ROBOT KINEMATICS

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Outline:

1. Kinematics, what is?
2. Open, closed kinematic mechanisms.
3. Sequence of joint transformations (matrix multiplications)
4. Direct vs. inverse kinematic task.

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.

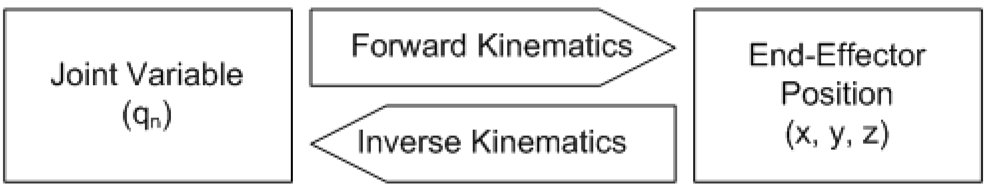
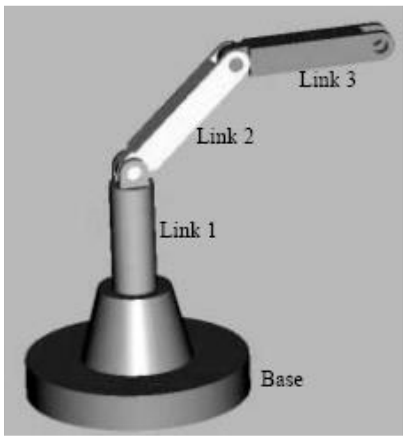


Figure: Forward and inverse kinematics diagram

Open Chain Manipulator Kinematics:



- ❖ Mechanics of a manipulator can be represented as a kinematic chain of rigid bodies (links) connected by revolute or prismatic joints.

- ❖ One end of the chain is constrained to a base, while an end effector is mounted to the other end of the chain.
- ❖ The resulting motion is obtained by composition of the elementary motions of each link with respect to the previous one.

Closed Kinematic Chain:

- ❖ Much more difficult.
- ❖ Even analysis must consider statics , constraints from other links, etc.
- ❖ Synthesis of closed kinematic mechanisms is very difficult.

Kinematics vs. Differential Kinematics:

- ❖ Kinematics describes the analytical relationship between the joint positions and the end-effector position and orientation.
- ❖ Differential kinematics describes the analytical relationship between the joint motion and the end-effector motion in terms of velocities.

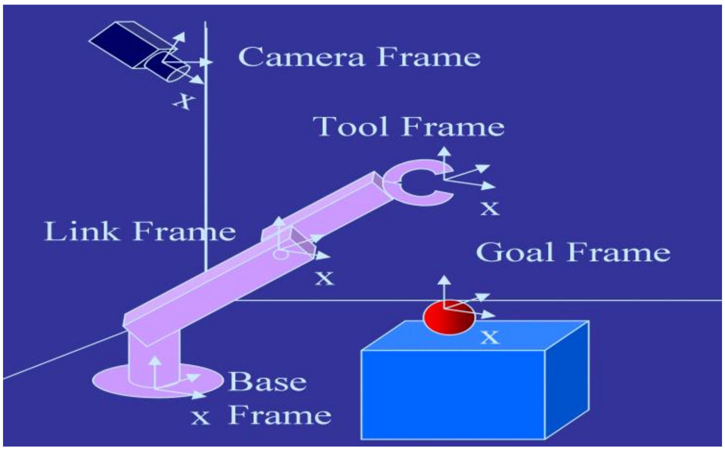
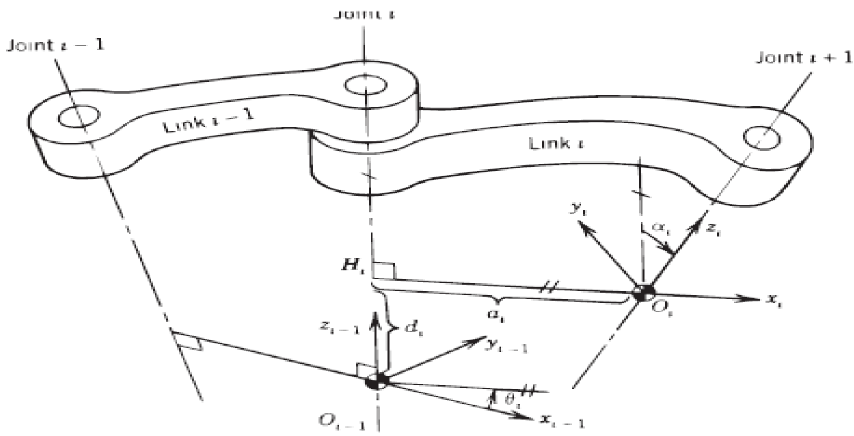


Figure: Coordinate Frames

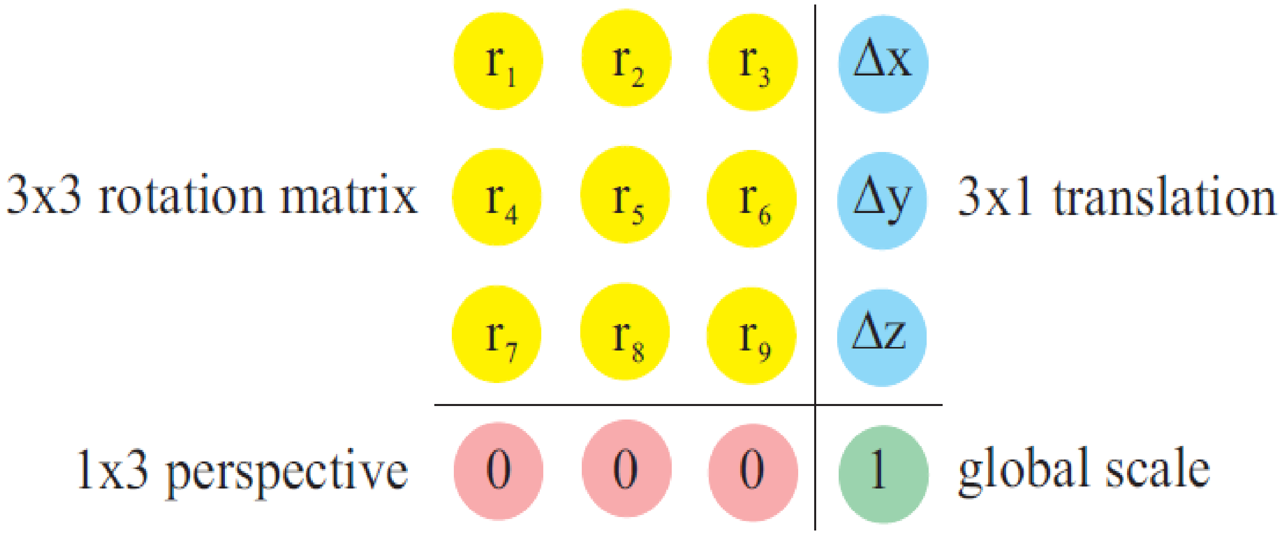
Two Frames Kinematic Relationship:



- There is a kinematic relationship between two frames, basically a translation and a rotation.

- This relationship is represented by a 4 × 4 homogeneous transformation matrix.

Homogeneous Transformation:



Rotation matrix R is orthogonal $\Leftrightarrow R^{\mathsf{T}}R = I \Rightarrow$ 3 independent entries, e.g., Euler angles.

Two Basic Joints:

Two types of joints used in commercial manipulators as given below:

(i) Revolute Joint
(ii) Prismatic Joint

(i) Revolute Joint:

Revolute joints allow pure rotation of one link about the joint axis of the preceding link.

This joint is like a hinge and allows relative rotation between two links. We use the convention [R] for representing revolute joints.

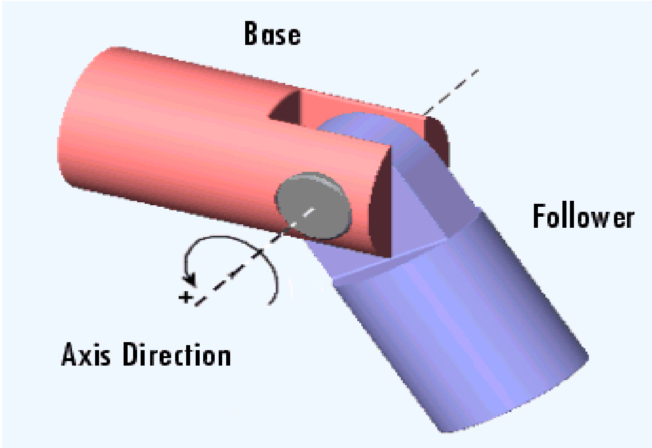


Fig: Revolute Joint

(ii) Prismatic Joint: A prismatic joint allows a linear relative motion between two links. We use the convention [P] for prismatic joint. Each joint represents the interconnection between two links.

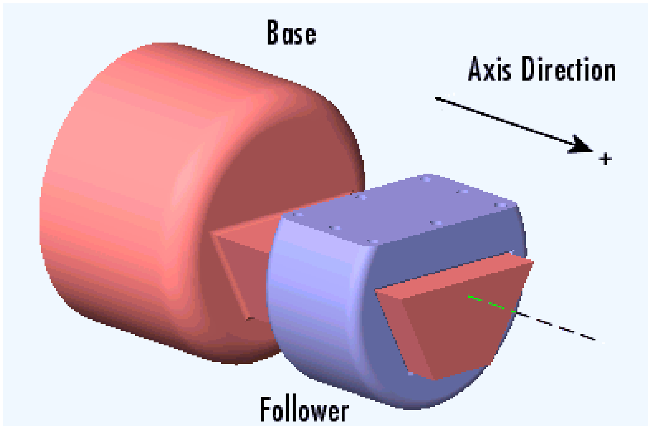
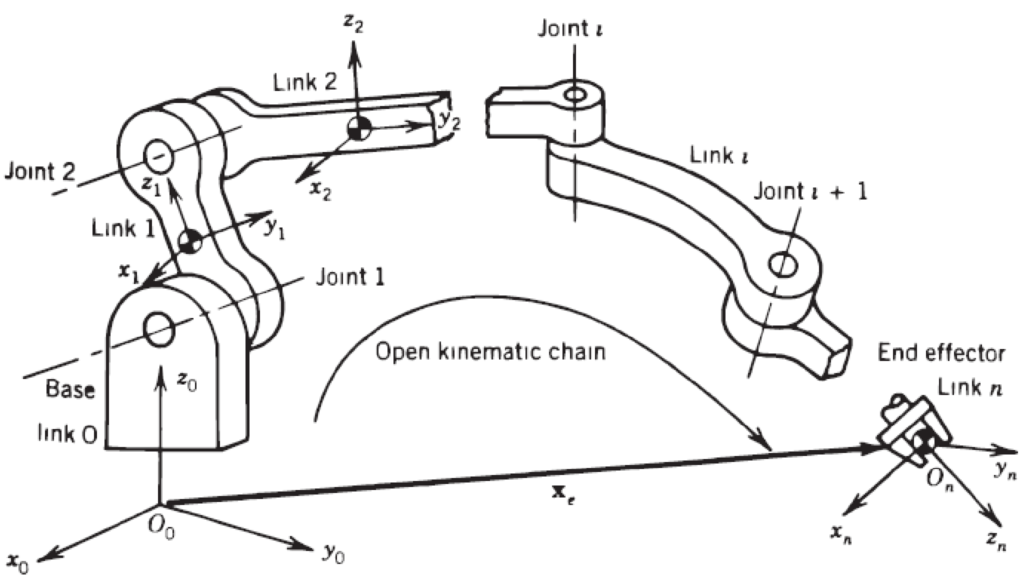


Fig: Prismatic Joint

Open Kinematic Chain:



Direct vs. Inverse Kinematics:

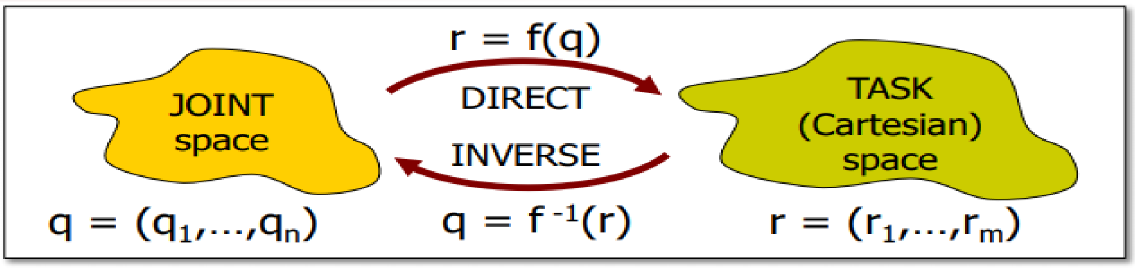
In manipulator robotics, there are two kinematic tasks:

Direct (also forward) kinematics: Direct or Forward kinematics refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters i.e. given are joint relations (rotations, translations) for the robot arm.

(Task: What is the orientation and position of the end effector?)

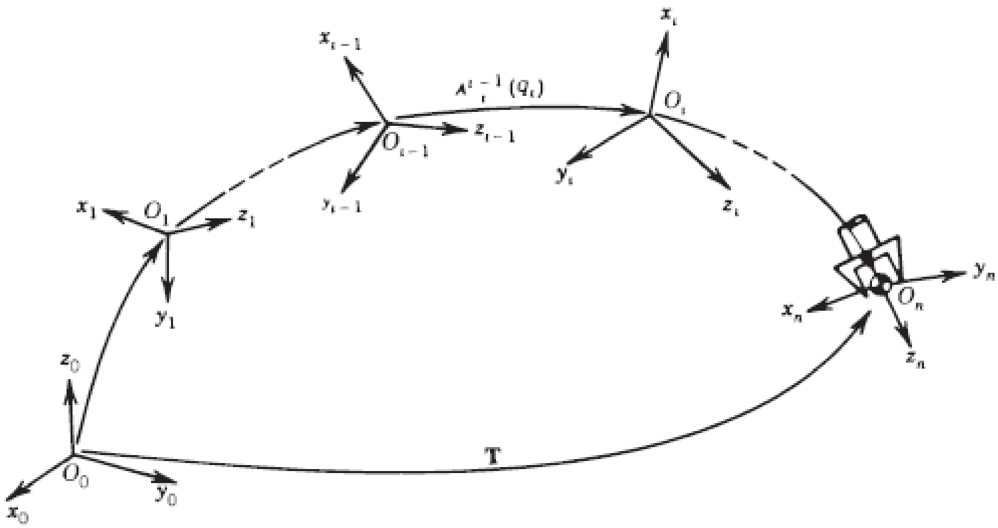
Inverse kinematics: In robotics, inverse kinematics is the mathematical process of calculating the variable joint parameters needed to place the end of a kinematic chain i.e. given is desired end effector position and orientation.

(Task: What are the joint rotations and orientations to achieve this?)



- choice of parameterization q
  - unambiguous and minimal characterization of robot configuration
  - n = # degrees of freedom (dof) = # robot joints (rotational or translational)
- choice of parameterization r
  - compact description of position and/or orientation (pose) variables of interest to the required task
  - usually, $m \leq n$ and $m \leq 6$ (but none of these is strictly necessary)

Direct Kinematics:



- One joint: $x_i = Ax_i - 1$.
- Chain of joints: $x_{n-1} = A_{n-1} A_{n-2} \ldots A_1 A_0 x_0$.
- Easy to compute (matrix multiplication).
- Unique solution.

Inverse Kinematics:

❖ For a kinematic mechanism, the inverse kinematic problem is difficult to solve.

❖ The robot controller must solve a set of non-linear simultaneous algebraic equations.

❖ Source of problems:
  - Non-linear equations (sin, cos in rotation matrices).
  - The existence of multiple solutions.
  - The possible non-existence of a solution.
  - Singularities.

Inverse Kinematics, Simplifications:

❖ Divide and conquer strategy. Decouple the problem into independent subproblems.

❖ The spherical wrist. Positioning of the wrist + positioning within the wrist.

❖ Design conventions, e.g. Denavit-Hartenberg systematic frame assignment.

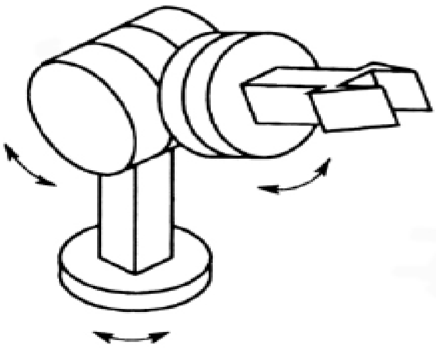


Fig: Symbolic representation of a Manipulator

(N.B: For further more details, Students are requested to go to the URL: https://robotacademy.net.au/masterclass/inverse-kinematics-and-robot-motion/**)**