RESEARCH PAPER | Engineering | Volume : 3 | Issue : 12 | Dec 2013 | ISSN - 2249-555X

A Study on Kinematic Analysis of 3-DOF R-R-R Type Manipulator ARM

KEYWORDS: robot, link mechanism, light weight, low cost.

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ABSTRACT *The aspect of this report entitled "Kinematics of 3-DOF R-R-R Type Manipulator Arm" is to give the brief idea about the Structure Design and Kinematics of the Manipulator Arm. Initially study has been done on the industrial robots, their applications, and the problems associated with the current robotic arms, and the work has been carried out on the solution of the problem. Literature Study has given ideas in the field of Structure design and Kinematics of linkages. 3-DOF non planer R-R-R type of manipulator is chosen for structural design and kinematic analysis. For structural design three different approaches i.e. "Combined Variable Normal Stress and Variable Shear Stress criteria, Torsional stress criteria Deflection criteria, Deflection criteria" have been used, for kinematic analysis D-H approach, has been used.*

INTRODUCTION

One of the primary objectives of robotics engineering is to design a manipulator capable of high link accelerations without sacrificing positional accuracy. Precise robotic manipulators were traditionally massive and slow whereas fast ones were light and flimsy, and affected with unwieldy end-effectors vibrations. The performance of robotic manipulators can be achieved by utilizing materials with very high stiffness-to-weight and strength to- weight ratios, minimize deflection and stress.

Concern of current robotic research has been to develop anthropomorphic (human-like) arms capable of emulating the dexterity, manipulability, and workspace volume and payload-to-weight ratio of a human arm. It would also make teleoperation in space, undersea and in hazardous environments that much easier for the human controller. The advent of composite materials, with very high stiffness-to-weight and strength-to-weight ratios as well as excellent damping properties, have made it possible for robotics engineers to build manipulators with excellent stiffness, strength, damping and low inertia.

Problems Associated with Current Robotic Arms

Most current robotic arms possess poor payload-to-weight ratios, poor damping and lack anthropomorphic manipulability and dexterity. Conventionally, to design a fast-moving arm required that the links have low inertia. Inevitably, this resulted in large end-effectors vibrations and long settling times. Conversely, to achieve high Positional accuracy required bulky, massive links. Due to the large inertia of the links, these robotic arms cannot move rapidly and require inordinate amounts of power. However, robot researchers the world over have already begun to offer many design solutions to these problems. To achieve the manipulability and dexterity of a human arm, innovative new joint mechanisms have been studied.

The study of Kinematics of manipulators and the machines, which are involves analysis of geometry of motion. Kinematic analysis is of prime importance in design of mechanisms and machines. The kinematic analysis of a mechanism constitutes the determination of the position, velocity and acceleration states of the mechanism. This study of motion involves linear as well as angular position, velocity and acceleration of different points on members of mechanisms.

Design of the Manipulator Arm:

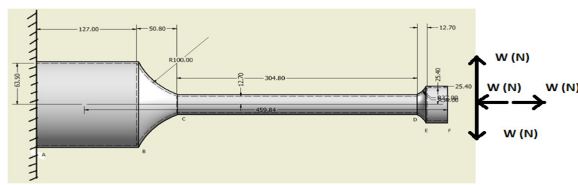

Figure1: Manipulator Arm Structure (Front View)

Consider a manipulator arm is the cantilever type of structure with payload to weight ratio 1:1with maximum deflection 1 CM. In fig.1 the structure is fixed at point A which will be attached to the robot base structure. Section AB is the hollow circular section of 3 mm thickness, which will be used to join the robot arm structure to the robot base structure. Section CD is the main arm structure which is hollow circular in cross section with 3 mm of thickness. Section EF is the hollow circular section of 3 mm thickness which will be used to fix the motor and the gripper mechanism. Further gripper will be attached to the section EF.

$$W = 0.81 \times \sigma e(N)$$

Table 1: Load calculation for the different materials:

Material	Endurance stress (N)	Calculated Load
ABS plastic	13.8	11.0 N
Acrylic	20.61	16.7 N
Al.Alloy 6061	111.11	90.0 N
Mildsteel	123.45	100 N

Kinematics of Manipulators

The structure of a manipulator is like a kinematic chain with the end-effectors at the free end. It has rigid links connected by joints such that there can be relative motion. The joints can be rotary or revolute and sliding or prismatic. At the rotary joints the motion is angular and measured in terms of joint angles. At the prismatic joint there is translational motion and is specified in units of length. The angle and length between links is measure by the position sensors attached to the joints.

Forward Kinematics

The forward kinematic analysis is to find the position and orientation of the end-effectors of the manipulator with respect to the base frame for the given set of joint parameters. For describing the position and orientation of the links, coordi-

Volume : 3 | Issue : 12 | Dec 2013 | ISSN - 2249-555X

nate frames to each of them are attached and then the position and orientation of these frames are used for specifying the links. This scheme is known as the "joint space description." The other form is called the Cartesian description. Forward kinematics is like defining the position of manipulator links in a base frame. This is done by sequential transformation of the reference frames attached to the links.

Inverse Kinematics

In the inverse kinematics problem the position and orientation of the end-effectors of the manipulator is given, and the exercise is to find the values of joint angles and displacements with which the specified position and orientation of the end-effectors can be attained. The equations formulated for solving the inverse kinematic problem are nonlinear and it's very difficult to obtain closed form solutions for that. There may be multiple solutions to the problem, and maybe any solution doesn't exist at all. The solutions of the inverse kinematic problem for manipulators are helpful to define the workspace of manipulators. If solutions exist for a point then it is in the workspace of the manipulator, and if no solution exists then the point is not in the workspace.

Position Analysis

Absolute Cartesian Method

The position analysis of a kinematic chain requires the determination of the joint positions, the position of the centers of gravity, and the angles of the links with the horizontal axis. A planar link with the end nodes A and B is considered in Fig.2 Let (x_A, y_A) be the coordinates of the joint A with respect to the reference frame xoy, and (x_B, y_B) be the coordinates of the joint B with the same reference frame. Using Pythagoras the following relation can be written

$$(X_B - X_A)^2 + (Y_B - Y_A)^2 = AB^2 = L_{AB}^2 \qquad \ldots\ldots\ldots\ldots 1.1$$

Where L_{AB} is the length of the link AB. Let Φ be the angle of the link AB with the horizontal axis Ox. Then, the slope m of the link AB is defined as

$$m = \tan\phi = \frac{Y_B - Y_A}{X_B - X_A} \qquad \ldots\ldots\ldots\ldots 1.2$$

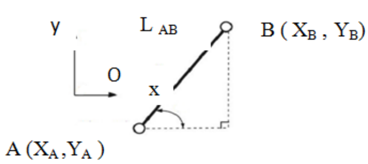

Figure.2 Planar rigid link with two nodes

Let n be the intercept of AB with the vertical axis O_y. Using the slope m and the intercept n, the Equation of the straight link, in the plane, is

$$Y = mx + n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3$$

Where x and y are the coordinates of any point on this link.6.4 Path of a Point on a Link with General Plane Motion For Fig., the path of point on a Link is calculated as the joint A is in the origin of the reference frame, that is, A=0, $X_A = 0$ and $Y_A = 0$ The coordinates of the joint B are

$X_B = ABCOS\Phi$ and $Y_B = ABSIN\Phi$ For $0^0 \le \phi \le 360^0$ The coordinates of the joint C are $X_C = X_B + BCCOS\Theta$ & $Y_C = X_B + BCSIN\Theta$ for$0^0 \le \Theta \le 360^0$

Algorithm for the Kinematics

Step 1: Define the reference point, angle of rotation of each link, length of each link.

Step 2: Calculate position vector for reference point r_0

Step 3: Calculate the Transformation Matrix for each Link $T_1, T_2, T_3 \ldots\ldots\ldots\ldots T_n$

Step 4: Calculate the pc⁻ⁱᵗion vectors of each link $T_1 r_0, T_1 T_2 r_0, \ldots\ldots\ldots$üüüü $T_n r_0$

Step 5: Calculate relative angular velocities $\omega_i = \frac{d\sum_1^n \theta_i}{dt}$ and relative angular acceleration $\alpha_i = \frac{d^2\sum_1^n \theta_i}{dt^2}$

Step 6: Calculate relative linear velocities $V_i = \frac{dr}{dt} = \omega_i \times r_i$ and relative linear acceleration $a_i = \frac{d^2 r}{dt^2} = \alpha_i \times r_i$

Kinematics Analysis Formulation for 3-DOF 4-Link RRR Type manipulator

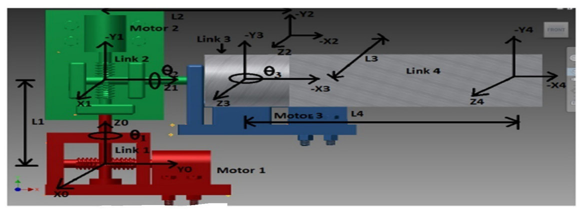

Figure.3 Frame assignment for 3-DOF R-R-R Type Manipulator Arm

The manipulator is shown in the Fig. 4, assumes that all the four links, Link 1, Link 2, Link 3,And Link 4 are cylinder with mass m1,m2,m3,m4 respectively at their desired end and link 4 is Rigidly connected with link 3. Link 1, 2, 3, 4 can rotate by angle θ1, θ2, θ3 respectively. Link 4 is rigidly attached with the Link 3, so for the θ3 degree angle of rotation for Link 3, the Link 4 will automatically gets rotated by θ3 degree So,θ3=θ4 Link4 will act as a anthropomorphic arm will be having a gyroscopic motion with help of the rotation of the link 1, 2, and 3. End point of the Link 4 could be connected with the gripper to grip the object or to perform the scheduled task.

Denavit-Hartenberg (D-H) Parameters:

Table.2 (D-H) parameters

i	Θ_i	D_i	a_i	α_i	C_Θ	$S\Theta_i$	$C\alpha_i$	$S\alpha_i$
1	Θ_1	L_1	0	-90	C_1	S_1	0	-1
2	Θ_2 - 90	L_2	0	-90	S_2	$-C_2$	0	-1
3	Θ_3	L_3	0	0	C_3	S_3	1	0
4	0	0	$-L_4$	0	1	0	1	0

By using (D-H) convention, the transformation matrices for different locations result in Transformation Matrices.

CONCLUSION:

Methods and techniques of analysis and synthesis of mechanisms necessary to find the position, Velocity and acceleration of end point of link during rotation are discussed. Then, the knowledge will be summarized in preparing algorithm for calculation of kinematic parameters, which was used to derive the kinematic parameters for 3-DOF 4-link RRR type Manipulator Arm using the knowledge of D-H approach. This formulation is used to prepare a MATLAB program for calculation of Torque.

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