Design and Analysis of RRPR Robot for Watering plants

Umapriya S R
Electrical Engineering
University of California
Riverside,CA
ureng001@ucr.edu

Sri Durga Sai Sowmya Kadali
Computer Engineering
University of California
Riverside,CA
skada009@ucr.ed

Abstract— **In this study, for the four degrees of freedom robot arm used, forward kinematics with Denavit-Hartenberg notation and product of exponentials, inverse kinematics, and velocity kinematics were designed and analysed. Numerous tasks can be programmed into this robot arm. A nursery's plants could be watered as an illustration of this use. It's crucial to water the plants appropriately for their heights, types, and water requirements. It is evident that a robotic system is required in many applications to reduce the requirement for human labor while offering excellent accuracy. This robot arm differs in that one of the joints is a prismatic joint rather than a revolute joint. Positioning error will be minimized as a result of the joint's linear motion, and so will robot arm will be able to approach from a safer distance to prevent from accidents. Design and analysis were performed on Python using ROS.**

Keywords— Robotics, Kinematic Analysis, Robot Arm, Denavit-Hartenberg, Product of Exponentials

Notation

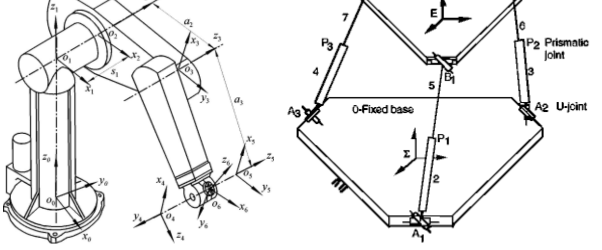
I. INTRODUCTION

Robotics is a field of modern technology that crosses traditional engineering boundaries. Understanding the complexity of robots and their applications requires knowledge of mechanical engineering, electrical engineering, systems and industrial engineering, computer science, economics, and mathematics [1]. Robots, initially meant for entertainment and fun, have dramatically changed the human life in recent years. The current technological revolution in robotics and automation has transformed the concept by accomplishing industrial tasks in a safer, optimized and much more efficient manner. Robotic manipulators are composed of rigid links interconnected by joints and are designed to function like a human arm but with enhanced strength and payload capacity [2]. Since the advent of the industrial robot, the world has been captivated by the idea of an automatically controlled agent that could make anything [3].

II. CLASSIFICATION OF ROBOTS

Robots can be classified according various criteria, such as
degrees of freedom, kinematic structure, drive technology,
workspace geometry, motion characteristics, and control [1]. The number of degrees of freedom that a manipulator possesses is the number of independent position variables that would have to be specified in order to locate all parts of the mechanism. This is a general term used for any mechanism [4]. Another classification of robots is according to their structural topologies. A robot is said to be a serial robot or serial (open-loop) manipulator if its kinematic structure takes the form of an open loop-chain, a parallel manipulator if it is made of a closed-loop chain, and
hybrid manipulator if it consists of both open and closed loop chains [1]. The samples of serial manipulator (a) and parallel manipulator (b) are shown in Figure 1.

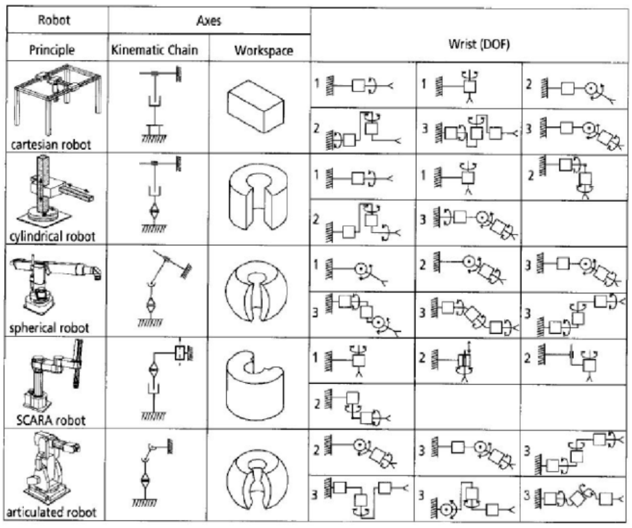
Figure 1. Serial (a) and parallel (b) manipulator samples [5,6].



Manipulators can also be classified by their drive technology. The three popular drive technologies are electric, hydraulic and pneumatic. Most manipulators use either electric dc servomotors or stepper motors, because they are clean and relatively easy to control. However, when high-speed and/or high-load-carrying capabilities are needed, hydraulic or pneumatic drive is preferred [7].

Robots come in a variety of shapes and sizes. The manipulator employs a variety of coordinate systems. The shape of the work envelope is influenced by the type of coordinate system, the placement of joints, and the length of the manipulator's segments. Instead of using the gripper tip or the end of the tool bit, the maximum work area is determined by a point on the robot's wrist. As a result, when the tool's tip is taken into account, the work envelope is a little bit larger. Depending on the precise design of the manipulator arm, work envelopes differ from manufacturer to manufacturer. incorporating many designs into one

A robot may lead to a different range of work envelope possibilities. Prior to selecting a specific robot configuration, the application must be studied carefully to determine the precise work envelope requirements. Some work envelopes have a geometric shape; others are irregular. One method of classifying a robot is by the configuration of its work envelope. The four major configurations are: revolute, Cartesian, cylindrical, and spherical. Each configuration is used for specific applications [8].

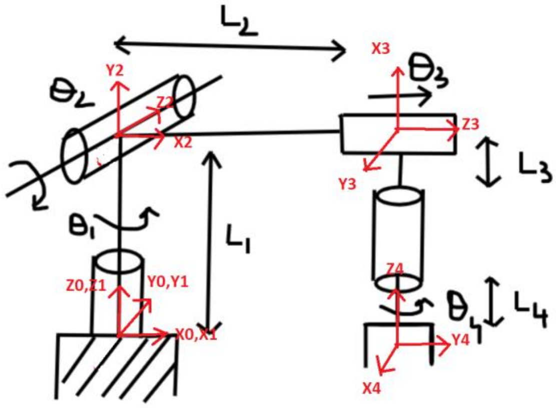


Robot manipulators can also be classified according to their nature of motion in planar, spherical and spatial [1]. Robots can also be classified by control method into servo (closed loop control) and non-servo (open loop control) robots. Servo controlled robots are further classified according to the method that the controller uses to guide the end-effector. Non-servo robots are essentially open-loop devices whose movement is limited to predetermined mechanical stops, and they are primarily used for materials transfer [9].

III. DESIGN

Four degrees of freedom are designed into the robot arm in Figure 3. It also features a prismatic joint in addition to the revolute joints. For wrist movement, it was chosen to employ a servo motor with one degree of freedom. Due to restrictions like carrying capacity, the manufacturing materials may vary.

Figure 3 : RRPR Robot arrangement with frames



Kinematics is the science of motion that treats the subject without regard to the forces that cause it. Within the science of kinematics, one studies the position, the velocity, the acceleration, and all higher order derivatives of the position variables (with respect to time or any other variable(s)). Hence, the study of the kinematics of manipulators refers to all the geometrical and time-based properties of the motion [4].

IV. KINEMATIC ANALYSIS

Forward Kinematics :

Table 1 displays the link parameters of the planned manipulator in Denavit-Hartenberg notation.

i	ai-1	αi-1	di	Φi-1
1	0	0	0	0
2	0	-90	L1	θ2
3	0	-90	L2+θ3	90
4	0	90	L3	0

The forward or direct kinematics is the transformation of kinematic information from the robot joint variable space to the Cartesian coordinate space. Finding the end-effector position and orientation for a given set of joint variables is the main problem in forward kinematics. This problem can be solved by determining transformation matrices to describe the kinematic information of link (i) in the base link coordinate frame. Hence, the forward kinematics is basically transformation matrix manipulation [9]. By using the parameters on Table 1, the transformation matrices

$$ {}^{0}_{4}T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & P_x \\ r_{21} & r_{22} & r_{23} & P_y \\ r_{31} & r_{32} & r_{33} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T $$

$$ T_{04} = T_{01}T_{12}T_{23}T_{34} \quad T_{04} = \begin{bmatrix} 0 & -\sin\theta_2 & \cos\theta_2 & L_3\cos\theta_2-(L_2+\theta_3)\sin\theta_2 \\ -1 & 0 & 0 & L_1 \\ 0 & -\cos\theta_2 & -\sin\theta_2 & -L_3\sin\theta_2-(L_2+\theta_3)\cos\theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Inverse Kinematics:

The determination of the joint variables reduces to solving a set of nonlinear coupled algebraic equations. Although there is no standard and generally applicable method to solve the inverse kinematic problem. There are a few analytic and numerical methods to solve the problem. The main difficulty of inverse kinematic is the multiple solutions [9].

Figure 4a - Side view of RRPR configuration

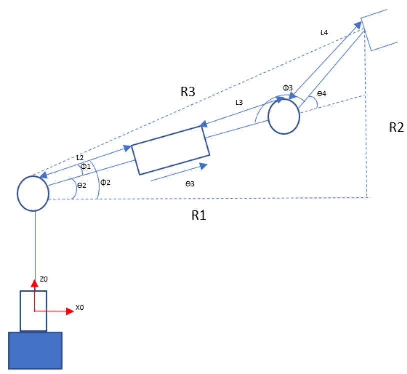
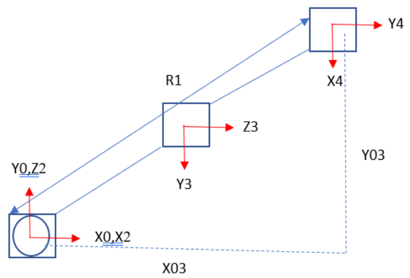


Figure 4b - Top view of RRPR configuration



The inverse Kinematics can be computed using the trigonometric formulas arrived as below :

$\varphi_2=\Theta_2+\varphi_1$ $\quad\varphi_2=\arctan(R2/R1)$

$\Theta_3=\sqrt{}(R1)^2+(R2)^2$ $\quad R2=Z_0^3-L1$

$R1=\sqrt{}(X_0^3)^2+(Y_0^3)^2$ $\quad X_0^3=\Theta_3+L2+L3$

$\Theta_3=X_0^3-L2-L3$

By Cosine Law :

$L4^2=(L2+L3+\Theta3)^2+R3^2-2R3(L2+L3+\Theta3)\mathrm{Cos}\,\varphi_1$

$\varphi_1=\mathrm{Cos}\text{-}1((L4^2-(L2+L3+\Theta_3)^2-R3^2)/-2R3(L2+L3+\Theta_3))$

$R3^2=(L2+L3+\Theta3)^2+L4^2-2L4^2(L2+L3+\Theta3)\mathrm{Cos}\,\varphi_3$

$\Phi_3=\mathrm{Cos}\text{-}1((R3^2-(L2+L3+\Theta3)^2-L4^2)/-2L4(L2+L3+\Theta_3))$

$\Theta_4=180-\Phi_3$

Velocity Analysis:

$$ {}^{0}_{1}R = \begin{bmatrix} c_1 & -s_1 & 0 \\ s_1 & c_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \Rightarrow {}^{1}_{0}R = \begin{bmatrix} c_1 & s_1 & 0 \\ -s_1 & c_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{1}_{2}R = \begin{bmatrix} c_2 & -s_2 & 0 \\ 0 & 0 & 1 \\ s_2 & c_2 & 0 \end{bmatrix} \Rightarrow {}^{2}_{1}R = \begin{bmatrix} c_2 & 0 & s_2 \\ -s_2 & 0 & c_2 \\ 0 & 1 & 0 \end{bmatrix} $$

$$ {}^{2}_{3}R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \Rightarrow {}^{3}_{2}R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{3}_{4}R = \begin{bmatrix} c_4 & -s_4 & 0 \\ s_4 & c_4 & 0 \\ 0 & 0 & 1 \end{bmatrix} \Rightarrow {}^{4}_{3}R = \begin{bmatrix} c_4 & s_4 & 0 \\ -s_4 & c_4 & 0 \\ 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{1}\omega_1 = {}^{1}_{0}R\,{}^{0}\omega_0 + \dot{\theta}_1{}^{1}z_1 = \begin{bmatrix} 0 & 0 & \dot{\theta}_1 \end{bmatrix}^T $$

$$ {}^{1}v_1 = {}^{1}_{0}R\left({}^{0}v_0 + {}^{0}\omega_0 x\,{}^{0}P_1\right) = \begin{bmatrix} 0 & 0 & 0 \end{bmatrix}^T $$

$$ {}^{2}\omega_2 = {}^{2}_{1}R\,{}^{1}\omega_1 + \dot{\theta}_2{}^{2}z_2 == \begin{bmatrix} s_2\dot{\theta}_1 & c_2\dot{\theta}_1 & \dot{\theta}_2 \end{bmatrix}^T $$

$$ {}^{2}v_2 = {}^{2}_{1}R\left({}^{1}v_1 + {}^{1}\omega_1 x\,{}^{1}P_2\right) = \begin{bmatrix} 0 & 0 & 0 \end{bmatrix}^T $$

$$ {}^{3}\omega_3 = {}^{3}_{2}R\,{}^{2}\omega_2 = \begin{bmatrix} s_2\dot{\theta}_1 & c_2\dot{\theta}_1 & \dot{\theta}_2 \end{bmatrix}^T $$

$$ {}^{3}v_3 = {}^{3}_{2}R\left({}^{2}v_2 + {}^{2}\omega_2 x\,{}^{2}P_3\right) + d_3 z_3 = \begin{bmatrix} c_2\dot{\theta}_1 d_3 \\ \dot{\theta}_2 l_2 - s_2\dot{\theta}_1 d_3 \\ d_3 - c_2\dot{\theta}_1 l_2 \end{bmatrix} $$

$$ {}^{4}\omega_4 = {}^{4}_{3}R\,{}^{3}\omega_3 + \dot{\theta}_4{}^{4}z_4 = \begin{bmatrix} s_{24}\dot{\theta}_1 & c_{24}\dot{\theta}_1 & \dot{\theta}_2 + \dot{\theta}_4 \end{bmatrix}^T $$

$$ {}^{4}v_4 = {}^{4}_{3}R\left({}^{3}v_3 + {}^{3}\omega_3 x\,{}^{3}P_4\right) + d_4 z_4 = \begin{bmatrix} c_{24}\dot{\theta}_1(l_3+d_3) + s_4\dot{\theta}_2 l_2 \\ c_4\dot{\theta}_2 l_2 - s_{24}\dot{\theta}_1(l_3+d_3) \\ d_3 - c_2\dot{\theta}_1 l_2 + l_3 \end{bmatrix} $$

Statics:

Statics is interested in how a mechanical system would function if everything were rigid and totally unmoving.It can be computed using the formula below :

$$\tau = J_s^{\mathrm{T}}(\theta)\mathcal{F}_s$$

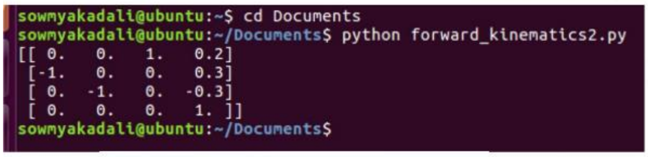
Where τ = Torque on the end effector

$J_s^T(\Theta)$ = Transpose of Jacobian matrix obtained from velocity kinematics

Fs = wrench on the end effector

V. CONCLUSIONS

In this paper, a four degrees of freedom robot arm which has linear motion ability was designed and the kinematic analysis of the robot arm were shown by using Denavit-Hartenberg notation. Calculations for forward Kinematics were performed on ROS using Python. It is tested and confirmed. Same results were obtained. Dynamic analysis of the robot arm can carry out in following works. Also mobility and perception options can be considered in following works instead of targeting a location.



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