Introduction

- Robot.

  Reprogrammable, multifunctional manipulator designed to move materials, parts or specialized devices through variable programmed motions for the performance of a variety of tasks.

  Universal machine that can do many tasks.

- There is continuing debate on what constitutes an industrial robot.

  Are numerically controlled (NC) milling machines robots?

Introduction

- Distinction is drawn somewhere in the level of programmability of the device.

  If it can be programmed to perform a wide variety of tasks, it is probably an industrial robot.

- Machines that do one class of task are termed fixed automation.

- We will focus mainly on one form of the industrial robot – the (mechanical) manipulator.

Basic Concepts and Definitions

- What are manipulators?

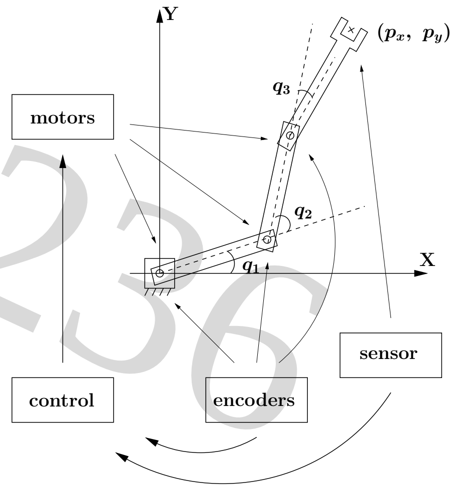
- Joints, links, base and end-effector.

- Applications of manipulators.
  - welding robot and spray painting
  - loading and unloading
  - batch processing
  - work cell operation

Basic Concepts and Definitions

- Robot system.
  - manipulator
  - intelligence
  - sensors

- Robot assembly features.
  - programmability
  - adaptability
  - flexibility



Control of Manipulators

- Study of mechanics and control of manipulators is a collection of different fields.

- Mechanical engineering.

  Study of machines in static and dynamic situations.

- Mathematics.

  Tools for describing and analyzing the mathematical models for manipulators.

Control of Manipulators

- Computer science.

  Programming the devices.

- Control theory.

  Designing and evaluating different methods of realizing the desired motions of manipulators.

- Electrical engineering.

  Design of sensors and electrical interfaces.

Mechanics of Manipulators

- In the study of robotics, we are concerned with the location of objects in three dimensional space.

- These objects can be
  - links of the manipulator.
  - parts and tools used by the manipulator.
  - other things in the manipulator's environment.

- We usually describe this location by the position and orientation of the different parts of a robotic system.

Mechanics of Manipulators

- We then need to represent the quantities efficiently and manipulate them (mathematically).

- Mathematical description.

  Use a coordinate system or attach a coordinate frame to the different parts of the robotic system.

- Define a reference coordinate frame as a basis of other coordinate systems.

Mechanics of Manipulators

- Other standard coordinate frames are
  - world coordinate frame
  - base coordinate frame
  - tool / end-effector coordinate frame
  - object coordinate frame
  - camera coordinate frame

- Use mathematical transformations to "move" from one coordinate system to another.

  Tools. Trigonometry, geometry and basic matrix operations.

Forward Kinematics

- Kinematics.

  Science of motion which treats motion without considering the forces which cause the motion.

- Position, velocity, acceleration and higher order derivatives.

  Relate these variables using manipulator geometric parameters such as
  - link length
  - link offsets

Forward Kinematics

- Manipulators.

  System of links (rigid?) which are connected at the joints.

- Types of joints.
  - revolute joint : rotational (joint angle)
  - prismatic joint : translational (joint offset)

- Joint angles or offsets are in general termed as joint positions.

Forward Kinematics

- Manipulator degrees of freedom (DOF) :

  Number of independent position variables required to specify the manipulator configuration.

- Degrees of freedom is generally used to describe mechanisms.

  For example, a four bar linkage has only one degree of freedom (even if there are three moving members).

- **Open chain, serial link manipulators :**

  Manipulator DOF is equal to the number of joints.

- **At the free end of the chain of links is usually an end-effector.**
  - **gripper.**
  - **welding torch.**
  - **electromagnet.**
  - **suction cup.**

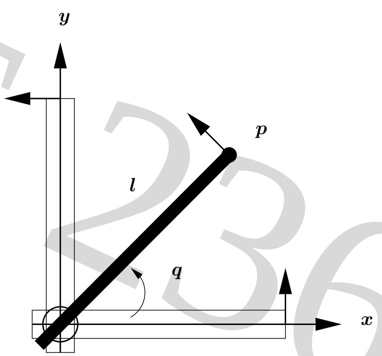
- **Forward kinematics : geometrical problem of computing the position and orientation of the end-effector given the joint positions.**

- **Joint space : mathematical space where the joint position is usually described.**

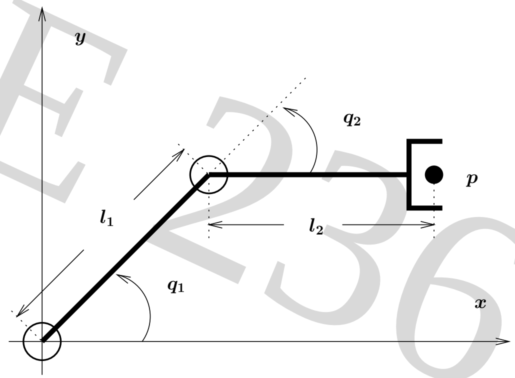
- **Cartesian space : mathematical space where the end-effector position is usually described.**

  Additional tool. vectors.

- **Simple example. One-link revolute manipulator.**



- **Example. Two-link planar revolute manipulator.**



Inverse Kinematics

- Forward kinematics : joint positions to end-effector position and orientation.
- Inverse kinematics : end-effector position and/or orientation to joint positions.
- Inverse kinematic problem :
  given the end-effector position and orientation, determine the possible joint positions.

Inverse Kinematics

- Trigonometric equations are involved. Closed form solution may not always be possible.
- The existence (or nonexistence) of a solution defines the workspace of a given manipulator.

  Lack of a solution means that the manipulator cannot attain the desired pose.

  The pose is outside the manipulator's workspace.

Inverse Kinematics

- Scenarios : unique solution exists, multiple solution exists, no solution exists.
- Workspace : range of end-effector position and orientation that can be achieved by the manipulator.
- Example : workspace of a one-link manipulator.

  How about for a two-link manipulator?

Dynamics

- Dynamics : study of forces required to cause motion
- To move a manipulator, torque/force must be applied to the joints.
- Joint actuators : used to generate the necessary joint torques to achieve the required motion.

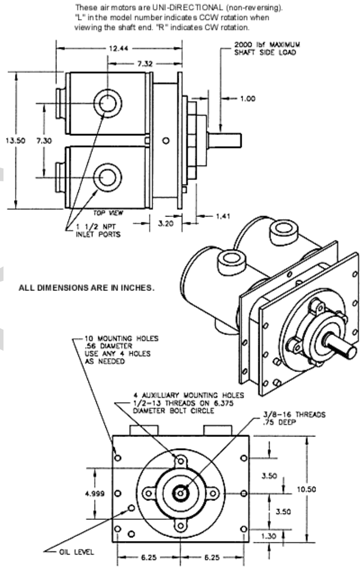
- Types of joint actuators.

  - hydraulic

    large force, bulky systems, slow, periodic maintenance.

- pneumatic

  resists moisture, dust and dirt, needs little maintenance, is quiet, and it does not use much energy.



- electrical

  wide range of applications, designs and models.

- Dynamic equations of a manipulator : relates the joint torques to the joint position variables and its higher order derivatives.
- Inverse dynamics : given the joint position variables and its derivatives, determine the joint torques.
- Inverse dynamics are used in the control of the motion of a manipulator.

Dynamics

- Forward dynamics : given the joint torques, determine the joint position variables (and its higher order derivatives).

- Forward dynamics are usually used in simulating manipulator motion.

Trajectory Generation

- Point-to-point motion : move the manipulator end-effector from one position (and/or orientation) to another without regard for the intermediate path the manipulator will take.

- Via points : Intermediate points the manipulator end-effector must pass through during the motion.

- Smooth motion is usually desirable in the motion of manipulators.

Trajectory Generation

- What is smooth - mathematical definition.

- Spline : a smooth function which passes through the via points.

Trajectory Generation

- Joint space trajectory : manipulator trajectory specified in terms of the required joint positions (and its derivatives).

- Cartesian space trajectory : specified in terms of the desired path the manipulator end-effector must follow.

- To achieve a smooth motion of a manipulator, one can specify the desired joint positions as smooth functions of time.