INDUSTRIAL AUTOMATION & ROBOTICS TECHNOLOGY

Introduction

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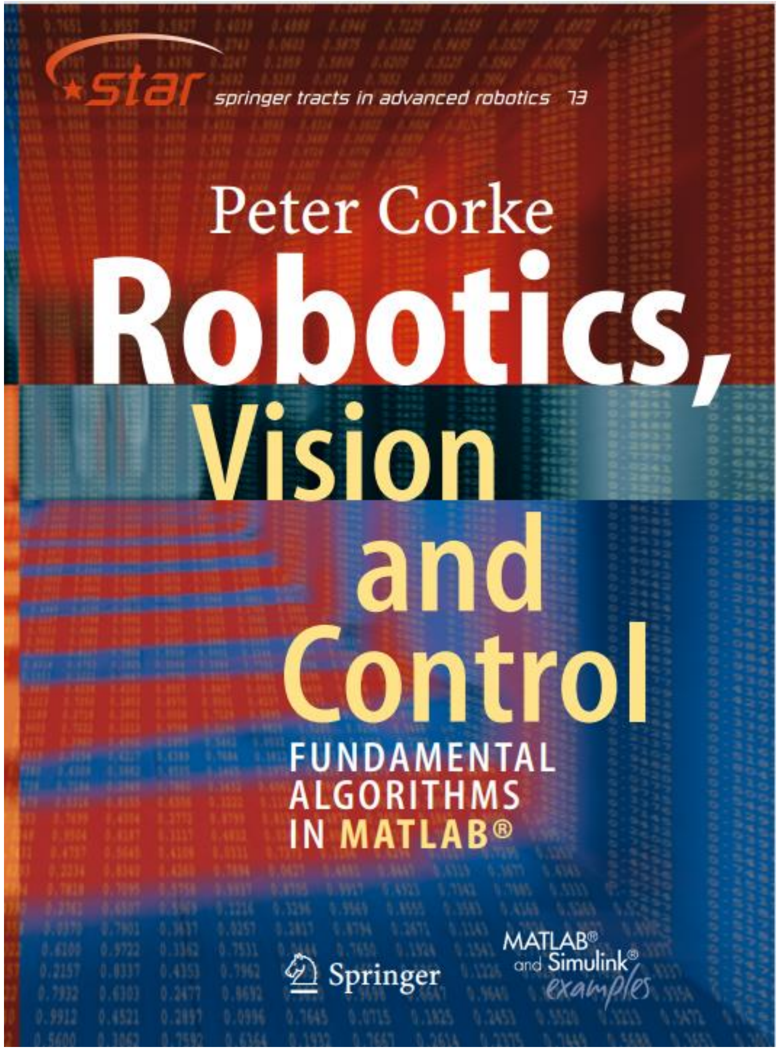
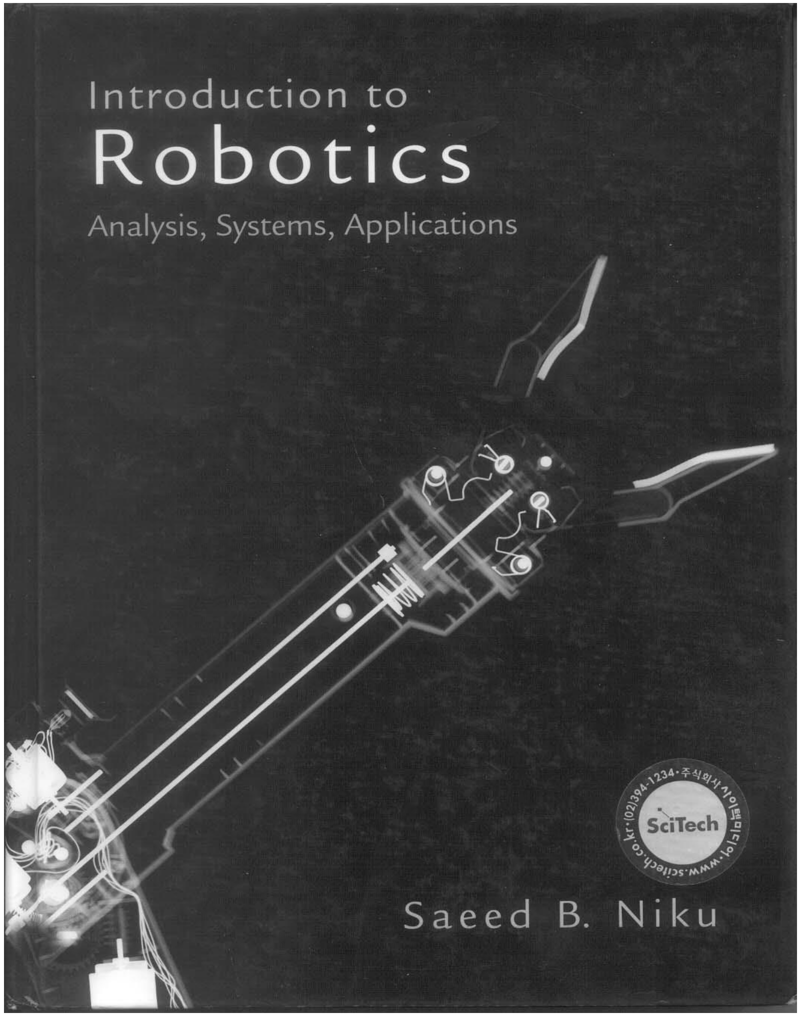
Pre-requisites

- The course is planned for fourth year undergraduate students and graduate students in their first year.
- Basic knowledge of programming, preferably MATLAB
- Basic knowledge of linear algebra, graph theory, vectors, dynamics, the Laplace transform and transfer functions, and linear control

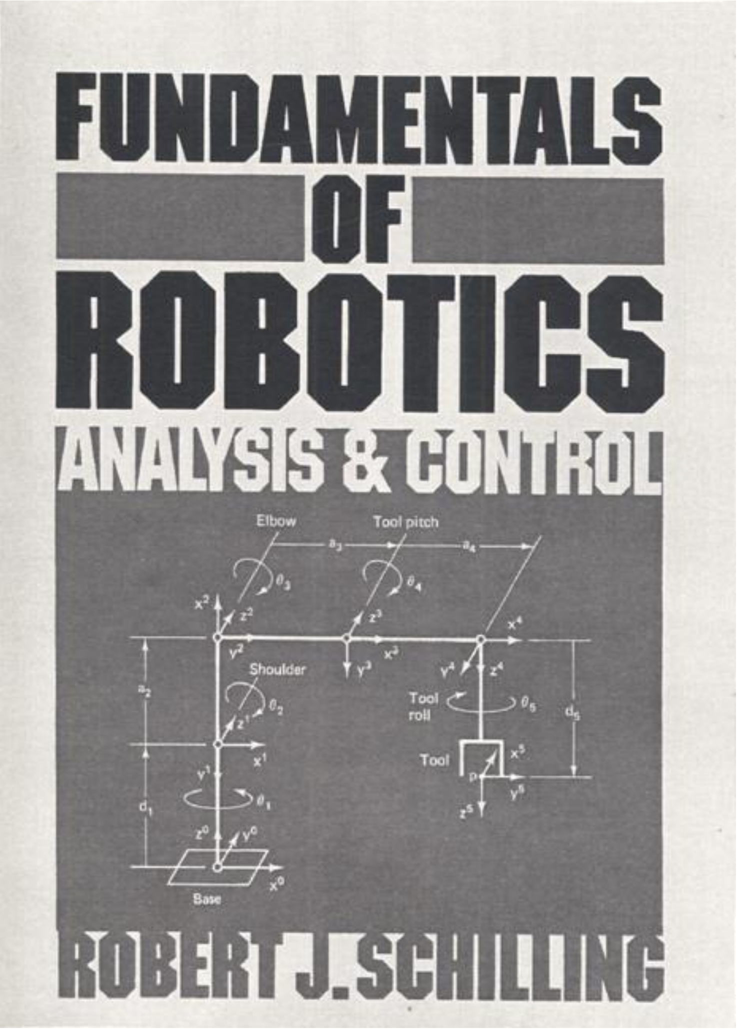
Robotics, vision and control



Introduction to robotics



Fundamentals of robotics: analysis and control



What is a robot?

- *Random House Dictionary* A machine that resembles a human being and does mechanical routine tasks on command.
- *Robotics Association of America* An industrial robot is a re-programmable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.
- Webster's Dictionary An automatic device that performs functions ordinarily ascribed to human beings ➔washing machine = robot?

What is a robot?

- Hollywood’s imagination

3PO

R2-D2

STAR WARS

What is a robot?

- A manipulator (or an industrial robot) is composed of a series of links connected to each other via joints. Each joint usually has an actuator (a motor for e.g.) connected to it.

- These actuators are used to cause relative motion between successive links. One end of the manipulator is usually connected to a stable base and the other end is used to deploy a tool.

What is a robot?

- By general agreement, a robot is:

  A programmable machine that imitates the actions or appearance of an intelligent creature–usually a human.

- 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

What is a robot?

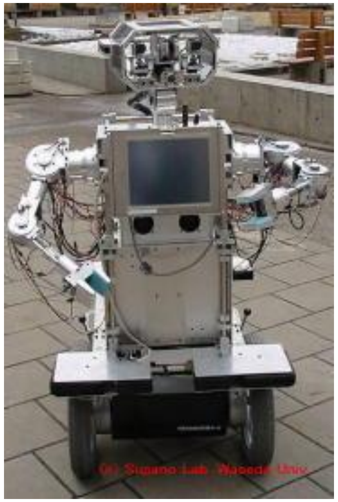
a goal-oriented machine that can

- sense,
- plan and
- act

Types of Robots

- Robot Manipulators

- Mobile Manipulators

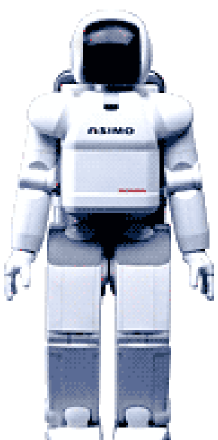


Types of Robots

Locomotion

Aerial Robots

Wheeled mobile robots



Humanoid

Underwater robots

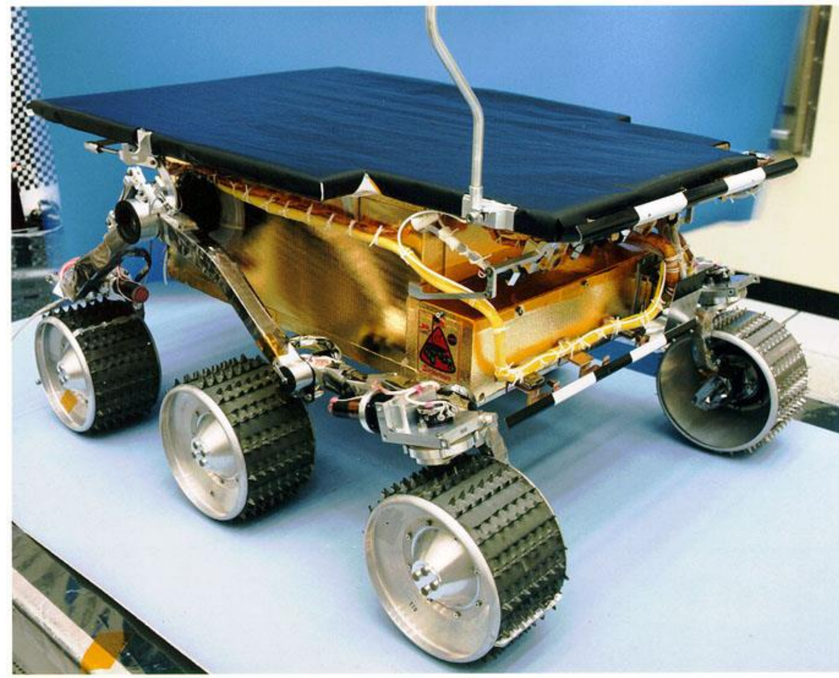
Legged robots

Mobile Robot Examples

Hilare II

http://www.laas.fr/~matthieu/robots/

Sojourner Rover



NASA and JPL, Mars exploration

Why Use Robots?

- Application in 4D environments
  - Dangerous
  - Dirty
  - Dull
  - Difficult
- 4A tasks
  - Automation
  - Augmentation
  - Assistance
  - Autonomous

Classification of robots

JIRA (Japanese Industrial Robot Association)

Class1 Manual-Handling Device

A device with multiple degrees of freedom that is actuated by an operator

Class2 Fixed Sequence Robot

A device that performs the successive stages of a task according to a predetermined, unchanging method and is hard to modify

Class3 Variable Sequence Robot

Same as class 2, but easy to modify

Classification of robots

Class4 Playback Robot

A human operator performs the task manually by leading the robot, which records the motions for later playback

Class5 Numerical Control Robot

The operator supplies the robot with a movement program rather than teaching it the task manually

Class6 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

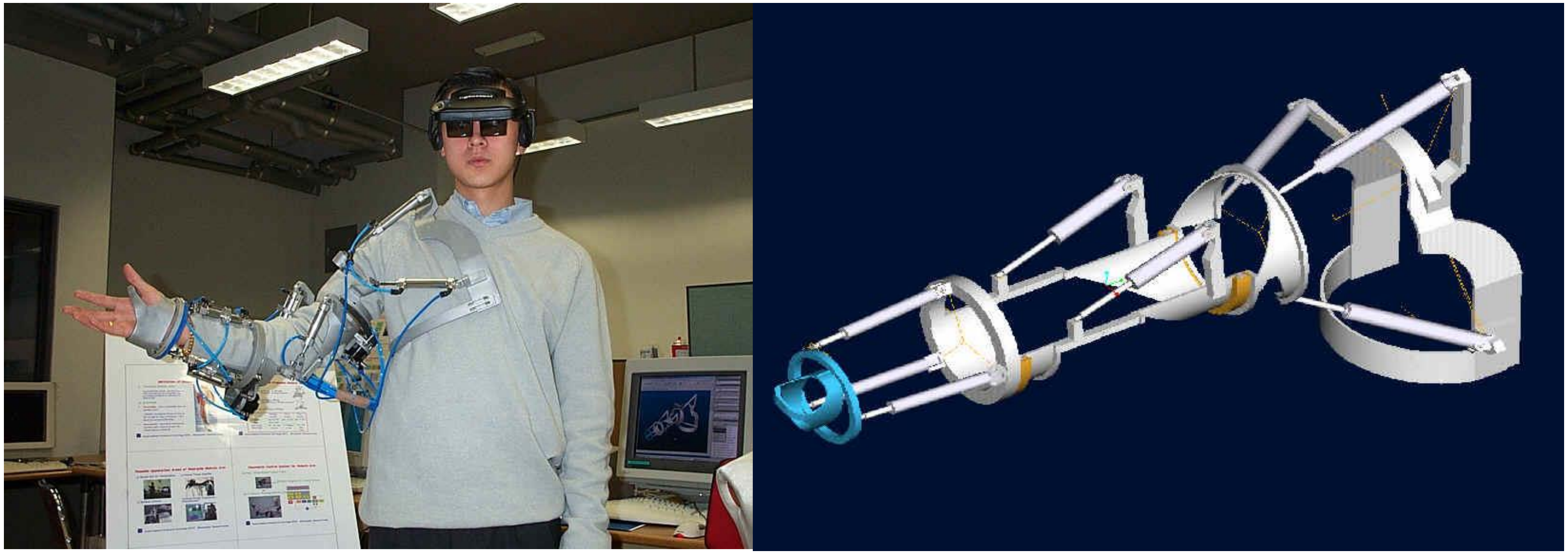
ROBOT IN THE WORLD

Painting Robot in Motor Company

Assembly Robot in Electronic Company

Robot in the world

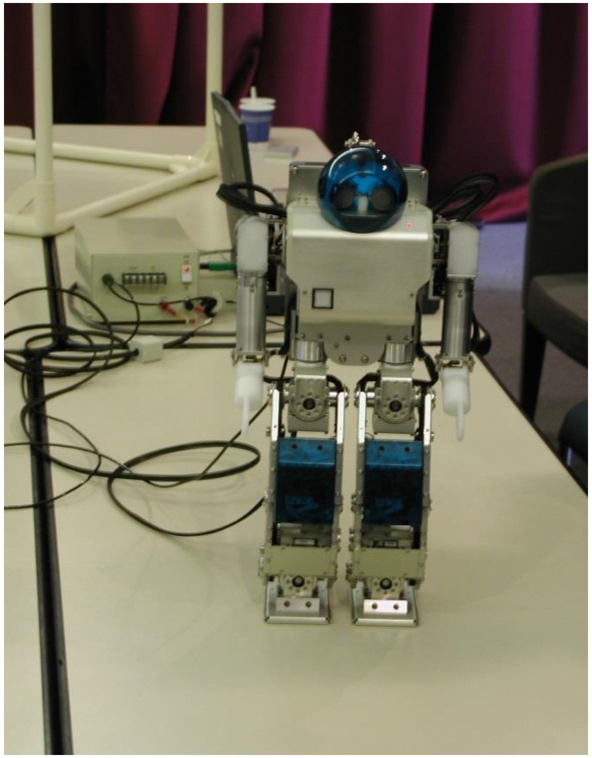
- Robot in the world



Wearable Robotic Arm and Tele-Operated Robot (KIST)

Robot in the world

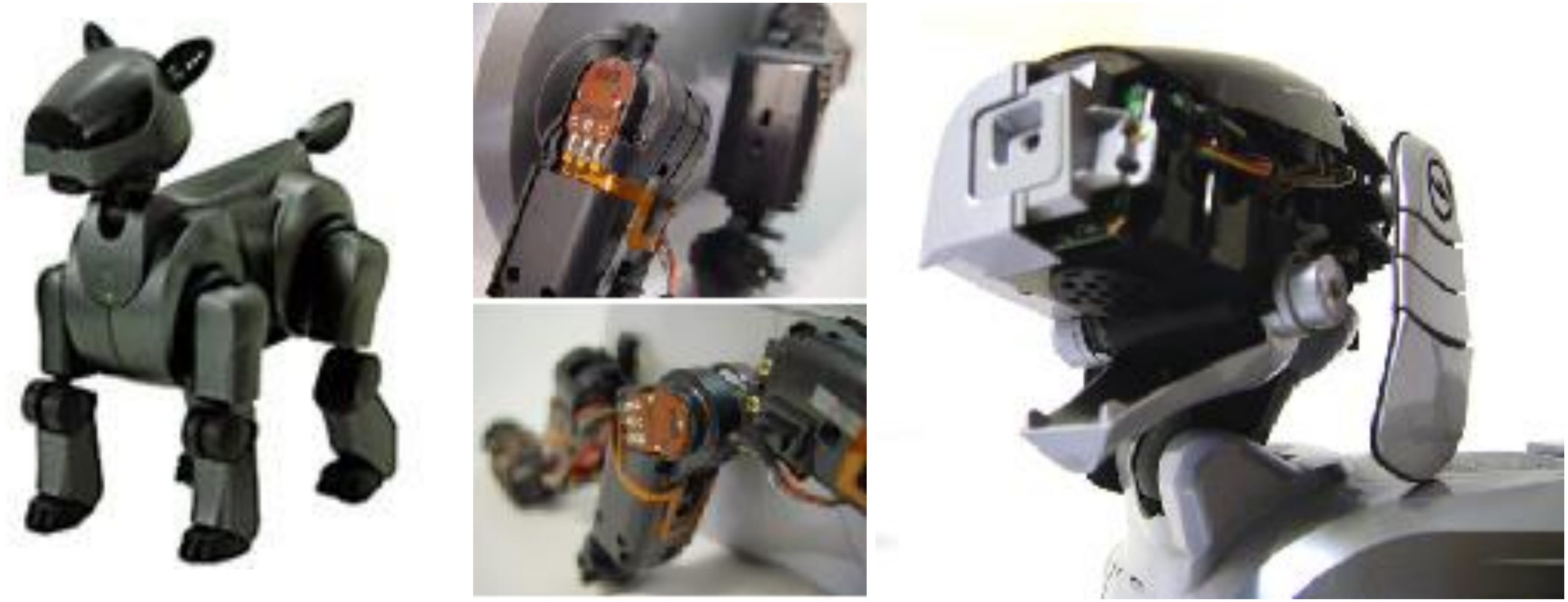
HONDA (ASIMO) – Biped Robot



Fujitsu – Biped Robot (Laptop Size)

Robot in the world

- Robot in the world



Sony (AIBO) – Toy robot

What is Robotics?

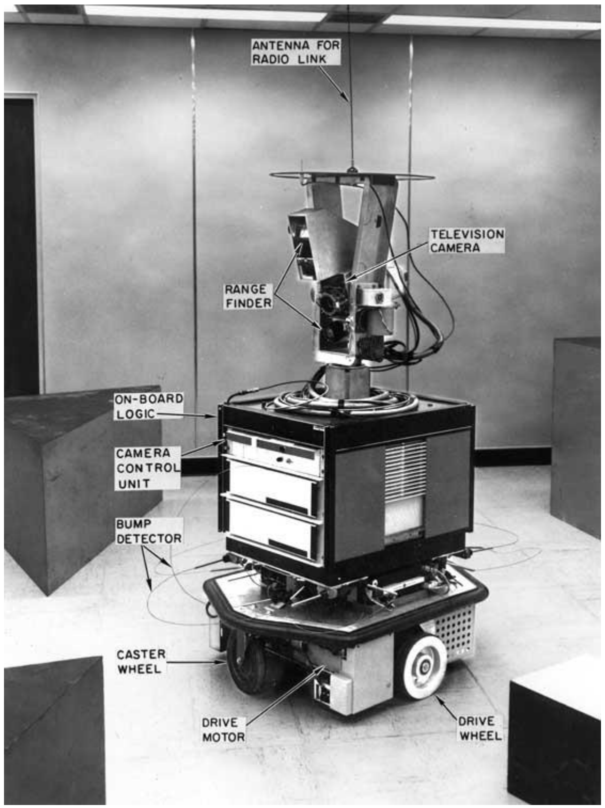
- Robotics is the art, knowledge base, and the know-how of designing, applying, and using robots in human endeavors.

- Robotics is an interdisciplinary subject that benefits from mechanical engineering, electrical and electronic engineering, computer science, biology, and many other disciplines.

History of robotics

1922: Karel Čapek's novel, Rossum's Universal Robots, word "Robota" (worker)
1952: NC machine (MIT)
1955: Denavit-Hartenberg Homogeneous Transformation
1967: Mark II (Unimation Inc.)
1968: Shakey (SRI) - intelligent robot
1973: T3 (Cincinnati Milacron Inc.)
1978: PUMA (Unimation Inc.)
1983: Robotics Courses
21C: Walking Robots, Mobile Robots, Humanoid Robots

History of robotics



- **Shakey** (Stanford Research Institute)
  - the first mobile robot to be operated using AI techniques
- **S**imple tasks to solve:
  - To recognize an object using vision
  - Find its way to the object
  - Perform some action on the object (for example, to push it over)

http://www.frc.ri.cmu.edu/~hpm/book98/fig.ch2/p027.html

Advantages vs. Disadvantages of Robots

- Robots increase productivity, safety, efficiency, quality, and consistency of products.
- Robots can work in hazardous environments without the need.
- Robots need no environmental comfort.
- Robots work continuously without experiencing fatigue of problem.
- Robots have repeatable precision at all times.
- Robots can be much more accurate than human.
- Robots replace human workers creating economic problems.
- Robots can process multiple stimuli or tasks simultaneously.

Advantages vs. Disadvantages of Robots

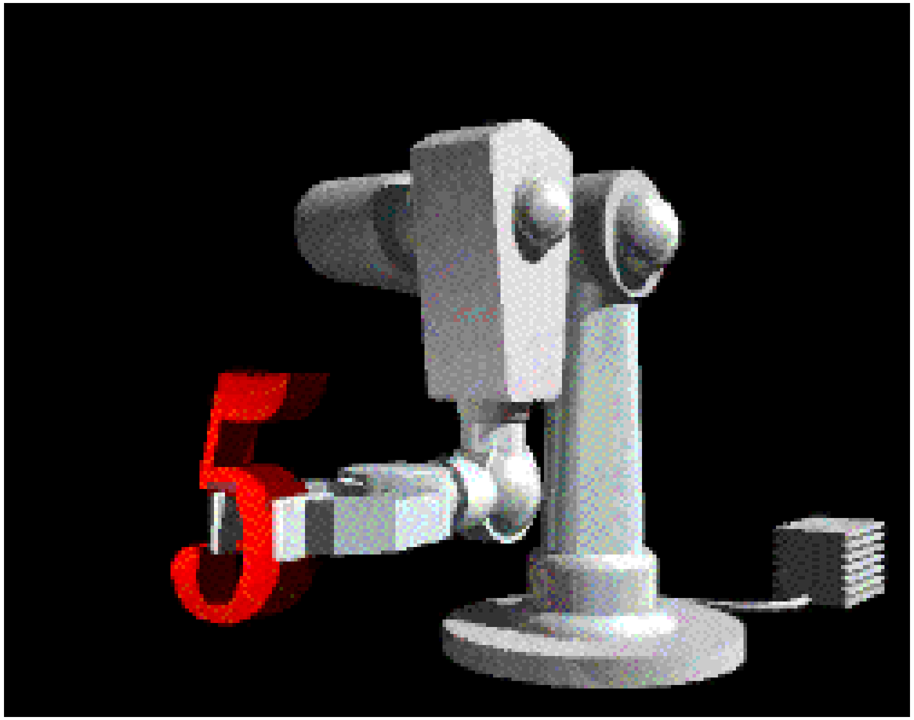
- Robots lack capability to respond in emergencies.

- Robots, although superior in certain senses, have limited capabilities in Degree of freedom, Dexterity, Sensors, Vision system, real time response.

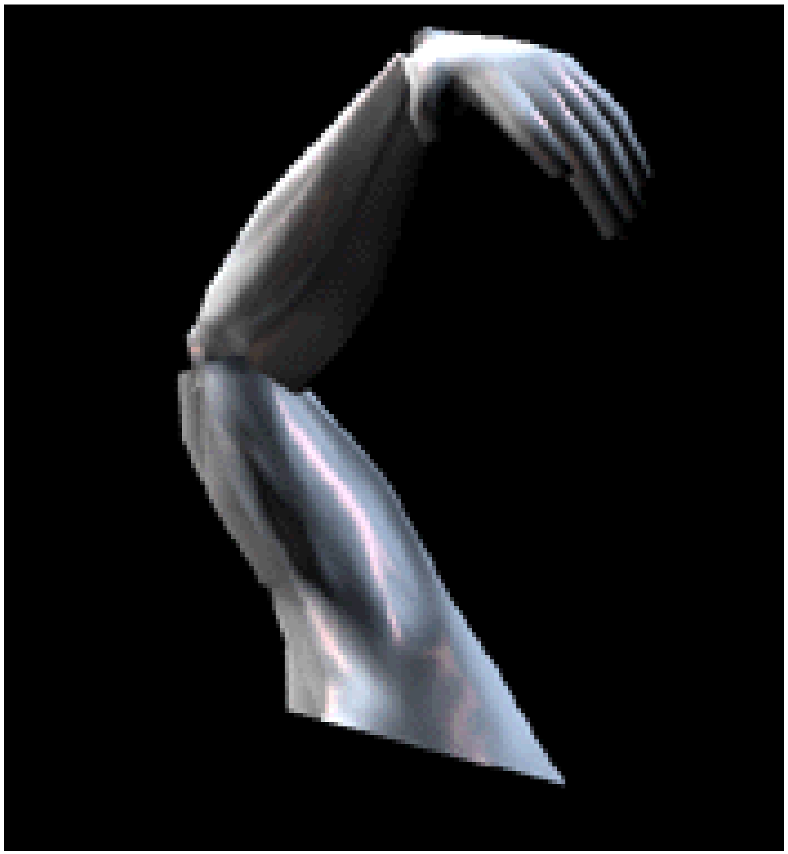
- Robots are costly, due to Initial cost of equipment, Installation costs, Need for Peripherals, Need for training, Need for programming.

What are the parts of a robot?

- Manipulator
- Pedestal
- End effector
- Actuator
- Sensors
- Controller
- Processor
- Software



Manipulator



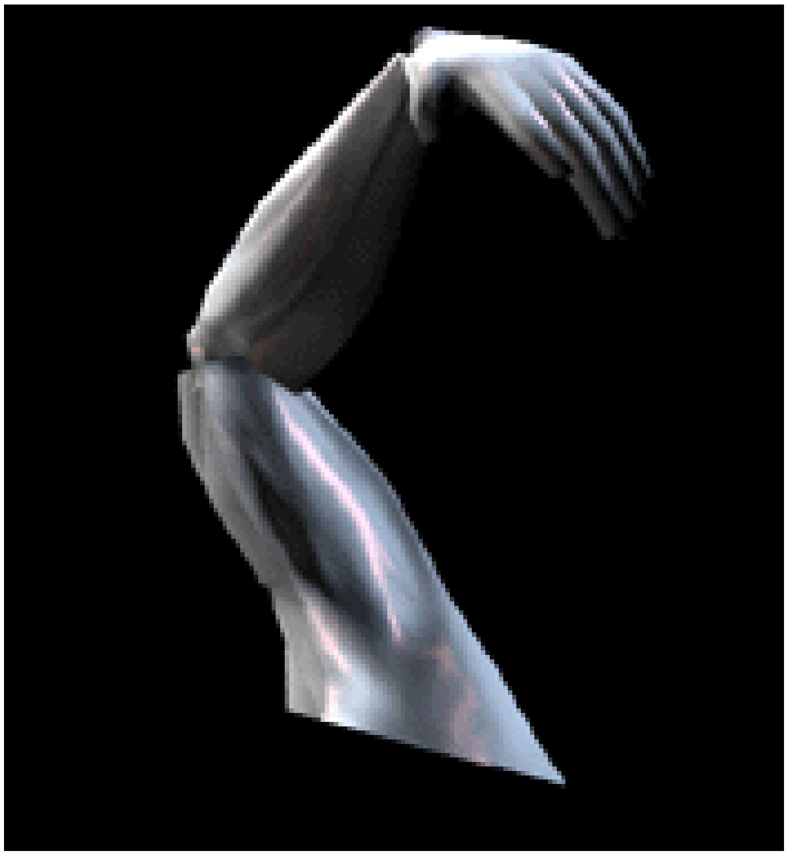
- **Base**
- **Appendages**

  Shoulder

  Arm

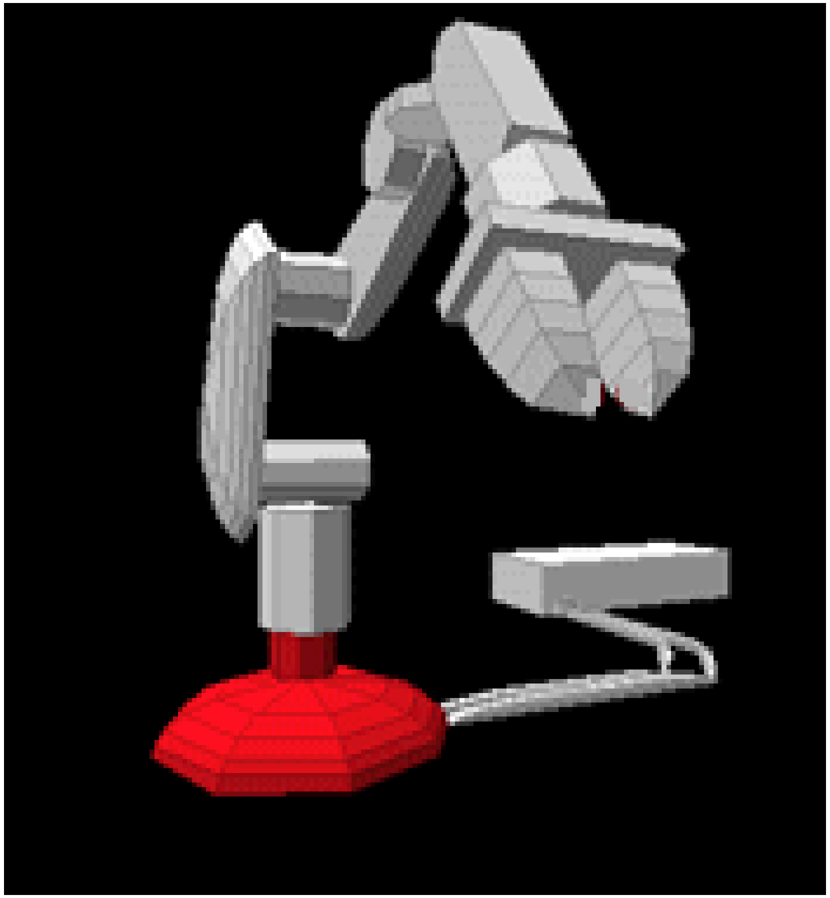
  Grippers

Manipulator



This is the main body of the robot which consists of the links, the joints, and other structural elements of the robot. Without other elements, the manipulator alone is not a robot

Pedestal

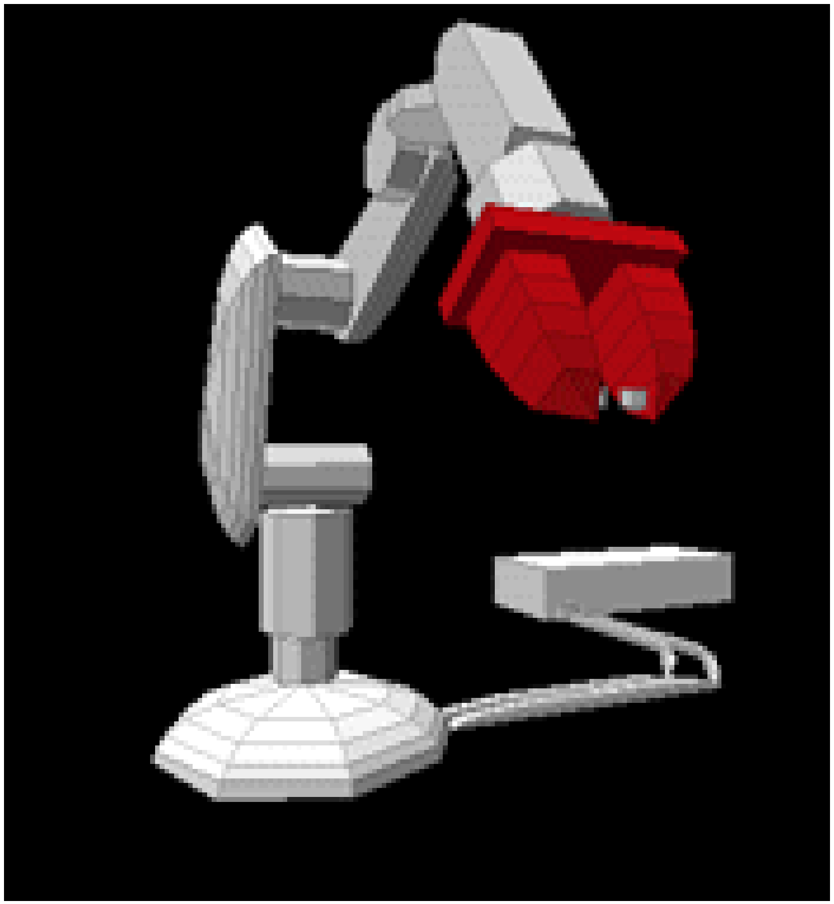


(Human waist)

- **Supports the manipulator.**
- **Acts as a counterbalance.**

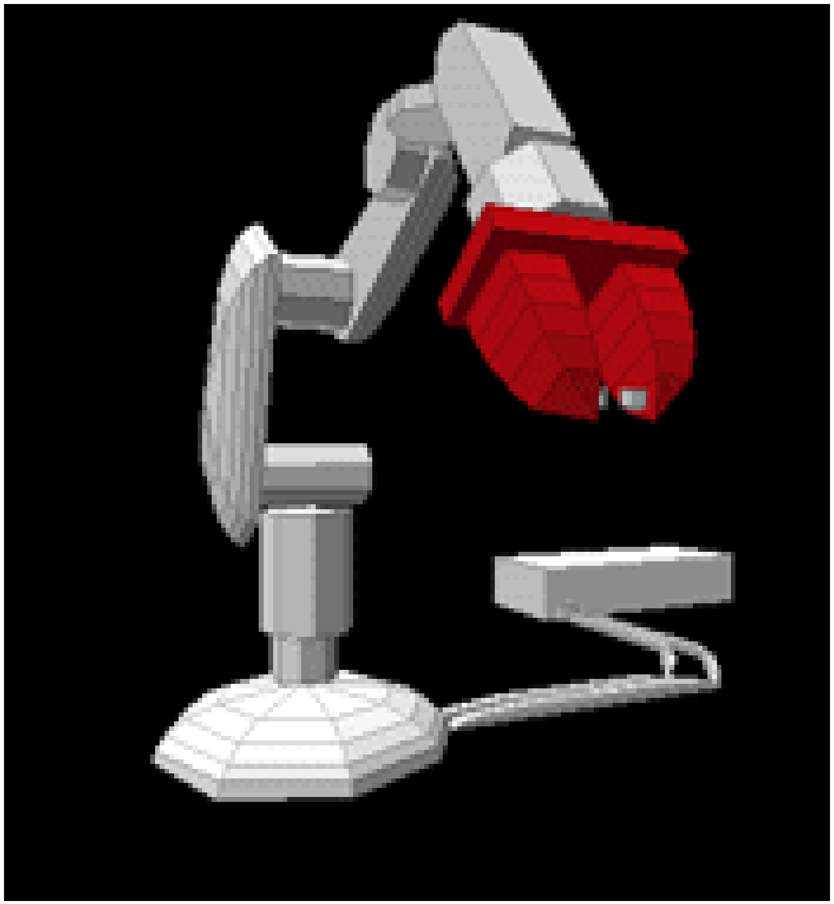
End Effectors

(The hand)



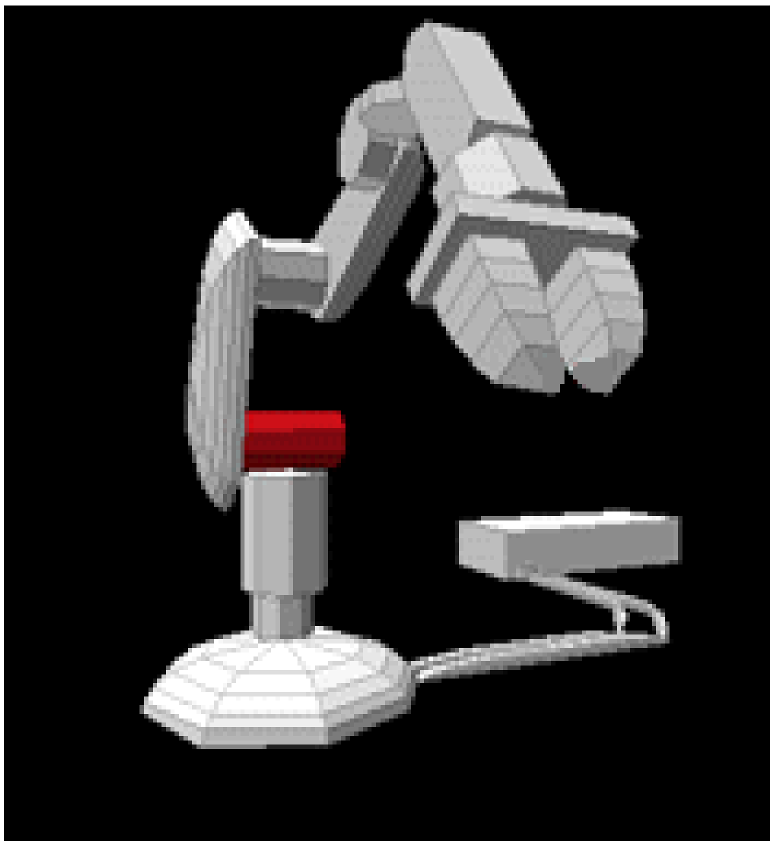
- Spray paint attachments
- Welding attachments
- Vacuum heads
- Hands
- Grippers

End Effectors



This part is connected to the last joint (hand) of a manipulator that generally handles objects, makes connections to other machines, or performs the required tasks

Actuators



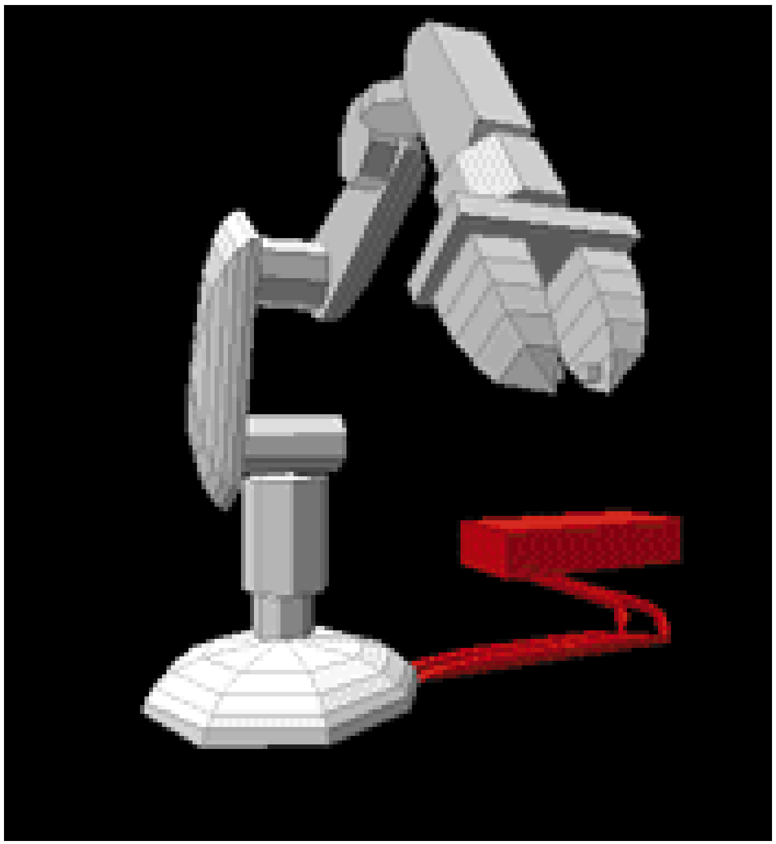
Actuators are the ‘‘muscles’’ of the manipulators. The controller sends signals to the actuators, which, in turn, move the robot joints and links. Common types are servomotors, stepper motors, pneumatic actuators, and hydraulic actuators.

Sensors

Sensors are used to collect information about the internal state of the robot or to communicate with the outside environment. As in humans, the robot controller needs to know the location of each link of the robot in order to know the robot's configuration.

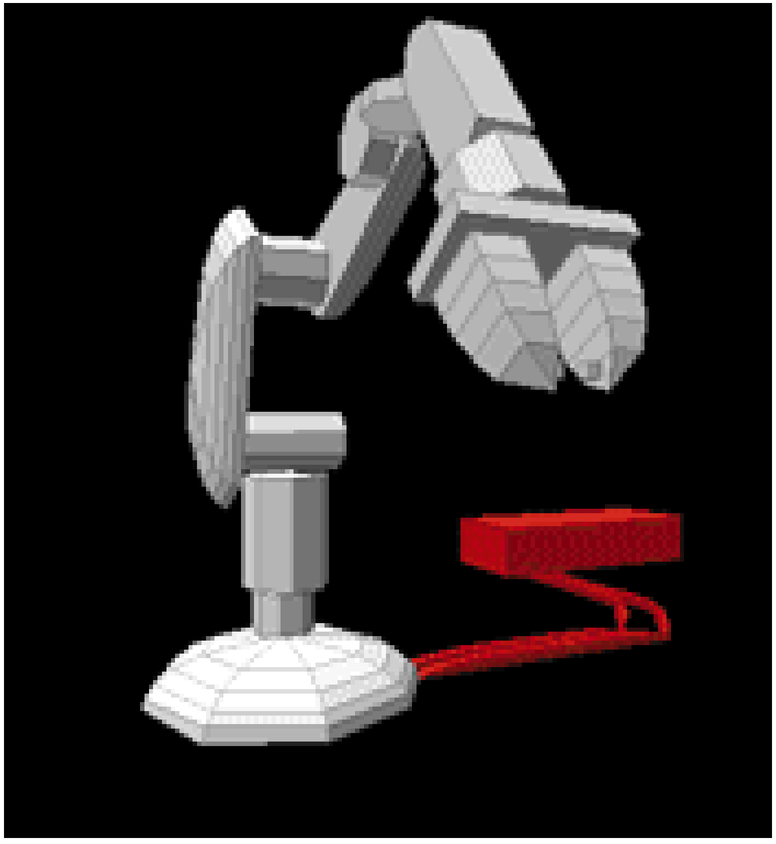
Still similar to your major senses of sight, touch, hearing, taste, and speech, robots are equipped with external sensory devices such as a vision system, touch and tactile sensors, speech synthesizer, and the like that enable the robot to communicate with the outside world

Controller



- **Issues instructions to the robot.**
- **Controls peripheral devices.**
- **Interfaces with robot.**
- **Interfaces with humans.**

Controller



The controller is rather similar to your cerebellum; although it does not have the power of the brain, it still controls your motions. The controller receives its data from the computer (the brain of the system), controls the motions of the actuators, and coordinates the motions with the sensory feedback information.

Processor

- The processor is the brain of the robot.
- It calculates the motions of the robot's joints, determines how much and how fast each joint must move to achieve the desired location and speeds, and oversees the coordinated actions of the controller and the sensors.
- The processor is generally a computer, which works like all other computers, but is dedicated to this purpose.
- It requires an operating system, programs, peripheral equipment like a monitor, and has the same limitations and capabilities.
- In some systems, the controller and the processor are integrated together into one unit.

Software

Three groups of software programs are used in a robot.

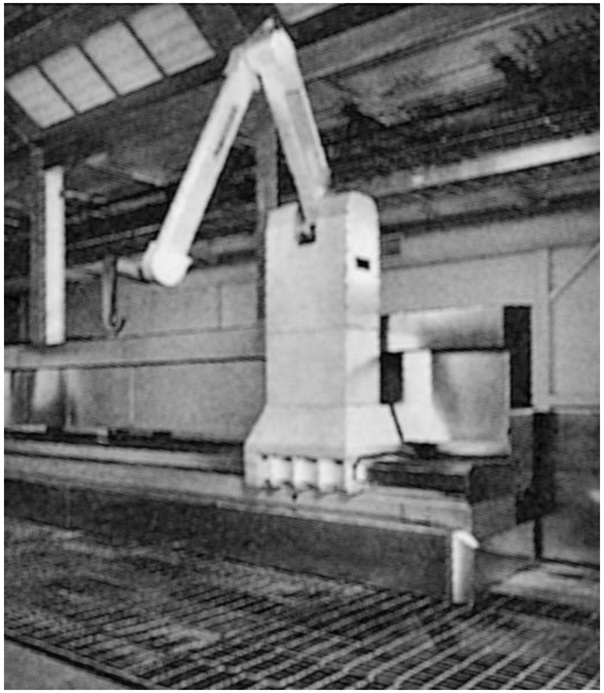
- One is the operating system that operates the processor.
- The second is the robotic software that calculates the necessary motions of each joint based on the kinematic equations of the robot. This information is sent to the controller. This software may be at many different levels, from machine language to sophisticated languages used by modern robots.
- The third group is the collection of application-oriented routines and programs developed to use the robot or its peripherals for specific tasks such as assembly, machine loading, material handling, and vision routines.

Robots degrees of freedom

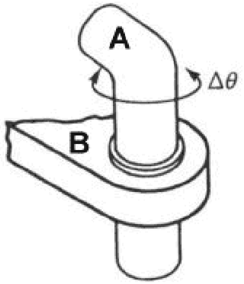
- Degrees of Freedom: Number of independent position variables which would has to be specified to locate all parts of a mechanism.

- In most manipulators this is usually the number of joints.

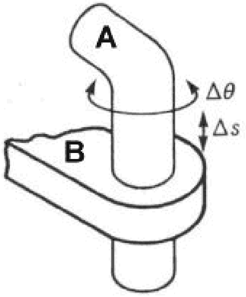
Robots degrees of freedom



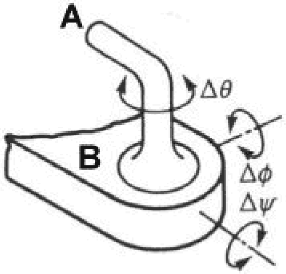
Consider what is the degree of Fig. 1.4



1 D.O.F.



2 D.O.F.



3 D.O.F.

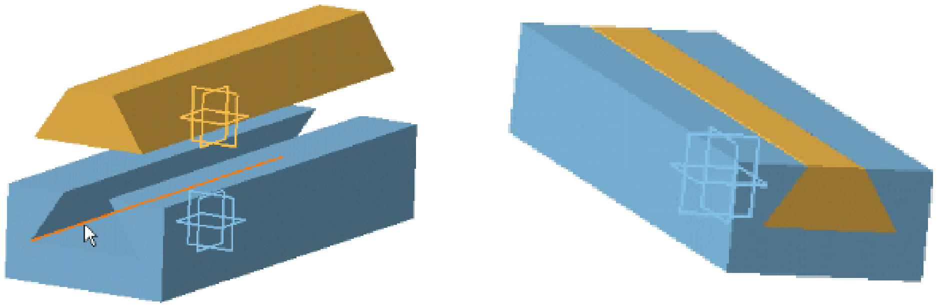
Fig. 1.4 A Fanuc P-15 robot.

Reprinted with permission from Fanuc Robotics, North America, Inc.

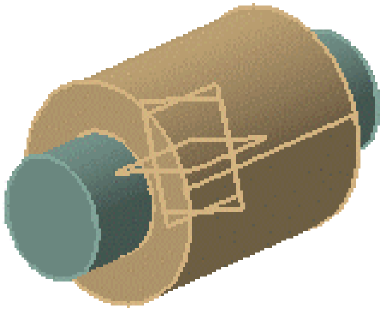
Robot Joints

Prismatic Joint: Linear, No rotation involved.

(Hydraulic or pneumatic cylinder)



Revolute Joint: Rotary, (electrically driven with stepper motor, servo motor)



Robot Coordinates

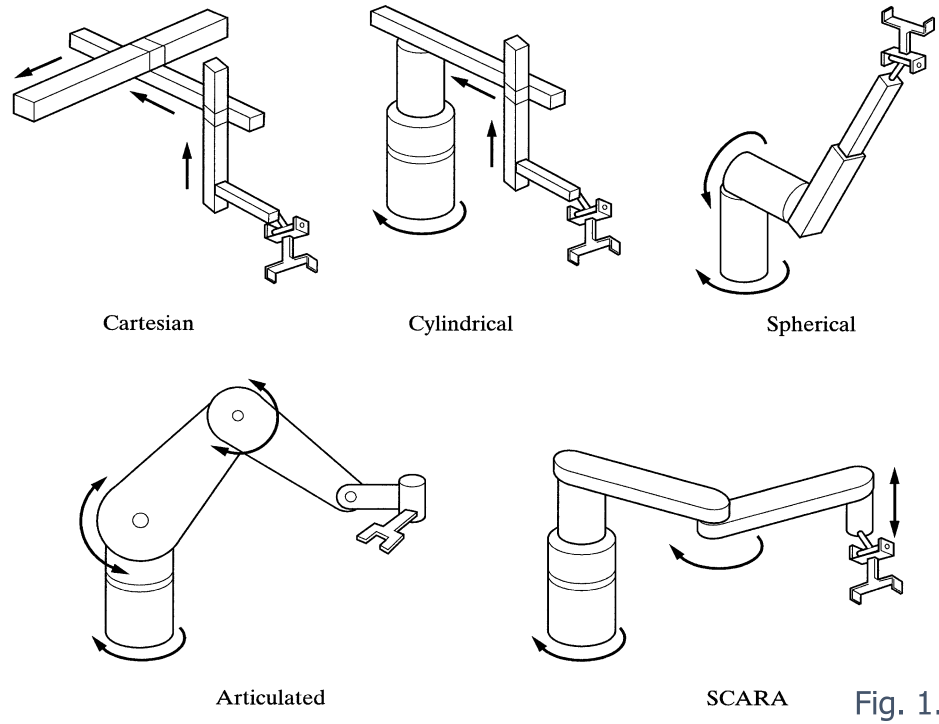


Fig. 1.5

- Cartesian/rectangular/gantry (3P) : 3 cylinders joint
- Cylindrical (R2P) : 2 Prismatic joint and 1 revolute joint
- Spherical (2RP) : 1 Prismatic joint and 2 revolute joint
- Articulated/anthropomorphic (3R) : All revolute(Human arm)
- Selective Compliance Assembly Robot Arm (SCARA):
  2 paralleled revolute joint and 1 additional prismatic joint

Robot Reference Frames

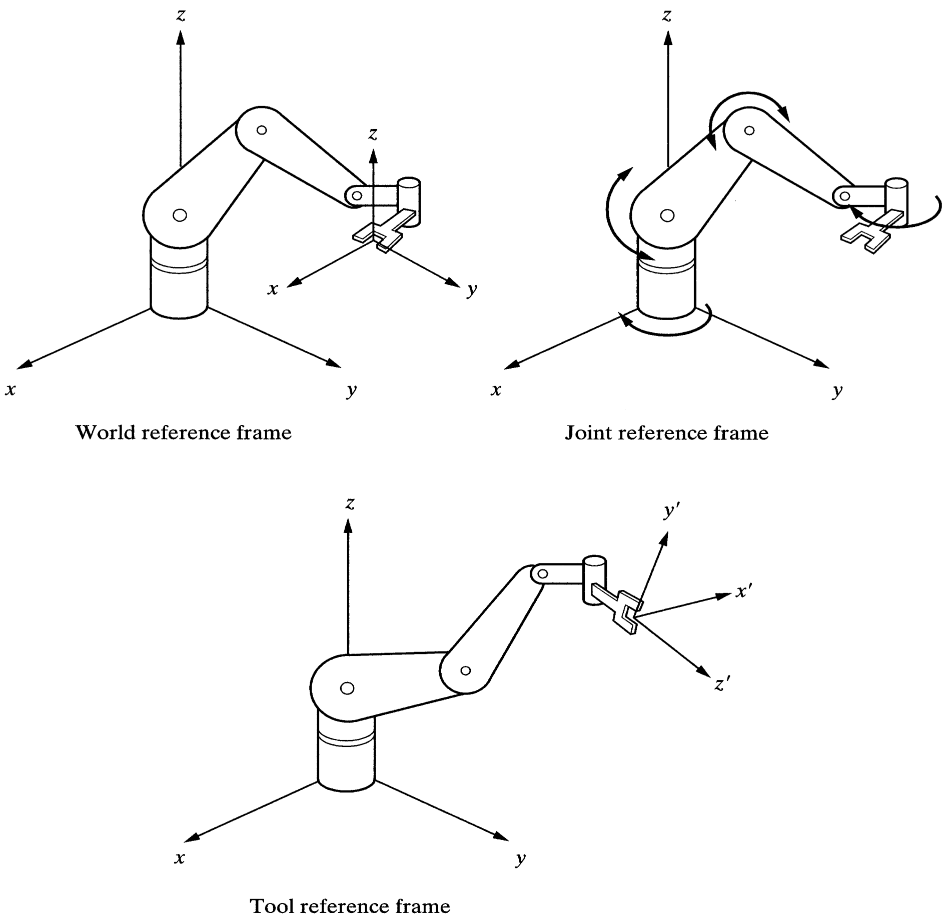


Fig. 1.7 A robot's World, Joint, and Tool reference frames.

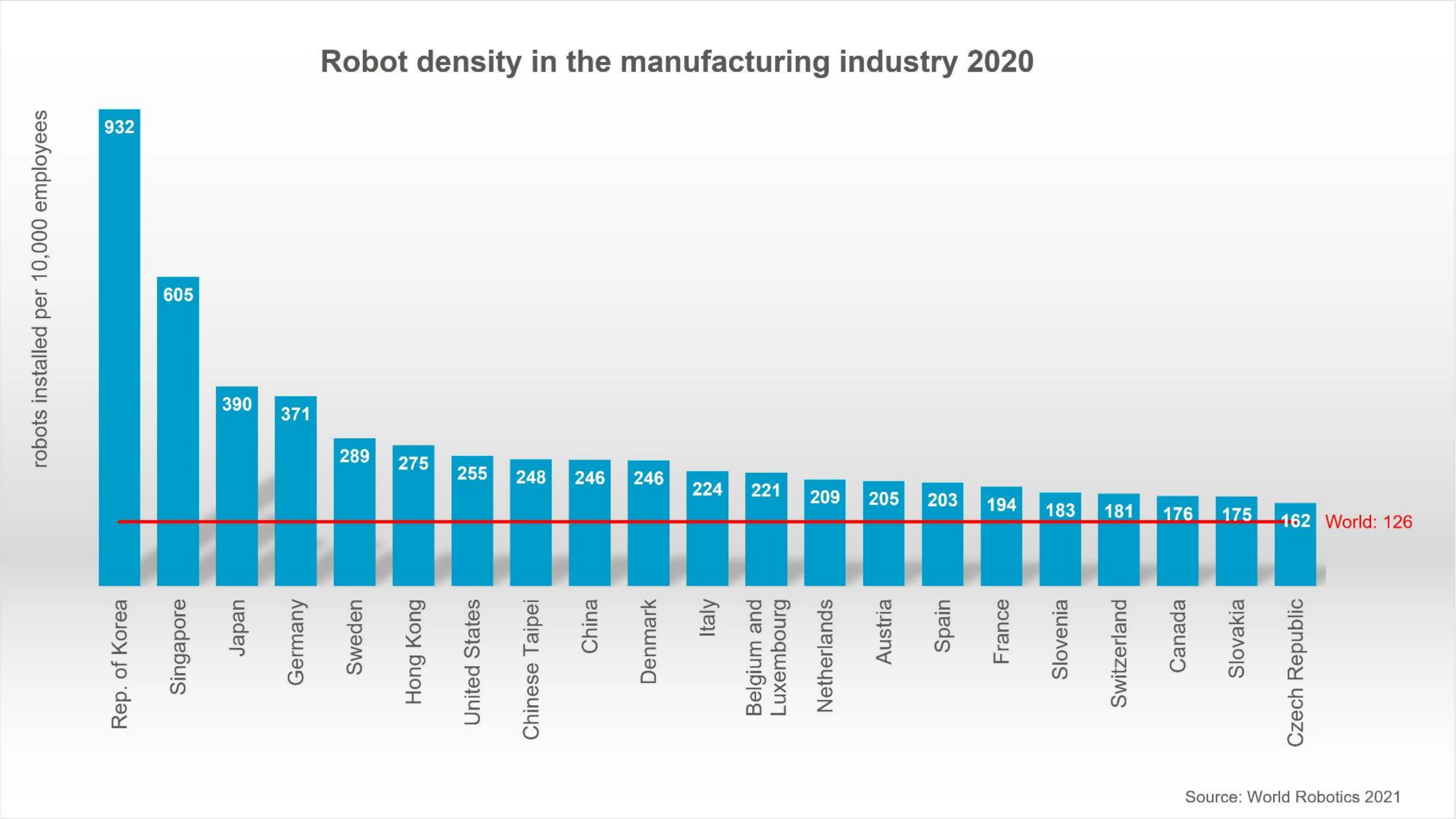
Most robots may be programmed to move relative to either of these reference frames.

Distribution of world robot population

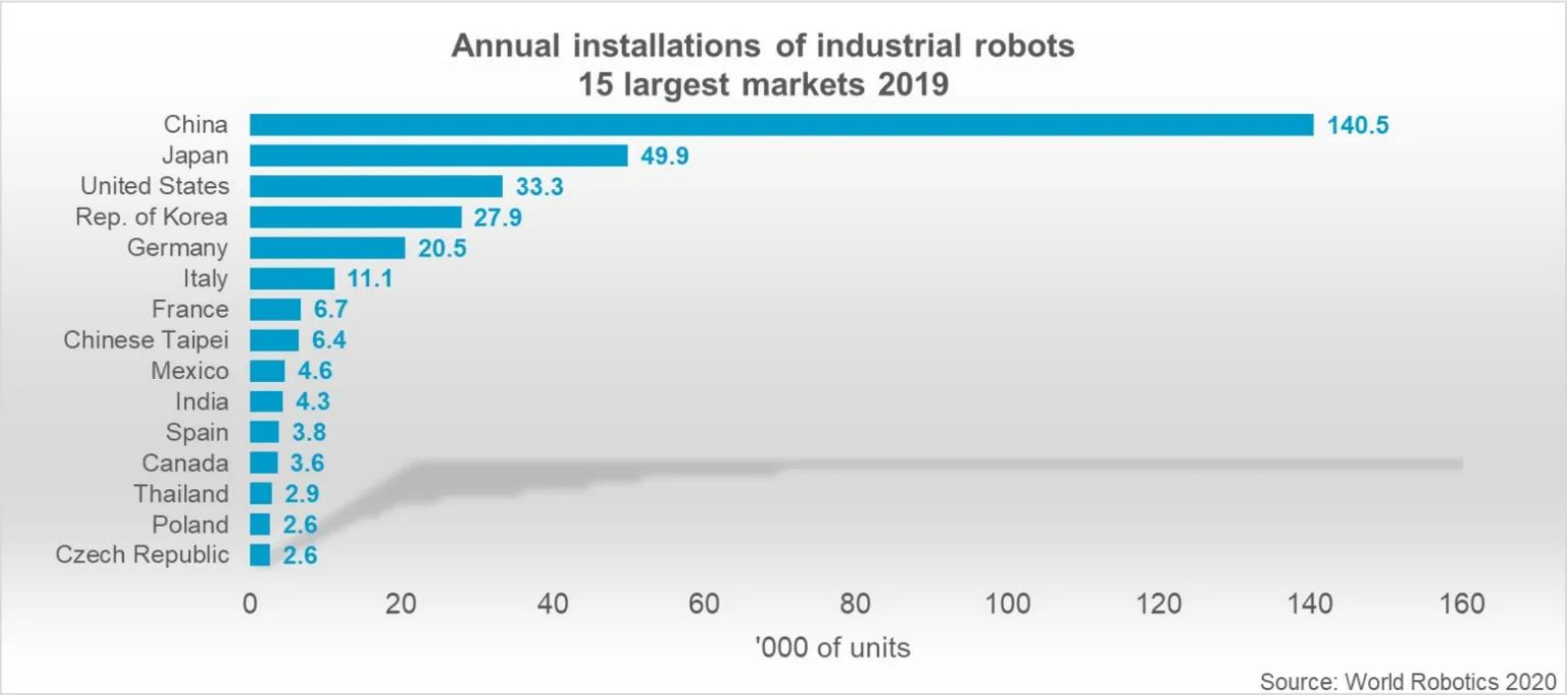
The use of industrial robots in factories around the world is accelerating at a high rate: 126 robots per 10,000 employees is the new average of global robot density in the manufacturing industries – nearly double the number five years ago (2015: 66 units). This is according to the 2021 World Robot Report.

By regions, the average robot density in Asia/Australia is 134 units, in Europe 123 units and in the Americas 111 units. The top 5 most automated countries in the world are: South Korea, Singapore, Japan, Germany, and Sweden.

Distribution of world robot population



Annual installation of industrial robots



Global robot sales

- 70% of the global robot sales went to five countries
  - China
  - Japan
  - USA
  - Korea
  - Germany

PROGRAMMING MODES

Physical Setup: In this mode, an operator sets up switches and hard stops that control the motions of the robot.
This mode is usually used along with other devices such as Programmable Logic Controllers (PLC)

Lead Through/ Teach Mode: In this mode, the robot's joints are moved with a teach pendant.
When the desired location and orientation is achieved, the location is entered (taught) into the controller. During playback, the controller moves the joints to the same locations and orientations. This mode is usually point-to-point; as such, the motion between points is not specified or controlled.
Only the points that are taught are guaranteed to reach

PROGRAMMING MODES

Continuous Walk-Through Mode: In this mode, all robot joints are moved simultaneously, while the motion is continuously sampled and recorded by the controller. During playback, the exact motion that was recorded is executed. The motions are taught by an operator, either through a model, by physically moving the end-effector, or by "wearing" the robot arm and moving it through its workspace. Painting robots, for example, may be programmed by skilled painters t hrough this mode

Software Mode: Use of feedback information

PROGRAMMING MODES

Software Mode: In this mode of programming the robot, a program is written offline or online and is executed by the controller to control the motions. The programming mode is the most sophisticated and versatile mode and can include sensory information, conditional state ments (such as if . . . then statements), and branching. However, it requires a working knowledge of the programming syntax of the robot before any program is written.

Most industrial robots can be programmed in more than one mode

Robot Specifications

Characteristics	Units
Number of axes	--
Load carrying capacity	kg
Maximum speed, cycle time	mm/sec
Reach and stroke	mm
Tool orientation	deg
Repeatability	mm
Precision and accuracy	mm
Operating environment	--

Robot Specifications

- Number of axes

Axes	Type	Function
1-3	Major	Position the wrist
4-6	Minor	Orient the tool
7-n	Redundant	Avoid obstacles

Robot Specifications

- Capacity and Speed

Load carrying capacity varies greatly between robots

- Minimover 5 Microbot has a load carrying capacity of 2.2 kg
- GCA-XR6 has a load carrying capacity of 4928 kg

Maximum tool tip speed can also vary substantially between manipulators

- Westinghouse Series 4000 robot has a tool-tip speed of 92 mm/sec
- Adept One SCARA robot has a tool-tip speed of 9000 mm/sec

Robot Specifications

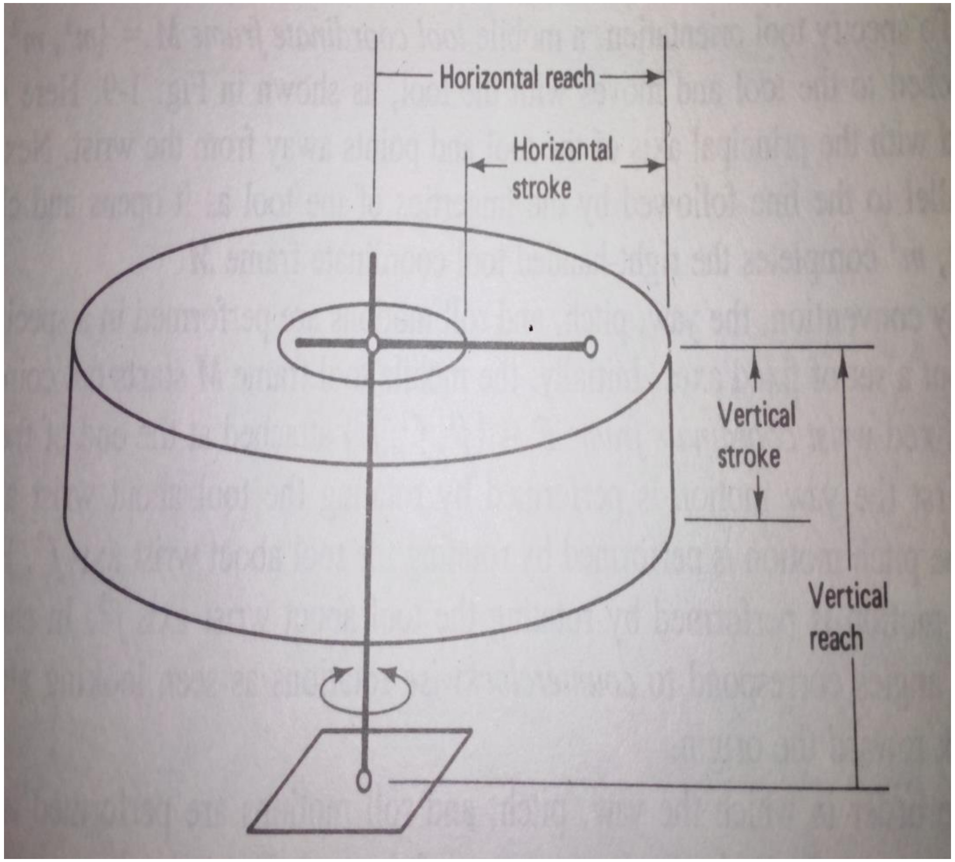
- Reach and Stroke

Rough measures of the size of work envelope.

  - Horizontal reach is defined as the maximum radial distance the wrist mounting flange can be positioned from the vertical axis about which the robot rotates
  - Horizontal stroke represents the total radial distance the wrist can travel

Robot Specifications

- Reach and Stroke



Robot Specifications

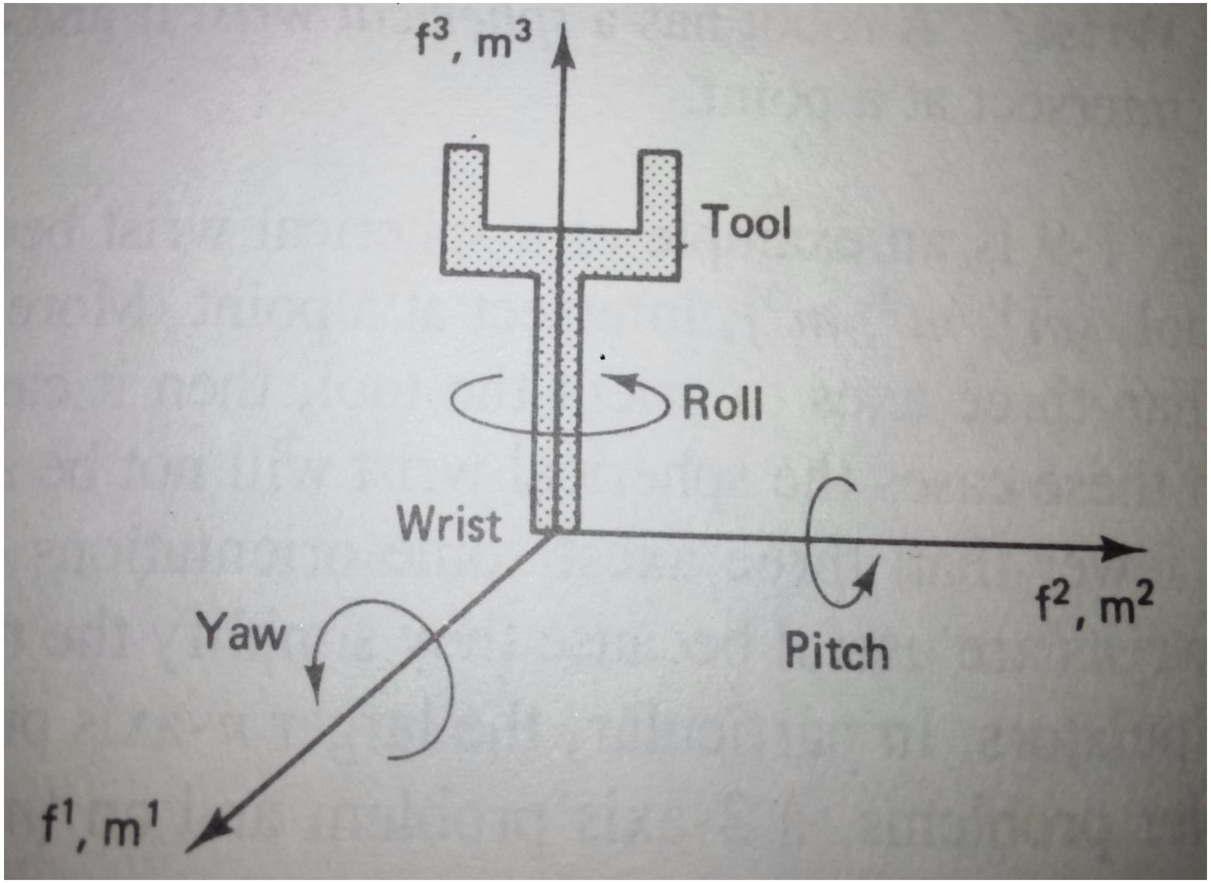
- Reach and Stroke

  - Vertical reach of a robot is the maximum elevation above the work surface that the wrist mounting flange can reach

  - Vertical stroke is the total vertical distance the wrist can travel.

Robot Specifications

- Tool Orientation



Robot Specifications

- Repeatability, Precision and Accuracy
  - Repeatability is a measure of the ability of the robot to position the tool tip in the same place repeatedly
  - Precision is a measure of the spatial resolution with which the tool can be positioned within the work envelope
  - Accuracy is a measure of the ability of the robot to place the tool tip at an arbitrarily prescribed location in the work envelope

Robot Specifications

- Operating Environment

Suitable robots are picked based upon the nature of task and the work place

- Harsh, dangerous or unhealthy environment
  - Transportation of radioactive material
  - Spray painting
  - welding

Robot Workspace

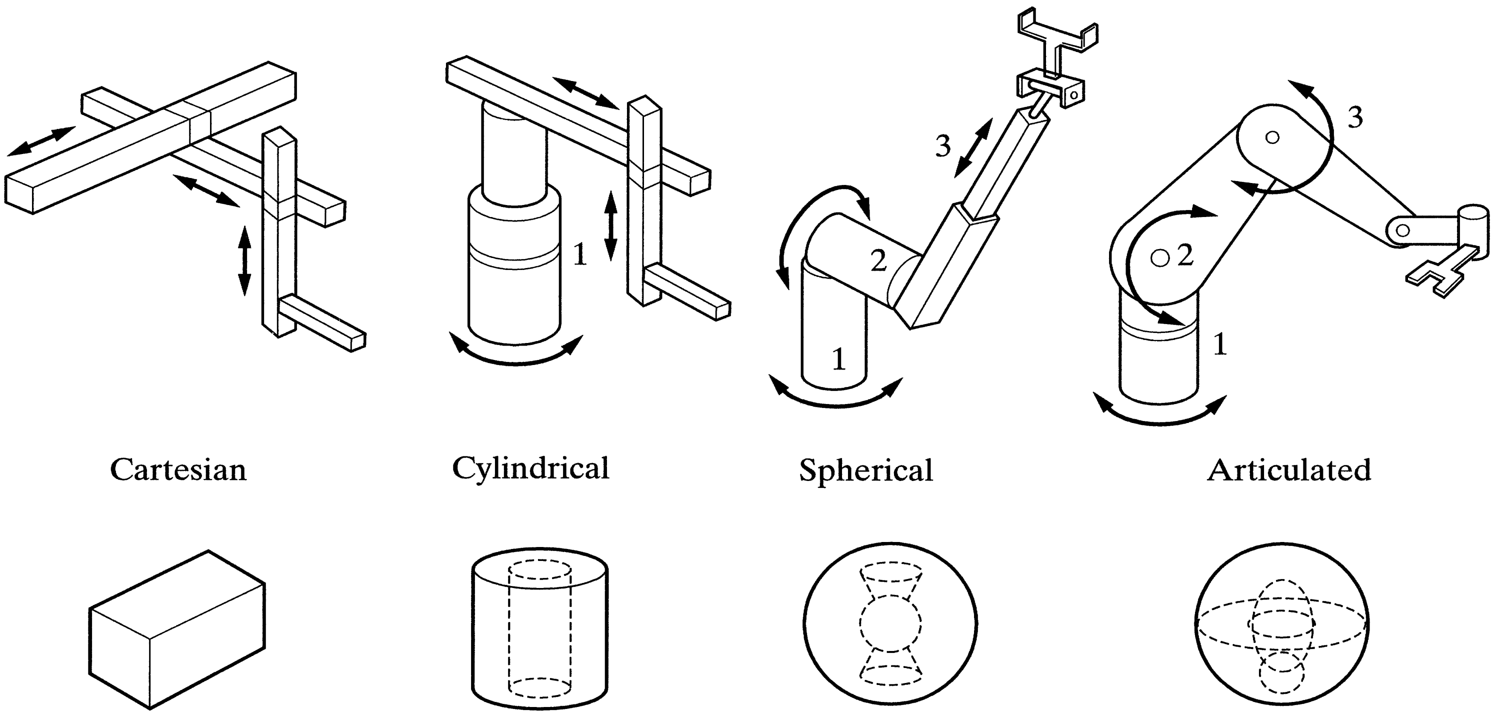


Fig. 1.8 Typical workspaces for common robot configurations

Robot Languages

Microcomputer Machine Language Level: the most basic and very efficient but difficult to understand to follow.

Point-to-Point Level: Funky® Cincinnati Milacron's T3©
It lacks branching, sensory information.

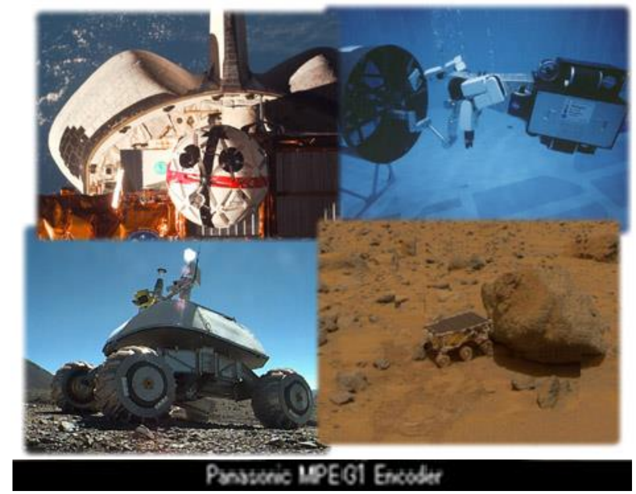
Primitive Motion Level: VAL by Unimation™
Interpreter based language.

Structured Programming Level: This is a compiler based but more difficult to learn.

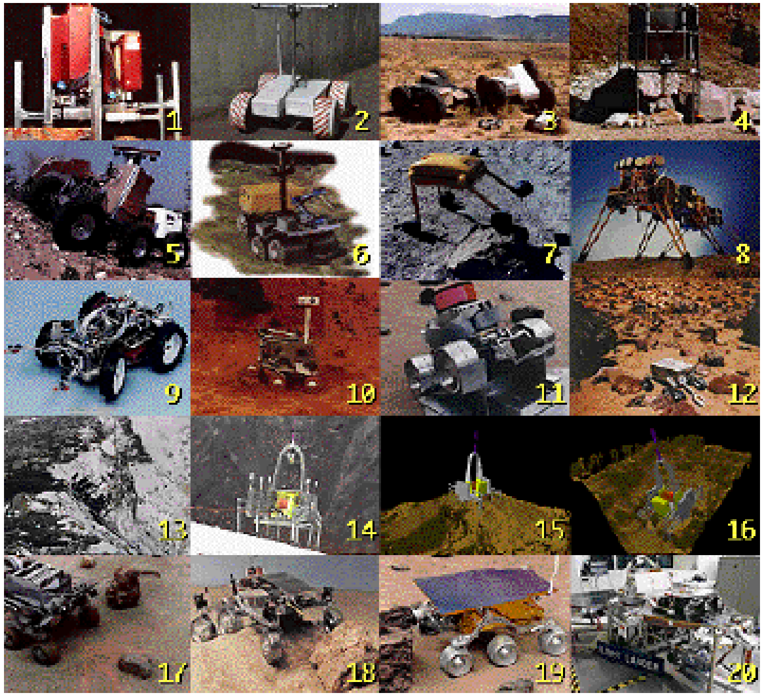
Task-Oriented Level: Not exist yet and proposed by IBM in the 1980s.

Robotics: a much bigger industry

- Robot Manipulators
  - Assembly, automation
- Field robots
  - Military applications
  - Space exploration
- Service robots
  - Cleaning robots
  - Medical robots
- Entertainment robots



Field Robots



Service robots

Service robots as low volume specialists: floor cleaning, sewer inspection, entertainment

Robots as household appliances for large volume markets: Lawn-mower, Vacuum cleaner and tennis ball collectors

Service robot systems based on conventional robot arms: refueling, orthopedic surgery, automated drink terminal

Service robots

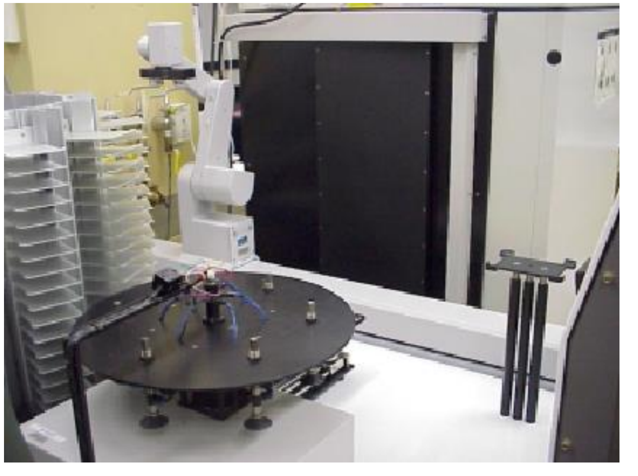
iRobot Scooba Robot

http://www.irobot.com/

iRobot Verro 600 Pool Cleaning Robot

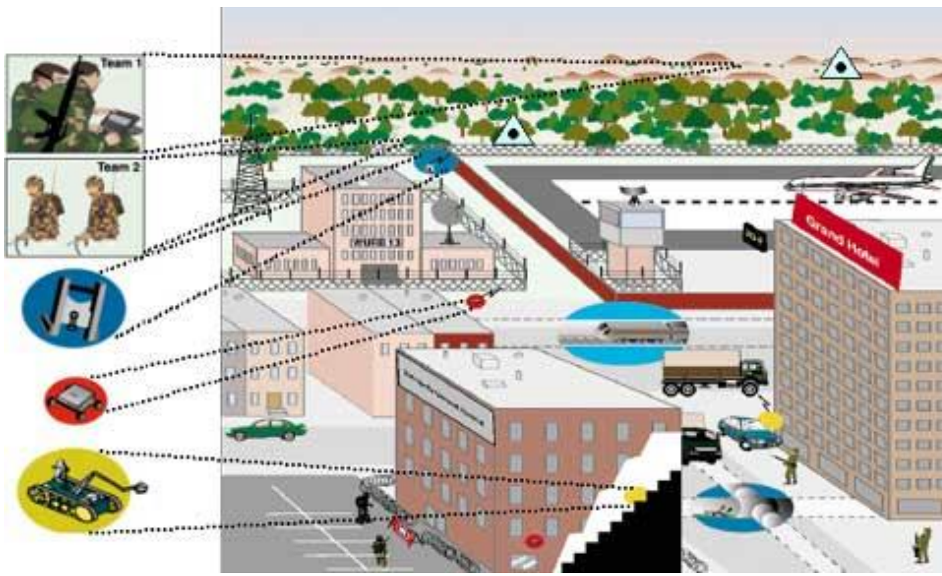
Robot Applications

- Manufacture Industry
    - Assembling
    - Automation
- Biotechnology
    - Micro/Nano manipulation
    - Sample Handling
    - Automated Analysis



Robot Applications

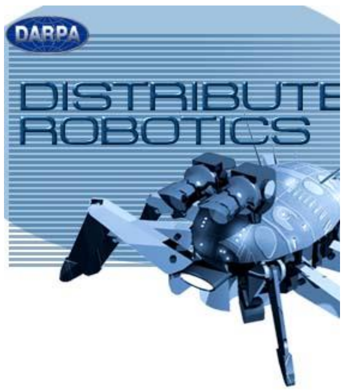
- Military Applications

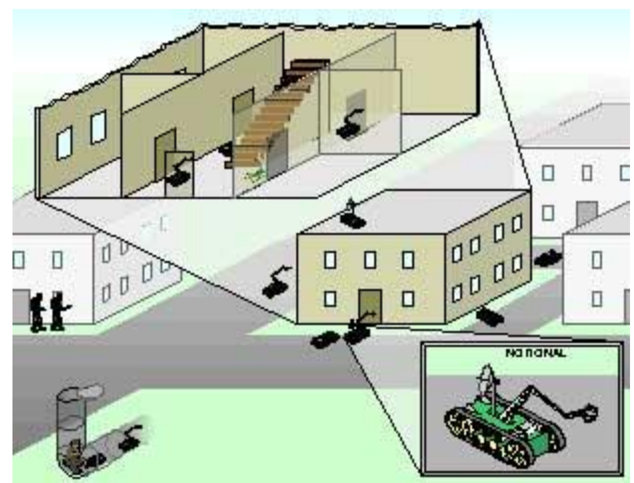


Military Applications

- DARPA Programs:

(Defense Advanced Research Projects Agency)

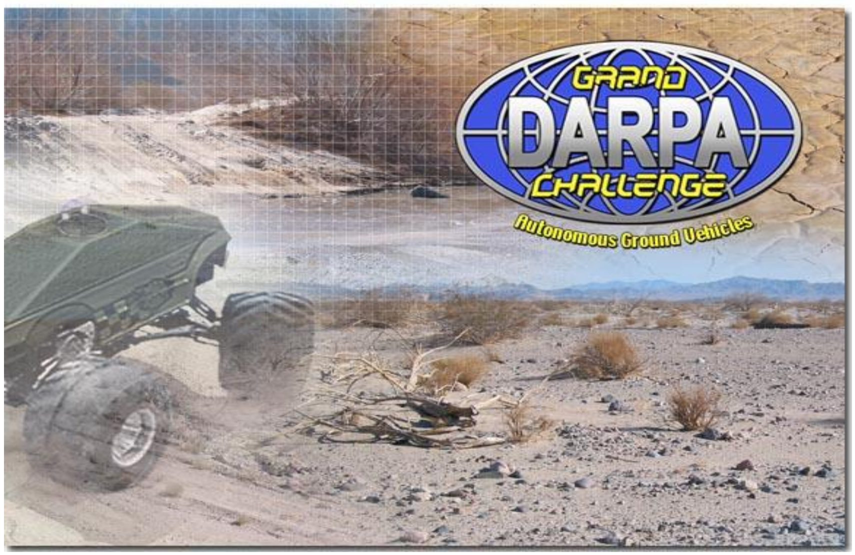




Tactical Mobile Robotics

DARPA Grand Challenge

Field test of autonomous ground vehicles.
Desert terrain featuring natural and man-made obstacles.
The route not revealed until 2 hours before the event begins.



2004, no team entry completed the designated route
Best result: Red Team (CMU) - 7.4 miles
$1 million prize unclaimed

2005, 5 teams finished 132 miles
Results: Stanley (Stanford) - 6h 54m
Red Team (CMU) - 7h 5m
Red Team 2 (CMU) - 7h 14m
$2 million prize awarded to stanford

DARPA Urban Challenge

Autonomous ground vehicles maneuvering in a mock city environment:
executing simulated military supply missions while merging into moving traffic,
navigating traffic circles, negotiating busy intersections, and avoiding obstacles.

November 3, 2007

Robot Applications

- Fire Fighting, Search and Rescue

Robot Applications

- Space Robotics:

Mars Exploration Rovers: Spirit and Opportunity --- twin robot geologists,

landed on Mars: Jan 3, and Jan 24, 2004, and still alive, today in 2006!

Website: http://marsrovers.jpl.nasa.gov/overview/

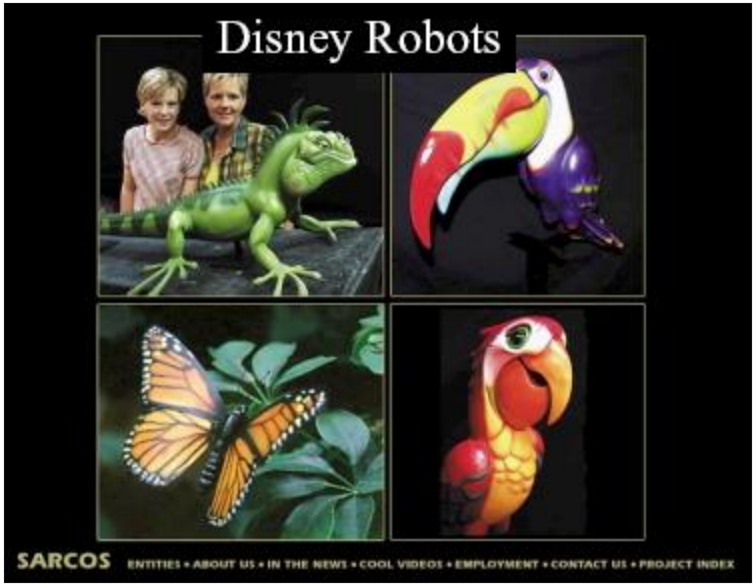
NASA/DARPA Robonaut project: a humanoid robot that can function as an astronaut equivalent for spacewalks. Human operators on earth can control the robot's movements from distance.
Website: http://vesuvius.jsc.nasa.gov/er_er/html/robonaut/robonaut.html

Robot Applications

- Robots for Assistive Technology

Robot Applications

- Entertainment Industry



Robot Applications

- Entertainment Robots

Sony-Qrio

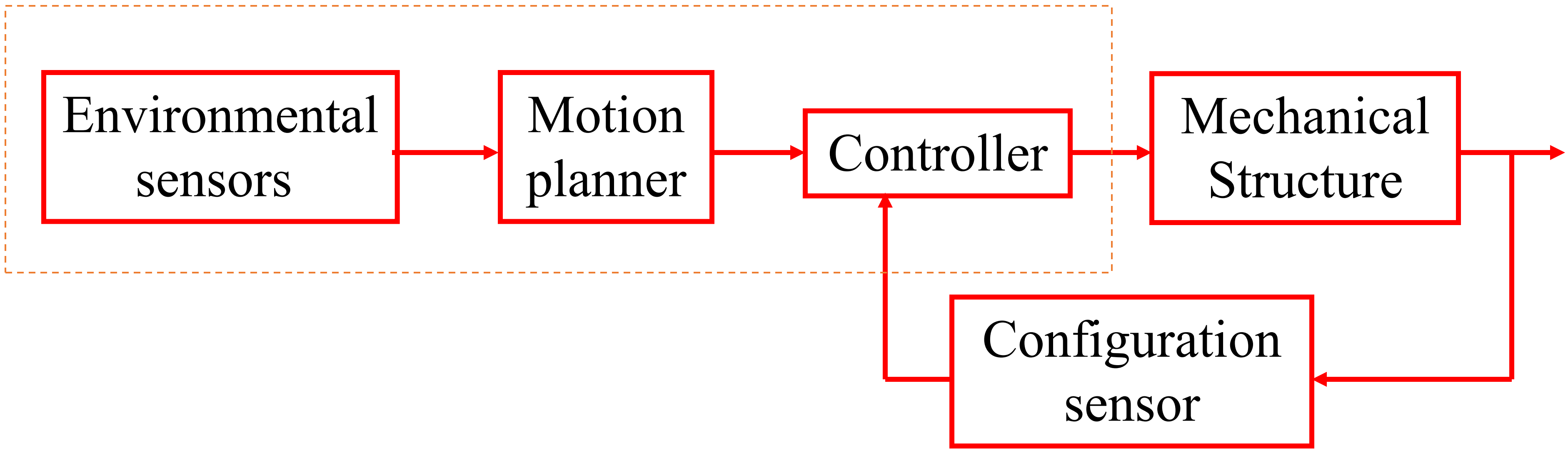
Personal Robot?

http://www.personalrobots.com

- Just as the personal computer is used for automated information management even in households, robots can be used to execute domestic tasks.
- Manipulation of bits of information (PC)
- Manipulation of physical objects (PR)

Architecture of Robotic Systems

- Computation and controllers
- Sensors
- Communications
- User interface
- Power conversion unit
- Mechanical Structure
  - Kinematics model
  - Dynamics model
- Actuators: Electrical, Hydraulic, Pneumatic, Artificial Muscle



Thank you!