CHAPTER 1

INTRODUCTION

1.1 BASICS

Robots have emerged as indispensable part of modern manufacturing systems. They know no boundaries and can be applied across a broad spectrum of manufacturing disciplines in diverse industries. For controlling the motion of a manipulator, it is necessary to solve problems of kinematics for representing the position of the arm at required points in time.

Kinematics is the analysis of the robot motion with respect to a fixed reference coordinate frame, without regard to the forces and moments that cause motion. It deals the relations between the variable joint coordinates of the robot mechanism and the positions and orientations of the end effector. Ever since the first industrial robots appeared, there has been a big concern about computing kinematics in a simple, reliable and quick way in order to improve the robot performance.

The aim of this research is to develop forward and inverse kinematic models of SCORBOT ER V Plus using LabVIEW in order to optimize the manipulative task execution. In this research work, forward kinematics analysis is done for the fixed twist angle, link lengths, and link offsets of each joints by varying joint angles to specify the position and orientation of the end effector. Forward analysis can be used to provide the position of some point on the end effector together with the orientation of the end effector measured relative to a coordinate system fixed to ground for a specified set of joint variables.

As inverse kinematics is crucial in motion planning of industrial robots, the iterative solution of inverse kinematics solution for SCORBOT ER V Plus is obtained to provide the joint variables to approach the object positioned and oriented as needed. The inverse kinematics solution can be applied within the workspace of the robot and also for possible reachable position of the end effector. Path analysis and workspace analysis are fundamentally important in robotic system design. The kinematics solution of any robot manipulator consists of two sub problems forward and inverse kinematics (Figure 1.1).

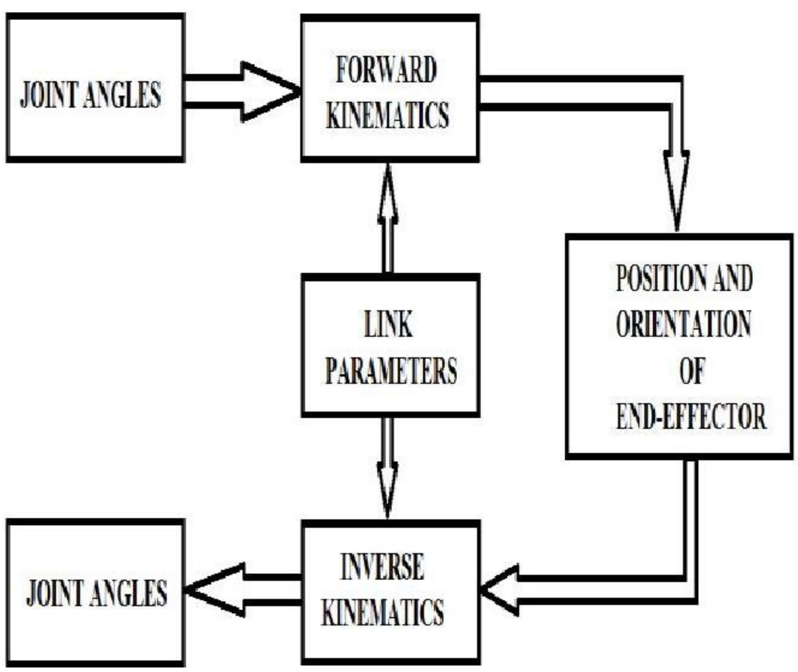

Figure 1.1 Forward and Inverse Kinematics

1.2 INDUSTRIAL ROBOTS

Industrial robot as defined by ISO 8373: 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. It should be designed with high endurance, speed, and precision for the following reasons:

- Improving quality of work for employees
- Increasing production output rates
- Improving product quality and consistency
- Increasing flexibility in product manufacturing
- Reducing operating costs

An industrial robot does task specified operations based on specifications for defined motion. The most basic application of an industrial robot is pick and place operation in which it picks up a part at one location and moves it to another location. For pick and place operation, one of the major element in the specifications of task is kinematics.

1.2.1 Classifications of Robots

The robots are generally classified as follows:

Articulated, Cartesian, Cylindrical, Polar, SCARA, and DELTA

Articulated - This robot design features rotary joints and can range from simple two joint structures to ten or more joints. The arm is connected to the base with a twisting joint. The links in the arm are connected by rotary joints. Each joint is called an axis and provides an additional DOF, or range of motion. Industrial robots commonly have 4 or 6 axes.

Cartesian - These are also called rectilinear or gantry robots. Cartesian robots have three linear joints that use the Cartesian coordinate system (X, Y, and Z). They also may have an attached wrist to allow for rotational movement. The three prismatic joints deliver a linear motion along the axis.

Cylindrical - This robot has at least one rotary joint at the base and at least one prismatic joint to connect the links. The rotary joint uses a rotational motion along the joint axis, while the prismatic joint moves in a linear motion. Cylindrical robots operate within a cylindrical shaped work envelope.

Polar – These are also known as spherical robots. In this configuration the arm is connected to the base with a twisting joint and a combination of two rotary joints and one linear joint. The axes form a polar coordinate system and create a spherical-shaped work envelope.

SCARA - This SCARA (Selectively Compliant Arm for Robotic Assembly) is primarily cylindrical in design. It features two parallel joints that provide compliance in one selected plane. These robots are commonly used in assembly applications.

DELTA - These spider-like robots are built from jointed parallelograms connected to a common base. The parallelograms move a single EOAT (End of Arm Tooling) in a dome shaped work area. These are heavily used in the food, pharmaceutical, and electronic industries. This robot configuration is capable of delicate, precise movement.

1.2.2 Applications

Industrial robots are employed in many industrial applications like: arc welding, spot welding, material handling, machine tending, painting, assembly, pick and place operations (such as packaging, palletizing and surface mount technology), product inspection and testing, die cast, dispensing, machining, material removal (cutting, deburring, polishing and finishing), part transfer, pick and pack, press/forming, spot welding and other applications.

1.2.3 Kinematics Issues in Industrial Robots

To obtain the accurate solution of the reverse or inverse analysis is a tedious process. In the inverse kinematics, the position of a point on the object together with the object's orientation is specified. It is required to determine a corresponding set of joint variables that will position and orient the end effector as desired. As there are multiple solution sets of the joint variables, in contrast to the forward analysis where only one solution exists, it is difficult to get single solution in inverse kinematics.

To compute the joint trajectories needed for the robot in order to guide the TCP (Tool Centre Point or Tip of Gripper) along the part using inverse kinematics is complex, as multiple solutions are existing. It adds on to the challenge of solving the inverse kinematics problem. It is also computationally expensive and generally takes a very long time in the real time control of manipulators.

Vision guidance (Machine vision) is bringing a lot of flexibility to robotic cells. However, the end effector attached to a robot is often a simple pneumatic, two-position chuck. This does not allow the robotic cell to easily handle different parts, in different orientations. Hand-in-hand with increasing off-line programmed applications, robot calibration is becoming more and more important in order to guarantee a good positioning accuracy.

Other developments include downsizing industrial arms for light industrial use such as production of small products, sealing and dispensing, quality control, handling samples in the laboratory. Such robots are usually classified as "Bench Top" robots. Robots are used in pharmaceutical research in a technique called High-throughput screening. Bench top robots are also used in consumer applications like micro-robotic arms. Industrial arms may be used in combination with or even mounted on AGVs (Automated Guided Vehicles) to make the automation chain more flexible between pick-up and drop-off.

Controlling the position of a robot is not trivial. Serial robots are composed of concatenated joints, forming an open chain structure. With this structure, the inverse kinematic problem might not have a closed analytical solution. Not having such an analytical solution calls for Alternative Solutions for robots kinematics. And even when a closed analytical form exists, its equations may have multiple solutions.

1.3 SCORBOT ER V PLUS

For this research the SCORBOT ER V Plus is used. It is a vertical articulated robot, with five revolute joints. With gripper attached, the robot has six DOF (Degrees of Freedom). Figure 1.2 identifies the SCORBOT arm links and Figure 1.3 identifies the SCORBOT arm joints. This design permits the end effector to be positioned and oriented arbitrarily within a large work space. The ranges of all the axes are as follows: Axis 1: Base rotation ($\pm 155^o$), Axis 2: Shoulder rotation (-35^o to $+130^o$), Axis 3: Elbow rotation ($\pm 130^o$), Axis 4: Wrist pitch ($\pm 130^o$), Axis 5: Wrist roll (±570° - electrically, Unlimited - mechanically).

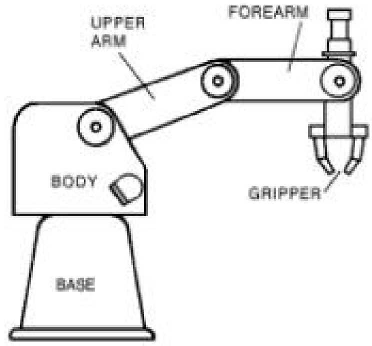

Figure 1.2 SCORBOT arm Links

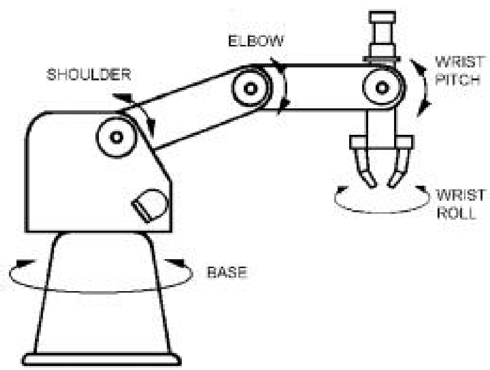

Figure 1.3 SCORBOT arm Joints

Maximum Operating Radius is 610mm (24.4"), Position Repeatability is ±0.5 mm (0.02") at TCP. Figure 1.4 identifies close up view of SCORBOT base and shoulder joints and Figure 1.5 identifies the SCORBOT arm parts.

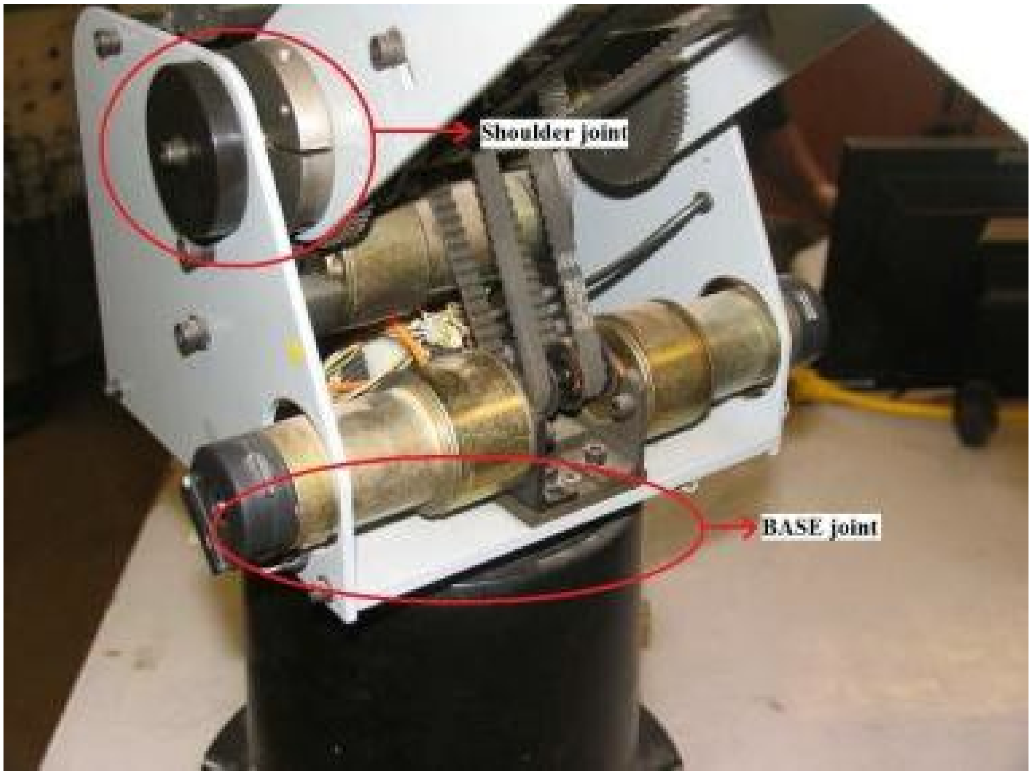

Figure 1.4 SCORBOT base and shoulder Joints

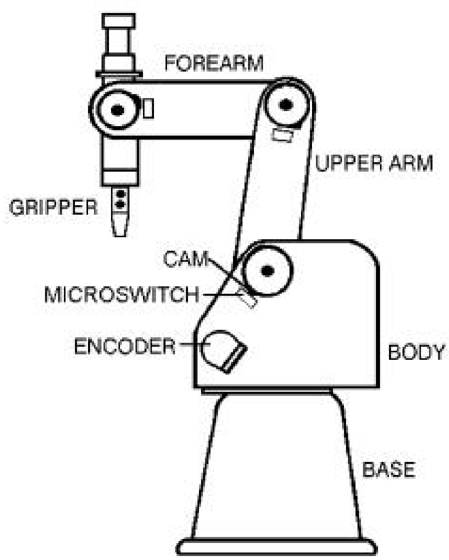

Figure 1.5 SCORBOT arm Parts

The movements of the joints are described in Table 1.1

Table 1.1 Movements of the Joints

Axis Number	**Joint Name**	**Motion**
1	Base	Rotates the body.
2	Shoulder	Raises and lowers the upper arm.
3	Elbow	Raises and lowers the forearm.
4	Wrist Pitch	Raises and lowers the end effector (gripper).
5	Wrist Roll	Rotates the end effector (gripper).

1.3.1 Work Envelope

The length of the links and the degree of rotation of the joints determine the robot's work envelope. Figures 1.6 and 1.7 show the dimensions and reach (top view and side view) of the SCORBOT ER V Plus.

The base of the robot is normally fixed to a stationary work surface. It may, however, be attached to a slide base, resulting in an extended working range. The sixth DOF is added to the SCORBOT as a linear motion below the base which is also controlled by the teach pendant and ATS (Advance Terminal Software). This greatly expands the robots reachable workspace.

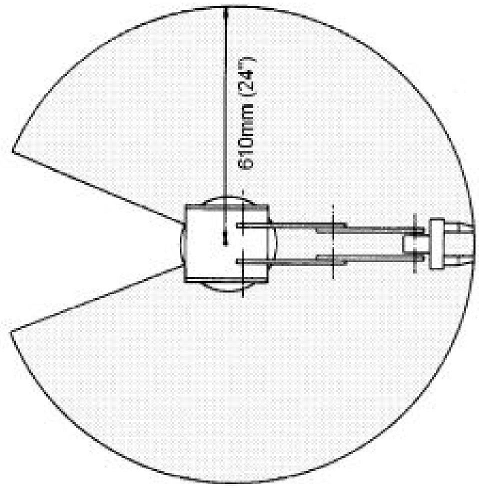

Figure 1.6 Operating Range (Top View)

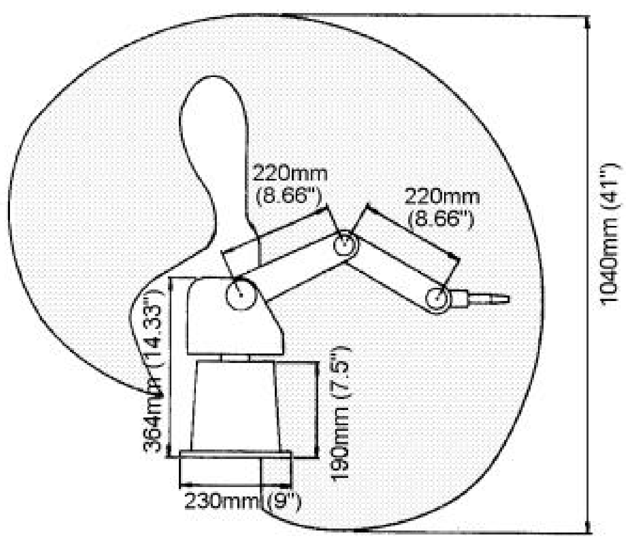

Figure 1.7 Operating Range (Side View)

1.3.2 Operating the SCORBOT

SCORBOT ER V Plus can be programmed and operated in a number of ways by means of both the ACL (Advanced Control Language) software and the teach pendant.

DIRECT Mode

In the DIRECT mode, all commands are executed by pressing <Enter>. As soon as the command is entered in teach pendant (Figure 1.8), the controller executes the command and controls the axes.

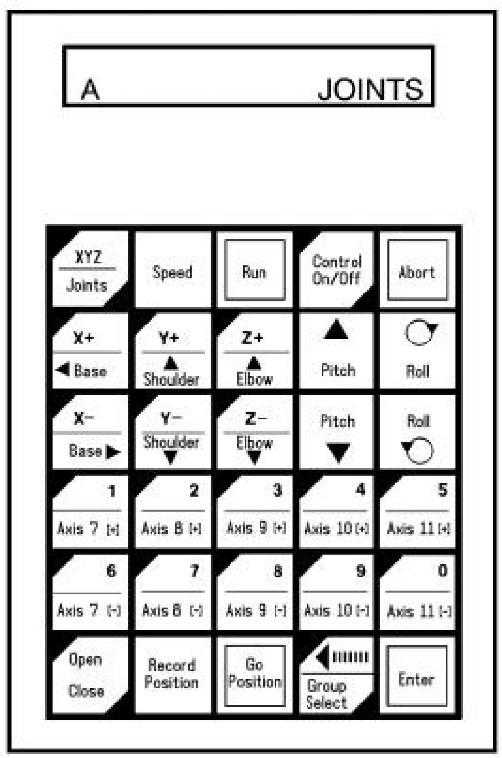

Figure 1.8 DIRECT Mode (Teach Pendant)

Manual Mode.

Manual mode is available when the system is in DIRECT Mode (Figure 1.9). It enables the direct control of the robot axes when a teach pendant is not connected. In manual mode the keyboard is used to perform certain procedure.

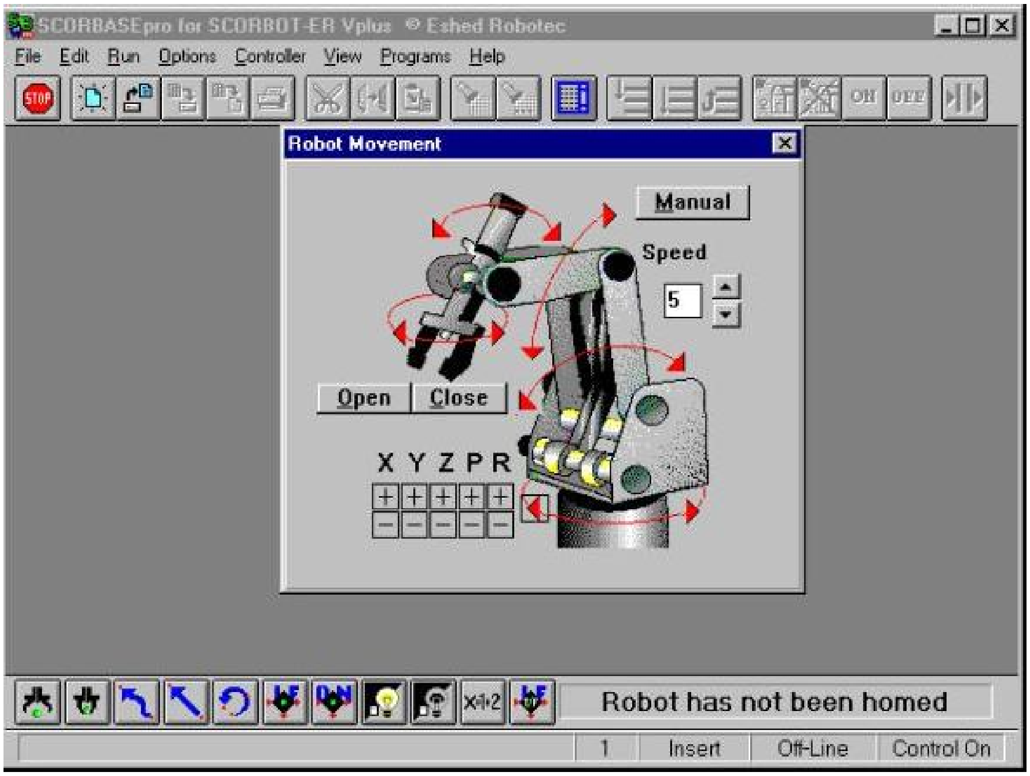

Figure 1.9 Manual Mode

1.3.3 Homing and Peripheral Axes

The location of the robot axes is monitored by encoders which track the amount of movement relative to an initial home position. To obtain repeatable robot performance, this reference position must be identical each time the robot is used. Thus, whenever the system is activated, the homing program, which is internally programmed into the controller, must be executed. During the homing procedure, the robot joints move and search for their home positions, one at a time, in the following sequence: shoulder (axis 2), elbow (axis 3), pitch (axis 4), roll (axis 5), base (axis 1), and gripper (axis 6).

To find its home position, the axis is moved until the micro switch which is mounted on the joint sends a specific signal to the controller, indicating the axis is at home. When the homing is completed, the robot assumes the position shown in Figure 1.10.

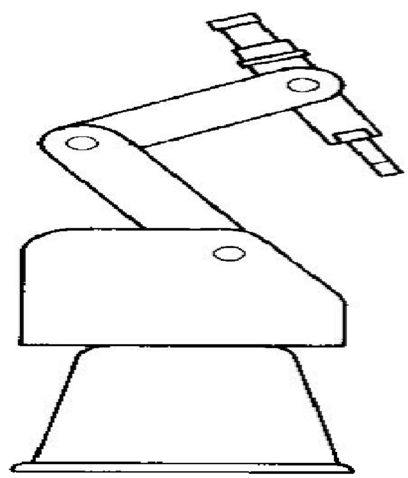

Figure 1.10 Home Position

1.3.4 Coordinate Systems

The SCORBOT ER V Plus can be operated and programmed in two different coordinate systems: Joint and Cartesian (XYZ) coordinate systems.

1.3.4.1 Joint coordinate system

Joint coordinates specify the location of each axis in encoder counts. When the axes move, the optical encoders generate a series of alternating high and low electrical signals. The number of signals is proportional to the amount of axis motion; the controller counts the signals and determines how far an axis has moved.

Similarly, a robot movement or position can be defined as a specific number of encoder counts for each axis, relative to the home position, or another coordinate. When robot motion is executed in Joint mode, individual axes move according to the command. If any peripheral devices are connected to the robotic system, the position of their axes is always stated in encoder counts.

1.3.4.2 Cartesian (XYZ) coordinate system

The Cartesian, or XYZ coordinate system is a geometric system used to specify the position of the robot's TCP by defining its distance, in linear units, from the point of origin (the centre bottom of its base) along three linear axes, as shown in Figure 1.11. To complete the position definition, the pitch and roll are specified in angular units. When robot motion is executed in XYZ mode, all or some of the axes move in order to move the TCP along an X, Y or Z axis.

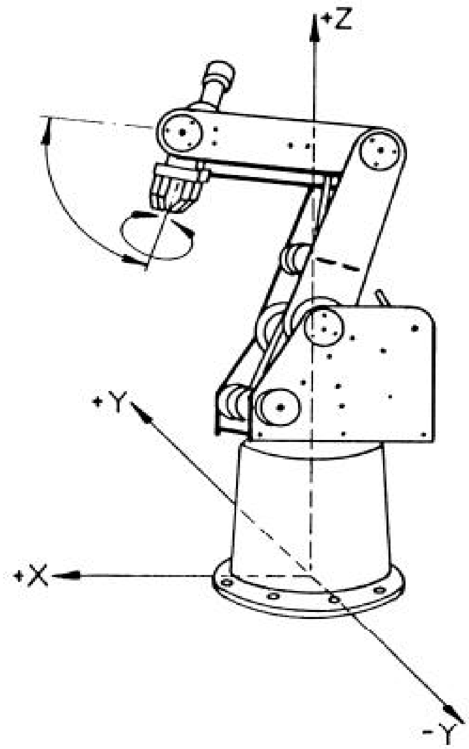

Figure 1.11 SCORBOT XYZ Coordinate System

1.3.4.3 Moving the axes

The joints (base, shoulder, elbow, wrist pitch and roll) move independently when the teach pendant is put in joint mode and in Cartesian coordinates plane when the teach pendant is put in XYZ mode.

1.3.4.4 XYZ and Joint movements

When the coordinate system is set to the XYZ mode, movement commands cause linear motion of the TCP along the X, Y and Z axes, while maintaining the angles of the pitch and roll relative to the robot's point of origin. When the coordinate system is set to the Joint mode, the robot responds to movement commands by moving from one defined point to another. Peripheral axes always move according to joint coordinates.

In XYZ mode, moving the robot to positions at the maximum range of reach may result in jerky movements. Use Joint mode to reach these positions. While moving the arm, one may alternate between XYZ and joint modes as often as required.

1.4 APPLICATIONS

SCORBOT ER V Plus is a dependable and safe robotic system specially designed for laboratory and training applications. This versatile system allows students to gain theoretical and practical experience in robotics, automation and control systems. The SCORBOT ER V Plus robot arm is used as an educational tool for undergraduate robotics courses and also in various industrial applications.

1.5 OBJECTIVES OF THIS WORK

- To develop a FKM (Forward Kinematics Model) of SCORBOT ER V Plus using LabVIEW and validate it with the AutoCAD modelling and RoboCell software.

- To do Reachability analysis using LabVIEW software, considering the three different positions and four unique rotations.

- To do path analysis from the results obtained from the FKM and to compare the output is with RoboCell. Also to perform the workspace analysis using AutoCAD from the results obtained from the FKM.

- To develop IKM (Inverse Kinematics Model) using LabVIEW.

- To address the most important problems in inverse kinematics of SCORBOT ER V Plus within its working space considering:

1. Combined Position and Orientation
2. Complete Iteration without Inverse formulae
3. Partial Iteration with Inverse formulae

1.6 OVERVIEW OF THE THESIS

The prime objective of the research work is to develop a LabVIEW based mathematical model of the SCORBOT ER V Plus (FKM) to obtain the position and orientation of TCP. To achieve this, in Stage I a LabVIEW programme (consists of 12 kinematic equations and 5 inputs besides the D-H Parameters) has been developed. The results are validated using RoboCell software and also using an AutoCAD model.

Reachability analysis, Path and Workspace for SCORBOT ER V Plus are given in stages. During the analysis, three different positions and four unique rotations are considered. (Positions: 1.Minimum, 2.Home and 3.Maximum, and Rotations: 1.Base, 2.Shoulder, 3.Elbow and 4.Wrist).

In Stage II, using the results obtained from the FKM, the reachability analysis is done for determining the reachability of TCP considering three positions (1.Minimum, 2.Home and 3.Maximum) with 5 inputs besides the D-H Parameters as design variables.

In Stage III, Path analysis considering four Rotations (1.Base, 2.Shoulder, 3.Elbow and 4.Wrist) is done by developing separate LabVIEW programmes and is verified using RoboCell software and work space analysis considering three Positions (1.Minimum, 2.Home and 3.Maximum) is done using AutoCAD.

The joint trajectories needed for the robot to guide the TCP along the path are computed by Inverse kinematics. To address this issue, in Stage IV IKM using LabVIEW has been developed to analyse Inverse kinematics considering combined position and orientation.

In Stage V, two LabVIEW programmes have been developed to analyse inverse kinematics problems by two iterative methods namely CIIKM (Complete Iterative Inverse Kinematics Method) and PIIKM (Partial Iterative Inverse Kinematics Method).