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Modular Robotic Arm

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Abstract - *The flexibility and control of a robotic arm has been a challenge since earlier days of robots. K.H.Wurst developed the first Reconfigurable modular robots in the context of manipulator arms. P.K. Khosla developed a system which combines the flexibility of reconfigurable modular hardware with modular programming tools, allowing the users to rapidly create a manipulator which is custom-tailored for a given task. In the present paper, kinematic homogenous 4X4 matrix calculation is used to control the 3-axes modular robotic arm. With this approach it is possible to develop algorithms for controlling movements. Actual robotic arm has been designed using INVENTOR modelling software. Joints are moved using DC servo motors and the end effector is positioned using a pneumatic cylinder which is actuated using a solenoid valve with flow control valve to adjust the stroke speed. Arduino is used for controlling the robotic arm. The testing was carried out on a Jominy End Quench Apparatus and it was observed that the robot was working appropriately.*

Key Words: Modular robotic arm, Kinematic modelling, Jominy End Quench Test

1. INTRODUCTION

Today's industry's focus is to minimize human intervention in handling critical environmental applications. With so much advancement and research works carried out across the world, this dream can be absolutely made into reality in the age of automation with the current technology. Pick and place robots are able to provide solutions in many applications.

Among the earlier work on this area, K.H.Wurst [1] developed the first Reconfigurable modular robots in the context of manipulator arms. He pointed out that, in the selection of robots in production environments, an optimal robotic device can seldom be reached and in most cases one has to make a compromise between selected robots and factors such as working range, speed, load and rigidity. P.K. Khosla [2] developed a system which combines the flexibility of reconfigurable modular hardware with modular programming tools, allowing the users to rapidly create a manipulator which is custom-tailored for a given task. The central building block of a rapidly deployable system is a Reconfiguration Modular Manipulator System (RMMS). Y. Koga and J.C. Latombe [3] proposed a practical planner for PUMA arms manipulating an object using a predefined set of grasps. More recent work addressed a similar problem for the case of dual-arm manipulation with regrasping for a humanoid robot by N. Vahrenkamp [4].

In the present study, 3-DOF manipulator is designed and analyzed in order to gain an in depth understanding of positioning issues and solving with the use of kinematic modeling method. A 3-DOF modular robot is designed which uses 4x4 homogenous matrix to solve the position and orientation of end-effector from base. Position here, refers to position control in space of end-effector of robot arm of last link or base. The designed 3-DOF robot arm consists of 3 axes to generate arbitrary position in a specified space and last link is needed to handle the object. The end effector is positioned using a pneumatic cylinder which is actuated using a solenoid valve with flow control valve to adjust the stroke speed. This robotic arm is designed in INVENTOR software and MATLAB software is used for simulating the links. The fabrication is done by two high torque DC servo motors for joints moments and they are connected through the steel pipes. Arduino is used for controlling all DC servos.

The paper is organized as follows, in section 2 & 3, a brief description about kinematic analysis is given. In section 4, a brief discussion about design criteria of 3-dof robotic arm is given and Section 5, 6 & 7 represents simulation, testing and conclusion.

2. KINEMATIC ANALYSIS ALGORITHM

Robotic arm kinematics deals with the analytical study of geometric motion of robotic arm from fixed reference of coordinate system as a function of time [5] . 3-DOF Modular robotic arm is designed by inverse kinematic analysis methods. Direct kinematics usually refers to home position of geometric link parameters. It is used to find the position and orientation of end effector. Inverse kinematics usually refers to position and orientation of end effector. It helps to find joint variables to archive correct position of source location part [6]. The relationship between direct and inverse kinematics problem is shown in Figure 1 with the help of simple block diagram.

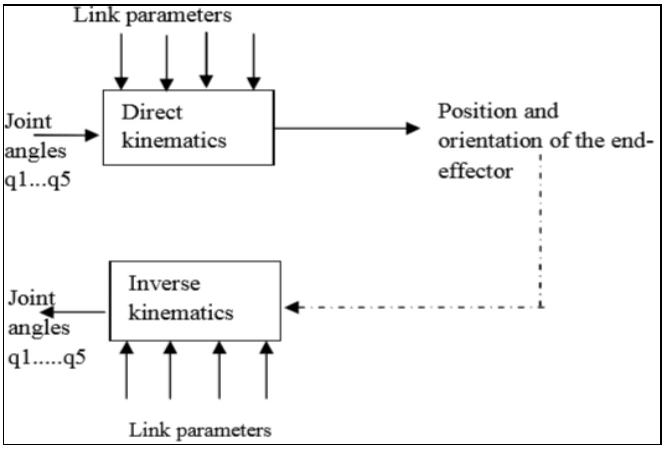

Fig -1: Direct and Inverse kinematics problem [7]

3. INVERSE KINEMATIC ANALYSIS

The first step in the present study involved reviewing and understanding the configuration of a robotic arm. The details of forward and inverse kinematics for precise positioning of the end effector were studied. By using Denavit-Hartenberg (D-H) [5] inverse kinematics, the solution for the required configuration is obtained. The D-H parameters are shown in table 1.

Table -1: Parameters of Robotic Arm

i	a_i	α_i	d_i	θ_i
1	0	–90	d_1	θ_1
2	a_2	0	d_2	θ_2
3	a_3	0	d_3	θ_3

where,

θ_i = angle between x_i and x_{i-1} along z_{i-1} axis.

d_i = distance between x_i and x_{i-1} along z_{i-1} axis.

a_i = distance between z_i and z_{i-1}.

α_i = angle between z_i and z_{i-1}.

Global co-ordinate axis is set at the ground and with respect to that the other co-ordinate axes are set and from those co-ordinate axes the required parameter which describes the position and orientation of the end effector is obtained.

General representation of the local co-ordinate axis with respect to global co-ordinate axis is as shown in equation (1)

$$\left[T^{G}_{L}\right] = \begin{bmatrix} \cos\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i \cos\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i C\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Global co-ordinate axis is set at the ground and with respect to that the other co-ordinate axes are set and from those co-ordinate axes we get the required parameter which describes the position and orientation of the end effector.

Transformation is given by the following matrix multiplication and generally represented as follow,

$$T_2^0 = T_1^0\, T_2^1 = \begin{bmatrix} n_x & S_x & a_x & P_x \\ n_y & S_y & a_y & P_y \\ n_z & S_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

where,

$$\begin{Bmatrix} n_x & S_x & a_x \\ n_y & S_y & a_y \\ n_z & S_z & a_z \end{Bmatrix} = \text{rotational element}$$

and,

$$\begin{Bmatrix} P_x \\ P_y \\ P_z \end{Bmatrix} = \text{elements of positional vector}$$

Local Co-ordinate frame 1 with respect to global frame 0 is obtained by substituting the parameters of table 1 in equation 1, the matrix for T_1^0, T_2^1 obtained are as given below,

$$T_1^0 = \begin{bmatrix} \cos\theta_1 & 0 & -\sin\theta_1 & 0 \\ \sin\theta_1 & 0 & \cos\theta_1 & 0 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_2^1 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & a_2\cos\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & a_2\sin\theta_2 \\ 0 & 0 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Substituting the obtained values of T_1^0, T_2^1 in equation 2 we get,

$$T_2^0 = \begin{bmatrix} C_1C_2 & -C_1S_2 & 0 & a_2C_1C_2 - d_2S_1 \\ -S_1S_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Comparing Matrix (3) with the general Matrix (2), we get

$$n_x = C_1C_2$$
$$n_y = -S_1S_2$$
$$n_z = 0$$
$$S_x = -C_1S_2$$
$$S_y = 0$$
$$S_z = 0$$
$$a_x = 0$$
$$a_y = 0$$
$$a_z = 0$$
$$P_x = a_2C_1C_2 - d_2S_1$$
$$P_y = 0$$
$$P_z = 0$$

where,

$$C_i = \cos\theta_i$$
$$S_i = \sin\theta_i$$
$$S_{ij} = \sin(\theta_i + \theta_j)$$
$$C_{ij} = \cos(\theta_i + \theta_j)$$

Modelling equations can be used to find the position and orientation of robot arm by giving the value of joint variables and geometric link parameters.

In order to control the position and orientation of end-effector of a robot arm to reach its object, the inverse kinematics solution is more important [7]. In this project, inverse kinematics problem is solved by geometric approach method. This method provides more insight into solving simple manipulators with rotatory joints [5].

4. DESIGN SPECIFICATIONS OF 3-DOF ROBOTIC ARM

The presented mechanical design of robot consists of 2 links i.e., base, elbow. Gripper is connected at the end of elbow. Through the elbow, a pneumatic cylinder is fitted which has a 25 cm stroke length. This is actuated using a solenoid valve with flow control to have a desired speed of the forward and return stroke. The elbow is provided with a motor block assembly as shown in Figure 2. These motor assemblies are connected to each other through steel rods. This forms the whole assembly of a robotic arm as shown in Figure 3.

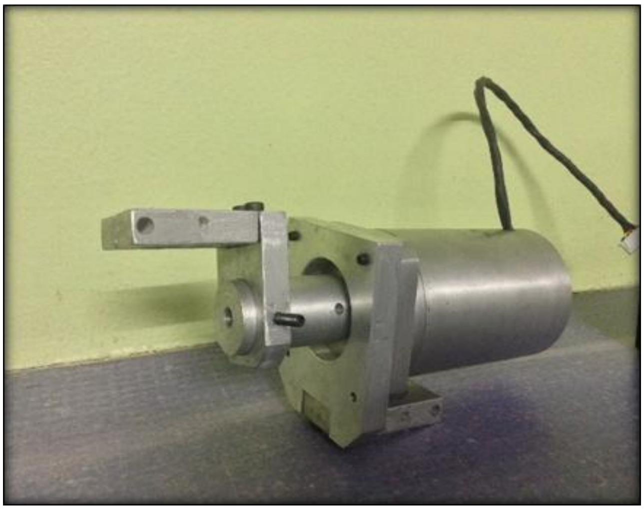

Fig -2: Assembly of the motor block

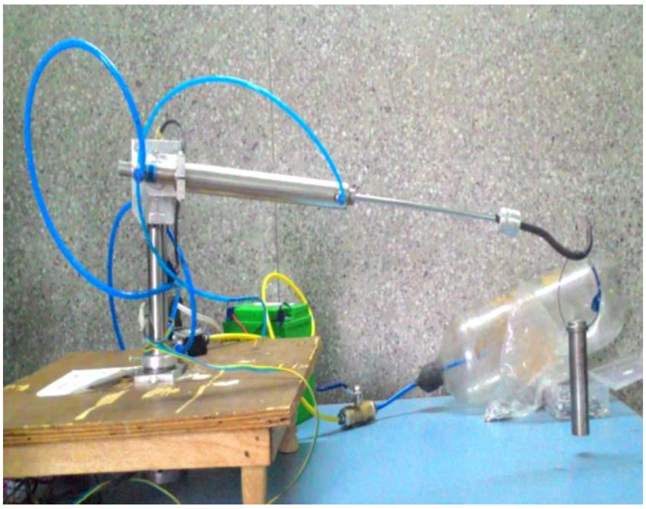

Fig -3: Fully assembled robotic arm

A Servo motor is a geared DC motor with encoder that allows rotor to be positioned accurately. Internally, a servo consists of DC motor and control circuit. The control circuitry compares an angular position, determined by a control signal, to the current position of the motor shaft. This DC servo motors are used to move the joints of robotic arm to achieve the desired position. The actuation of the motor is achieved through Arduino.

5. CONTROL SOFTWARE

The robotic arm is controlled using Matlab software. A GUI designed in Matlab computes the required angles of each joint using inverse kinematics. The computed values are sent to the Arduino MEGA 2560 microcontroller which then relay the information to the motors. The communication between Matlab and Arduino is done using serial protocol via USB. The different components of the Matlab GUI is shown in Figure 4.

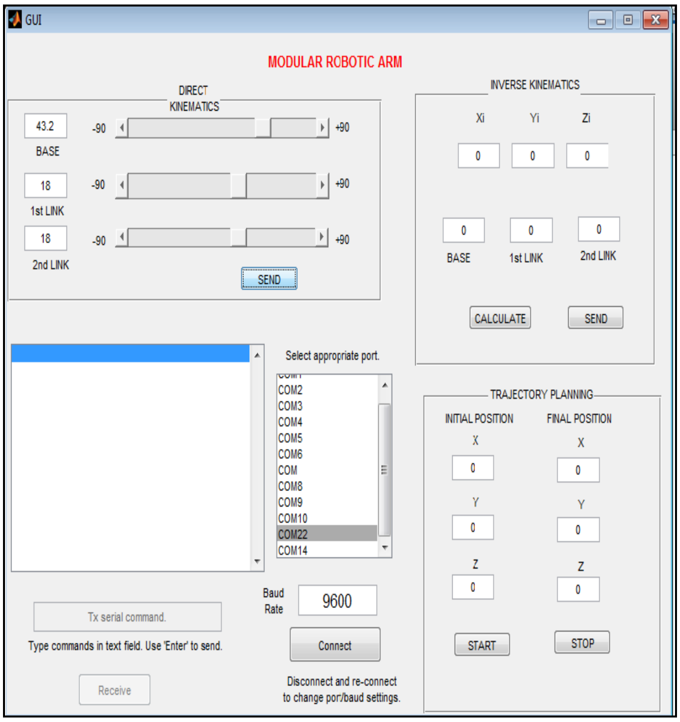

Fig -4: Matlab GUI

6. TESTING

Fig -5: Jominy End Quench Setup

The fabricated 3-DOF modular robot arm is introduced for real time handling of hot work piece in heat treatment operation (i.e., for Jominy End Quench test) and it controls the pick and place task during the testing. MATLAB interfacing with the robotic arm provides ease of operation in picking up the object.

7. CONCLUSIONS

In the present study, we have suggested a modular robotic arm which is easy to assemble and has low cost. This robotic arm that can be used in a collaborative environment working alongside human operator because of its light construction. The main objective of the project was to automate manual operation of object handling. This was achieved through the interfacing of robotic arm with MATLAB software. GUI is developed in MATLAB which calculates the link angles using inverse kinematics principle. Arduino MEGA 2560 is used which takes these link angles from GUI and actuates the motors.

The testing was carried out on a Jominy End Quench Apparatus and it was observed that the robot was working appropriately. The application of this robotic arm can be extended to pick and place any object whose weight is below 0.4 kg within a distance of 0.5 m from the base motor.

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