Robotics: Advanced Concepts & Analysis

Module 1 - Introduction

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- Introduction & Brief history.
- Types and classification of robots.
- Science of robotics.
- Technology of robotics.

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- From Czech word 'robota' meaning slave labour!!
- Designed to replace human beings, and depicted as *very efficient* and *lacking emotion* – even now this description is prevalent!!. Robots rebel against their human masters and destroy the entire human race except one man so that he can continue making robots! Unfortunately, the formula gets lost in the destruction.
- Asimov (Asimov 1970) in story '*Roundabout*' coins *robotics* in his *three laws of robotics* — Robots are portrayed as *harmless* and in *control of humans*!
- First modern industrial robot patent in 1954 by George C. Devol (US Patent No. 2,988,237) for *Universal Automation* or *Unimation*.
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INTRODUCTION

Space Shuttle Arm
http://en.wikipedia.org/wiki/Canadarm

PUMA 560 Robot
http://vlabs.iitkgp.ernet.in/MRLab/experiment1.html

MARS Rover http://www.dlr.de/en/

Industrial Robots from Fanuc Robotics, Japan
http://www.fanucindia.com/

da Vinci Surgical Robot (Patient Cart)
http://www.intuitivesurgical.com/

Robotic Surgery System – Can be remotely operated via Internet

http://world.honda.com/ASIMO/history/

http://mindstorms.lego.com/en-us/Default.aspx

A popular kit for making robots

Figure 1: Some modern robots

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Definition

- No clear definition of a "robot"!
- The Robot Institute of America (1969) defines robot as "*.... a re-programmable, multi-functional manipulator designed to move materials, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks*".
- Currently the term "robots" are used more broadly as an "*intelligent agent, physical or virtual, capable of doing a task autonomously or with guidance*".
- Robot – An electro-mechanical machine with sensors, electronics and guided by computers.
- Key concept is *re-programmable* and the extent of programming — distinguishes a robot from CNC machine tools.

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- According to Wikipedia article, Devol used his patent on magnetic recording devices for the "brains" of his Unimate.
- First computer, ENIAC, was developed at University of Pennsylvania in 1946 and the first transistor device was built by Shockley and Pearson in Bell Labs in late 1940's[1].
- Another key ingredient, concept of *feedback control* — first textbook on feedback control is by Prof. Norbert Wiener of MIT in 1948.
- Feedback allows execution of a programmed (desired) motion by a robot (and a large number of devices) with the required accuracy.

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- Initial robot usage was primarily in industrial application such as part/material handling, welding and painting and few in handling of hazardous material.
- Most initial robots operated in *teach-playback* mode, and mostly used to replace 'repetitive' and 'back-breaking' tasks.
- Growth and usage of robots slowed significantly in late 1980's and early 1990's due to "lack of intelligence" and "ability to adapt" to changing environment – Robots were essentially blind, deaf and dumb!!
- Last 15 years or so, sophisticated sensors and programming allow robots to act much more *"intelligently"*, *autonomously* and *react to changes in environments faster*.
- Present-day robots
  - Used in *cluttered* workspaces in homes and factories,
  - Interact *safely* with humans in close proximity,
  - Operate *autonomously* in hazardous environments,
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Sampling of Robot Application

- Industrial robots: Fanuc ArcMate 120iB/10L welding robot and material handling robots.
  Many other examples in this website.
- Hazardous environment:
  - Radioactive environment and use of robots for clean-up in Three mile island, Chernobyl and recently in Fukushima, Japan, using PackBot robots, for measurement of radiation and taking pictures.
  - Deep sea: Discovery of Titanic by submersible *Alvin* and underwater robots *Argo, 1985*, *Jason Junior, 1986*.
  - Space: Shuttle Remote Manipulator System is used to deploy and retrieve satellite and other equipment.
  - Electronic assembly and pharmaceutical manufacturing in clean rooms: Human presence introduces dirt and is hazardous to the product! (See example of electronics assembly using robots)

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- Autonomous mobile robots/vehicles: Mars Exploration Rover Mission, and DARPA Grand Challenge (2008)
- Robotic surgery using da Vinci robot.
- Micro and nano robots at Carnegie Mellon & KTH, Sweden.
- Other miscellaneous robots: Robocup Soccer 2010, and dancing Sony robots, robotic fish, NASA Robonaut humanoid space robot from this website.
  Japanese humanoid robot capable of feeling pain and facial expressions can be seen at this website.

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Introduction

Important dates in history of robots

- 1770 – Mechanism-driven life-like machines that can draw, play instruments, and clocks made in Germany and Switzerland.
- 1830 – Cam programmable lathe invented.
- 1923 – Karel Capek's play R.U.R.
- 1942 – Asimov coins the word 'robotics' and gives his three laws of robotics.
- 1946 – ENIAC, the first electronic computer, developed at the University of Pennsylvania.
- 1947 – The first servo electric-powered tele-operated robot at MIT.
- 1948 – Book on feedback control, *Cybernetics*, written by Prof. Norbert Weiner of MIT.
- 1948 – Transistor invented at Bell Laboratories.
- 1952 – IBM's first commercial computer, IBM 701, marketed.
- 1954 – First programmable robot patented and designed by Devol.

Introduction

Important dates in history of robots (Contd.)

- 1955 – Paper by J. Denavit and R. S. Hartenberg (1955) provides a notation to describe links and joints in a manipulator.
- 1959 – Unimation Inc. founded by Engelberger; CNC lathe demonstrated at MIT.
- 1961 – General Motors buys and installs the first Unimate at a plant in New Jersey to tend a die casting machine.
- 1968 – Shakey, first mobile robot with vision capability, made at SRI.
- 1970 – The Stanford Arm designed with electrical actuators and controlled by a computer.
- 1973 – Cincinnati Milacron's (T3) electrically actuated, mini-computer controlled industrial robot.
- 1976 – Viking II lands on Mars and an arm scoops Martian soil for analysis.
- 1978 – Unimation develops PUMA, which can still be seen in many research labs.

Introduction

Important dates in history of robots (Contd.)

- 1981 – *Robot Manipulators* by R. Paul, one of the first textbooks on robotics.
- 1982 – First educational robots introduced by Microbot and Rhino.
- 1983 – Adept Technology, maker of SCARA robot, started.
- 1995 – Intuitive Surgical formed to design and market surgical robots.
- 1997 – *Sojourner* robot sends back pictures of Mars; the Honda P3 humanoid robot, started in 1986, unveiled.
- 2000 – Honda demonstrates *Asimo* humanoid robot capable of walking.
- 2001 – Sony releases second generation *Aibo* robot dog.
- 2004 – *Spirit* and *Opportunity* explore Mars surface and detect evidence of past water.
- 2007 – Humanoid robot *Aiko* capable of demonstrating feeling of pain.
- 2009 – Micro-robots and emerging field of nano-robots marrying biology with engineering.

Outline

Types and Classification of Robots

- Various ways of classifying a robot
  - Fixed or mobile.
  - Serial or parallel.
  - According to degree of freedom (DOF).
  - Rigid or flexible.
  - Control – point-to-point, autonomy and "intelligence".
- Most older industrial robots – *fixed* base and consisting of *links* connected by *actuated joints*.
- Many modern robots can *move* on factory floors, uneven terrains or even walk, swim and fly (see Module 9 for wheeled mobile robots)!

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Types and Classification of Robots (Contd.)

Serial Vs. Parallel

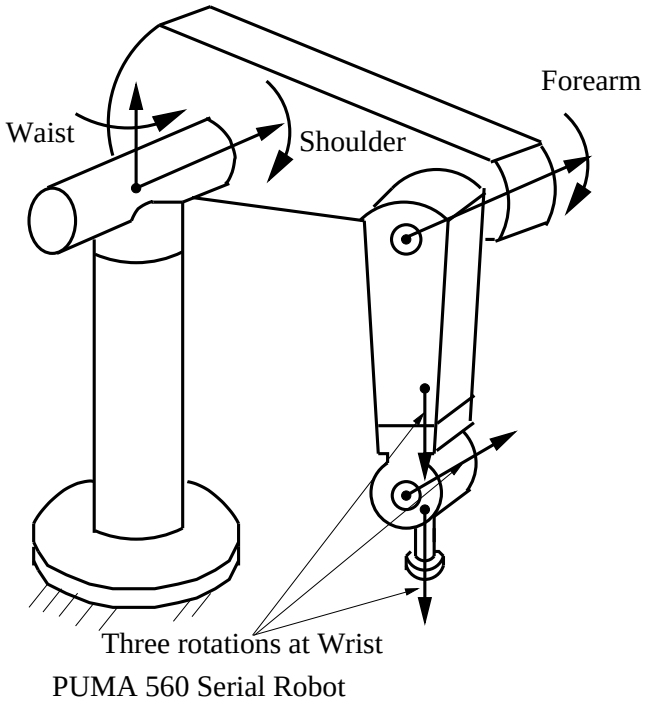

Figure 2: PUMA 560 serial robot

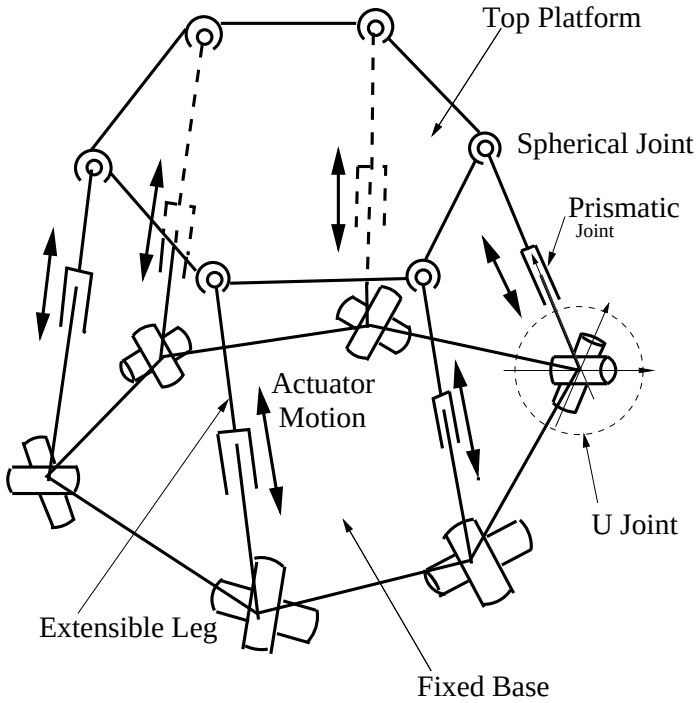

Figure 3: Parallel robot – Gough-Stewart platform

- Serial robot – a fixed base, links and joints connected sequentially and ending in a end-effector (see Module 3).
- Parallel robot – More than one loop, no natural end-effector (see Module 4).

Types and Classification of Robots (Contd.)

DOF

- Degree of freedom (DOF) determines capability of a robot and the number of actuated joints (see Module 3, Lecture 1).
  - 6 (DOF) required for *arbitrary* task in three dimensional space
  - Painting and welding can be done by 5 DOF (fixed base) robot.
  - Electronics assembly usually done by 4 DOF SCARA robot.
  - For extra flexibility and working volume, a 5 or 6 DOF robot is mounted on a 2 or 3 DOF gantry or a wheeled mobile robot.
  - Redundant robot with more than 6 DOF for avoiding obstacles, more flexibility etc.
- First three joints (in fixed robots) are classified as *Cartesian*, *spherical*, *cylindrical* or *anthropomorphic*.
  - Cartesian, spherical and cylindrical – motion described by Cartesian, spherical or cylindrical coordinates.
  - Anthropomorphic – human arm like.
  - SCARA – Selective Compliance Adaptive Robot Arm – used in electronic assembly.
- Last three joints in fixed base serial robots form a wrist – orients the end-effector.

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Rigid Vs. Flexible

Figure 4: PUMA 700 series industrial robot

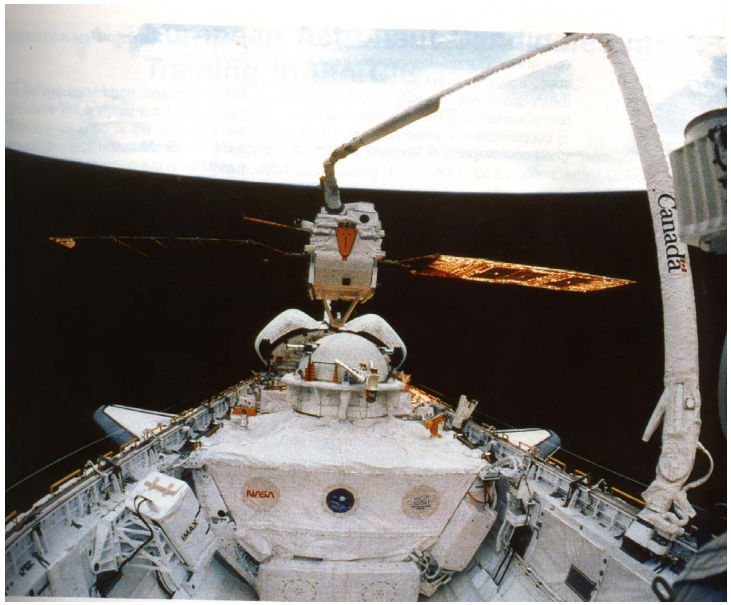

Figure 5: Space shuttle robot arm

- Most industrial robots are built heavy and rigid – for required accuracy.
- Minimising weight for space applications – links and joints are flexible! (See Module 8).

Types and Classification of Robots (Contd.)

Control and Mode of Operation

- Most older industrial robots were *teach and playback*
  - Robot is taken (manually) through the tasks and positions *recorded*.
  - During actual operation, the robot *plays back* the taught sequence.
  - Very time consuming to teach and robot cannot react to any changes in the environment.
- Computer controlled – inputs are given from a computer often after being tried out in an *off-line* programming system.
- Sensor driven – Sensors are used to avoid obstacles and take decisions.
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Outline

The Science of Robots

- New robots with improved capabilities made every day.
- Technology changes but the basic science/principles change more slowly.
- Basic ingredients – kinematics, dynamics, control, sensing and programming.
- Kinematics – motion of a object in three dimensional space without worrying about the *cause*.
  - 6 degrees of freedom (DOF) – 3 translations and 3 rotations of a *rigid link*(see Module 2).
  - 6 actuators at *joints* to achieve 6 DOF – *direct* and *inverse* kinematics problem (see Module 3 and Module 4).
  - Linear and angular velocities of rigid bodies and links (see Module 5)
  - Loss/gain of DOF in velocities and ability to apply/resist external force/moment.
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- Dynamics –Motion of links and end-effector due to the action of external forces/moments.
- Obtain equations of motion by using Newton Laws or Lagrangian formulation (see Module 6).
- *Direct* and *inverse* problem in dynamics for simulation and control.
- Desired motion and feedback control (see Module 7).
  - A desired task is converted to a smooth desired motion – cubic trajectories.
  - Controller ensures that the robot achieves the desired motion.
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- Robot is a sophisticated and expensive equipment!
- Components making up a robot undergoes constant improvement and advancement and hard to keep up!!
- Main components: mechanical components, actuators, transmission devices, sensors, electronics and computers.
- Mechanical components – links and joints (see Module 2, Lectures 2 and 3).
  - Links should be strong and lightweight – usually die-cast sections.
  - Joints are friction and backlash free to the extent possible.
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The Technology of Robots

- Sensors enable a robot to posses "touch and feel", sense motion and force, and to "see" and "learn"(see Module 2, Lecture 5).
- Sensors are required for feedback control – internal sensors.
- External sensors – touch and force, distance measuring and cameras to "see".
- Specialised sensors for welding, painting, assembly and other industrial operations.
- Computers and software – more expensive than hardware!!
  - One or more processors to control motion of actuators.
  - Processor for signal processing and sensing.
  - Processor for user interface, data logging, communication and other activities.
- Off-line programming system with user friendly GUI to train operator, verify motion and reducing downtime of a robot.

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