UNIT III KINEMATICS, DYNAMICS AND DESIGN OF ROBOTS & END-EFFECTORS

3.1 ROBOT KINEMATICS

Robot kinematics applies geometry to the study of the movement of multi-degree of freedom kinematic chains that form the structure of robotic systems. The emphasis on geometry means that the links of the robot are modeled as rigid bodies and its joints are assumed to provide pure rotation or translation.

Robot kinematics studies the relationship between the dimensions and connectivity of kinematic chains and the position, velocity and acceleration of each of the links in the robotic system, in order to plan and control movement and to compute actuator forces and torques. The relationship between mass and inertia properties, motion, and the associated forces and torques is studied as part of robot dynamics. The robot kinematics concepts related to both open and closed kinematics chains. Forward kinematics is distinguished from inverse kinematics.

SERIAL MANIPULATOR:

Serial manipulators are the most common industrial robots. They are designed as a series of links connected by motor-actuated joints that extend from a base to an end-effector. Often they have an anthropomorphic arm structure described as having a "shoulder", an "elbow", and a "wrist". Serial robots usually have six joints, because it requires at least six degrees of freedom to place a manipulated object in an arbitrary position and orientation in the workspace of the robot. A popular application for serial robots in today's industry is the pick-and-place assembly robot, called a SCARA robot, which has four degrees of freedom.

Fig 3.1 SCARA robot

STRUCTURE:

In its most general form, a serial robot consists of a number of rigid links connected with joints. Simplicity considerations in manufacturing and control have led to robots with only revolute or prismatic joints and orthogonal, parallel and/or intersecting joint axes the inverse kinematics of serial manipulators with six revolute joints, and with three consecutive joints intersecting, can be solved in closed-form, i.e. analytically this result had a tremendous influence on the design of industrial robots.

The main advantage of a serial manipulator is a large workspace with respect to the size of the robot and the floor space it occupies. The main disadvantages of these robots are:

- The low stiffness inherent to an open kinematic structure,
- Errors are accumulated and amplified from link to link,
- The fact that they have to carry and move the large weight of most of the actuators, and
- The relatively low effective load that they can manipulate.

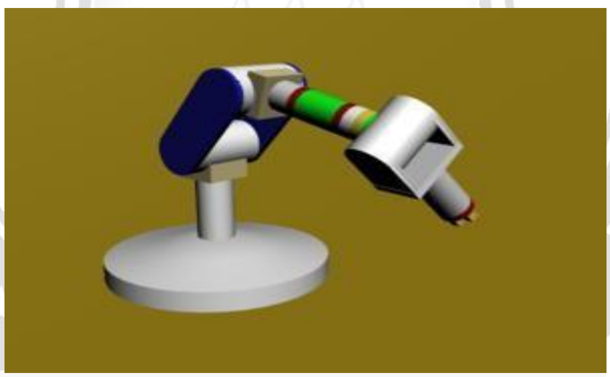


Fig.3.2 Serial manipulator with six DOF in a kinematic chain

PARALLEL MANIPULATOR:

A parallel manipulator is a mechanical system that uses several computer-controlled serial chains to support a single platform, or end-effector. Perhaps, the best known parallel manipulator is formed from six linear actuators that support a movable base for devices such as flight simulators. This device is called a Stewart platform or the Gough-Stewart platform in recognition of the engineers who first designed and used them.

Also known as parallel robots, or generalized Stewart platforms (in the Stewart platform, the actuators are paired together on both the basis and the platform), these systems are articulated robots that use similar mechanisms for the movement of either the robot on its base, or one or more manipulator arms. Their 'parallel' distinction, as opposed to a serial manipulator, is that the end effector (or 'hand') of this linkage (or 'arm') is connected to its base by a number of (usually three or six) separate and independent linkages working in parallel. 'Parallel' is used here in the computer science sense, rather than the geometrical; these linkages act together, but it is not implied that they are aligned as parallel lines; here *parallel* means that the position of the end point of each linkage is independent of the position of the other linkages.

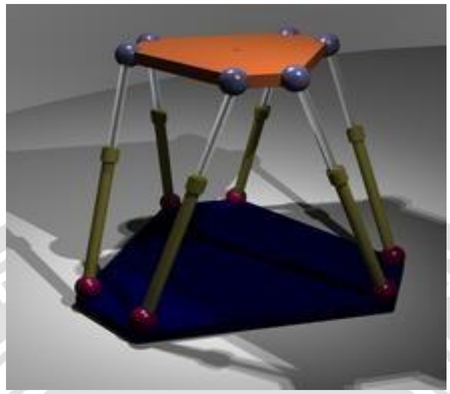


Fig: 3.3 Abstract render of a Hexapod platform (Stewart Platform)

Forward Kinematics:

It is used to determine where the robot's hand, if all joint variables are known)

Inverse Kinematics:

It is used to calculate what each joint variable, if we desire that the hand be located at a particular point.

3.2 ROBOTS AS MECHANISMS

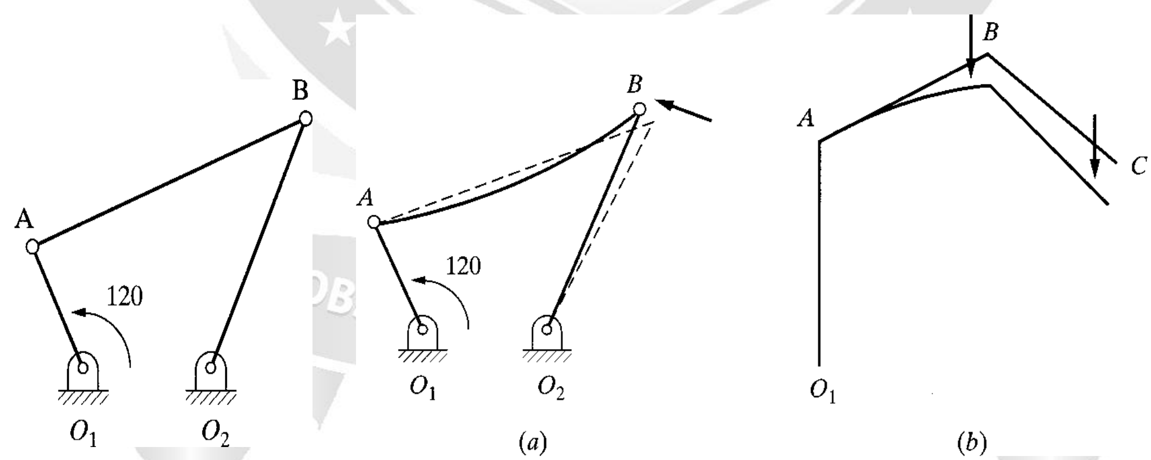


Fig 3.4 a one-degree-of-freedom closed-loop (a) Closed-loop versus (b) open-loop mechanism Four-bar mechanism

MATRIX REPRESENTATION

Representation of a Point in Space

A point *P* in space: 3 coordinate relative to a reference frame

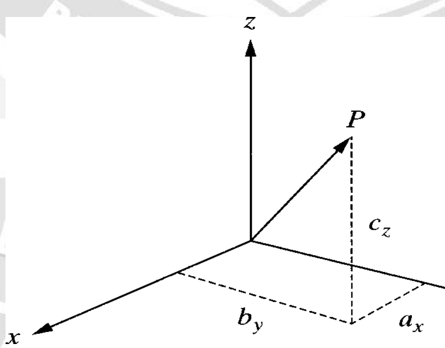
z

$$P = a_x \hat{i} + b_y \hat{j} + c_z \hat{k}$$

Fig. 3.5 Representation of a point in space

Representation of a Vector in Space

A Vector *P* in space: 3 coordinates of its tail and of its head



$$\overline{P} = a_x \hat{i} + b_y \hat{j} + c_z \hat{k}$$

Fig. 3.6 Representation of a vector in space

$$\overline{P} = \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

Representation of a Frame at the Origin of a Fixed-Reference Frame

Each Unit Vector is mutually perpendicular: normal, orientation, approach vector

$$F = \begin{bmatrix} n_x & o_x & a_x \\ n_y & o_y & a_y \\ n_z & o_z & a_z \end{bmatrix}$$

Fig. 3.7 Representation of a frame at the origin of the reference frame

Representation of a Frame in a Fixed Reference Frame

Each Unit Vector is mutually perpendicular: normal, orientation, approach vector

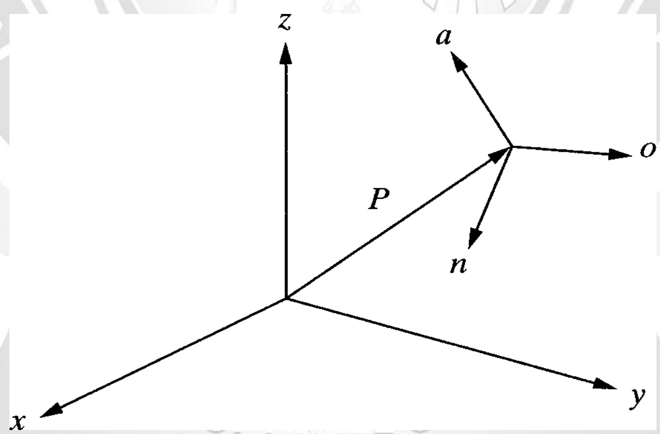


Fig. 3.8 Representation of a frame in a frame

$$F = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Representation of a Rigid Body

An object can be represented in space by attaching a frame to it and representing the frame in space.

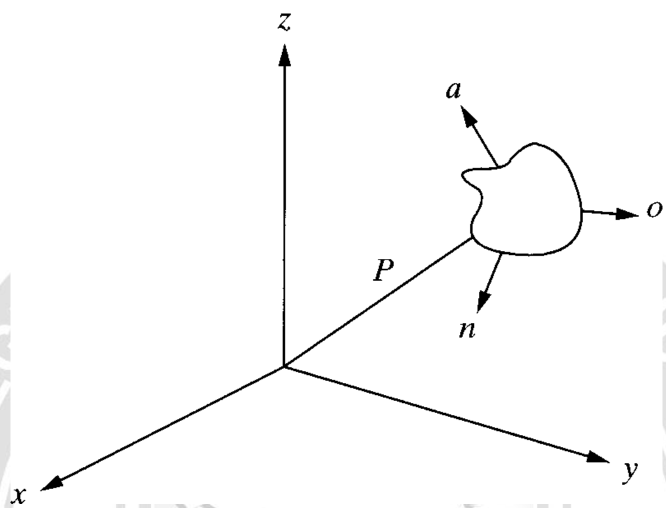


Fig. 3.9 Representation of an object in space

$$F_{object} = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3.3 HOMOGENEOUS TRANSFORMATION MATRICES

Transformation matrices must be in square form. It is much easier to calculate the inverse of square matrices. To multiply two matrices, their dimensions must match.

Representation of a Pure Translation

- A transformation is defined as making a movement in space.
- A pure translation.
- A pure rotation about an axis.
- A combination of translation or rotations

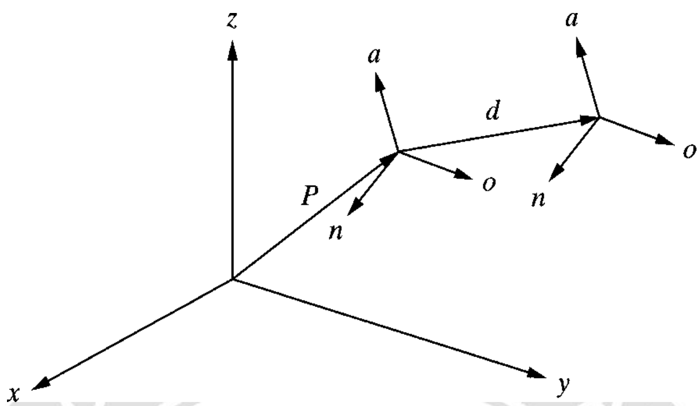


Fig. 3.10 Representation of a pure translation in space

$$T = \begin{bmatrix} 1 & 0 & 0 & d_x \\ 0 & 1 & 0 & d_y \\ 0 & 0 & 1 & d_z \\ & & 0 & 1 \end{bmatrix}$$

Representation of a Pure Rotation about an Axis

Assumption: The frame is at the origin of the reference frame and parallel to it.

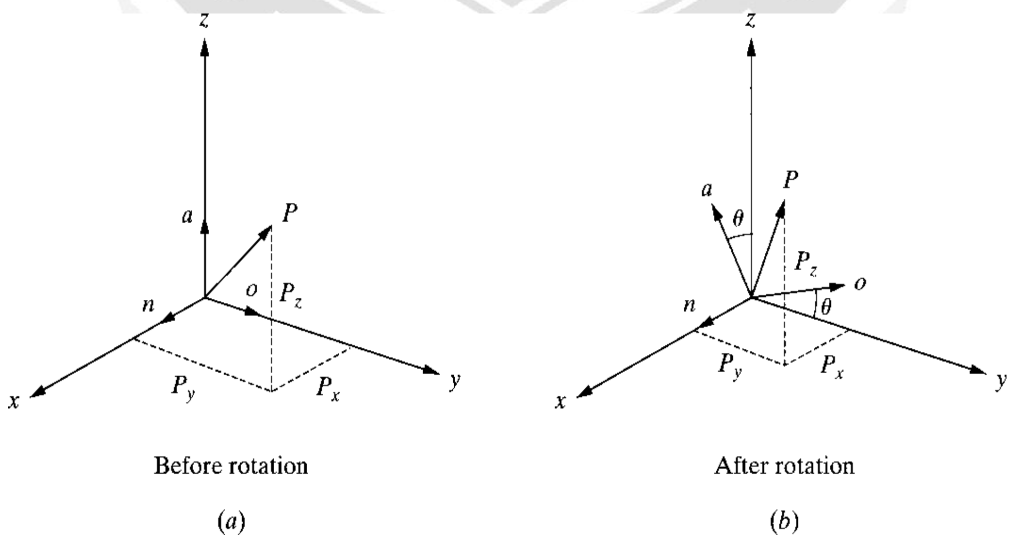


Fig. 3.11 Coordinates of a point in a rotating frame before and after rotation

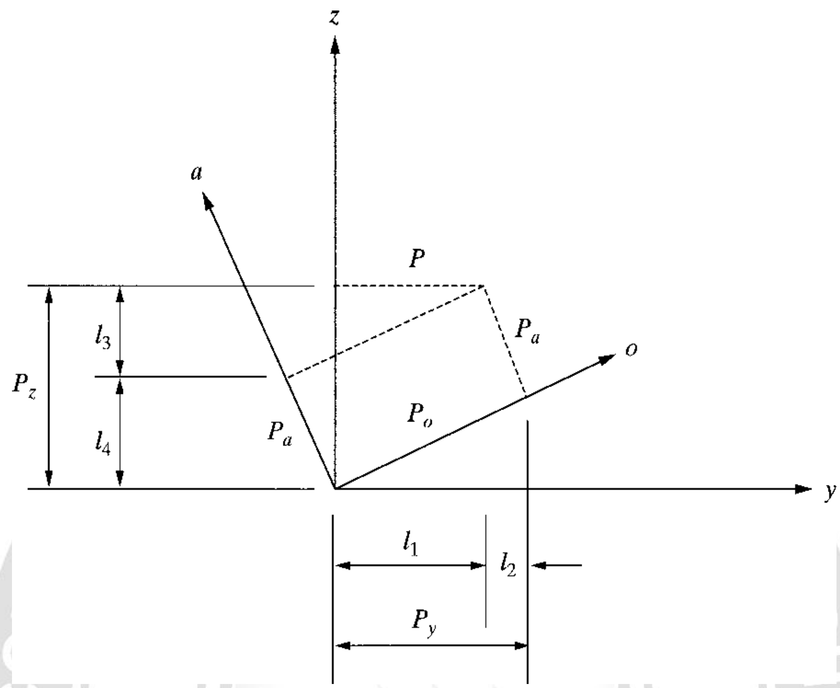


Fig. 3.12 Coordinates of a point relative to the reference

Representation of Combined Transformations

A number of successive translations and rotations

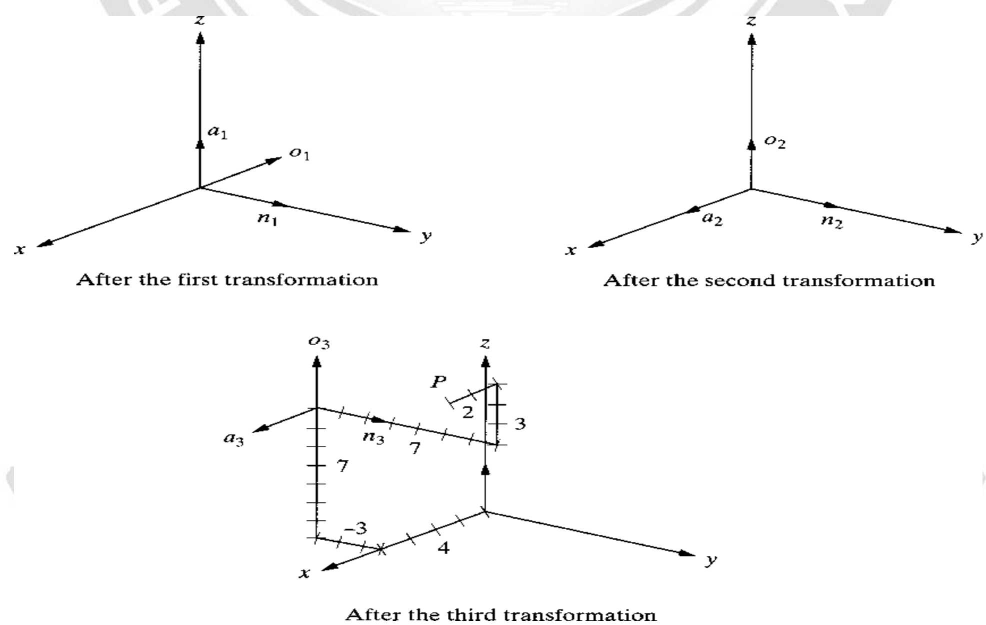


Fig. 3.13 Effects of three successive transformations

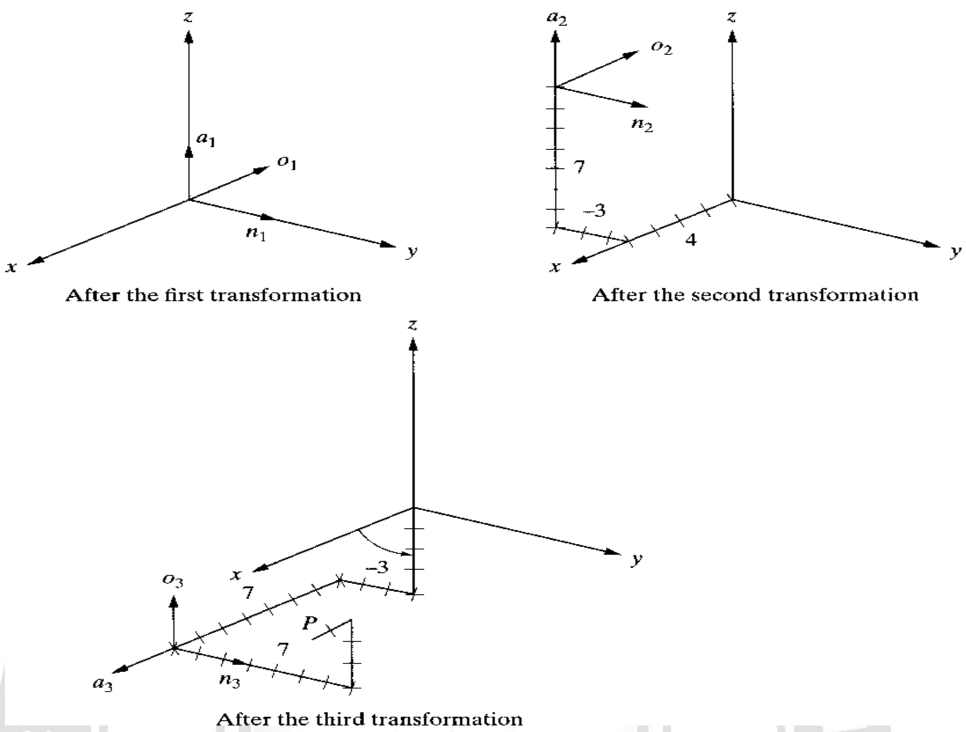


Fig 3.14 changing the order of transformations will change the final result

Transformations Relative to the Rotating Frame

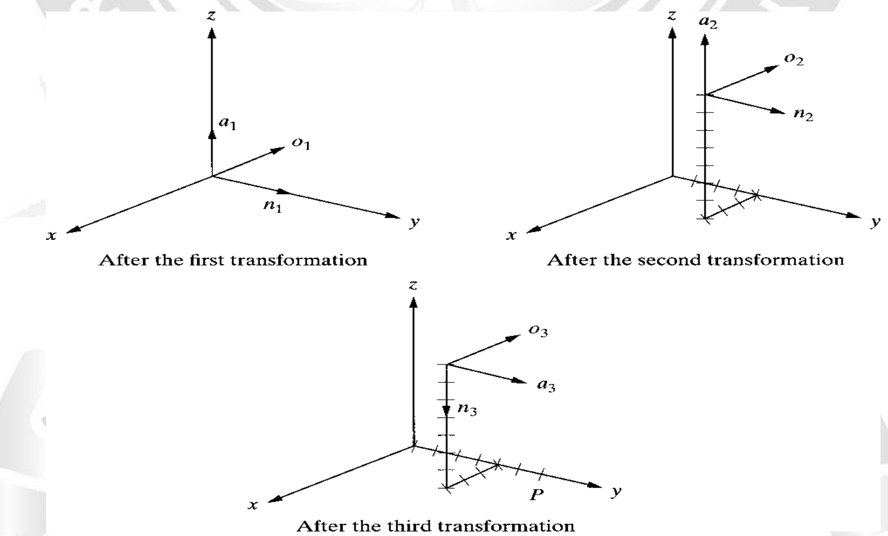


Fig. 3.15 Transformations relative to the current frames