Paper ID: AM-16

Modeling of a 5R Robotic Manipulating System with 5DoF using GUI MatLab Simulation

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Abstract

This paper focuses on a planner robotic arm system having 5 revolute joints and 5 degrees of freedom. It provides an innovative mechanical design of a robotic arm. The designed model is a small special robotic arm which is simulated to check each of the revolute joints. The aim of the robotic arm is to analyze the performance of the joints. The position and orientation of the end effector of the arm with respect to its base so that it can be used in industrial pick and place applications are also examined. The simulation model and is designed and simulated using SolidWorks and Matlab. The implemented model of the arm has four electric servo motors to establish the movement of the rotary joints and the gripper. Arduino Mega is used as the controller. The implemented robotic hand is able to detect basic three colors: green, red and blue, using color sensors and store objects according to their color.

Keywords: Revolute joints, 5DoF Robotic Arm, 5R Robot.

1. Introduction

Robots play an important role in the present world to make the people works ease and comfortable by performing complex task within limited time. The demand of industrial robots throughout the world is increasing due the low lost and high accuracy [1]. Reproduction of human mechanical hands with upgraded abilities is one of the major concerns now-a-days. The main goal is to balance the grabbing, speed and power of a robitic arm and thereby to provide a robust and cost effective solution [2].

The applicability of the robotic arms increases with the increase of degree of freedom that indicates the maximum directions of motion of this hand. A 2DOF robot has maximum two directions alone X- and Y-direction. A robot having high degree of freedom is more suitable for the industrial application because it provides high accuracy and reliability [3].

A 5R robot with 5 degrees of freedom is generally well suited for industrial pick and place operations. Simulating a robot prior to make in real is very useful because simulations are easier to setup, less expensive, more convenient [4]. Researches and works on robotic arms have been going on for many years. A 2-R robots modeling and simulation has been proposed in [4], [5]. The design of multi spindle drilling redundant SCARA (Selective Compliance Articulated Robot Arm) robot has been done using forward and inverse kinematics for pick and place task. Two revolute joints of this robot reduce the degree of freedom that is the main limitations of this paper. The design of 2R, 3R and 4R robotic arms are presented in [6], [7]. The modeling of the kinematics of these robotic arms is done based on Denavit-Hartenberg (DH) convention with exponential formula (EF). Low degree of freedom and motion restriction are the limitations of these robots.

Our main objective is to design a robotic arm in SolidWorks and then simulate the path of the robotic arm with MATLAB/SimMechanics Link. The simulation will show how the arm will move in real world as an animation. Simplicity is maintained in the design and simulation process so that it can be understood by every kind of people as uses of robotic arm is not only for engineers but for different kinds of people. Our designed robotic hand will be the best for applying in those industries because this robotic hand has a smooth movement in 5 directions. The simulation shows each movement individually.

2. Mathematical Model

Forward kinematics

Kinematics scheme
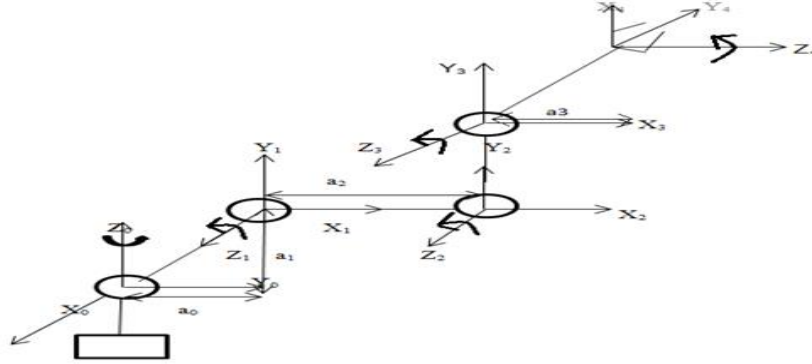By applying DH frame rules the kinematic model stands as in the figure.

Fig 1: Kinematic scheme.

DH parameter table
The DH parameter table has two translational and two rotational quantities. The translational or displacement quantities are d and r. The rotational quantities are Θ and α.

Θ is the angle of rotation if z_{n-1} is stationary and the (n-1) frame has to rotate to match x_n with x_{n-1}.

α is the angle of rotation if x_n is stationary and frame (n-1) has to rotate to match z_{n-1} with z_n.

r is the central displacement of (n-1) and n, only at the direction of x_n.

d is the central displacement of (n-1) and n, only at the direction of z_{n-1}.

Table 1: Denavit-Hartenberg parameter table

DH Table				
n	Θ	α	r	d
1	$90+\Theta_1$	90	a_0	a_1
2	Θ_2	0	a_2	0
3	Θ_3	0	0	0
4	$90+\Theta_4$	-90	0	0

HT matrics
The homogeneous transformation matrix is a 4×4 matrix [8] which has 3×3 rotational matrix, 3×1 position matrix and a row [0 0 0 1] is added with it. The [0 0 0] is perspective factor which is necessary to represent three dimensional object into other coordinate system. 1 is the scaling factor, which scales or multiplies some quantities. Here the C and S denotes cosine and sine respectively.

$$H_n^{n-1} = \begin{bmatrix} C(\theta_n) & -S(\theta_n)C(\alpha_n) & S(\theta_n)S(\alpha_n) & r_nC(\theta_n) \\ S(\theta_n) & C(\theta_n)C(\alpha_n) & -C(\theta_n)S((\alpha_n) & r_n(\theta_n) \\ 0 & S(\alpha_n) & C(\alpha_n) & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

Matrics calculation:
By following the standard form of homogeneous transformation matrix, each matrix is got from its previous frame to associated frame. We could get the $H^0{}_1, H^1{}_2, H^2{}_3, H^3{}_4$ in this way. To get the final transformation matrix from frame 0 to frame 4, the all previous matrices have to be multiplied. Thus we could get $H^0{}_4$.

$$H_1^0 = \begin{bmatrix} C(90+\theta_1) & 0 & S(90+\theta_1) & a_0C(90+\theta_1) \\ S(90+\theta_1) & 0 & -C(90+\theta_1) & a_0S(90+\theta_1) \\ 0 & 1 & 0 & a_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_2^1 = \begin{bmatrix} C(\theta_2) & -S(\theta_2) & 0 & a_2C(\theta_2) \\ S(\theta_2) & C(\theta_2) & 0 & a_2S(\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H_3^2 = \begin{bmatrix} C(\theta_3) & -S(\theta_3) & 0 & 0 \\ S(\theta_3) & C(\theta_3) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_4^3 = \begin{bmatrix} C(\theta_4) & 0 & -S(\theta_4) & 0 \\ S(\theta_4) & 0 & C(\theta_4) & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H_4^0 = H_1^0 H_2^1 H_3^2 H_4^3$$

$$r_p^0 = H_4^0 r_p^4 = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix} X \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} r_{14} \\ r_{24} \\ r_{34} \\ r_{44} \end{bmatrix}$$

(2)

The next step is to get the position of the final frame with respect to the initial frame. To get this the position of the end effector with respect to the initial point, the matrix has to be multiplied with the position matrix. .
The multiplication results actually d_x, d_y, d_z. Where $r_{14} = d_x$,
$r_{24} = d_y$, $r_{34} = d_z$ and the last element of the resulted matrix r_{44} is actually 1. So by eliminating this, the value remains unchanged.
The value of each element is stated below:

$$d_x = \cos(90+\theta_1)[a_0 \cos(\theta_2 + \theta_3) + [a_3 \cos(90+\theta_1)\cos(\theta_2 + \theta_3 + 90 + \theta_4)]$$
$$d_y = \sin(90+\theta_1)[a_0 \cos\theta_2 + a_2 \cos(\theta_2 + \theta_3) + [a_3 \sin(90+\theta_1)\cos(\theta_2 + \theta_3 + 90 + \theta_4)]$$
$$d_z = [a_1 + a_0 \sin\theta_2 + a_2 \sin(\theta_2 + \theta_3) + a_3 \sin(\theta_2 + \theta_3 + 90 + \theta_4)]$$
$$\varphi = \theta_1 + \theta_2 + \theta_3 + \theta_4$$

5. Result and Discussion
SimMechanics Link Simulation Result
To understand the movement of the rotational joints some snapshots are given:
In the proposed robotic arm model, shown in Fig. 3, the base and the 1st link is jointed with a revolute joint. The arrow sign shows how the 1st link rotates.
In Fig. 4 the revolute joint between the 1st and 2nd link is shown. The arrow sign shows the rotation of the 2nd link.
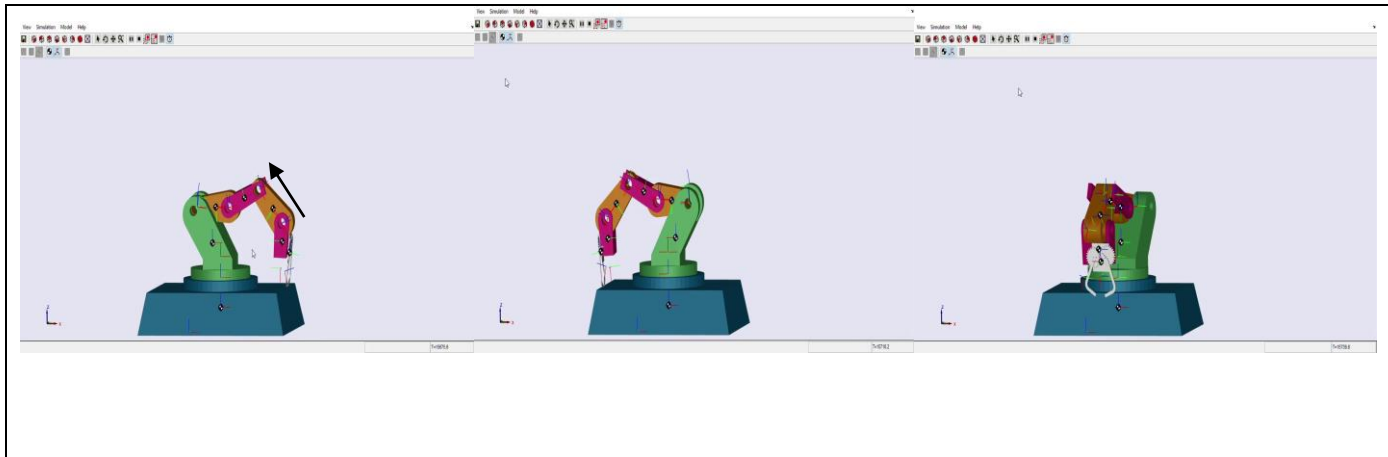

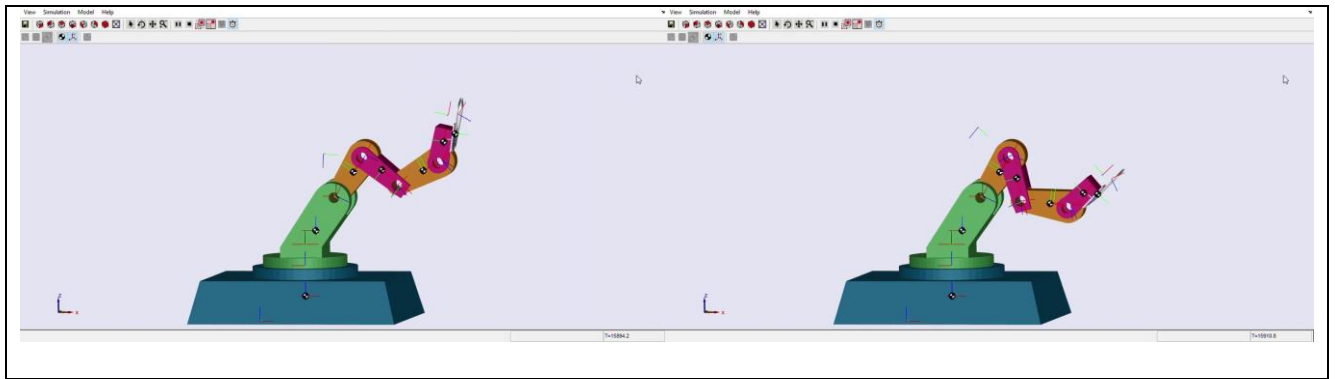Fig. 3: Rotation of the first revolute joint of the proposed robotic arm.

Fig. 4: Rotation of the third revolute joint of the proposed Robotic Arm.
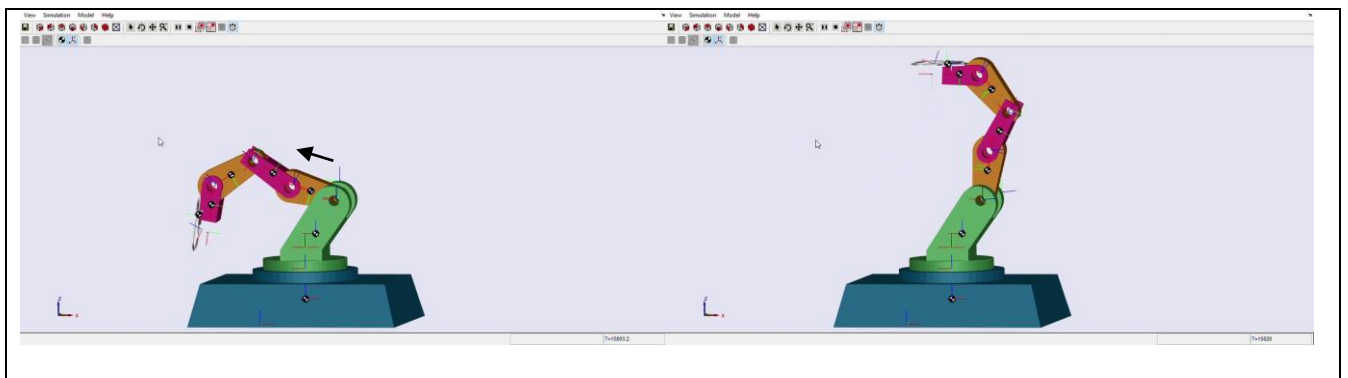

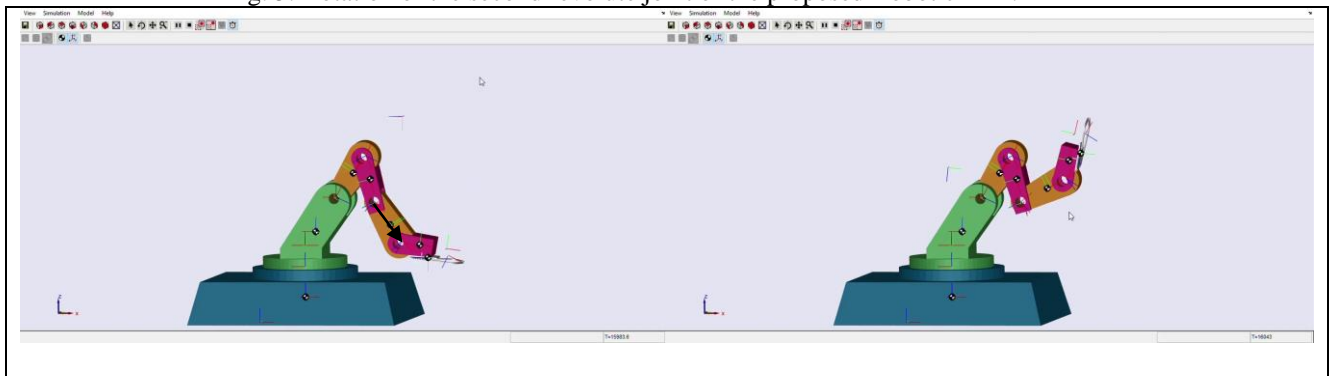Fig. 5: Rotation of the second revolute joint of the proposed Robotic Arm.

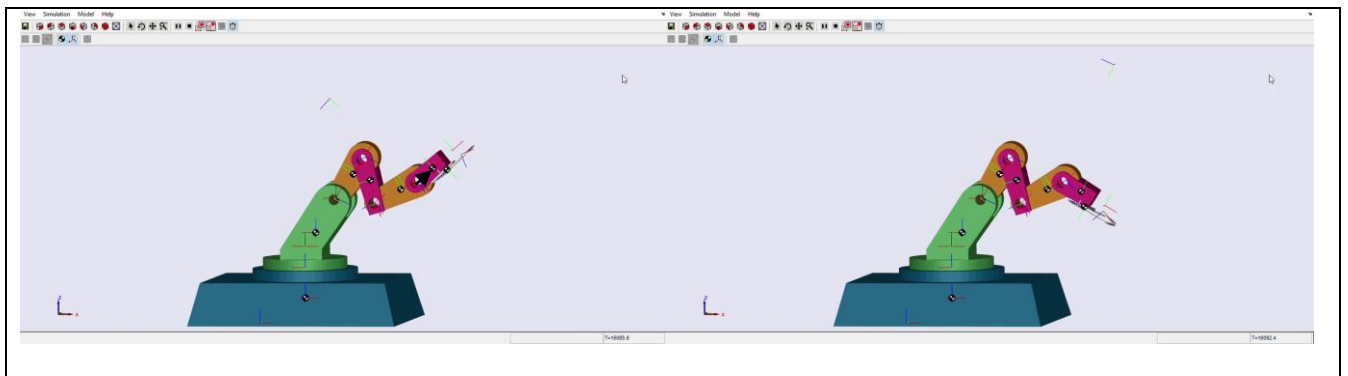Fig. 6: Rotation of the fourth revolute joint.

Fig. 7: Rotation of the fifth revolute joint of the proposed Robotic Arm.

In Fig. 5 and 6 the revolute joint between the 3rd and 4th link is shown. The arrow sign shows the rotation of the 4th link.

In Fig. 7 the revolute joint between the 4th and 5th link is shown. The arrow sign shows the rotation of the 5th link.

GUI simulation result

The name MATLAB stands for Matrix Laboratory. MatLab was originally written to provide easy access to matrix software developed by LINPACK and EISPACK projects [13]. LINPACK is for linear algebra and EISPACK is for numerical computation of eigen valued and eigen vectors of matrices. MATLAB is high performance language for technical computing. It integrates computation, visualization and programing in an easy to use environment where problem and solution are expressed as familiar mathematical notation.

The push button has to be pressed to bring the result window. A message box shows the matrix of the end effector with respect to the base frame.
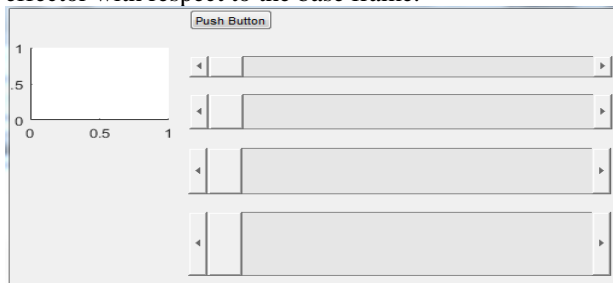

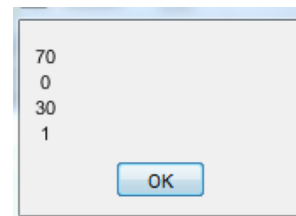Fig. 8: Home position of the GUI model   Fig. 9: Message box showing end effector position.
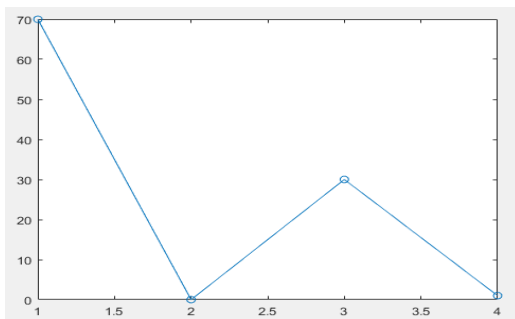

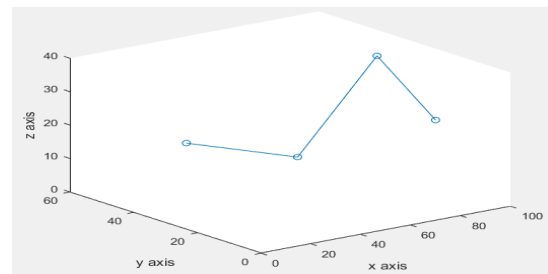Fig. 10: Robotic arm output with initial slider position.   Fig. 11: Robotic arm in 3D plotting.

The result stands for the initial position, when all of the angles are in zero position.
Our previous result was in 2D plotting system, so we make a 3D plotting for our robotic arm for better visualization.

Experimental result

The experimental model has four basic parts. All the parts are made of 2mm thick wood plastic. Each of the parts is mentioned bellow with their dimensions:

First of all, the fixed base, it is about 30×30 cm^2. It is bigger than any other parts of the arm because it holds the circuit board, the controller and the sensor. In the fixed base, there are three certain spaces, red, green and blue in color, specified for red, green and blue objects. The object should be placed in front of the sensor so that the arm can recognize the color and then gripper picks the object and put it in the certain space according to its color.

Then the rotary base which rotates about 180 degrees so that it can reach to each of the specified spaces of the fixed base stated above. This rotation helps to pick the object from the sensor face and also to put the object in the color blocks.

Then the first link of the robotic arm, it is about 4×3×11 cm^3. It bends up and down to pick or to put the objects. The second link or the forearm of the robotic arm is also about 3.5×3×10 cm^3 and it has the same duty as the first link.

Finally the most important part, it is the gripper of the robotic hand. The ending part of the second link can be considered as the wrist of the robotic. From the wrist to the tip of the gripper it is about 11 cm long. The gripper

can open up about 40 degrees which is enough to catch the objects used in this project. Fig. 4.1 shows the complete robotic arm.
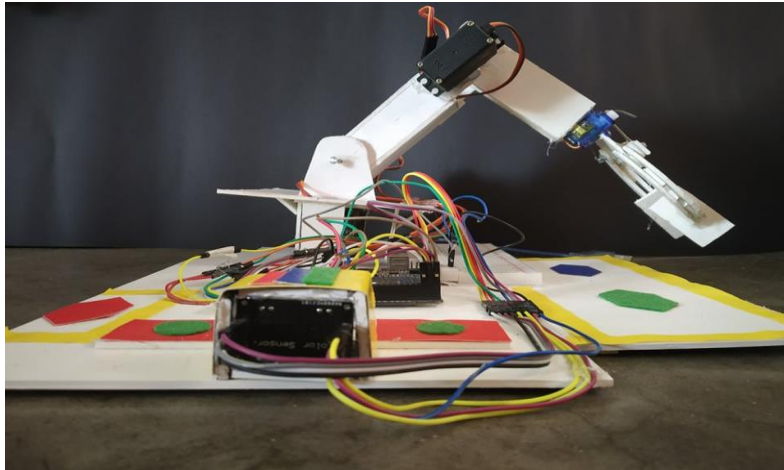

Fig. 2: Experimental Model of the Robotic Arm.

6. Conclusion

This paper contains a SolidWorks design of a 5DoF 5R robotic hand GUI interface and simulation model prepared in MatLab/SimMechanics Link. Movement of each rotational joint of the robotic hand has been shown properly. From the GUI model position and orientation of the whole robotic arm has been shown. This type of robotic hand can be implemented in industries to pick and place tools or materials very quickly and approximately. On the other hand it will create job opportunity for the trained people. So it will be very beneficial for our industries. Future work on the proposed model will evaluate the process of animating and implementing of this model so that the main framing and frame changing of the arm can be understood easily.

7. References

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