CHAPTER 1

1-1 Reprogrammablity, multifunctionality.

1-2 **Forward Kinematics:** Position and orientation of the end effector in terms of the joint variable.
Inverse Kinematics: Joint variables in terms of position/orientation of the end effector.
Trajectory Planning: Planning the time history of the joint variables necessary for the robot to execute a given task.
Workspace: The total volume swept out by the end-effector as the manipulator executes all possible motions.
Accuracy: A measure of how close the manipulator can come to a given point within its workspace.
Repeatability: A measure of how close a manipulator can return to a previously taught point.
Resolution: The smallest increment of motion that can be sensed. The resolution is a function of the distance traveled and the number of bits of encoder accuracy.
Joint Variable: The relative displacement between adjacent links, denoted θ_i for revolute joints and d_i for prismatic joints.
Spherical Wrist: RRR wrist configuration with joint axes intersecting at a common point.
End Effector: A gripper or tool used to perform the robot's task.

1-3 Geometry, power source, application area, method of control.

1-4

Robotica
Robotics
Robotics and Autonomous Systems
Robotics Age
Robotics Engineering
Robotics and Computer-Integrated Manufacturing
Robotics Today
International Journal of Robotics Research
IEEE Journal of Robotics and Automation
Journal of Robotics Systems
IASTED Journal of Robotics and Automation
ASME Journal of Dynamics Systems, Measurement and Control
IEEE Transactions on Automatic Control
IEEE Transactions on Systems, Man, and Cybernetics.

1-6 **Non-servo robots:** Materials handling, servicing a special purpose machine such as a press.
Point-to-point robots: Materials handling, spot welding, forging.

Continuous path: Arc welding, grinding and deburring, spray painting, assembly, sheep shearing.

1-7 Welding, painting, deburring, grinding, polishing.

1-8 Automating inspection of goods for defects, monitoring unknown terrain, sorting objects by color or shape, painting an object, picking up randomly placed objects.

1-9 Handling fragile objects (glass, eggs, etc.), grinding, assembly defusing explosives, machining.

1-10 As of 1983-1984, number of industrial robots. Figures from *"Robotics: Basic Analysis and Design"* by William A. Wolovich

US	15,000	Italy	1,500
Japan	30,000	Communist Block	1,500
W. Germany	6,000	Canada & rest of Europe	5,000
Sweden	5,000	UK	2,000
France	2,000		

1-11 The key point of this question is the rapidity of change. An overnight change would not allow time for workers to be retrained or to find other jobs, thus negating the beneficial effects of increased productivity. This point can be discussed at length in a classroom setting.

1-12 Here again the key point is in the extreme nature of allowing no robotic automation. While no one would be put out of work by robots, the productivity and quality of goods produced would soon lag behind that of other countries. The long term effect would likely be higher unemployment than would result by phased automation. This point can also be discussed in a classroom setting.

1-13 Applications involving reaching around or behind obstacles, assembly of a complex, intricate object, defusing explosives, artificial limbs.

1-14 Using the law of cosines: $c^2 = a^2 + b^2 - 2ab\ cos\theta$

let $a = l = b$ and $c = d$. Then $d^2 = 2l^2(1 - cos\theta)$.

Hence

$d = l\sqrt{2(1 - cos\theta)}$.

With $l = 1\ m$, $\theta = 90°, d = \sqrt{2}$ meters $= 1.4142136$ meters.

On the other hand, $s = l\theta = \frac{\pi}{2}$ meters $= 1.5707963$ meters.

Resolution $= \frac{\text{Total distance}}{2^n}$ where $n =$ number of bits of encoder accuracy.

The linear resolution is $\frac{\sqrt{2}}{2^{10}} = 0.003811 = 1.3811 \times 10^{-3}$ meters.

The rotational resolution is $\frac{\pi}{2.2^{10}} = \frac{\pi}{2^{11}} = 0.001534 = 1.534 \times 10^{-3}$ meters.

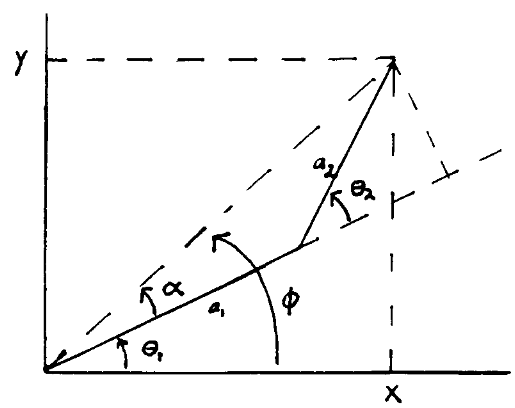
1-15 resolution $= \frac{l\theta}{2^n} = \frac{(50\ m)(\pi)}{2^8} = 0.6136\ m$.

1-16 $l_1 = 0.5\ m \qquad \theta = \pi \qquad r = \frac{\text{total distance}}{2^n} = \frac{\frac{1}{2}\cdot\pi\cdot\frac{1}{50}}{2^8}\ m = 1.227 \times 10^{-2} cm$ ·

1-17 The position of the TCP is not measured directly but is computed from encoder measuring joint positions. Thus the accuracy is affected by computational errors, machining accuracy in construction of robot parts, etc.

1-18 If direct end-point sensing were used, less uncertainty could enter the measurement of the end-effector position. Difficulties include introducing a vision system at the end-effector and feeding back the end-effector position which could cause the control system to become unstable.

1-19



From the Figure $\theta_1 = \phi - \alpha$ where $\phi = tan^{-1}(y/x)$; $\quad \alpha = tan^{-1}(\frac{a_2 sin\theta_2}{a_1 + a_2 cos\theta_2})$.

1-20

$$x = a_1 cos\theta_1 + a_2 cos(\theta_1 + \theta_2) = cos(\frac{\pi}{6}) + cos(\frac{2\pi}{3}) = 0.366025$$

$$y = a_1 sin\theta_1 + a_2 sin(\theta_1 + \theta_2) = sin(\frac{\pi}{6}) + sin(\frac{2\pi}{3}) = 1.3660254.$$

1-21

$$cos\ \theta_2 = \frac{x^2 + y^2 - a_1^2 - a_2^2}{2a_1,\ a_2} = \frac{(\frac{1}{2})^2 + (\frac{1}{2})^2 - 1 - 1}{2(1)(1)} = -0.75$$

$$\theta_2 = \ tan^{-1} \frac{\pm\sqrt{1-(-.75)^2}}{(-.75)} = -41.4096^\circ \text{ (elbow up) or } 41.4096^\circ \text{ (elbow down).}$$

$\theta_1 = \ tan^{-1}(y/x) - \ tan^{-1}(\frac{a_2 \ sin \ \theta_2}{a_1 - a_2 \ \ cos \ \theta_2})$

so the two solutions are

$\theta_1 = 24.2952°$ $\qquad \theta_1 = 65.7098°$

$\theta_2 = 41.4096°$ $\qquad \theta_2 = -41.4096°$

1-22

$\dot{x} = -sin\theta_1 - 3 \ sin(\theta_1 + \theta_2)$

$\dot{y} = \ cos\theta_1 + 3 \ cos(\theta_1 + \theta_2)$

At $\theta_1 = \theta_2 = \frac{\phi}{4}$,

$\dot{x} = -(sin\frac{\pi}{4} + 3 \ sin\frac{\pi}{2}) = -3.7071068,$

$\dot{y} = \ cos\frac{\pi}{4} + 3 \ cos\frac{\pi}{2} = 0.7071068.$

1-25 If both links are equal length then $x = 0, \ y = 0$ can be reached by infinitely many configurations, namely, $\theta_2 = 180°, \ \theta_1 =$ arbitrary.