Lecture 02
Industrial Robot Manipulators

Industrial Applications of Robots

- Paletizing / Unitizing in warehouses
- Laser cutting
- Arc welding / Spot Welding
- Assembly lines
- List goes on ..... 

Joint Primitives

- Describes how adjacent links are connected to each other
- Two primitive joint types
  - Prismatic (sliding) joint: Pair of links makes a translational displacement along a fixed axis. One link slides on the other along a straight line
  - Revolute (rotary) joint: Two links rotate about a fixed axis. This type of joint is often referred to as a hinge, articulated, or rotational joint
- Many useful mechanisms for robot manipulation and locomotion can be designed by combining these primitive joints.

Industrial Robot Manipulators

- IFR Def: An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications
- Robot manipulators consists of rigid links, which are connected through joint actuators that create relative motion of neighboring links. Joints are attached with sensors that read joint position and speed

In robotics, constant monitoring of positions and orientations of manipulator links, tools, objects it handles, and other objects in the vicinity is essential
Serial Link Manipulators

• Most of the industrial robots are serial combinations of revolute and prismatic joints.

• The most fundamental functional requirements for a robotic system is to be able to locate its end-effector (hand, tool, or end-device), in 3D space, with respect to the world coordinate frame.

• Following types of robot mechanisms are available:
  • Cartesian co-ordinate robot
  • Cylindrical co-ordinate robot
  • Spherical co-ordinate robot
  • SCARA robot
  • Articulated robot

Cartesian Co-ordinate Robot

• PPP: three prismatic joints independently adjust the three coordinates \((x,y,z)\) of the end-effector position.

Applications

pick and place applications (where either there are no orientation requirements or the parts can be pre-oriented before the robot picks them up such as surface mounted circuit board assembly), position a wide variety of end-effectors such as: automatic screwdrivers, automatic drills, dispensing heads, welding heads, waterjet cutting heads and grippers, material handling applications such as pick and place, machine loading and unloading, stacking, unitizing, palletizing, and co-ordinate measuring devices.

Cylindrical Co-ordinate Robot

• RPP
  R(spans a cylindrical workspace)
  P(adjusts the height)
  P(adjusts the radius)

Spherical Co-ordinate Robot

• RRP: called as polar co-ordinate robot
  R (horizontal swing)
  R (vertical swing)
  P (radius).
SCARA Robot
• SCARA: Selective Compliant Assembly Robot Arm
• No analogy with common coordinate systems, however, it is useful in locating the end-effector in space, and it has salient features desirable for specific tasks.

Applications
Assembly automation in manufacturing systems, having a wide workspace in the horizontal direction and an independent vertical axis appropriate for insertion of parts.

Articulated Robot
• RRR (all rotary) known as Elbow Robot
• Great amount of flexibility, manipulatability, and versatality

Resolution and Accuracy

<table>
<thead>
<tr>
<th>Robot Type</th>
<th>Horizontal Resolution</th>
<th>Vertical Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cartesian</td>
<td>Uniform</td>
<td>Uniform</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>Decrease radially</td>
<td>Uniform</td>
</tr>
<tr>
<td>Spherical</td>
<td>Decrease radially</td>
<td>Decrease radially</td>
</tr>
<tr>
<td>SCARA</td>
<td>Varies</td>
<td>Uniform</td>
</tr>
<tr>
<td>Articulated</td>
<td>Varies</td>
<td>Varies</td>
</tr>
</tbody>
</table>

Parallel Linkages
• Joints are constrained with each other
• Possesses active joints as well as passive joints
• Complex, mechanisms, yet provide some useful behaviors

Three of the five joints should be passive joints, which are free to rotate. Only two joints should be active joints, driven by independent actuators.

Closed kinematic chain is formed by five links and, thereby, the two serial link arms must conform to a certain geometric constraint. End-effector position is determined if two of the five joint angles are given.

The robot arm can be made lighter by placing both actuators at the base. A larger load at the end-effector can be born with the two serial linkage arms sharing the load.
Stewart Mechanism

- Consists of a moving platform, a fixed base, six prismatic joints connecting moving platform to the base
- The position and orientation of the moving platform are determined by the six independent actuators

The load acting on the moving platform is born by the six "arms". Therefore, the load capacity is generally large, and dynamic response is fast.

Degrees of Freedom

- Degrees of Freedom: is the number of independent position variables that would have to be specified in order to locate all parts of the mechanism
- In open kinematic chains, where each joint contributes a single joint variable (joint angle or link offset), number of degrees of freedom is equal to the number of joints

End-Effector

- At the end of the manipulator is the end-effector. It could be a gripper, a welding torch, electromagnet, or any other tool/device that is required to perform the intended task.

Manipulator Control System

- Controller calculates at each loop, the torque commands for joint actuators. Loop time is usually 2~10ms
- Calculated torque commands are sent to the individual joint servo controllers

Robot Control

CTM, PID, etc

Joint Trajectory (pos, vel)

Tracking Performance Evaluation

Robot Dynamic Model

Robot Arm

Robot Arm motion (pos, vel)

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Control Loop

- At each loop, control algorithm reads the desired joint position/velocity from the reference data file. Also reads actual joint position/velocity of each joint from built-in joint encoders. Then, required joint torques to reduce the error in position and velocity are calculated using the dynamic model (computed torque method) of the manipulator or using any other control law such as PID.
- User specifies the movements of the tool by a set of via points, and speeds at various path segments. The trajectory generator plans the corresponding joint angle profiles.
- Using sensor feedback, changes can be adapted to manipulator's motion on-line.
- Causes of error: actuator saturation, Backlash, gravity, friction

Manipulator Design Approach

- Mechanical and control attributes
  size, speed, loading/unloading capability, number of joints and there geometric arrangement, stiffness/compliance.
- No of DoF
  The more joints a robot arm contains, the more dexterous and capable it will be. It will also be harder to build and more expensive
- Specialized or general design
  - Specialized Design: just for the intended task/application. Guiding question: how many joints is just enough for robot arm to pick and place electronic components on a circuit board?
  - General Design: able to perform a wide variety of tasks. Guiding question: How many DoFs is just enough position and orient the end-effector in 3D space?
- Sensors
  tactile, force, pressure, vision etc

Constrained Motion

- Delicate control of the contact force when the end-effector touches parts/fixtures
- Important control capability in robotic applications such as window washing, robotic surgery, and polishing
- Force and position control is generally complementary
- Hybrid control: Force and motion control are implemented along orthogonal directions

Manipulator Programming

- Teaching the robot a series of points to go through
Manipulator Simulation

- Off-line programming and simulation helps to test and validate various maneuvers involved in manufacturing processes. Therefore, changes in roboticized manufacturing lines can be quickly and effectively implemented with minimum down time.

Usage of Industrial Manipulators

- Altogether 1 million industrial robots are in the world

- Japan records highest density (10 times the average)

- First 3 countries are Asian

- Europe is the regional epicenter of industrial robots

Industrial Robots: Recent Statistics

- Worldwide stock of operational industrial robots at the end of 2011 was in the range of 1,153,000 and 1,400,000 units. Value of the market of robot systems (HW/SW+) was up to US$25.5 billion
Distribution Among Industries

Estimated worldwide annual supply of industrial robots at year-end by industries 2009 - 2011

Usage Trend in Regions

Annual supply of industrial robots 2010-2011 and forecast for 2012-2015

Factory Roboticization is Demanding

The major reasons for the increasing demand for factory roboticization are:

- Declining cost of robots and increasing cost of human labor
- Robots continue to getting speed, accuracy, capability, and reprogrammability for a variety of jobs (welding, painting etc.)
- Deployability of robots for tasks that might be dangerous, or impossible for human workers to perform (space, undersea, radioactive sites)

Robots and Automatic Machines

- Small volumes ⇒ use human labor
- volume ∈ [v1,v2] ⇒ use robots
- volume > v2 ⇒ hard automation

The distinction between a robot and a factory machine (such as NC machines) lies in the programmability of the device. Robots can be re-programmable to perform a wide variety of tasks, whereas factory machines, which are generally limited to one class of tasks (fixed automation)