CHAPTER 1

1.1 BACKGROUND

Application of Robots

(a) Automation - {Repeated jobs, Repetitive jobs}

(b) Hazardous or Inaccessible Environment

Hazardous - Nuclear Reactors

- Furnaces operations

- Mines

Inaccessible Environment - Deep sea

- Outer space

What is Robot?

If a mechanical device can be programmed to perform a wide variety of works then it is a robot.

The mechanical devices which perform to produce one class of task are called machines. In general, robotics involves more sophisticated knowledge of kinematics, dynamics and controls than machines.

It is quite difficult to very precisely define these terms. Mechanical Engineers are mainly involved in the statics and dynamic analysis of Robots.

Control Theory provides tools for designing and evaluating algorithms to REALIZE OR ACHIEVE DESIRED MOTIONS OR FORCES.


CAUTION
DO NOT MOVE AXIS 1 or AXIS 2 MANUALLY
PEGASUS
DANGER
THIS MACHINE STARTS AUTOMATICALLY

1.2 SOME TERMINOLOGIES IN MECHANICS AND CONTROL

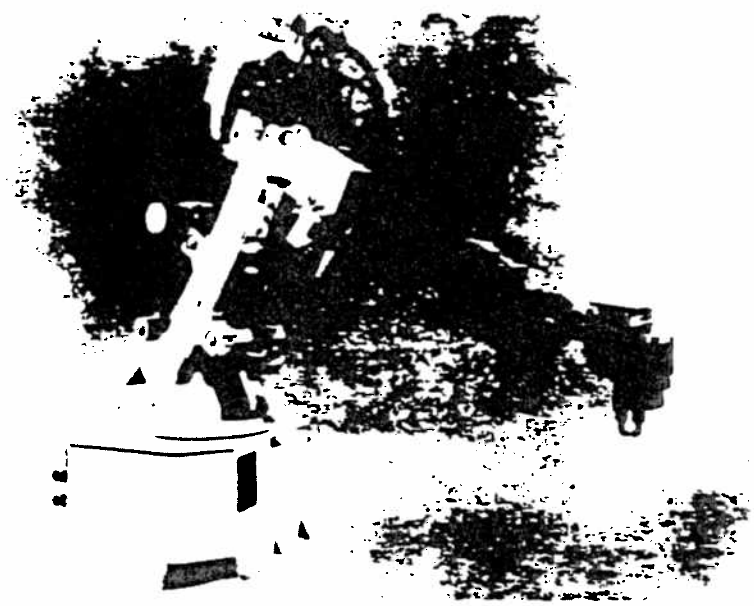

FIGURE 1.4 The Cincinnati Milacron 776 manipulator has six rotational joints and is popular in spot welding applications. Courtesy of Cincinnati Milacron.

(a) POSITION AND ORIENTATION

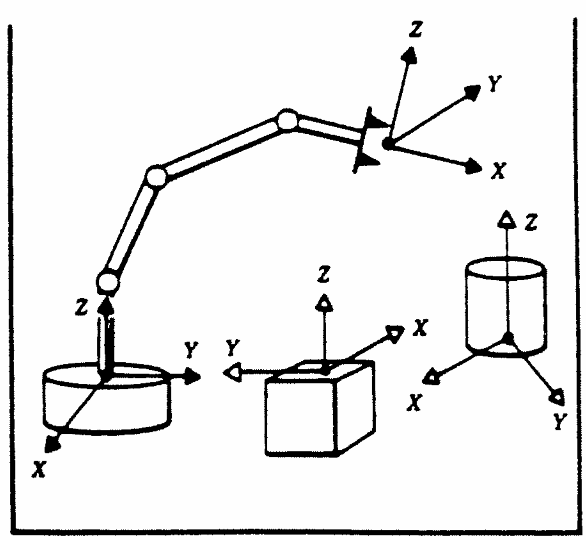

FIGURE 1.5 Coordinate systems or "frames" are attached to the

In the use of robots, we are constantly concerned about the location and orientation of objects in three dimensional space.

This requires a systematic analysis where different coordinate systems, one each, on every link, are set up. There is a separate coordinate system attached to the ground (stationary) and is called the REFERENCE OR GLOBAL COORDINATE SYSTEM OR FRAME. Any coordinate system can be described either with reference to another moving coordinate system or the REFERENCE COORDINATE SYSTEM.

The description of any coordinate system requires the knowledge of

(a) the position vector of its origin

(b) the orientations (direction cosines) of each of its x, y, and z axes with respect to the FRAME OR THE REFERENCE SYSTEM.

(a) POSITION VECTOR OF ITS ORIGIN

It is a vector, in three dimensions joining the origin of the FRAME to the origin of the coordinate system. This vector will have three components along the REFERENCE AXES.

(b) ORIENTATION

The orientation of any of the axes is represented by its direction cosine which is nothing but the cosines of the angle between this axis and the reference axis. The angle has to be measured in a plane containing this axis and the reference axis - it is an unique plane. Suppose α_1, β_1, and γ_1 are the angles the O_1x_1 axis makes respectively with the X, Y, and Z axes, then we can represent the $x_1 - O_1 - y_1 - z_1$ system by a (4x4) matrix as

$$\begin{matrix} & x_1 & y_1 & z_1 & R_{O,O} \end{matrix}$$

$${}^{o}_{o1}[\ T\ ] = \begin{bmatrix} \text{Cos}\alpha_1 & \text{Cos}\alpha_2 & \text{Cos}A_3 & (R_{O,O})_x \\ \cos\beta_1 & \text{Cos}\beta_2 & \text{Cos}\beta_3 & (R_{O,O})_y \\ \text{Cos}\gamma_1 & \text{Cos}\gamma_2 & \text{Cos}\gamma_3 & (R_{O,O})_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

The first three columns show the direction cosines of each of the axes of the O_1 system. The fourth column contains the three components of the position vector of the origin, O_1. The FOURTH ROW contains three zeros and a one and the reason for it will be made clear later on.

If we want to grip certain objects in the Cartesian space using the manipulator then we have to have our end effector oriented in the space in a certain way. To do this, all the connecting links have to have certain angular relationships with each other. If we attach one frame to each of these links then we can (a) either write relationships between each of these frames with the Global Frame or (b) relationship between the consecutive frames.

In Chapter 2, it will be shown that given the relationships in either forms (a) and (b), one can obtain the other. In other words, it is sufficient to provide information in one of the two forms.

FORWARD KINEMATICS OF MANIPULATORS

Kinematics is a science of motion where parameters (velocity, displacement, acceleration etc.) are determined without taking into consideration, the forces. All these parameters are time dependent.

The links are considered rigid i.e., they are not stretchable or bendable. The connections between the links are called JOINTS and there is only one degree of freedom at each joint in this course.

These joints are usually instrumented with position sensors which enable us to know the relative position of each link at a given instant of time. If we obtain the continuous time histories of the relative positions, and if we use the data set where the each of the link lengths are given, then we can calculate the KINEMATICS PARAMETERS at any instant of time.

In this course we would study two types of joints:

(a) Revolute Joints.

(b) Sliding Joints.

END EFFECTOR - At the free end of the chain of links which make up the manipulator is the END EFFECTOR. Depending on the intended application of the robot, the end effector may be a gripper, welding torch, electromagnet or any other device.

We generally describe the position of the manipulator by giving the description of the tool frame which is attached to the gripper relative to the base frame which is attached to the nonmoving base of the manipulator.

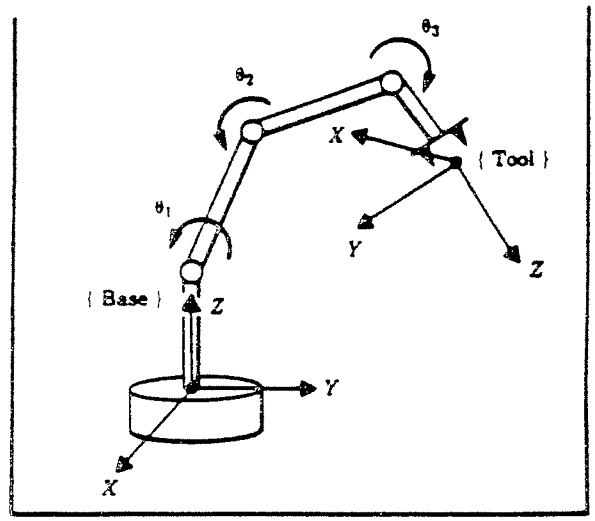

FIGURE 1.6 Kinematic equations describe the tool frame relative to the base frame as a function of the joint variables.

In FORWARD KINEMATICS we compute the position and orientation of the end effector given the joint angles. In other words, we are given the JOINT SPACE DATA as well as Link Lengths etc. and then we compute the orientation and location (x,y,z) of the end effector coordinate system. Here the calculations are done with respect to the base frame. It is the option (a) on page 7.

INVERSE KINEMATICS OF MANIPULATOR

In the INVERSE KINEMATICS problems we have: Given the position and orientation of the end effector, calculate ALL POSSIBLE sets of joint angles.

The Inverse solutions are:

1) Difficult to obtain (Equations are non-linear).

2) Multiple solutions exist.

3) Closed form solutions may not be possible to obtain.

4) Sometimes the solutions may not exist.

VELOCITIES, STATIC FORCES, SINGULARITIES

The vector containing the joint angles

$$\underline{\theta} = \begin{Bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{Bmatrix} \qquad (2)$$

represents the JOINT SPACE. The vector involving the coordinates of the point or points represents the Cartesian Space.

In Equation

$$^{0}\{ V \} = {}^{0}[J]\{ \dot{\theta} \} \qquad (4)$$

$$\underline{V} = \begin{Bmatrix} X_1 \\ y_1 \\ z_1 \\ x_2 \\ y_2 \\ z_2 \end{Bmatrix} \tag{3}$$

The vector $\{V\}$ is related to the vector $\{\dot{\theta}\}$ by a matrix [J].

If $\{V\}$ represents the various components of the tip velocity in the Cartesian space and $\{\dot{\theta}\}$, the joint velocities of the manipulator then the matrix [J] is called a JACOBIAN. If this matrix [J] is SINGULAR i.e., if its determinant for a given $\theta_i = 0$ then $[J]^{-1}$ will not exist. This particular combination of $\theta_i = 0$ defines the singularity of the manipulator. In these configurations, infinite torques are required to impart given tip velocities. Therefore in planning tip paths, singular configurations are avoided.

DYNAMICS

It is a field of study where forces which cause the motion are also included in the analysis. To give certain type of motion, say a constant speed or Velocity in the

Cartesian space would require a complex or intricate time history of motor torques to each of the arms. These torques are calculated using either Lagrange's Equations of Motion or Newton's Equations of Motion. These are actually called Newton-Euler Dynamic Equations.

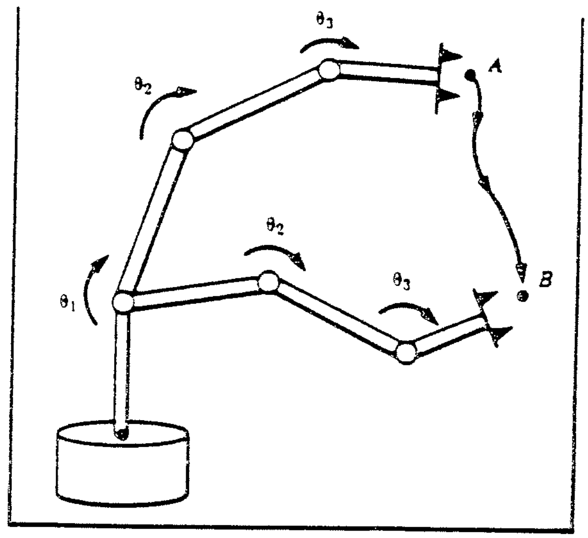

FIGURE 1.10 In order to move the end-effector through space from point A to point B we must compute a trajectory for each joint to follow.

For the end effector to move along certain path with certain velocity etc. requires, at every instant of time, a set of $\{\theta\}$ vectors i.e., a synchronized joint angle variations or coordinated joint angle variations. If this does not take place then the end effector will not traverse along its trajectory.

The path is defined by a series of points along the trajectory which are very close to each other. For each point, there exists <u>at least</u> one $\{\theta\}$ vector. These points are called VIA POINTS and the SMOOTH FUNCTION passing through these points is called a SPLINE FUNCTION.

MANIPULATOR DESIGN AND SENSORS

The parameters or the variables involved in the design are:

1) Size of links.

2) Number of joints.

3) Load capability.

4) Maximum tip speed.

5) Workspace size.

6) Deflection of links.

7) Choice and location of actuators.

8) Transmission system.

9) Position and Force sensors.

LINEAR POSITION CONTROL

Vast majority of manipulators are driven by actuators which supply a force or a torque to cause motion of links.

In the POSITION CONTROL SYSTEM, the errors in the trajectory chosen are minimized. The system computes the torques based on the LINEARIZATION of the Non-Linear Dynamic Equations. Such control methods are used in industries these days.

NON-LINEAR CONTROL

Some attempts have been made to use the Non-Linear Dynamic Control Algorithms in the CONTROLLERS. These algorithms are superior to the linear ones.

FORCE CONTROL

In certain applications, the forces of application must be very closely controlled. For example, if a manipulator is moving in free space then the POSITION CONTROL is important but when it touches a rigid object then a FORCE CONTROL may become important.

In HYBRID CONTROLS, a position control is applied in certain directions and force control

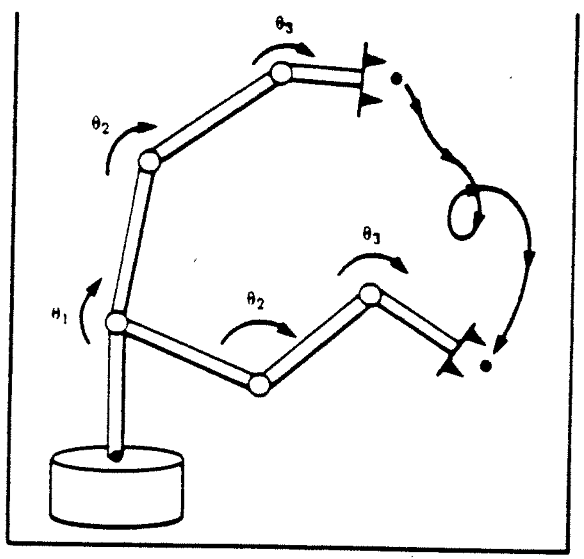

FIGURE 1.12 In order to cause the manipulator to follow the desired trajectory, a position control system must be implemented. Such a system uses feedback from joint sensors to keep the manipulator on course.

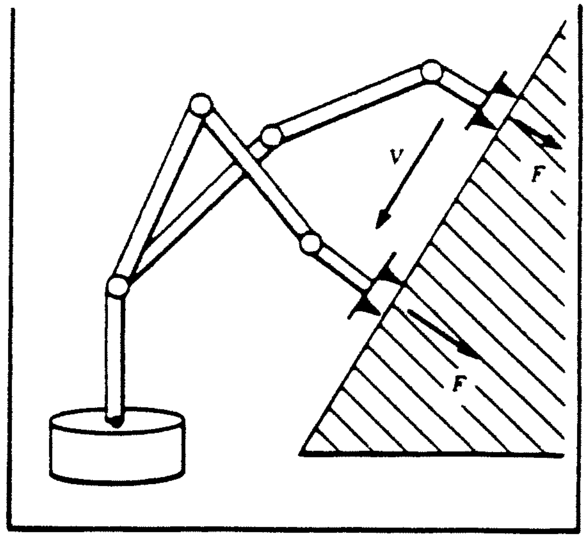

FIGURE 1.13 In order for a manipulator to slide across a surface while applying a constant force, a hybrid position-force control system must be used.

in some others.

NOTATIONS

1) $\underline{A}$, {A} VECTOR, Also (2) Co-ordinate System {A}

2) [B] matrix

3) $[B]^T$ Transpose of matrix [B]

4) $[B]^{-1}$ Inverse of matrix [B]