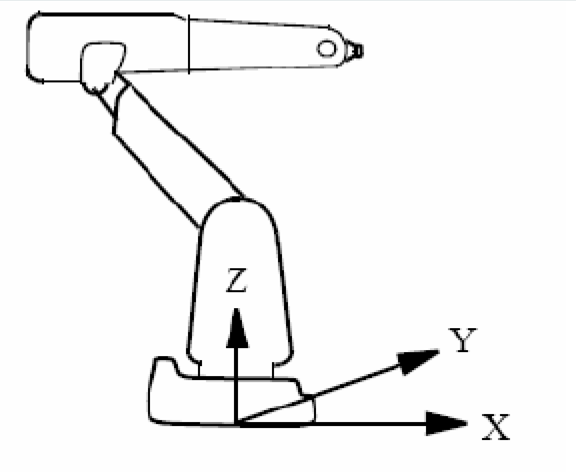


Robot Components

- **Mechanical**
  - Body, frames, gears, belts, end-effector
- **Sensors**
  - Five human senses and more?
  - Vision, force, proximity, tilt
- **Actuators**
  - Electric (DC, stepper, AC), hydraulic, pneumatic
- **Power**
  - Battery, AC/DC, or Solar
- **Electronics**
  - Conditioning and power circuits
- **Controller**
  - Process sensory information and provides appropriate commands
- **Software and user interface**

Mechanical Components

- **Body (Links and Joints)**
  - A manipulator is a set of bodies (links) connected in a chain by joints.
  - Links are rigid material



- **Gears and Belts**
  - Transmit power

Mechanical Components

- **End-effectors** are the tools attached to the end of the robot arm that enable it to do useful work. Examples:
- **Grippers**
  - Most common in fixed manipulators.
  - Allows the robot to grasp parts and manipulate them.
- **Wheels or legs**
  - Move the robot
- **Machine Tools , Welding Torches, and Laser Cutters**
  - Drills
  - Welding (widely used in automotive industry)
  - High-intensity laser beams to cut metal sheets

Actuators

- Actuators are the components used by the robot to apply force or move itself.
- The most commonly-used actuators are:
  1. **Electric motors (DC servomotors)**
     - Accurate, but are limited in their load-bearing capacity.
  2. **Hydraulic cylinders (fluid pressure)**
     - Can carry very heavy objects, but may not be very accurate.
  3. **Pneumatic cylinders (air pressure)**
     - It can carry less weight (than hydraulic), but is more compliant (less rigid to disturbing forces).

Actuators

- Other actuators not as common, but are gaining interest:

1. **Artificial Muscles (air pressure)**
   - Like the human muscle, these artificial muscles can only contract, and cannot push. They have natural compliance and a very high payload-to-weight ratio. An example is the McKibben artificial muscles.
2. **Piezoelectric materials**
   - A piezoelectric material can be used as an actuator since it deflects when a voltage is applied.

Sensors: Five Human Senses

- **Vision** . Computer-controlled camera that allows the robot to see its environment and adjust its motion accordingly.

- **Sound**. Microphone systems allow the control of the robots using voice commands.

- **Touch, Feel, and Smell** ?
  - **Tactile.** Provide the robot with the ability to touch and feel.

Sensors

- **Force/Pressure**
  - Provide the robot with a sense of the force being applied. Can be used to help the robot adjust power on different loads and correct for misalignments
- **Proximity**
  - Proximity sensors allow the robot to detect the presence of close objects
- **Limit Switches**
  - Limit switches can be installed in the workspace to automatically stop the robot or reverse its direction when attempts to go out of bounds

Sensors

- Also, the following sensors are used in robots
  - **Encoders** to measure position and angle
  - **Potentiometer** to measure position and angle
  - **LVDT** to measures position
  - **Strain gauge** to measure deflect and force
  - **Ultrasonic** sensor to measure distance
  - **Infrared** sensor to measure distance
  - **Light** sensor to detect presence

Sensors

- More sensors used in robots:
- **Accelerometer** measures acceleration.
  - A 3-axis accelerometer will tell you the orientation of a stationary platform relative to earth's surface
- **Gyro** measures rate of rotation around a particular axis
- Both are used together for orientation and balance

Electronics

- Conditioning circuits to amplify and filter the signals from the sensors

- Power electronic circuits to amplify the signals sent to the actuators

Power

- Where does the robot gets its power from?
- Battery
  - Most commonly used in mobile robots, but can be very costly and not effective
- Solar
  - Gaining much momentum. Specifically for outer space missions
- AC power
  - Most commonly used in manufacturing

Controller

- Microcontrollers
  - Low level control for mobile robots
- PLC
  - Industrial robots
- Computer Controlled
  - High level control and communication for mobile robots
  - Can be used in manufacturing

Software

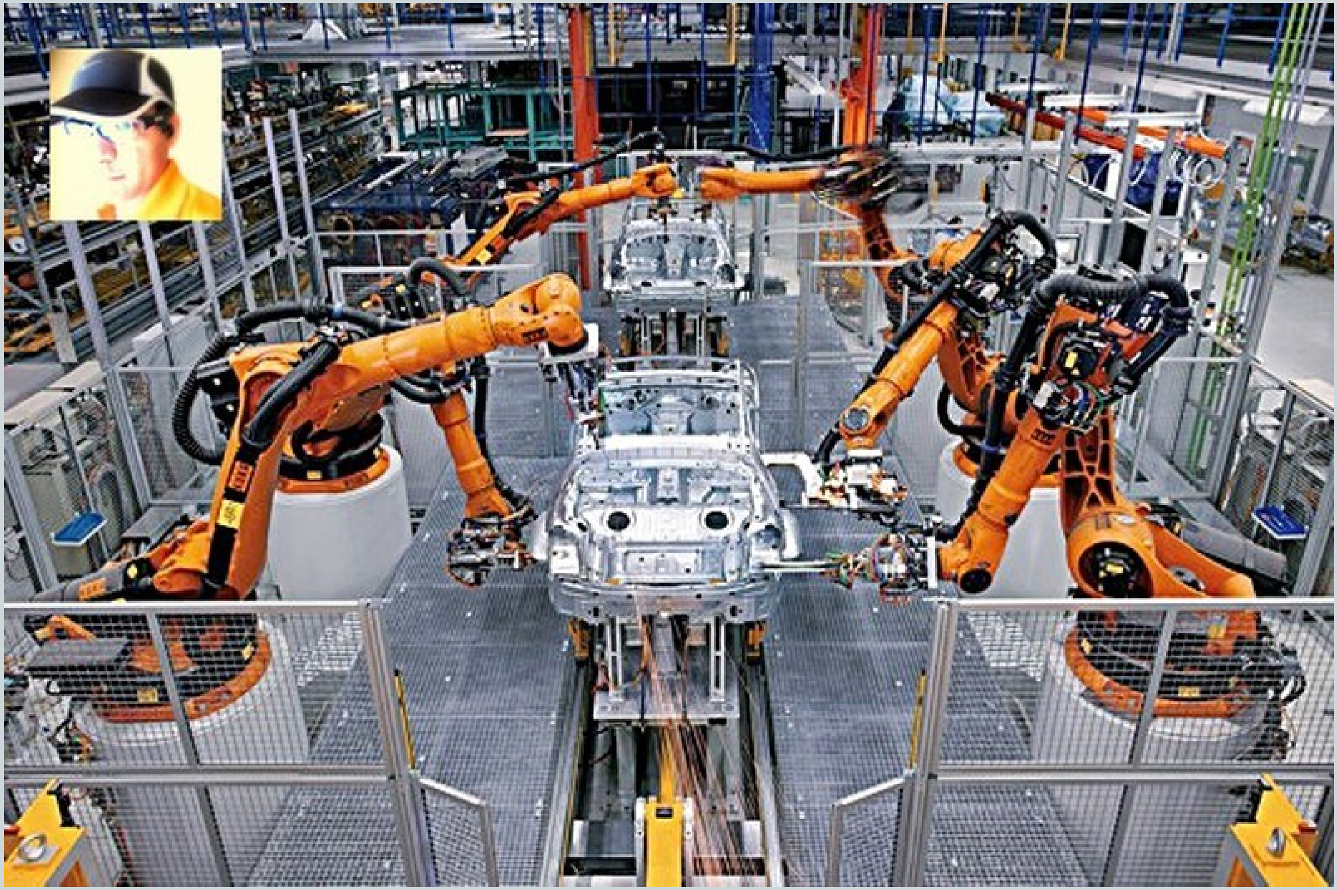
- The software (or firmware) is where the mathematical calculations, analysis, and decisions are coded.

- They are programmed (embedded) on the computer (controller)

Applications

- Industry
- Military
- Space Exploration
- Transportation
- Healthcare
- Entertainment
- Household

Applications: Industry



Automobile Industry

Industrial Robotics

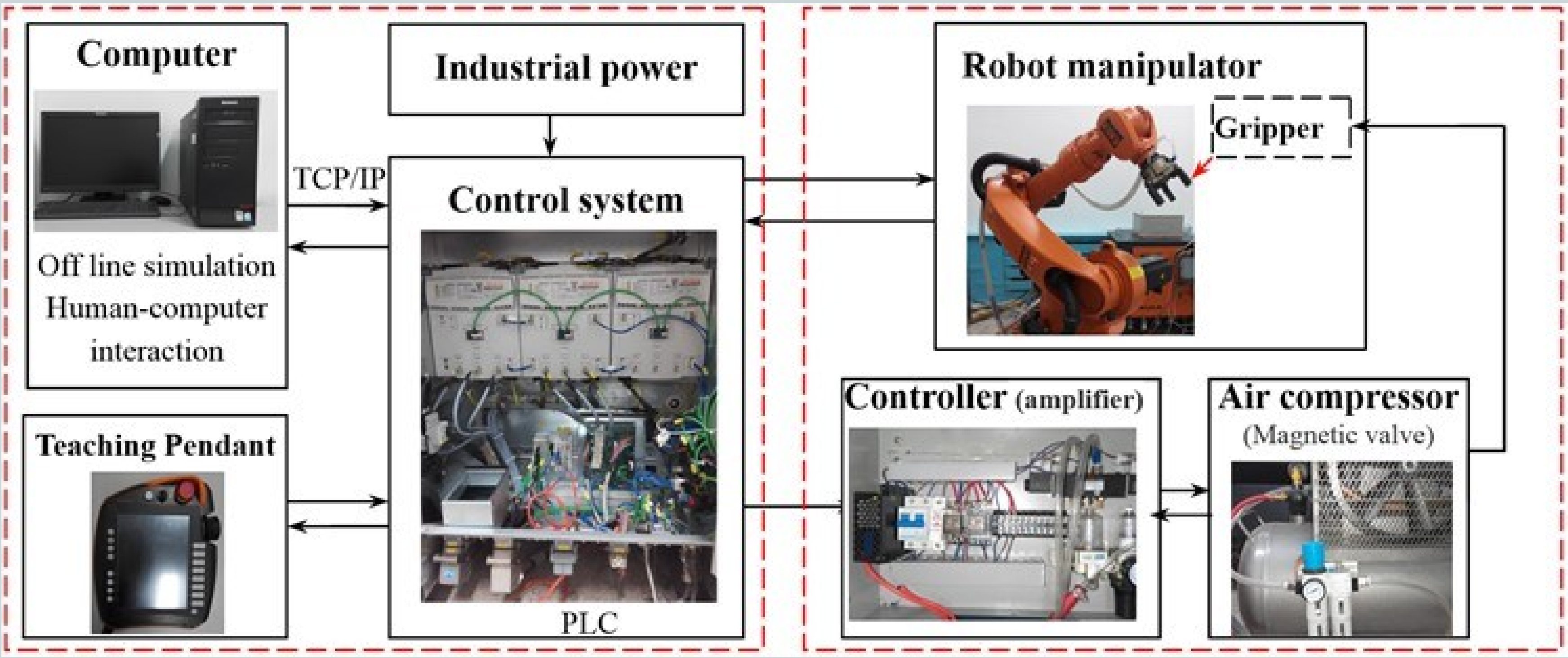
- **Industrial robotics** is the discipline concerning robot design, control, and applications in the industry.

- **Industrial robots** present three fundamental capacities useful for manufacturing
  - Material handling
  - Manipulation
  - Measurement

Applications: Industry

Pick and Place

Industrial Robotic System



https://www.youtube.com/watch?v=-CRPcHH6uJ8

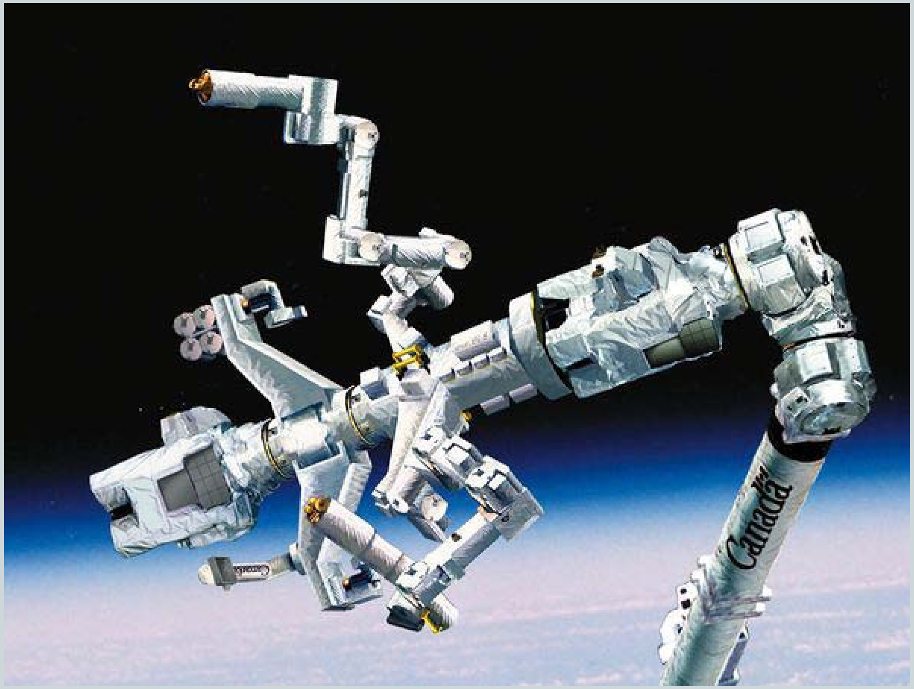
Automation

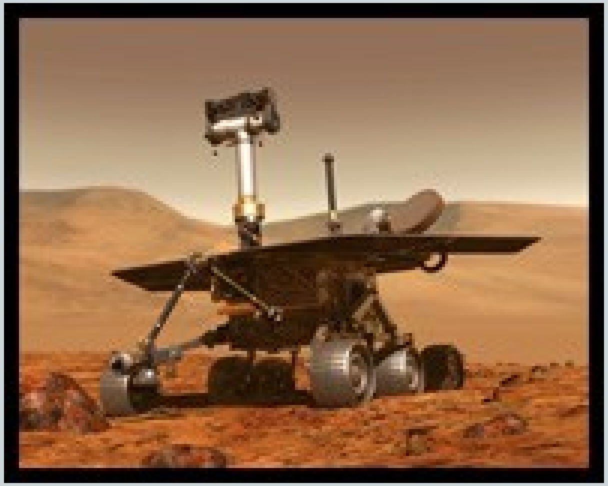
- **Automation** is the synthesis of industrial technologies typical of the manufacturing process and computer technologies allowing information management.

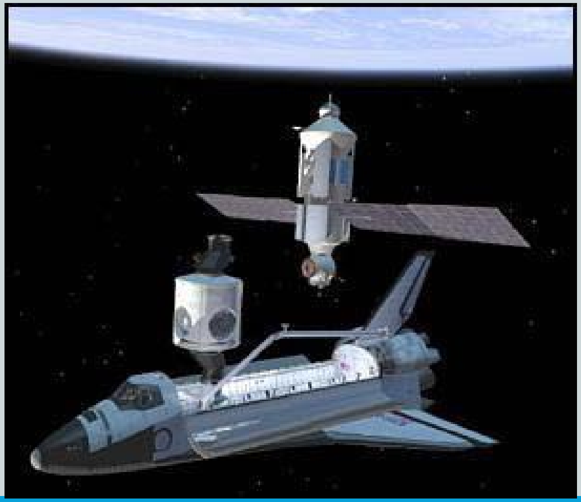
- Automation Levels
  - Rigid Automation
  - Programmable Automation
  - Flexible Automation

Applications: Military

Applications: Space Exploration

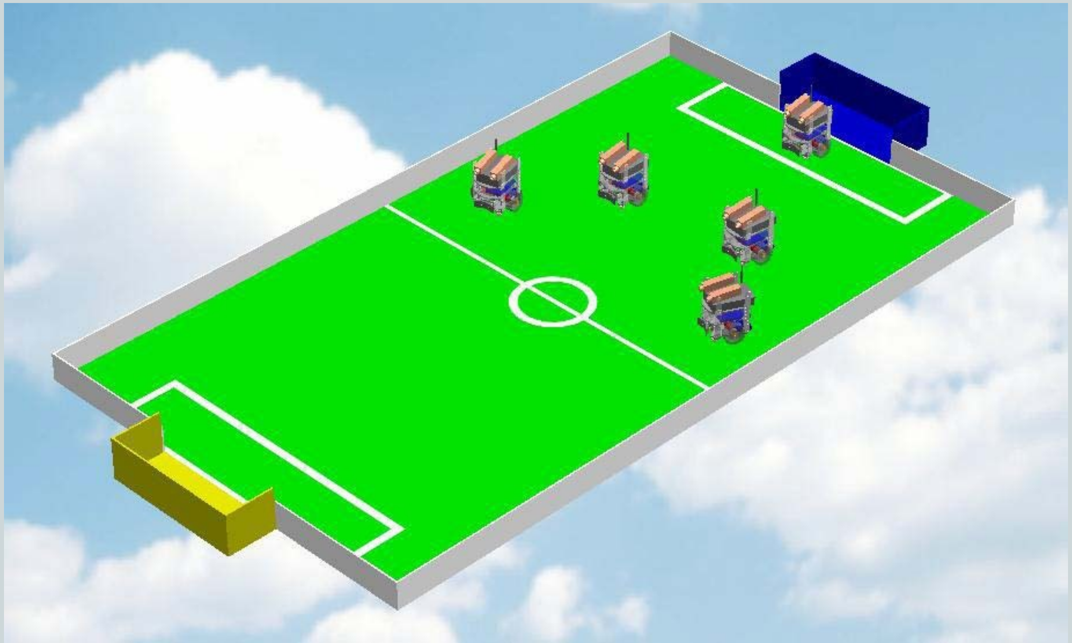


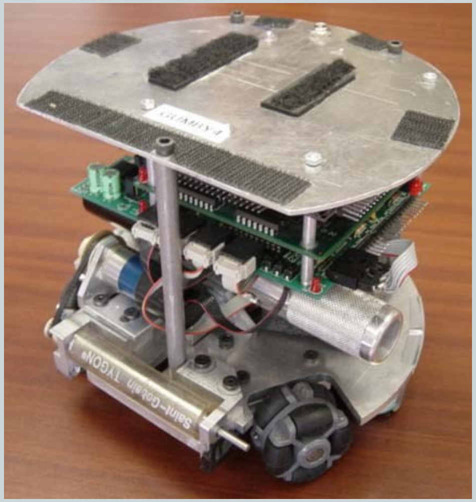




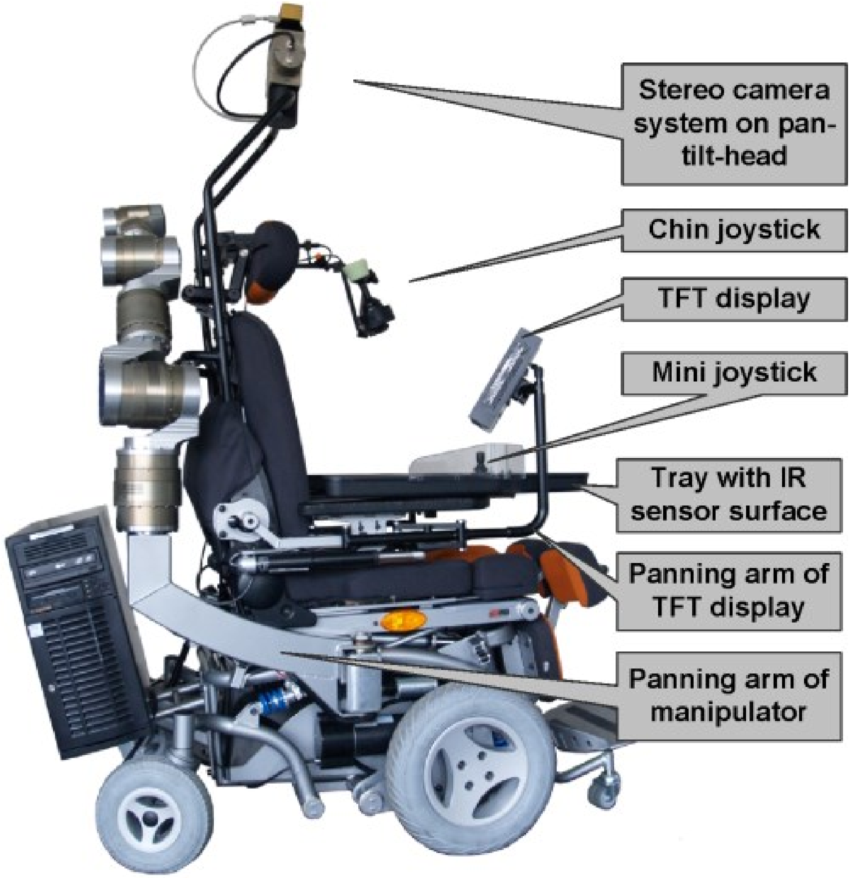
Applications: Transportation

Applications: Entertainment

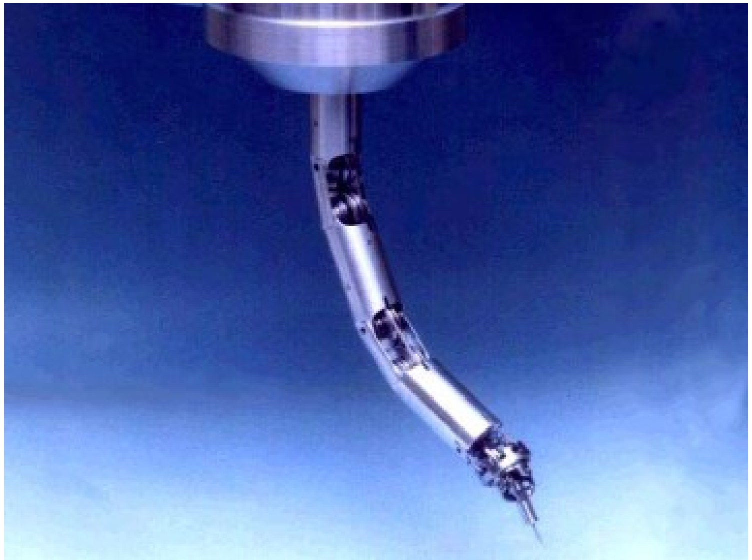




Application: Health Care



Wheel Chair



Medical Surgery

Science Fiction and Future Robots

Conclusion

- Robots can be divided into two categories
  - Fixed manipulators
  - Mobile

- Robots are composed of the following
  - Mechanical structure
  - Electronics
  - Sensors
  - Actuators
  - Digital Controller