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Department of Biomedical Engineering

Course Name: 19BMT401 – Virtual Reality in Medicine

IV Year : VII Semester

Unit II –MODELING

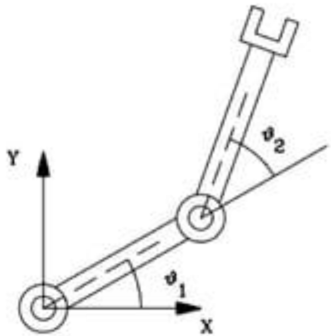
Topic : KINEMATICS MODELING

KINEMATIC MODEL

- **DEFINITION:**
  - The kinematic model studies the motion of a robot mechanism regardless of forces and torque that cause it.
  - It allows to compute the position and orientation of robot manipulator's end-effector relative to the base of the manipulator as a function of the joint variables.

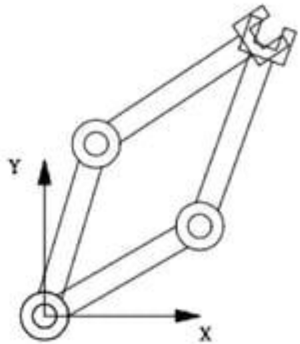
KINEMATIC MODEL

- **FORWARD KINEMATIC MODEL:**
  - The forward kinematic problem asks: once the joint position, velocity, acceleration are known, compute the corresponding variables of the end-effector in a given reference frame (e.g. a Cartesian frame).
  - The forward kinematic model can be defined as a function f defined between the joint space R^n and the work space R^m:
    $x=f(q)$; $x \in R^m, q \in R^n$



KINEMATIC MODEL

- **INVERSE KINEMATIC MODEL:**
  - Inverse Kinematic Problem: computation of the relevant variables (positions, velocities, accelerations) from the work space to the joint space.
  - Inverse Kinematic Model: function $g=f^{-1}$ from R^m to R^n:
    $\mathbf{q = g(x) = f^{-1}(x); \quad q \in R^n, x \in R^m}$



KINEMATIC MODEL

- **DENAVIT-HARTENBERG NOTATIONS:**
- In DH convention notation system, each link can be represented by two parameters, namely the link length $\boldsymbol{a}_i$ and the link twist angle $\boldsymbol{\alpha}_i$. The link twist angle $\boldsymbol{\alpha}_i$ indicates the axis twist angle of two adjacent joints $\boldsymbol{i}$ and $\boldsymbol{i}$ - 1. Joints are also described by two parameters, namely the link offset $\boldsymbol{d}_i$, which indicates the distance from a link to next link along the axis of joint $\boldsymbol{i}$, and the joint revolute angle θ_i, whichis the rotation of one link with respect to the next about the joint axis .Usually, three of these four parameters are fixed while one variable is called joint variable.
For a revolute joint, the joint variable is parameter θ_i, while for a prismatic joint, it will be $\boldsymbol{d}_i$.

KINEMATIC MODEL

- **DENAVIT-HARTENBERG NOTATIONS (contd.):**
- The four parameters of each link can be specified using DH notation method. With these parameters, link homogeneous transform matrix which transforms link coordinate frame ***i*-1** to frame ***i***.

$$
\begin{aligned}
{}^{i-1}A_i(\theta_i, d_i, a_i, \alpha_i) &= R_z(\theta_i)T_z(d_i)T_x(a_i)R_x(\alpha_i) \\
&= \begin{bmatrix} c\theta_i & -s\theta_i c\alpha_i & s\theta_i s\alpha_i & a_i c\theta_i \\ c\theta_i & c\theta_i c\alpha_i & -c\theta_i s\alpha_i & a_i s\theta_i \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
\end{aligned}
$$

here **sin(*θ*)** is abbreviated as ***s*θ** and **cos(*θ*)** as ***c*θ**, R_j denotes rotation about axis
j, and T_j denotes translation along axis *j* .

KINEMATIC MODEL

- **USES:**
- The robotic kinematics is essential for describing an end-effector's position, orientation as well as motion of all the joints.
- In order to deal with the complex geometry of a robot manipulator, the properly chosen coordinate frames are fixed to various parts of the mechanism and then we can formulate the relationships between these frames. The manipulator kinematics mainly studies how the locations of these frames change as the robot joints move.

DYNAMIC MODEL

- **DEFINITION:**
  - Robot dynamics is the study of the relation between the applied forces/torques and the resulting motion of an industrial manipulator.
  - The dynamic model of a robot studies the relation between the joint actuator torques
    and the resulting motion.

DYNAMIC MODEL

- **DIRECT DYNAMIC MODEL:**
  - Problem: Once the forces/torques applied to the joints, as well as the joint positions and velocities are known, compute the joint accelerations.

$$\ddot{\mathbf{q}} = f(\mathbf{q}, \dot{\mathbf{q}}, \tau)$$

and then

$$\dot{\mathbf{q}} = \int \ddot{\mathbf{q}}\, dt, \qquad \mathbf{q} = \int \dot{\mathbf{q}}\, dt$$

DYNAMIC MODEL

- **INVERSE DYNAMIC MODEL:**
  - Problem: Once the joint accelerations, velocities and positions are known, compute the corresponding forces/torques.

$$\tau = f^{-1}(\ddot{\mathbf{q}}, \dot{\mathbf{q}}, \mathbf{q}) = g(\ddot{\mathbf{q}}, \dot{\mathbf{q}}, \mathbf{q})$$

DYNAMIC MODEL

- **FORMULATION METHODS:**
- There are two commonly used methods for formulating the dynamics,based on the specific geometric and inertial parameters of the robot:
  - **the Lagrange–Euler (L–E) formulation**
  - **the Newton–Euler (N–E) method**
- Both are equivalent, as both describe the dynamic behaviour of the robot motion, but are specifically useful for different purposes.

DYNAMIC MODEL

- **LAGRANGE-EULER FORMULATION:**
- The L–E method is based on simple and systematic methods to calculate the kinetic and potential energies of a rigid body system. The equations of dynamic motion for a robot manipulator are highly nonlinear, consisting of inertial and gravity terms, and are dependent on the link physical parameters and configuration (i.e., position, angular velocity and acceleration).
- This provides the closed form of the robot dynamics, and is therefore applicable to the analytical computation of robot dynamics, and therefore can be used to design joint-space (or task-space, using transformation via the Jacobian) control strategies.
- The L–E formulation may also be used for forward and inverse dynamic calculation, but this requires the calculation of a large number of coefficients in $M(q)$ and $C(q, \dot{q})$, which may take a long time. This makes this method somewhat unsuitable for online dynamic calculations.

DYNAMIC MODEL

- **NEWTON-EULER METHOD:**
- The N-E formulation is based on a balance of all the forces acting on the generic link of the manipulator; this forms a set of equations with a recursive solution, and was developed. A forward recursion propagates link velocities and accelerations, then a backward recursion propagates the forces and torques along the manipulator chain.
- This is developed as a more efficient method than L–E, and is based on the principle of the manipulator being a serial chain; when a force is applied to one link, it may also produce motion in connected links. Due to this effect, there may be considerable duplication of calculation, which can be avoided if expressed in a recursive form.
- This reduction in computational load greatly reduces calculation time, allowing the forward and inverse dynamics calculations to be performed in real-time; therefore, it can enable real-time torque control methods of robot manipulators.

DYNAMIC MODEL

- **USES:**
- Dynamics modelling is crucial
  for analyzing and synthesizing the dynamic behaviour of robot.
- An accurate dynamics model of a robot manipulator is useful in many ways: for the design of motion control systems, analysis of mechanical design, simulation of manipulator motion, etc.

KINEMATIC MODEL VS DYNAMIC MODEL

KINEMATIC MODEL

- Studies the motion of a robot mechanism regardless of forces and torque that cause it.
- DH notations are used.
- Essential for describing an end-effector's position, orientation as well as motion of all the joints.

DYNAMIC MODEL

- Studies the relation between the joint actuator torques and the resulting motion.
- LE and NE methods are used.
- Crucial for analyzing and synthesizing the dynamic behaviour of robot.

Thank You