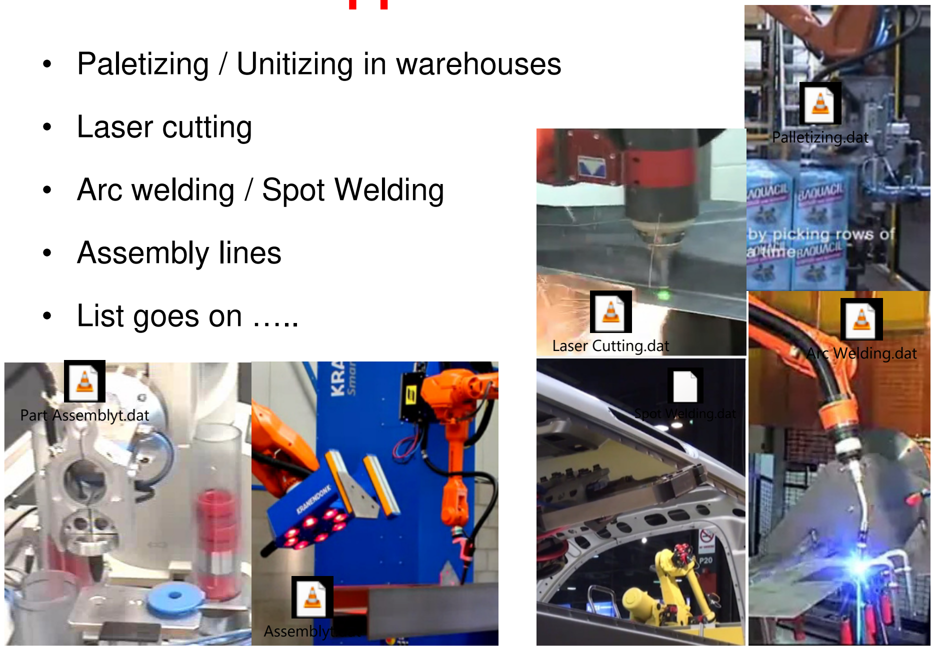
Lecture 02
Industrial Robot Manipulators

Prof. Rohan Munasinghe
Department of Electronic and Telecommunication Engineering
University of Moratuwa 10400

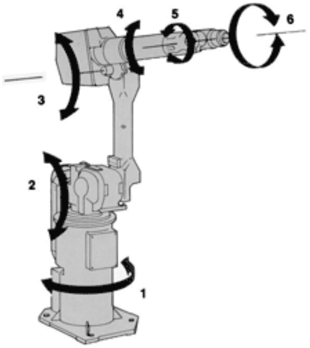
Industrial Applications of Robots

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



Industrial Robot Manipulators

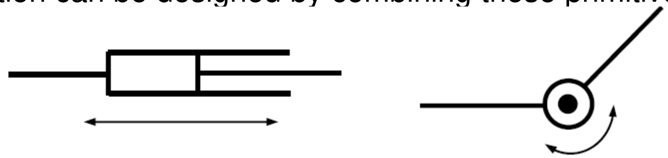
- IFR Def: An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications
- Robot manipulators consists of rigid links, which are connected through joint actuators that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

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.



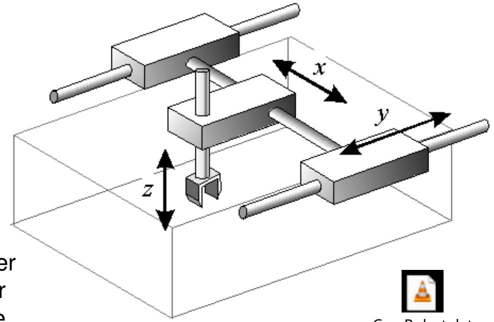
(a) Prismatic joint (b) Revolute joint

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-effecter (hand, tool, or end-device), in 3D space, with respect to the world co-ordinate 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

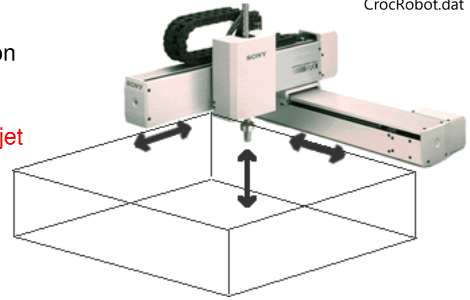
- PPP: three prismatic joints indpendently adjust the three co-ordinates (x,y,z) of the end-effector position



CrocRobot.dat

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)

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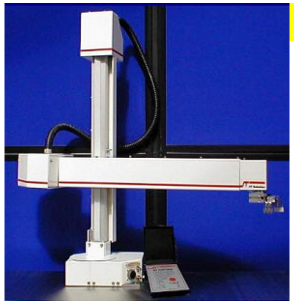

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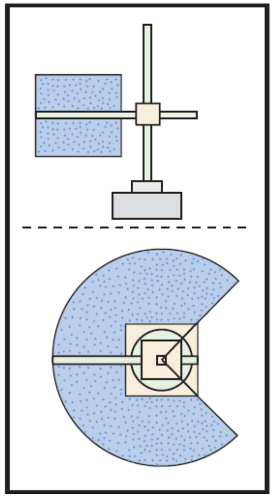

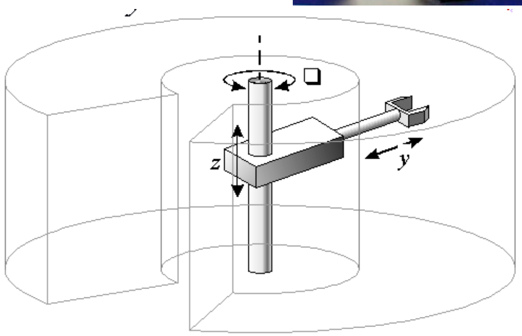

Spherical Co-ordinate Robot

- RRP: called as polar co-ordinate robot

  R (horizontal swing)

  R (vertical swing)

  P (radius).

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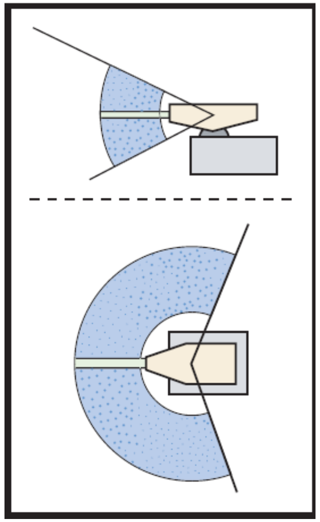

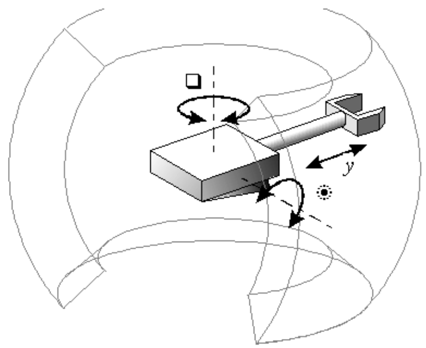

SCARA Robot

- SCARA: Selective Compliant Assembly Robot Arm
- No analogy with common coordinate systems, however, it is useful in locating the end-effecter in space, and it has salient features desirable for specific tasks.

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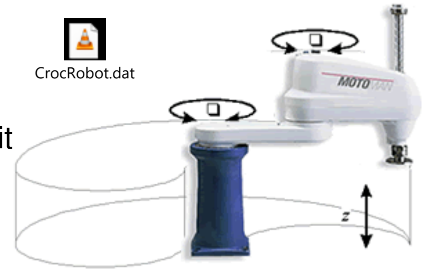
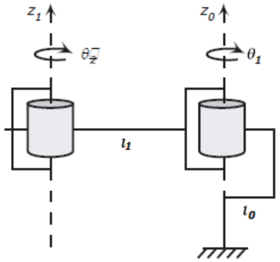


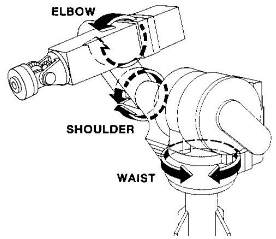
Applications

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



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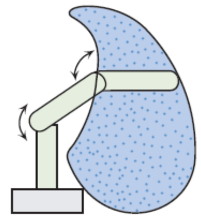
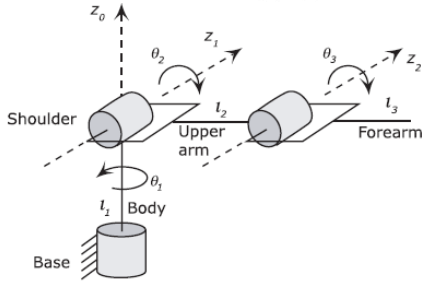
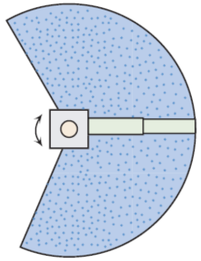
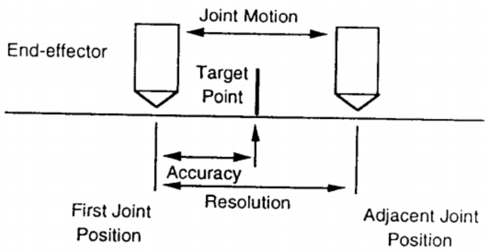


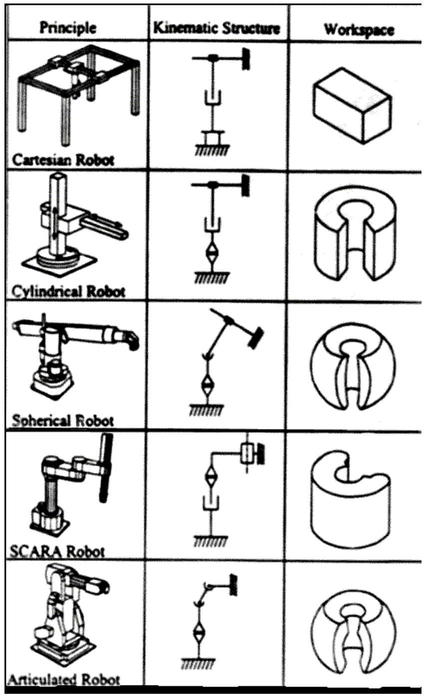




Resolution and Accuracy

Robot Type	Horizontal Resolution	Vertical Resolution
Cartesian	Uniform	Uniform
Cylindrical	Decrease radially	Uniform
Spherical	Decrease radially	Decrease radially
SCARA	Varies	Uniform
Articulated	Varies	Varies



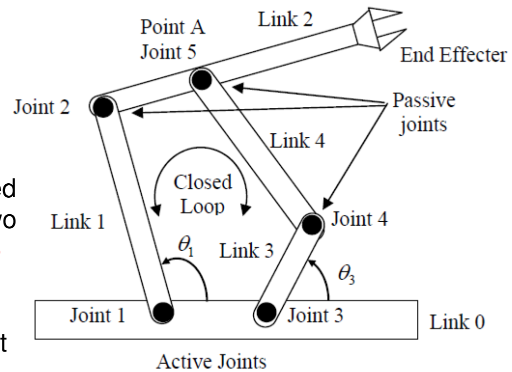


Parallel Linkages

- 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-effecter 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

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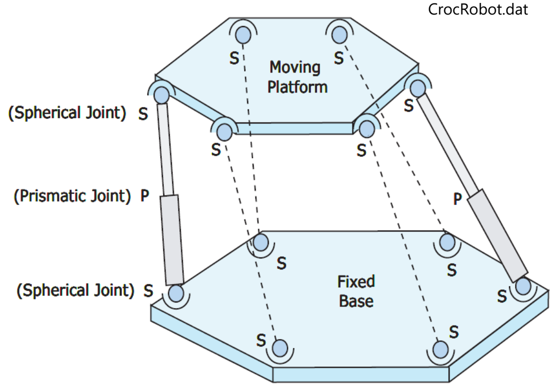


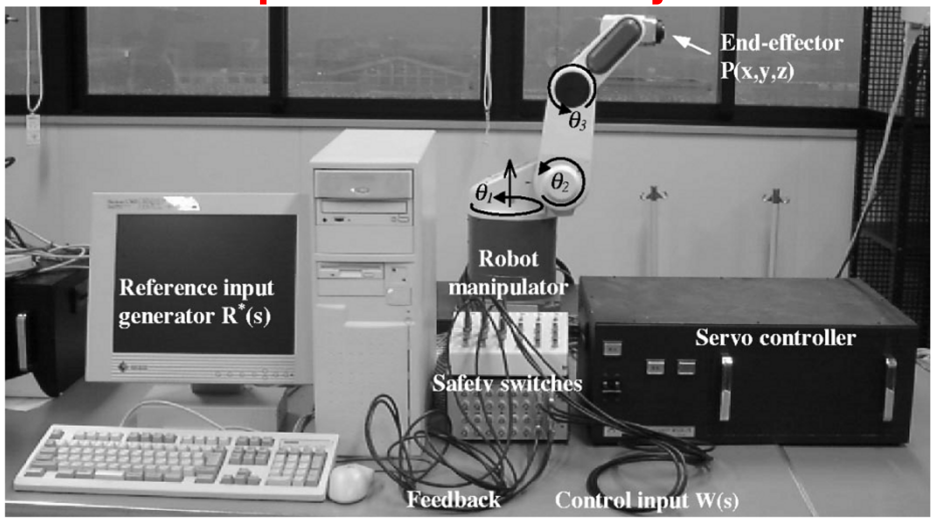
Degrees of Freedom

- 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

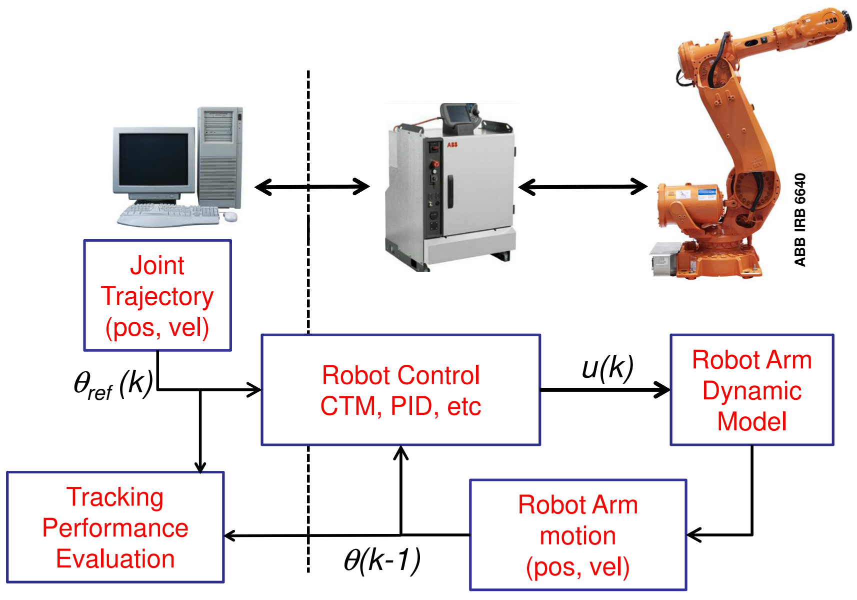
- At the end of the manipulator is the end-effector. It could be a gripper, a welding torch, electromagnet, or any other tool/device that is required to perform the intended task

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

Manipulator Control System



Control Loop

- Al each loop, control algorithm reads the desired joint position/velocity from the reference data file. Also reads actual joint position/velocity of each joint form 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?*

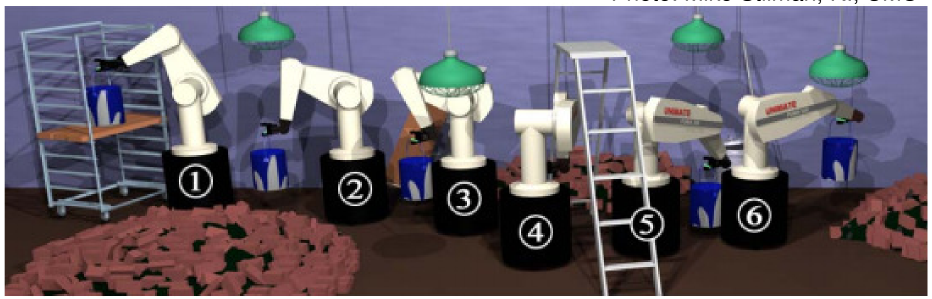
- **Sensors**

  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

Photo: Mike Stilman, RI, CMU

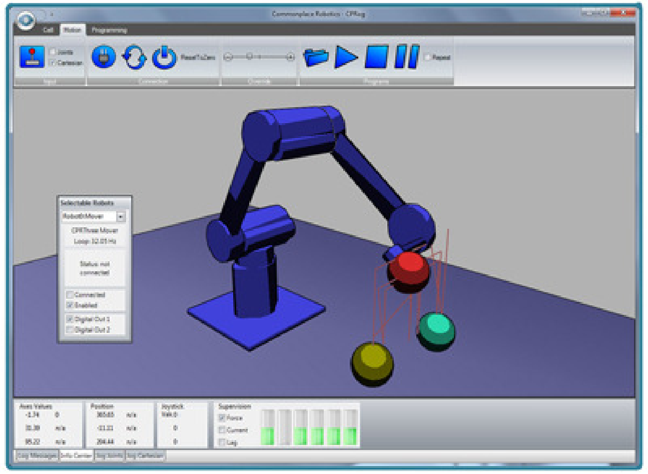


Manipulator Programming

- Teaching the robot a series of points to go through

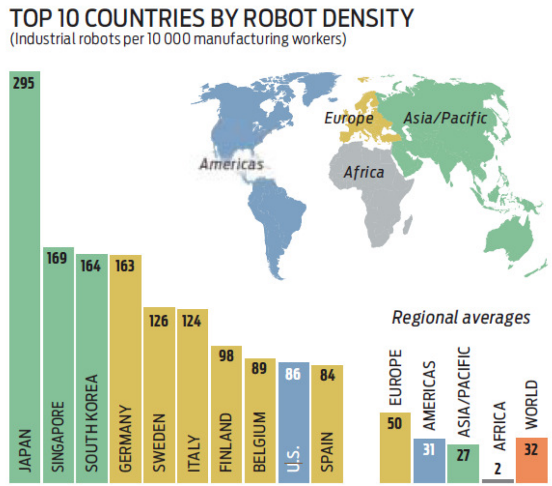
Manipulator Simulation

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



Usage of Industrial Mnipulators

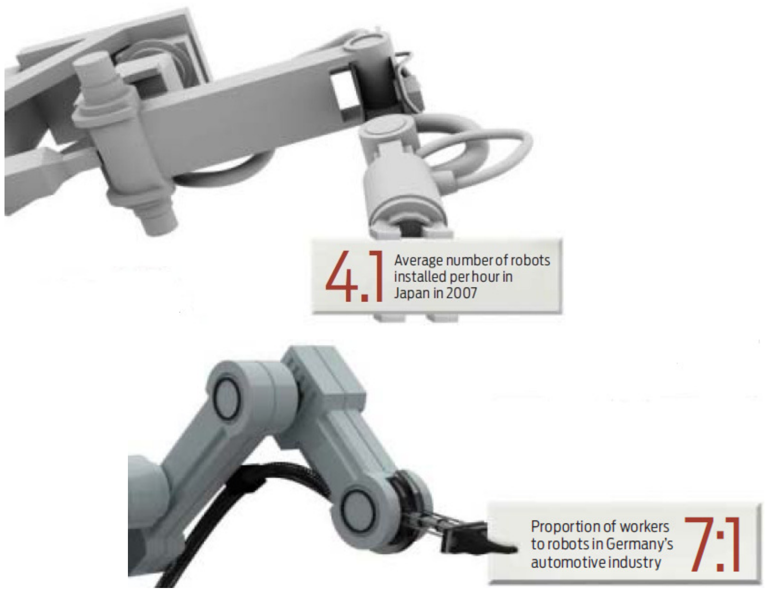
- Altogether 1million industrial robots are in the world
- Japan records highest density (10 times the average)
- First 3 countries are Asian



- Europe is the regional epicenter of industrial robots

Data*: International Federation of Robotics and Intl Labor Organization*

Industrial Robots: Recent Statistics

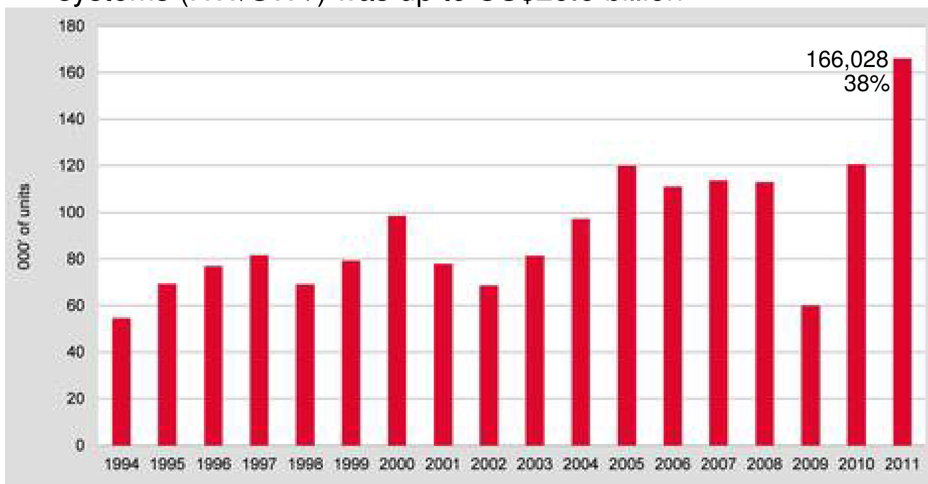


Data*: International Federation of Robotics and Intl Labor Organization*

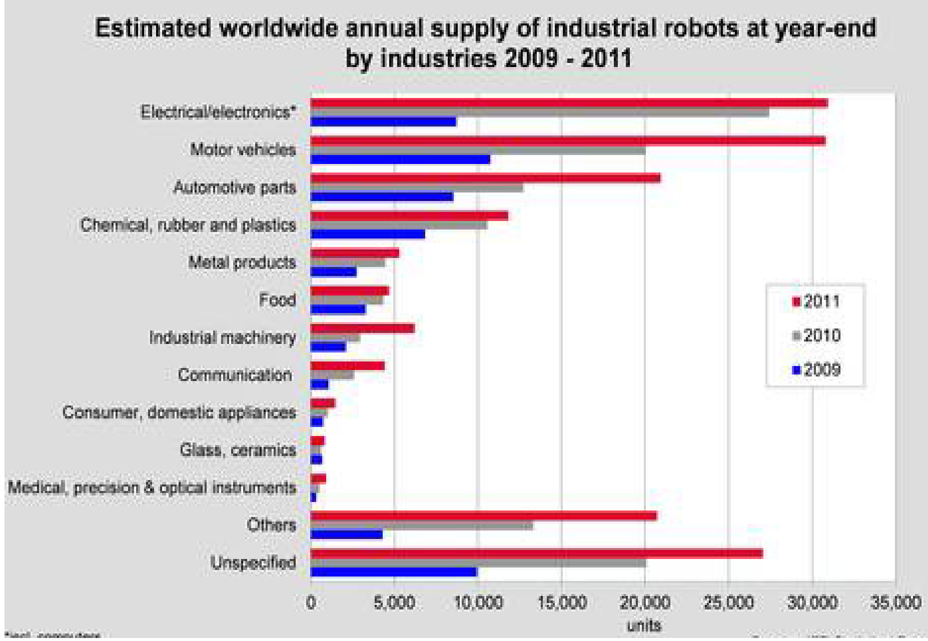
Growth of Market

IFR International Federation of Robotics

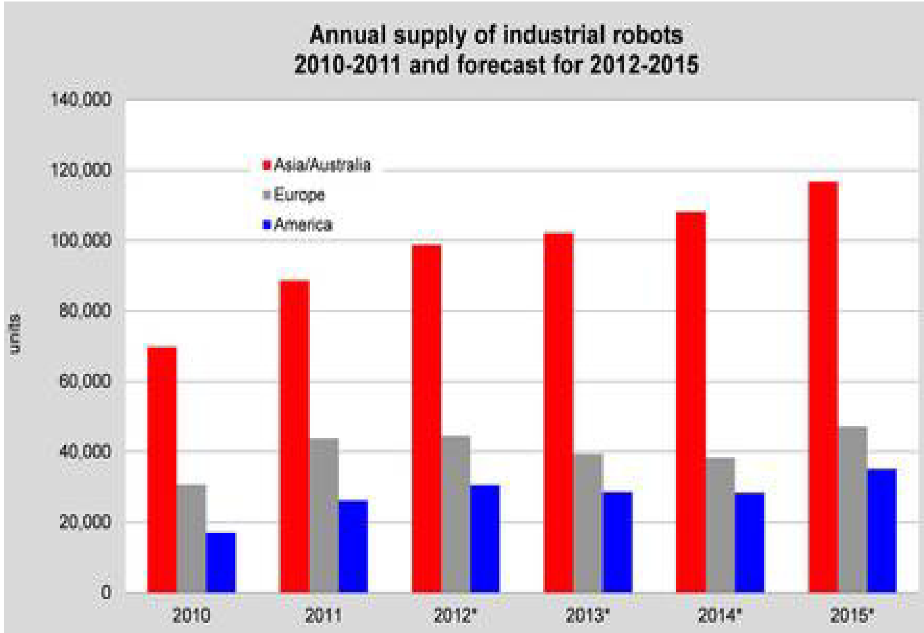
- Worldwide stock of operational industrial robots at the end of 2011 was in the range of 1,153,000 and 1,400,000 units. Value of the market ofrobot systems (HW/SW+) was up to US$25.5 billion



Distribution Among Industries



Usage Trend in Regions

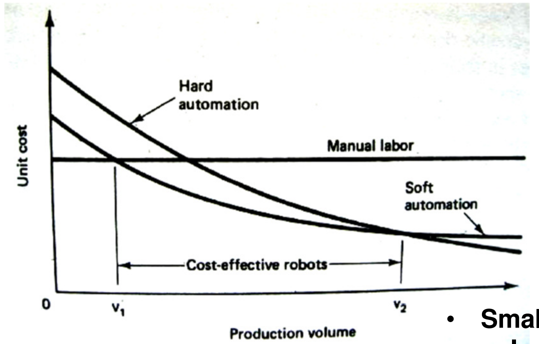


Factory Roboticization is Demanding

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 є [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)