دانشگاه سمنان

Semnan University
Faculty of Mechanical Engineering

دانشکده مهندسی مکانیک

دانشکده مهندسی مکانیک

درس رباتیک پیشرفته

Advanced Robotics

Chapter 1 – Introduction

Class Lecture

❑ CONTENTS:

1. INTRODUCTION

- Robotics:
  - Study of machines that can replace human beings in the execution of a task (physical activity and decision making).

- The most common mechanical structures:
  - Robot manipulators (with a fixed base)
  - Mobile robots (with a mobile base)

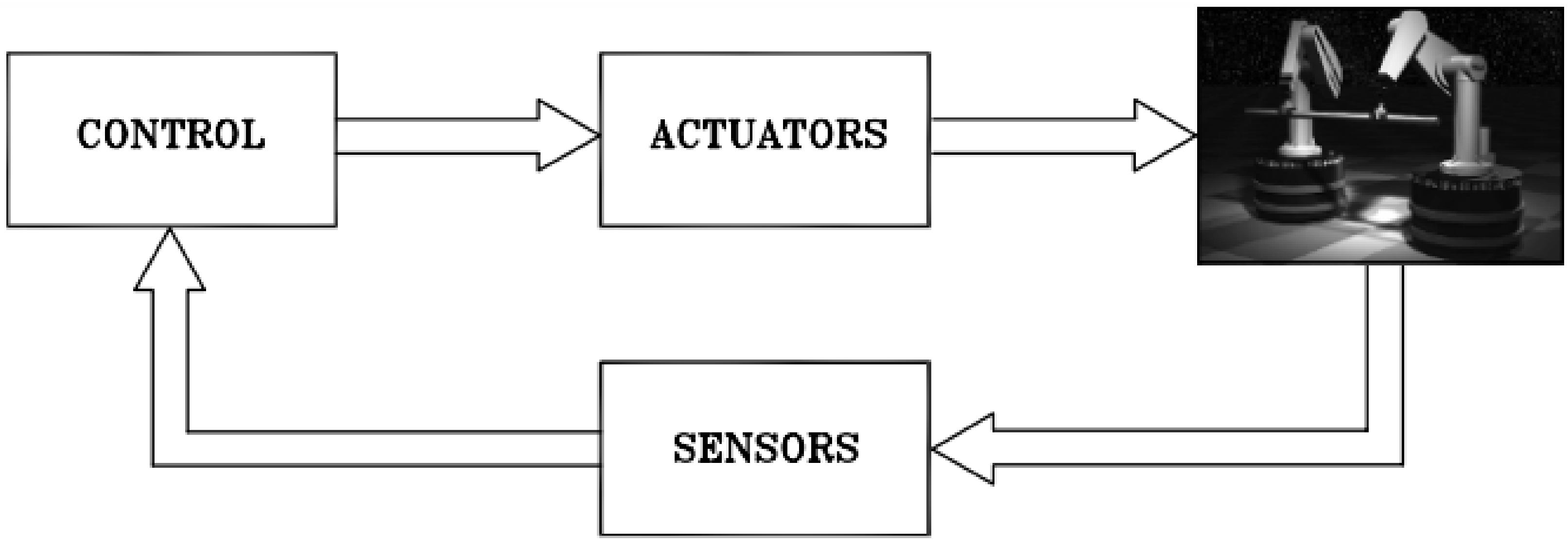
- Other topics:
  - Modelling
  - Planning
  - Control

1.1 Robotics

- The term robotics was then introduced by Asimov as the science devoted to the study of robots which was based on the three fundamental laws:
  - 1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
  - 2. A robot must obey the orders given by human beings, except when such orders would conflict with the first law.
  - 3. A robot must protect its own existence, as long as such protection does not conflict with the first or second law.

1.1 Robotics

- Components of a robotic system



1.2.1 Robot Manipulators

- The mechanical structure of a robot manipulator consists of a sequence of rigid bodies (links) interconnected by means of articulations (joints).

- A manipulator is characterized by an arm that ensures mobility, a wrist that confers dexterity, and an end-effector that performs the task required of the robot.

- The fundamental structure of a manipulator:
  - Serial or open kinematic chain. (only one sequence of links connecting the two ends of the chain).
  - Closed kinematic chain (when a sequence of links forms a loop)

1.2.1 Robot Manipulators

- A manipulator's mobility is ensured by the presence of joints.
  - Prismatic Joint (relative translational motion)
  - Revolute Joint (relative rotational motion)

  - Revolute joints are usually preferred to prismatic joints in view of their compactness and reliability.

- In an open kinematic chain, each prismatic or revolute joint provides the structure with a single degree of freedom (DOF).

- On the other hand, in a closed kinematic chain, the number of DOFs is less than the number of joints in view of the constraints imposed by the loop.

1.2.1 Robot Manipulators

- The degrees of freedom should be properly distributed along the mechanical structure in order to have a sufficient number to execute a given task.

- In the most general case of a task consisting of arbitrarily positioning and orienting an object in three-dimensional (3D) space, six DOFs are required, three for positioning a point on the object and three for orienting the object with respect to a reference coordinate frame.

- If more DOFs than task variables are available, the manipulator is said to be redundant from a kinematic viewpoint.

1.2.1 Robot Manipulators

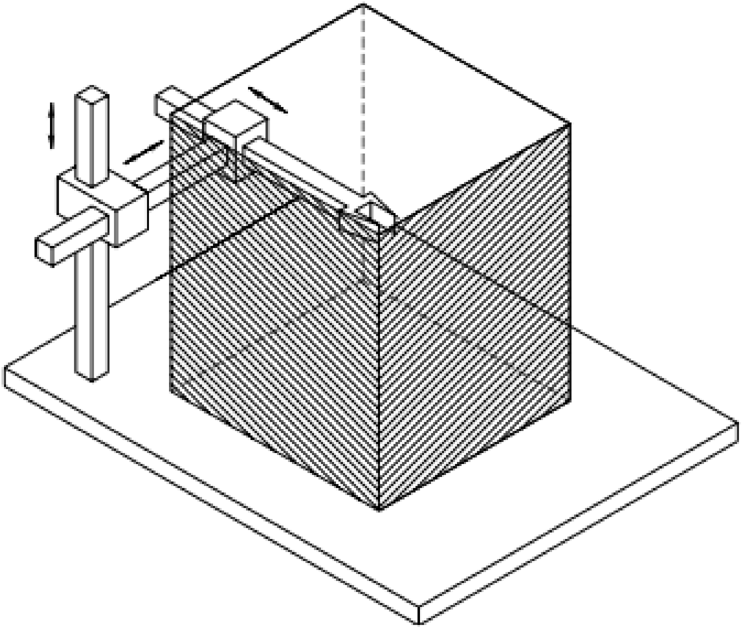
- The **Workspace**:
  - That portion of the environment the manipulator’s end-effector can access
  - Its shape and volume depend on the manipulator structure as well as on the presence of mechanical joint limits

1.2.1 Robot Manipulators

- The task required of the arm is to position the wrist which then is required to orient the end-effector.
- The type and sequence of the arm's DOFs, starting from the base joint, allows a classification of manipulators as:
  - Cartesian
  - Cylindrical
  - Spherical
  - SCARA

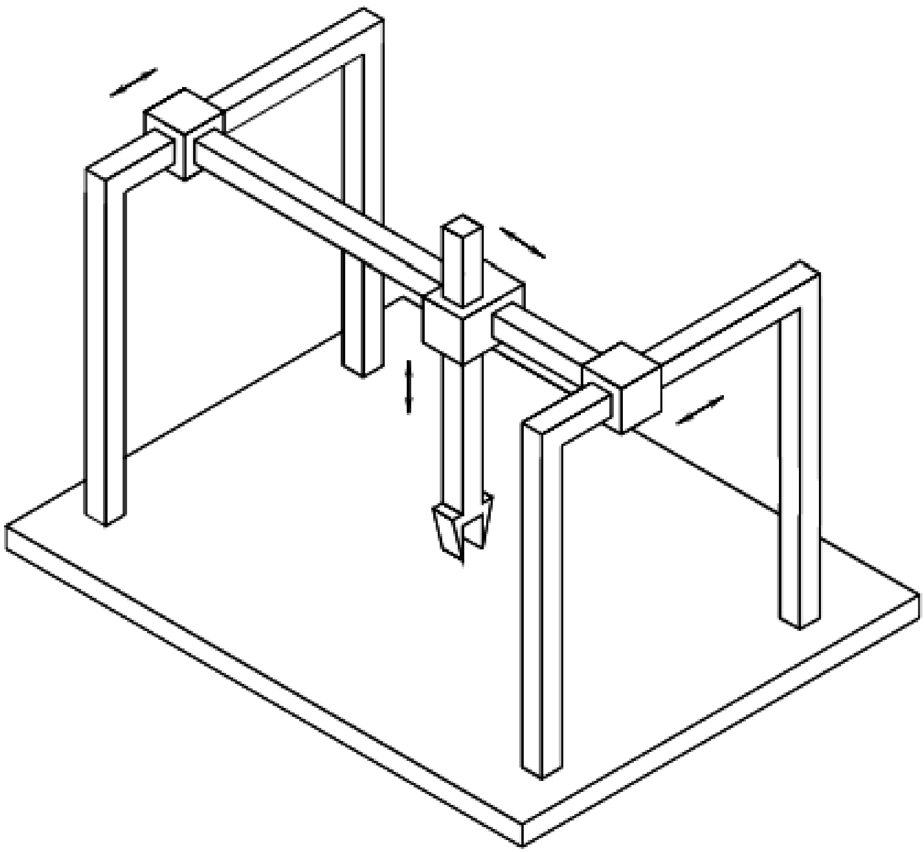
1.2.1 Robot Manipulators

- Cartesian manipulator and its workspace



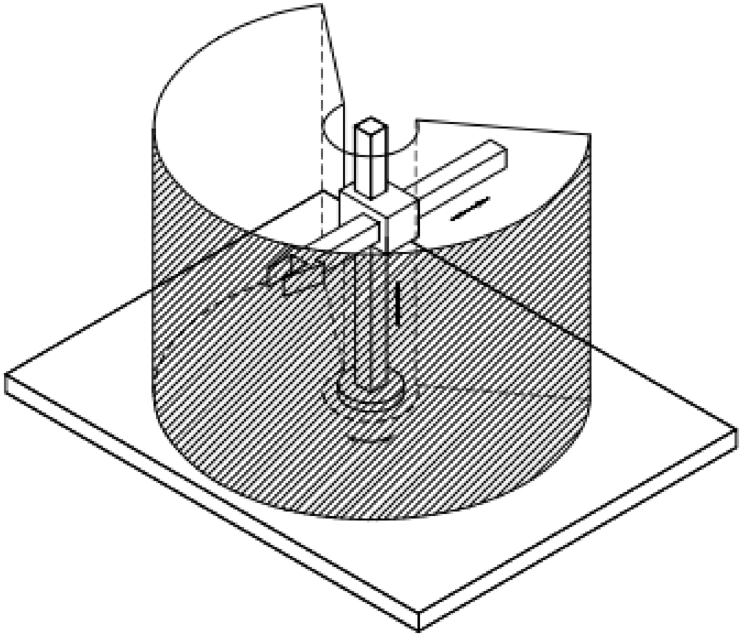
1.2.1 Robot Manipulators

- Gantry manipulator



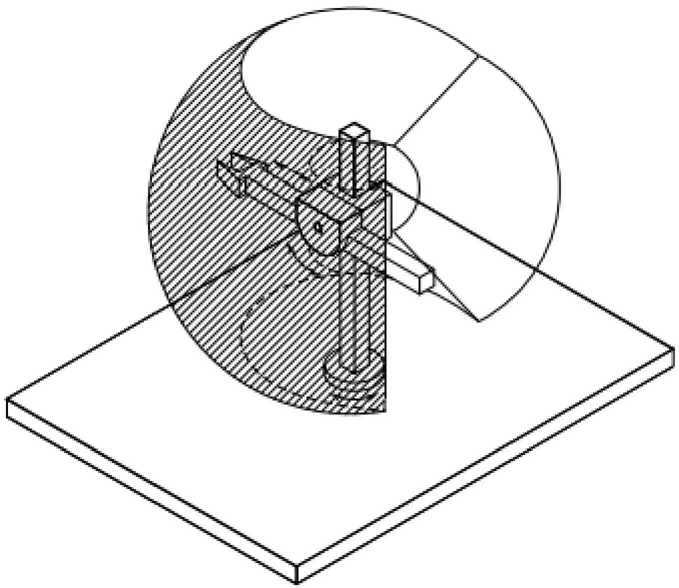
1.2.1 Robot Manipulators

- Cylindrical manipulator and its workspace



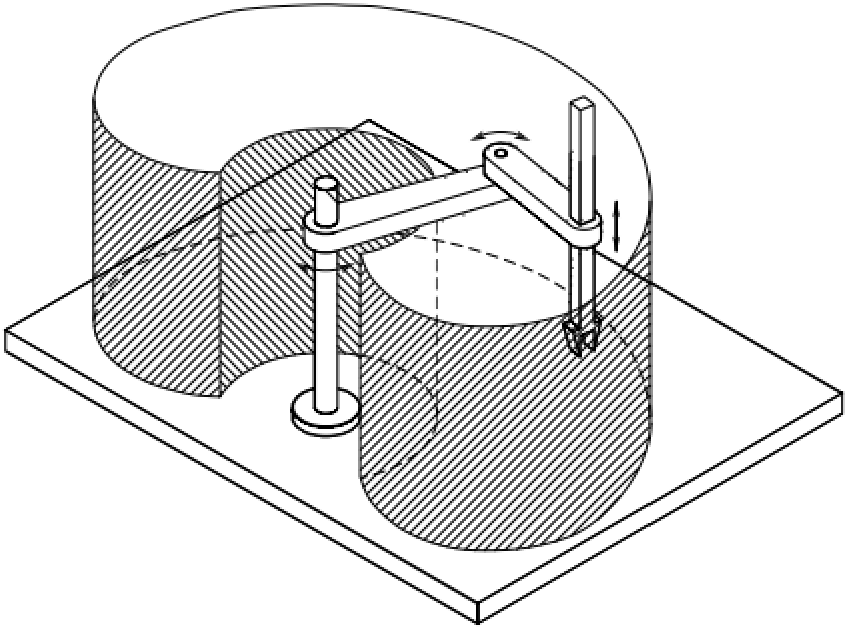
1.2.1 Robot Manipulators

- Spherical manipulator and its workspace



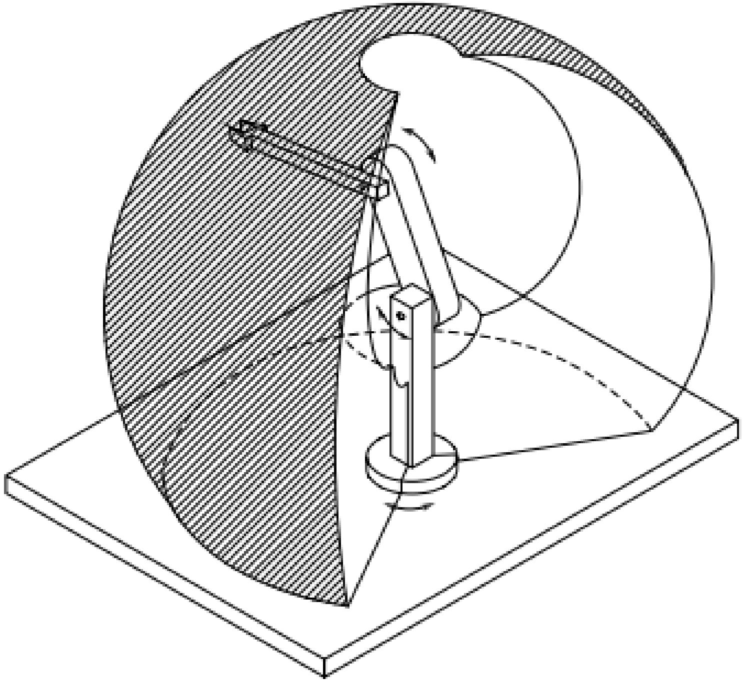
1.2.1 Robot Manipulators

- SCARA manipulator and its workspace
  - SCARA: Selective Compliance Assembly Robot Arm
  - Disposing two revolute joints and one prismatic joint in such a way that all the axes of motion are parallel
  - High stiffness to vertical loads and compliance to horizontal loads



1.2.1 Robot Manipulators

- Anthropomorphic manipulator and its workspace
  - Three revolute joints
  - Its similarity with the human arm (shoulder joint, elbow joint, arm, forearm)



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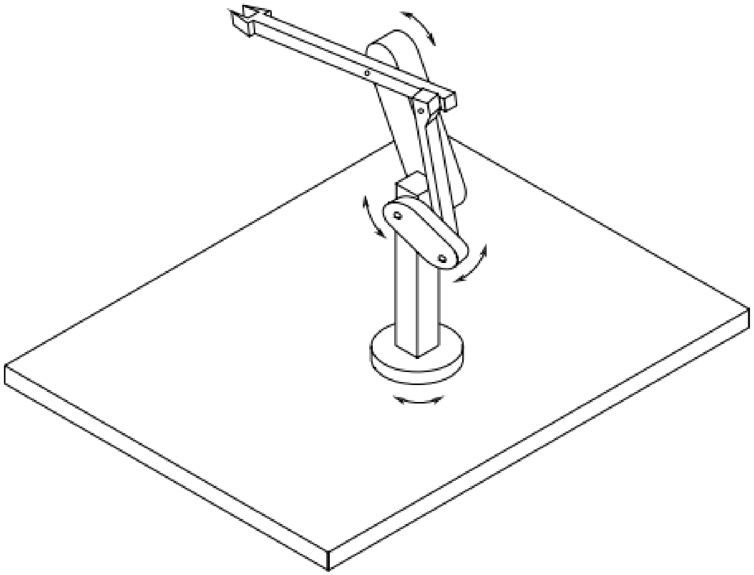
1.2.1 Robot Manipulators

- According to the International Federation of Robotics (IFR) report about installed robot manipulators worldwide, up to 2005:
  - **59% Anthropomorphic geometry**
  - **20% Cartesian geometry**
  - **12% Cylindrical geometry**
  - **8% SCARA geometry**

1.2.1 Robot Manipulators

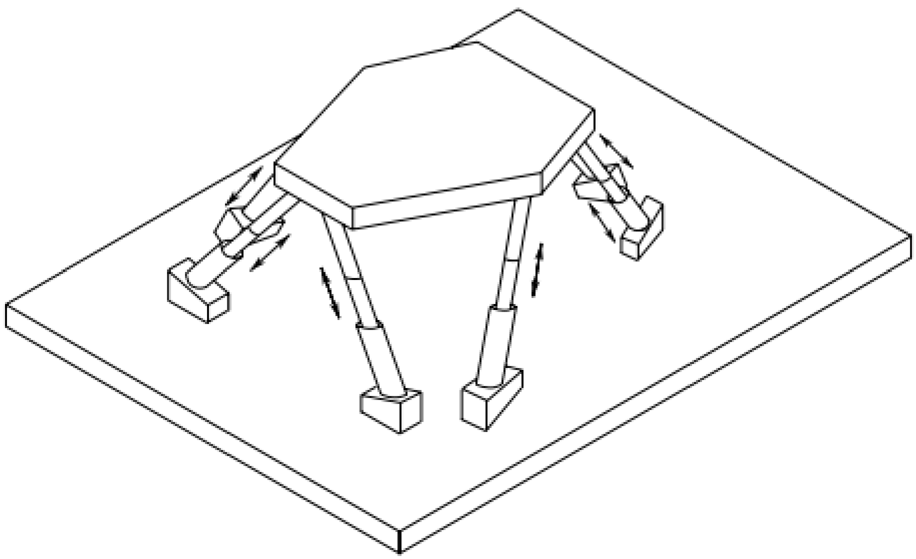
- Closed kinematic chain :
  - Whenever larger payloads are required, the mechanical structure will have higher stiffness to guarantee comparable positioning accuracy.

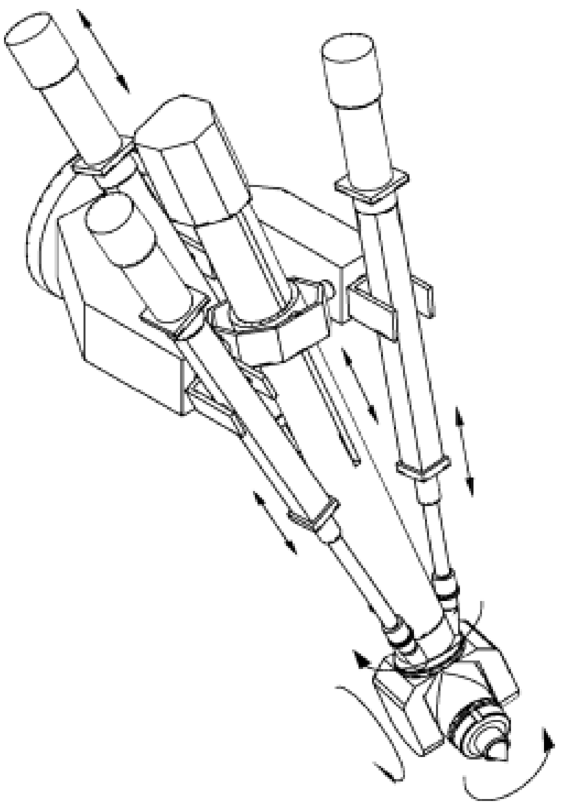
- Manipulator (anthropomorphic structure) with parallelogram



1.2.1 Robot Manipulators

- Parallel manipulator
- Hybrid parallel-serial manipulator



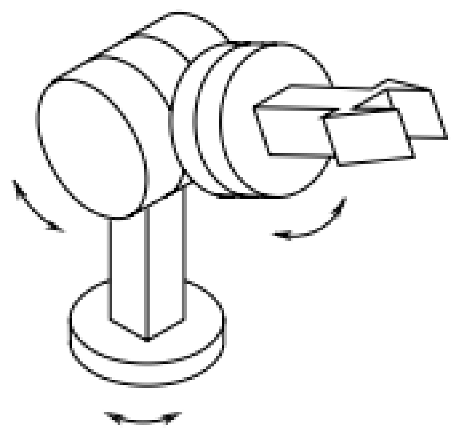


1.2.1 Robot Manipulators

- The manipulator structures presented above are required to position the wrist which is then required to orient the manipulator's end-effector.

- If arbitrary orientation in 3D space is desired, the wrist must possess at least three DOFs provided by revolute joints.

- Spherical wrist



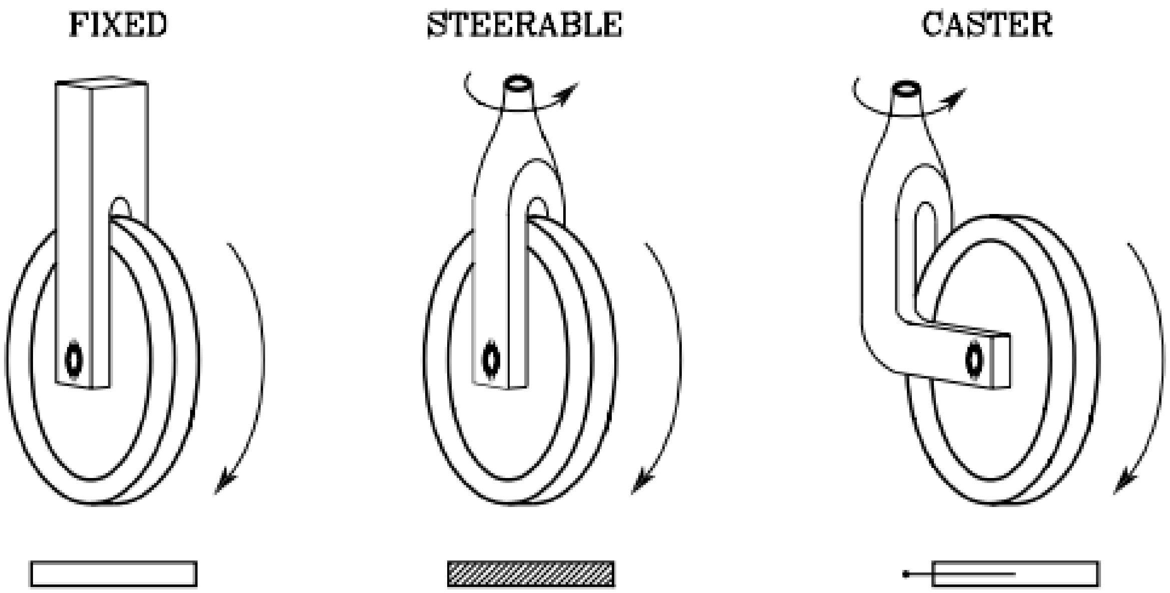
1.2.2 Mobile Robots

- A mobile base which allows the robot to move freely in the environment
- Mostly used in service applications, where extensive, autonomous motion capabilities are required.
- Consists of one or more rigid bodies equipped with a locomotion system.

1.2.2 Mobile Robots

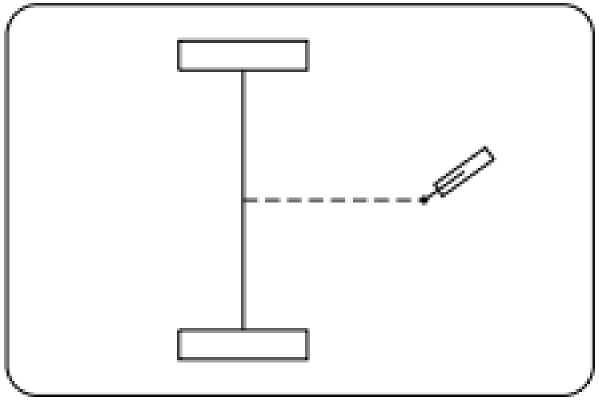
- Wheeled mobile robots typically consist of a rigid body (base or chassis) and a system of wheels which provide motion with respect to the ground.

- The three types of conventional wheels with their respective icons
  - The fixed wheel
  - The steerable wheel
  - The caster wheel

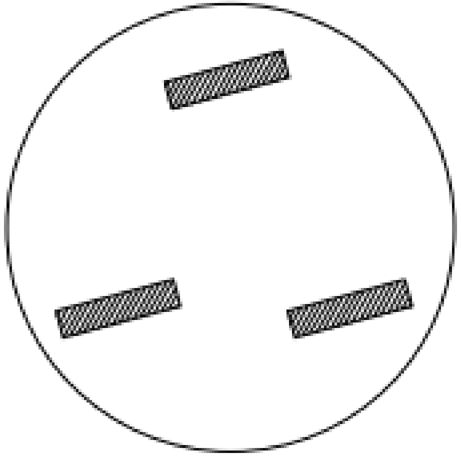


1.2.2 Mobile Robots

- A differential-drive mobile robot

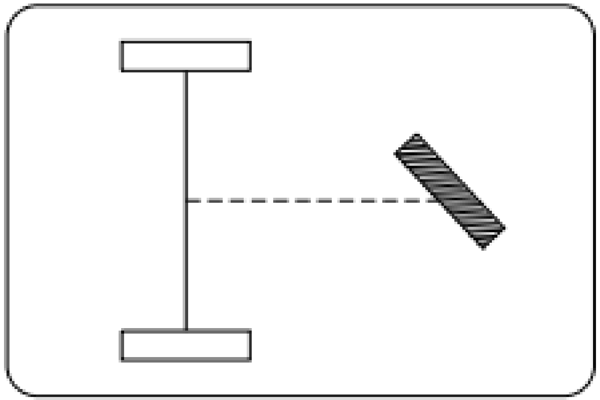


- A synchro-drive mobile robot

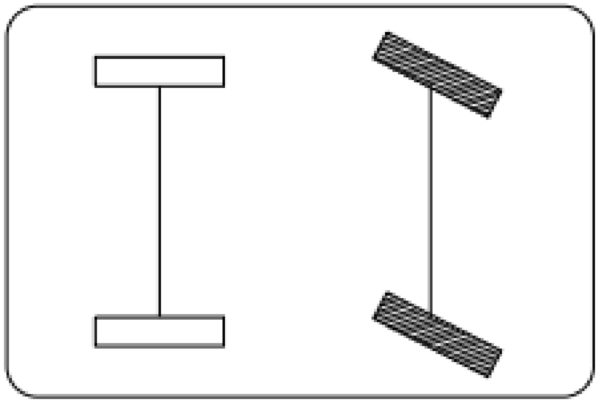


1.2.2 Mobile Robots

- A tricycle mobile robot

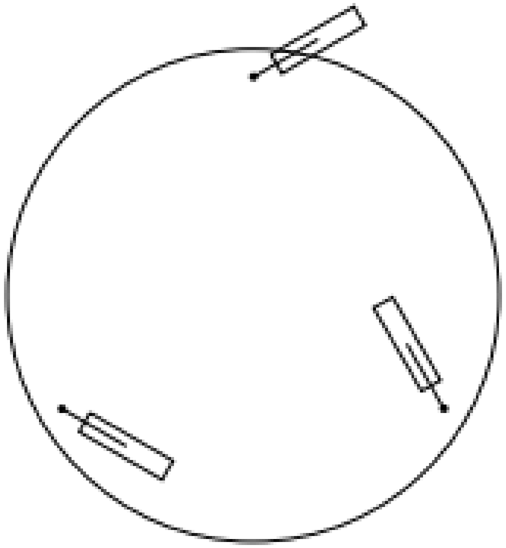


- A car-like mobile robot



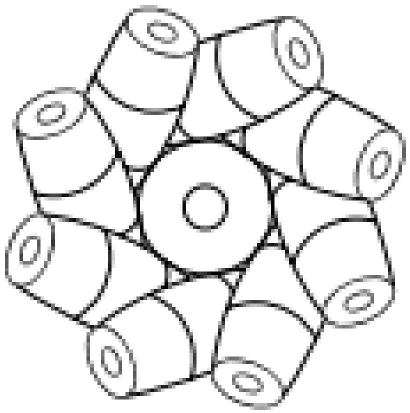
1.2.2 Mobile Robots

- An omnidirectional mobile robot with three independently driven caster wheels



1.2.2 Mobile Robots

- Other special types of wheels
  - A Mecanum (or Swedish) wheel
    - ✓ A vehicle equipped with four such wheels mounted in pairs on two parallel axles is also omnidirectional.



1.2.2 Mobile Robots

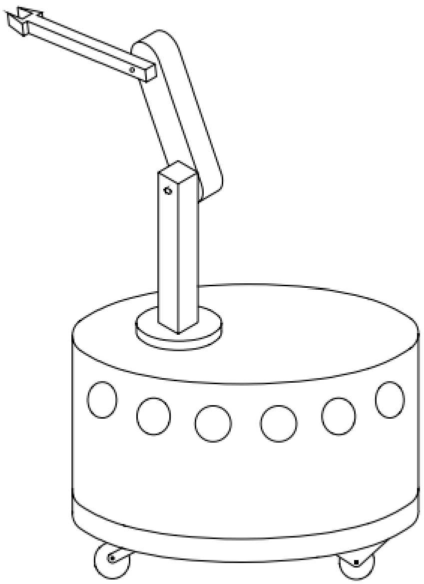
- Legged mobile robots
  - Multiple rigid bodies, interconnected by prismatic joints or revolute joints

1.2.2 Mobile Robots

- The workspace of a mobile robot is potentially unlimited.
- The local mobility of a non-omnidirectional mobile robot is always reduced.

1.2.2 Mobile Robots

- A mobile manipulator:
  - Merge the mechanical structure of a manipulator with that of a mobile vehicle
  - Combines the dexterity of the articulated arm with the unlimited mobility of the base.
  - For example, mounting an anthropomorphic arm on a differential-drive vehicle



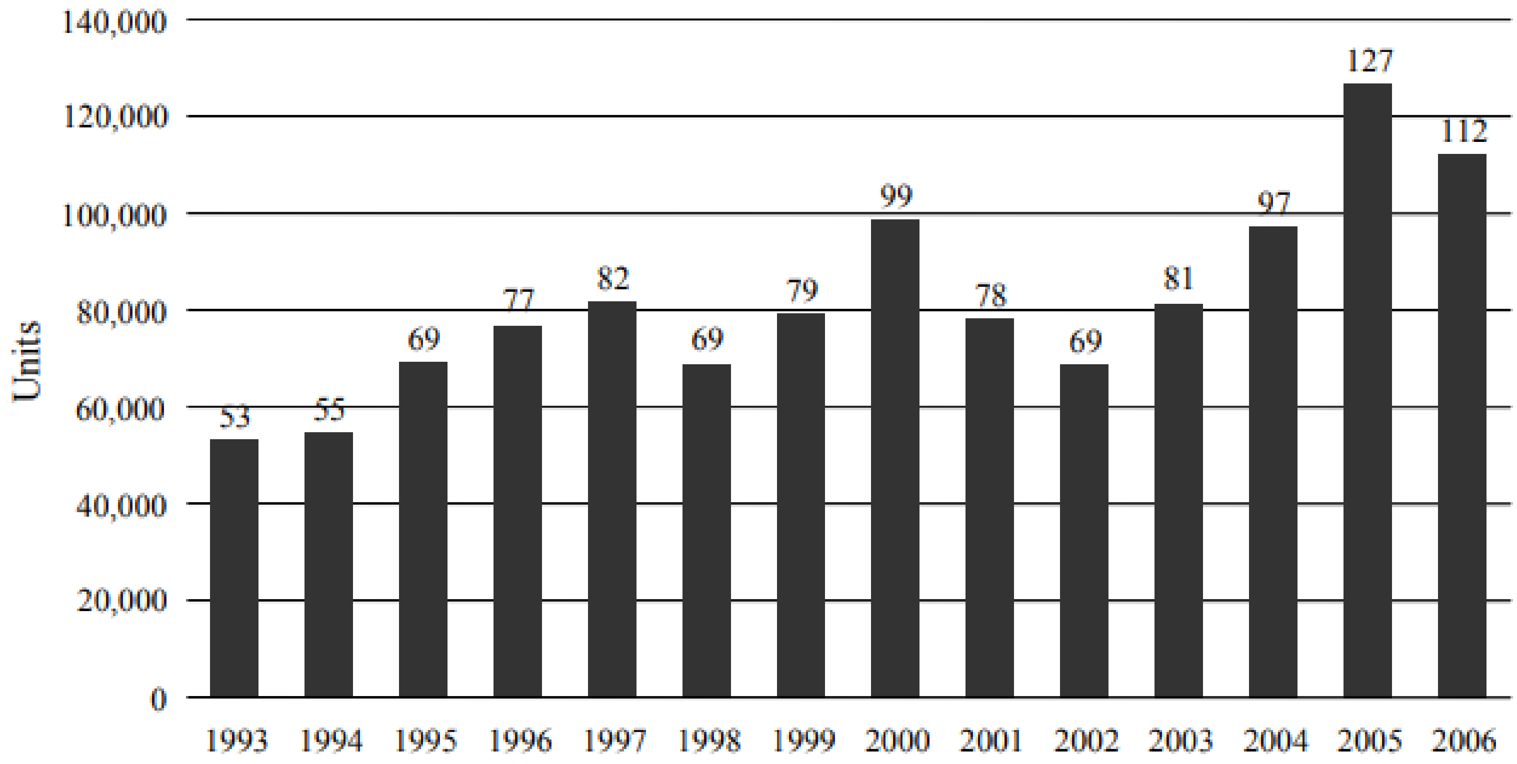
1.3 Industrial Robotics

- Industrial robotics is the discipline concerning robot design, control and applications in industry, and its products have by now reached the level of a mature technology.

- Robot manipulators characterization:
  - Versatility, in view of the employment of different end-effectors at the tip of the manipulator
  - Adaptability to a priori unknown situations, in view of the use of sensors
  - Positioning accuracy, in view of the adoption of feedback control techniques
  - Execution repeatability, in view of the programmability of various operations

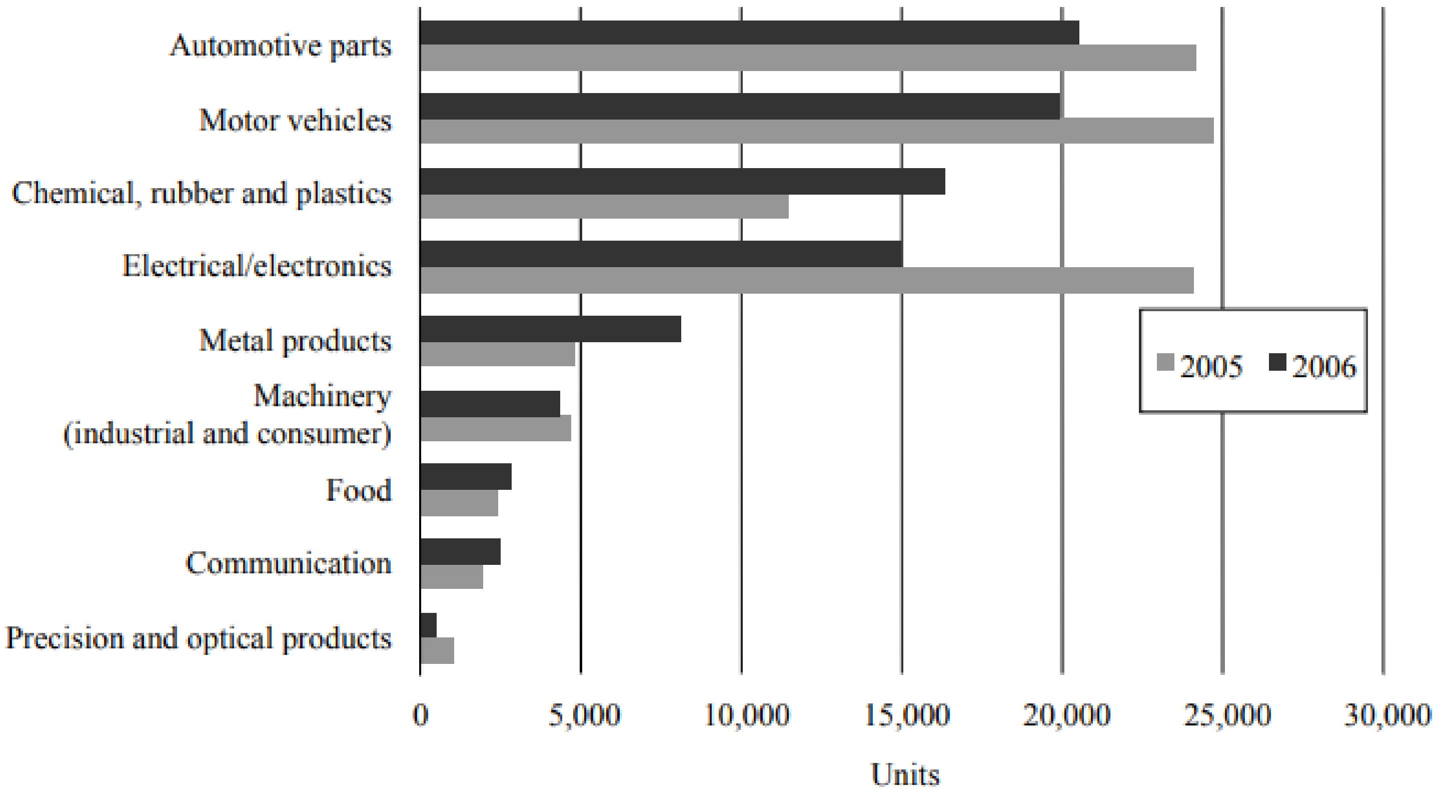
1.3 INDUSTRIAL ROBOTICS

- Yearly installations of industrial robots worldwide



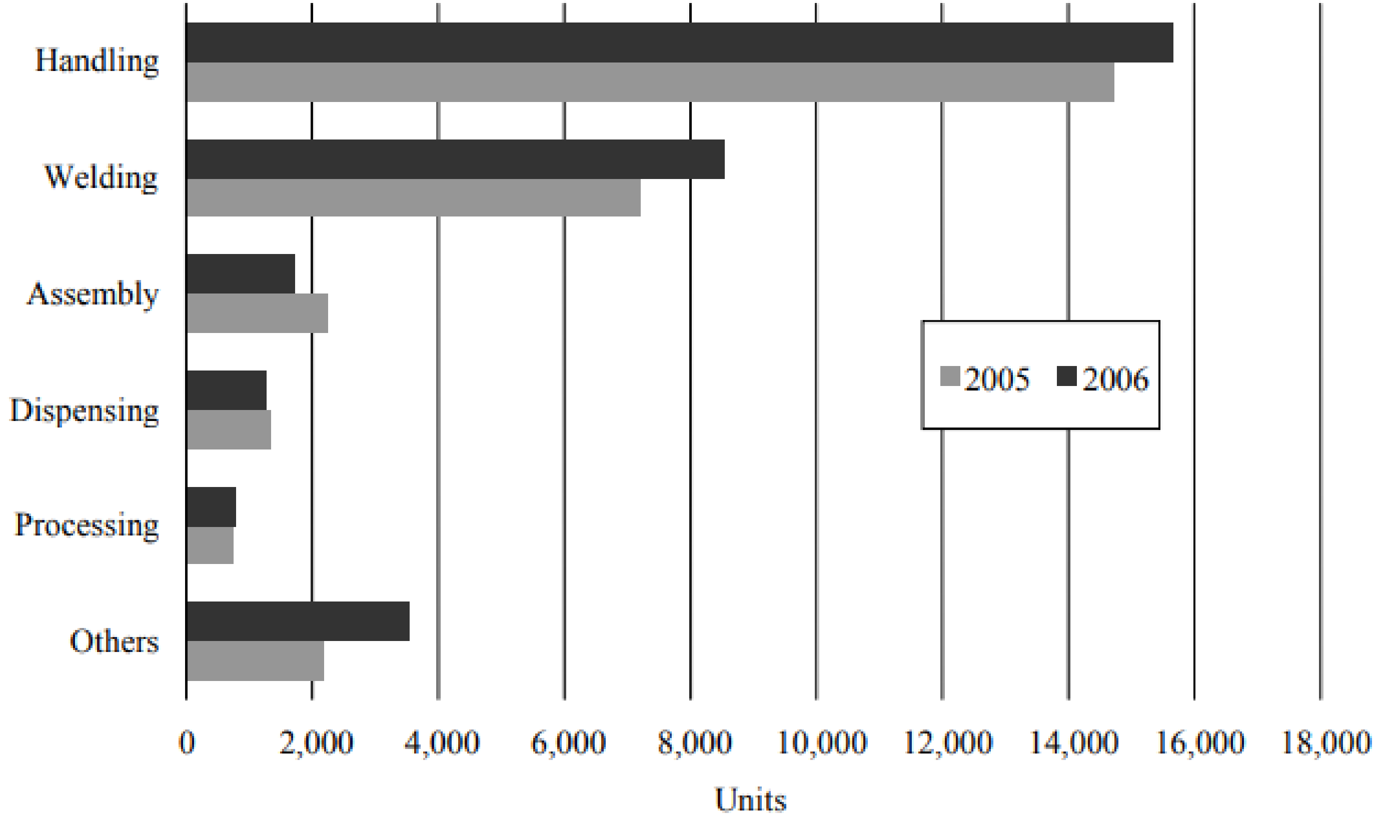
1.3 Industrial Robotics

- Yearly supply of industrial robots by main industries



1.3 Industrial Robotics

- Yearly supply of industrial robots in Europe for manufacturing operations



1.3 Industrial Robotics

- Industrial robots examples
  - The AdeptOne XL robot

1.3 Industrial Robotics

- Industrial robots examples
  - The COMAU Smart NS robot

1.3 Industrial Robotics

- Industrial robots examples
  - The ABB IRB 4400 robot

1.3 Industrial Robotics

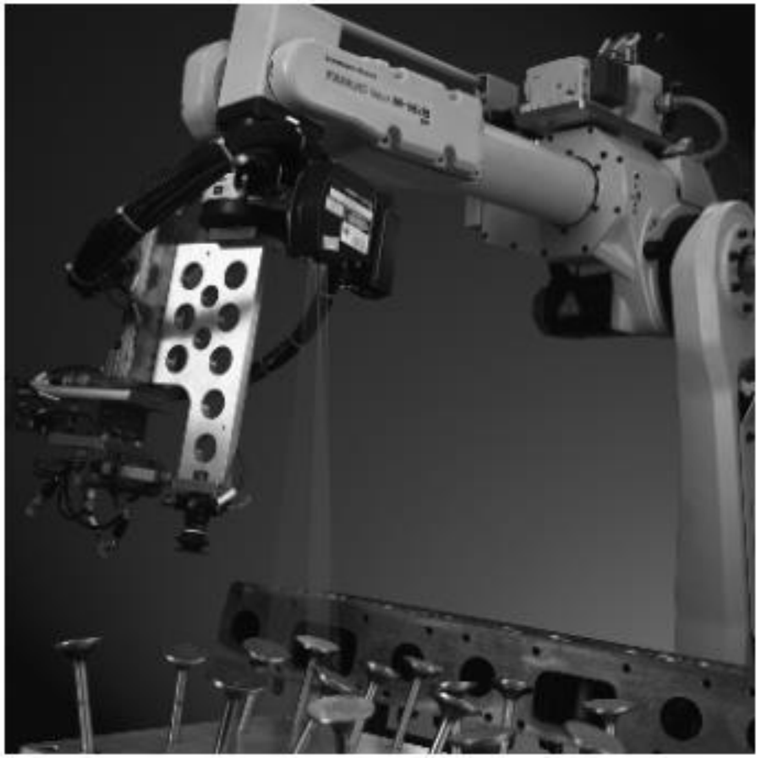
- Industrial robots examples
  - The KUKA KR 60 Jet robot

1.3 Industrial Robotics

- Industrial robots examples
  - The ABB IRB 340 FlexPicker robot

1.3 Industrial Robotics

- Industrial robots examples
  - The Fanuc M-16iB robot



1.3 Industrial Robotics

- Industrial robots examples
  - The KUKA LWR robot

1.3 Industrial Robotics

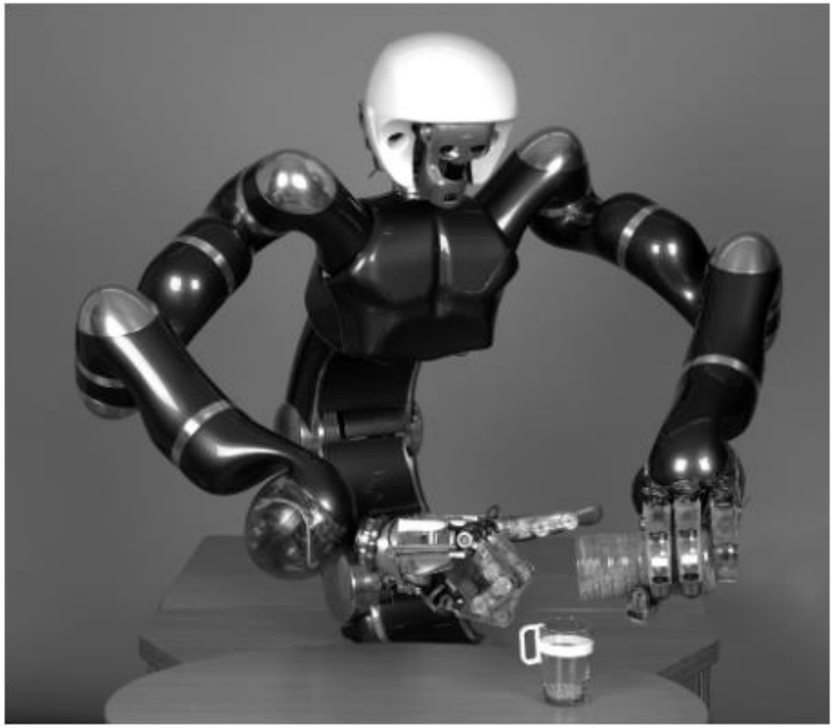
- Industrial robots examples
  - The BarrettHand

1.3 Industrial Robotics

- Industrial robots examples
  - The SCHUNK Anthropomorphic Hand

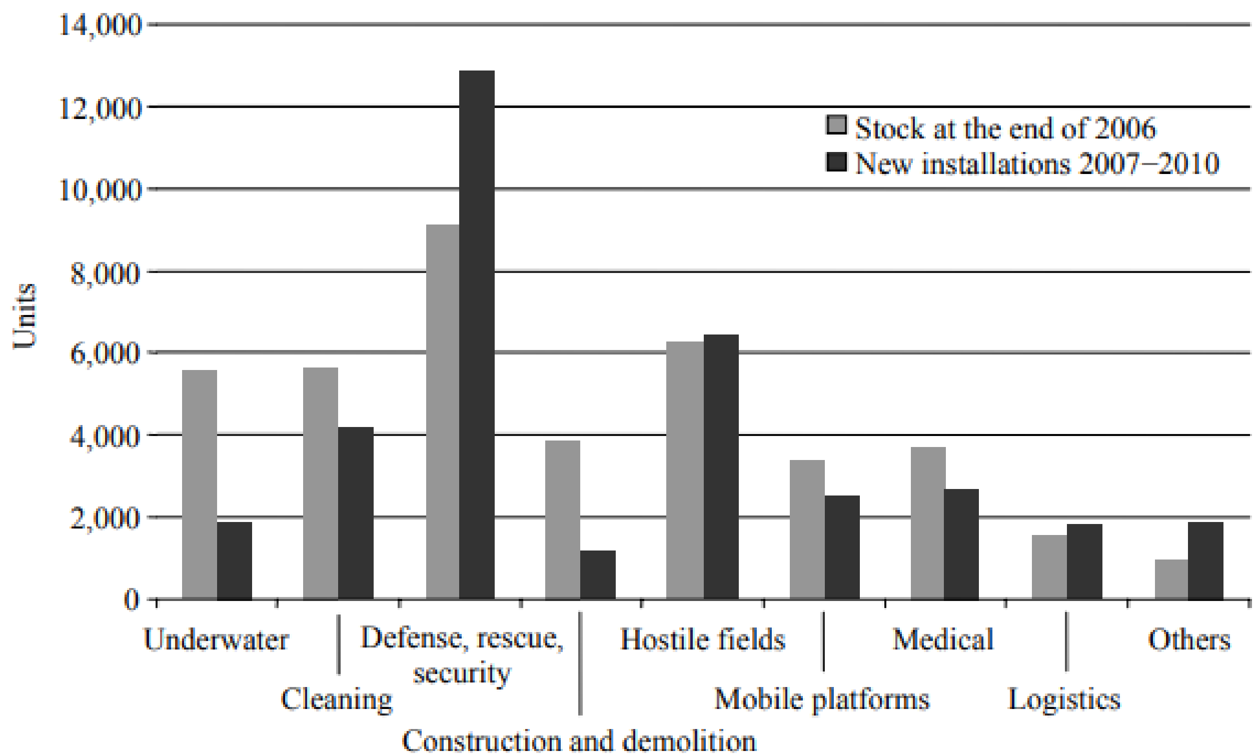
1.3 Industrial Robotics

- Industrial robots examples
  - The Justin humanoid robot manipulator



1.4 Advanced Robotics

- The science studying robots with marked characteristics of autonomy, operating in scarcely structured or unstructured environments
- Robots on stock for non-industrial applications



1.4.1 Field Robots

- The **Sojourner rover** was deployed by the Pathfinder lander and explored 250 m^2 of Martian soil in 1997

1.4.1 Field Robots

- The unmanned car Stanley autonomously completed a path of 132 miles in the record time of 6 h and 53 min

1.4.2 Service Robots

- The **Cycab** is an electrically-driven vehicle for autonomous transportation in urban environments

1.4.2 Service Robots

- **Rhino**, employing the synchro-drive mobile base B21 by Real World Interface, was one of the first robots for museum guided tours

1.4.2 Service Robots

- The vacuum robot Roomba, employing a differential-drive kinematics, autonomously sweeps and cleans floors

1.4.2 Service Robots

- The da Vinci robotic system for laparoscopic surgery

1.4.2 Service Robots

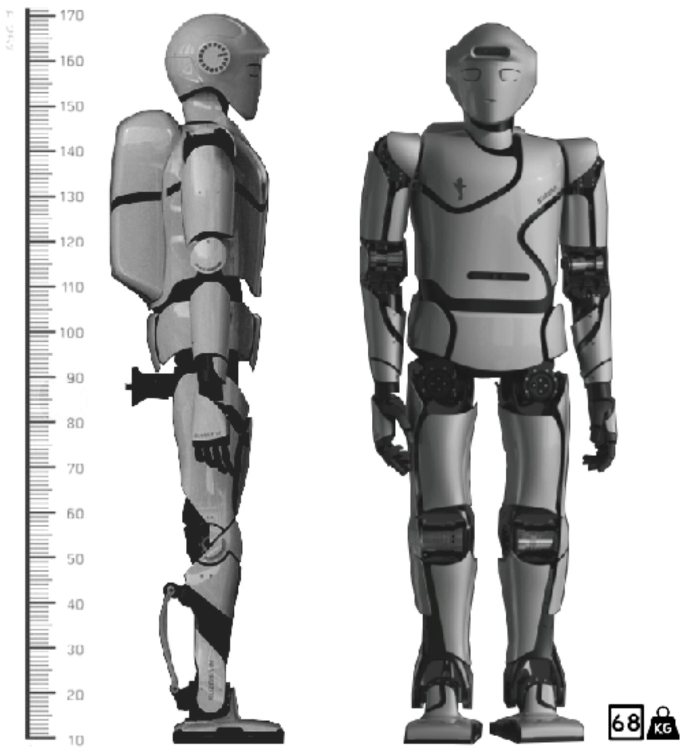
- The **Sina Surgical System** is a robotic surgical system that uses a minimally invasive surgical approach

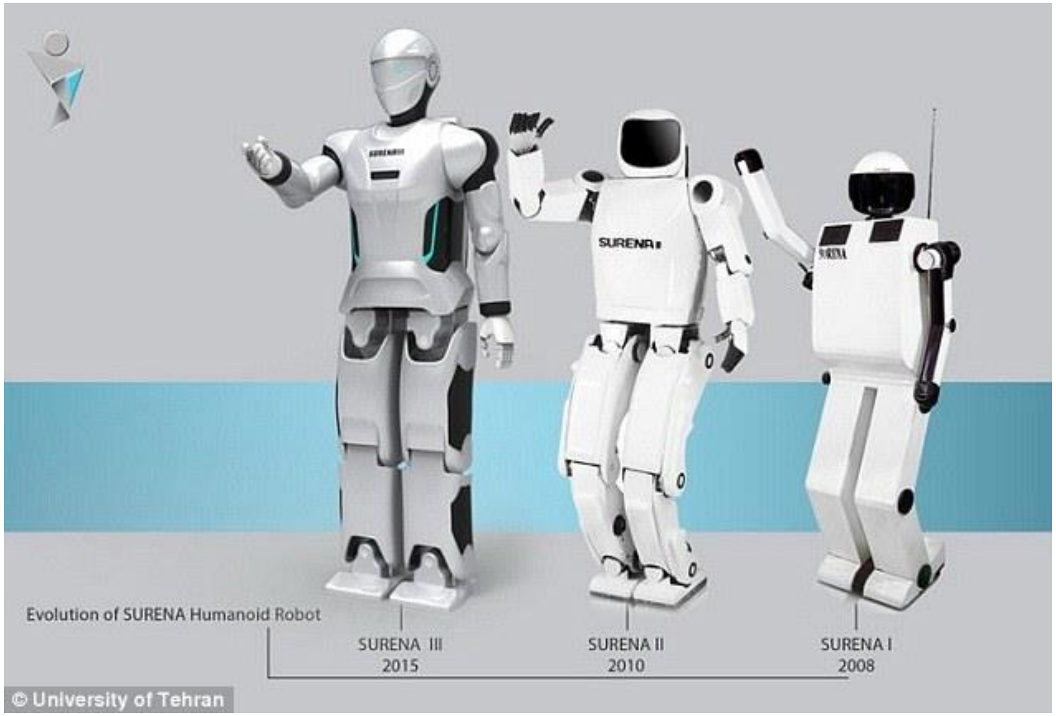
1.4.2 Service Robots

- The **Asimo** humanoid robot, launched in 1996, has been endowed with even more natural locomotion and human-robot interaction skills

1.4.2 Service Robots

- **Surena** is a series of Iranian humanoid robots





1.4.2 Service Robots

- The **AIBO** dog had been the most widely diffused entertainment robot in the recent years

1.5 Robot Modelling, Planning and Control

- 1.5.1 Modelling
  - 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, through the manipulator Jacobian.

- The formulation of the kinematics relationship allows the study of two key problems of robotics:
  - **The Direct Kinematics Problem**
  - **The Inverse Kinematics Problem**

1.5 Robot Modelling, Planning and Control

- 1.5.1 Modelling
  - The availability of a manipulator's kinematic model is also useful to determine the relationship between the forces and torques applied to the joints and the forces and moments applied to the end-effector in static equilibrium configurations.
  - Kinematics of a manipulator represents the basis of a systematic, general derivation of its dynamics, i.e., the equations of motion of the manipulator as a function of the forces and moments acting on it.
  - 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.

1.5 Robot Modelling, Planning and Control

- 1.5.2 Planning
  - The goal of trajectory planning is to generate the timing laws for the relevant variables (joint or end effector).

- 1.5.3 Control
  - Realization of the motion specified by the control law requires the employment of actuators and sensors.
  - The trajectories generated constitute the reference inputs to the motion control system of the mechanical structure. The problem of robot manipulator control is to find the time behaviour of the forces and torques to be delivered by the joint actuators so as to ensure the execution of the reference trajectories.