Lecture 1: Introduction

Reading: SHV Chapter 1
Assigned readings from several articles.

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Robots in Modern Industry and Society

- *Robot* comes from the Czech *robota*, which means “work”. Word used in 1920’s theater piece.

- A robot is a programmable mechanical device, typically powered by electric motors. In this course we concentrate on *manipulators*.

- The applications of robots have transcended the industrial (manufacturing) environment. Robotic devices are used in medicine, space exploration, entertainment and as household aides.

- The study of robotics comprises many highly-specialized sub-areas. Several of these are at the core of mechanical and electrical engineering.
The structural design of the linkages and joint drivers is in itself a mechanical design problem. The manipulator must be light and possess high stiffness, while the design must maximize the useful workspace.

The robot must be fitted with reliable sensors to be used as feedback by the motion/force control program.

The geometry of the robot must be precisely modeled using a systematic approach allowing the solution of the forward and inverse kinematic problems.

A dynamic model of the robot must be derived using a systematic approach, allowing analytical and simulation studies of the manipulator’s behavior at high speeds and under the influence of external forces.

Control algorithms must be designed on the basis of the dynamic model. These controllers are to be used to achieve precision motion profile following, possibly with additional force control requirements (Figure 1.19 in SHV).

Visual and other sensory information must be used in autonomous path following and obstacle avoidance applications.

A typical industrial application: deburring

Workpiece (on end effector) must be moved relative to the tool according to desired motion profile (in this case a flat surface must be obtained) and with a prescribed force (which results in desired tolerances and surface finish).

See also Fig. 1.19 in SHV textbook.
Robotics in medicine: surgery


Robotics in space exploration: Spirit and Opportunity

The vehicle itself is a mobile robot. In addition, the manipulator is fitted with several instruments (spectrometers, RAT (rock abrasion tool), microscope)
http://www.youtube.com/watch?v=qRUyVCfFh1U

Fundamental Concepts

- Manipulators are formed by *links* connected by *joints*. A joint can be prismatic (links slide relative to each other) or revolute (links rotate relative to each other). We will make the fundamental assumption that each joint has only one *degree of freedom*. That is, we are ruling out ball/socket joints.

- The *configuration* of a manipulator is the complete specification of the positions of every one of its points. The set of all possible configurations is the *configuration space*.

- A manipulator has \( n \) *degrees of freedom* if exactly \( n \) parameters are required to completely specify the configuration. A rigid, two-link planar manipulator has two degrees of freedom. If the links were flexible, more degrees of freedom would be needed to specify the configuration to an acceptable degree of accuracy.
Fundamental Concepts...

■ A configuration provides only geometric information. The state of the manipulator is a set of variables which describe the changes in configuration in time in response to joint forces (control inputs) and external influences. The state space is the set of all possible states. It coincides with the notion of state space used in systems and control.

■ The workspace of a manipulator is the set of all possible positions of the end effector (tool, gripper, etc.). It is determined by the geometry of the links and joints and the physical limits of the latter.

■ The dexterous workspace is a subset of the workspace, defined by the set of reachable points in which the end effector can be freely oriented. Example: in a planar manipulator, points at a distance equal to the total link length cannot be reached with the wrist at an angle different than 0 degrees.

Classification of Manipulators

■ Read SHV Section 1.2 for classification according to power source, geometry, method of control and application. We discuss two important classifications: by method of control and by geometry.

■ Recalling basic controls courses, a control system can be either open-loop or closed-loop. In an open-loop control architecture, the input commands sent to the joints (motor voltages, hydraulic/pneumatic flows, etc) are determined in advance using a mathematical model, and are not a function of the actual motion of the manipulator. These robots are called non-servo manipulators.

■ In a closed-loop or feedback control system, the input commands sent to the joints are a function of the actual motion of the manipulator. This motion (possibly including force information) is obtained by a set of sensors. A computer is used to evaluate a function called the control law, which gives the values of inputs to be sent to the joints. The process takes place online, that is, commands are continuously being calculated and applied to the joints. These robots are called servo manipulators.
The sophistication of the control algorithm determines whether a servo robot can operate as a point-to-point or as a continuous path device. In the former, the manipulator can achieve any desired fixed position and orientation, but there is no control of the trajectory followed between each position. This would be sufficient, for example, for a drilling robot used in the auto industry.

A continuous path robot can achieve precise tracking of a reference trajectory, including velocity and acceleration profile following. As an example, welding robots can produce complicated 3D welding seams.

Common Kinematic Arrangements

The types of the first three joints (prismatic or revolute) starting from the base, are used to generate a classification of manipulators according to kinematic (mechanical) configuration. The wrist is described separately.

Three joints of two possible kinds (R and P) yield 8 possible arrangements, however only 4 combinations are frequently used, with the RRP found in two varieties: articulated (RRR), spherical (RRP), SCARA (RRP), cylindrical (RPP) and Cartesian (PPP).

These combinations correspond to open kinematic chains (end effector is not joined to another link), also called serial robots. We restrict our study to these. Parallel manipulators use a closed kinematic chain (see Fig. 1.18) and require more advanced study.
Articulated Manipulator (RRR)

See also Figs. 1.9, 1.10 (workspace) in SHV. PUMA (Programmable Universal Manipulator for Assembly) robots are RRR. We have a PUMA robot in the lab.

Spherical Manipulator (RRP) non-SCARA

Known as Stanford Arm (historical reasons). See also Fig. 1.12 in SHV.
Spherical Manipulator (RRP) SCARA

SCARA: Selective Compliant Articulated Robot for Assembly. See also Fig. 1.13 in SHV.

Cylindrical Manipulator (RPP)

See also Fig. 1.15 in SHV.
Cartesian Manipulator (PPP)

See also Fig. 1.16 in SHV.

Mitsubishi RM-501 MoveMaster

We have a similar robot in the lab. How many DOF does it have and to which one of the 5 kinds does it belong?
Basic Problems in Robotics

- **Forward Kinematics**: Determine the position and orientation of the end effector given the values (pointwise in time) of the joint variables.

- **Inverse Kinematics**: Determine a solution for the joint variables that result in a desired position and orientation (pointwise in time) of the end effector.

- **Velocity Kinematics**: Similar to the forward and inverse kinematics problems, with the added requirement of following a path with prescribed velocity profile. Of particular importance is the study of *singularities*, which are points where the manipulator effectively loses one or more degrees of freedom due to rank deficiency in the Jacobian matrix.

- **Path Planning and Trajectory Generation**: This is the problem of how best to command the manipulator between specified points in the presence of obstacles and other constraints.

**Basic Problems in Robotics...**

- **Decoupled Control**: Also called Independent Joint Control, applies ideas from classical control to achieve trajectory tracking and disturbance rejection. The assumption is that each joint can be treated as a SISO system, without dynamic coupling between links.

- **Dynamics**: A derivation of the mathematical model of a manipulator that is suitable for subsequent controls-oriented studies. Certain properties of the model are also studied.

- **Force Control**: Similar to the kinematics problems, with the added requirement of maintaining a prescribed force (or at least maintaining the force within bounds) between tool and workpiece.

- **Machine Vision**: A study of camera systems and how they are used to determine the position and velocity of the robot, along with the location of workpieces and obstacles. Visual servoing implies using the output from the cameras as feedback sensors to be used in the control algorithm.
This is an introductory course directed at ME and EE students, with a focus on dynamics and control.

We go over forward, inverse and velocity kinematics as a brief overview. These topics are indispensable. MCE652: Robotics and Machine Vision focuses on these topics.

We cover decoupled control as a refresher of classical control ideas.

Dynamics will be studied with a focus on obtaining the model of any given manipulator configuration quickly, with little emphasis on the derivations. We also focus on the properties of the model: passivity, skew-symmetry, etc.

We introduce Lyapunov stability theory and related concepts applicable to nonlinear dynamical systems.

We study the standard MIMO nonlinear control techniques for robotic manipulators, including robust and adaptive approaches. An overview of force control techniques will be offered.

An introduction to geometric nonlinear control will be offered if time allows it.

Homework 1: Part I

1. Select an applications-oriented article on robotics from one of the journals available through the CSU Library’s Journal Finder, for example:
   - Robotics
   - IEEE Transactions on Robotics
   - International Journal of Robotics Research

   In addition, feel free to use other literature sources, but obtain approval from the instructor. Prepare 2-3 slides (please save as pdf) showing the complete citation and a short summary of the article, focusing on the purpose of the robot/system described, the author’s objectives, methodology and results. Be prepared to offer a 5-minute presentation to the class. Please bring a USB stick with the pdf file containing the slide and a pdf version of the article used.

2. Answer questions 1-5 and 1-10 in SHV.

Part I is due on January 30th. A few students will be selected at random for the 5-minute presentation.
What Robots Can’t Do

- http://www.youtube.com/watch?v=gsOaQGF7kiQ
- http://www.youtube.com/watch?v=hC-Wg5jHkmg