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Optimal Workspace Design of 2-DOF Parallel Manipulator

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ABSTRACT: The parallel manipulator (PM) is made up of five-bars, two prismatic joints and three revolute joints, where two prismatic joints that are attached to the base. In this paper, PM designed as lightweight manipulator to provide an alternative high-speed writing positioning mechanism to serial architecture manipulator. Lightweight mechanism is more likely to exhibit structural defection and vibrate due to the force from high-speed motion and external force from actuators. This paper proposes a new method of modeling and simulation of 2-DOF (degree-of-freedom). PM with flexible links calculated base on SolidWorks, MATLAB, $C^{\#}$ programming language. PM builds up with direct and inverse kinematic. The servo motor (Futaba-S3003) constructed under the environment of the controller (Arduino Pro-mini) to satisfy the performance requirement for making the end-effector track within the determined workspace. The determined workspaces are calculated by Geometric Analysis equations. End-effector points are shown by applying MATLAB. In additional the hardware result shows that the controller can control the movement of the robot effectively.

KEYWORDS: 2-DOF, Arduino Pro-mini, Futaba S3003, MATLAB, PM, SolidWorks.

1 INTRODUCTION

PM is the most popular form of Robotics. Nowadays, considering the promising characteristics of parallel manipulators and light weight manipulators are used to better meet the demands of high-speed and high-acceleration placement. In this field are only a few application which implements both robot and simulation control. The new approach is to have a reality over a mechanism. PM will be presented the realization of the robot from the mechanism (mechanical), electrical point of view (controller, servo motor) and via programming language increasing the performance and accuracy. It describes the parts of the mechanism drew by SolidWorks and software control of the system.

2 OPTIMAL DESIGN OF PARALLEL MANIPULATOR

2.1 MAIN IDEA OF CONSTRUCTING THE PM

Table 1 shows the input/output description of the parallel manipulator (PM). Only the inputs degrees of active joint angle (θ_1 & θ_4). The passive joint angles (θ_2 & θ_3) and end-effector position points (X_c,Y_c) can get as the output of the system. Moreover, lengths of links L_1, L_2, L_3, L_4 & L_5 must be assigned that the main idea of constructing the PM. It can have many desire parameters of link length. For example, case I, $L_1= L_2= L_3= L_4$, case II, $L_1> L_2$, $L_4> L_3$, ($L_1= L_4$), ($L_2 = L_3$), case III, $L_1< L_2$, $L_4< L_3$, ($L_1= L_4$), ($L_2 = L_3$) choice of length dimension (parameters) depend on the researcher but it is mainly effected to the systems' workspace. The choice of length parameter effects for getting the very convenient workspace. In this research, I have chosen the case II. This approach will achieve accurate solutions, yet the graphical theories allow the solutions to be visualized.[4]

Table 1. Input/output Description

No.	Name	Description
1.	θ_1 & θ_4	Input angles for the manipulator, Driving Angles, Active Joint angles
2.	θ_2 & θ_3	Getting result from calculating passive joint angles
3.	L_1, L_2, L_3, L_4 & L_5	Input Parameter of the system, Lengths of the Links
4.	X_c,Y_c	Position points of end-effector

2.1.1 KINEMATIC EQUATION NATURE

After assigning the input/output of the system, PM derives the nature of kinematic equation by case II.[1][7]

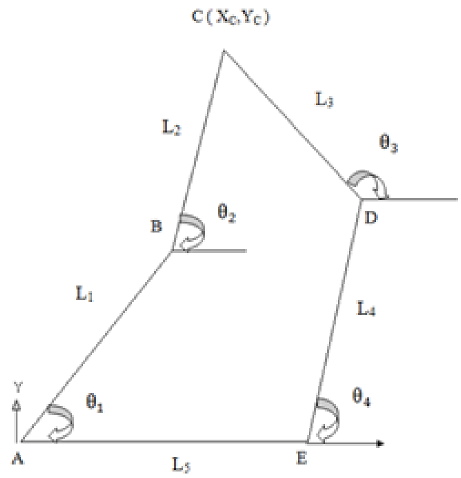


Fig. 1. Five-bar Mechanism

Case II, $L_1 > L_2$, $L_4 > L_3$, ($L_1 = L_4$), ($L_2 = L_3$)

L_1 = 18cm, L_2 = 15cm, L4 = 18cm, L_3 = 15cm, ($L_1 = L_4$), ($L_2 = L_3$)

L_5 = 22cm

According to geometric relations of mechanism, as shown in Fig. 1, it can be derived the coordinates of point C (X_c,Y_c);

$$X_C = L_1 \cos \theta_1 + L_2 \cos \theta_2 \qquad \text{Eq (1)}$$

$$Y_C = L_1 \sin \theta_1 + L_2 \sin \theta_2 \qquad \text{Eq (2)}$$

From eq (1) and (2), we need to calculate the angular point of point D's angle θ_2 & θ_3 (passive joint angles) by using following equation;

$$\theta_3 = 2 \tan^{-1} \frac{A+\sqrt{A^2+ B^2-C^2}}{B-C} = 2 \tan^{-1} \frac{D}{E} \qquad \text{Eq (3)}$$

$$A = 2L_3L_4 \sin \theta_4 - 2L_1L_3 \sin \theta_1 \qquad \text{Eq (4)}$$

$$B = 2L_3L_5 - 2L_1L_3 \cos \theta_1 + 2L_3 L_4 \cos \theta_4 \qquad \text{Eq(5)}$$

$$C = L_1^2 - L_2^2 + L_3^2 + L_4^2 + L_5^2 - 2 L_1L_4 \sin \theta_1 \sin \theta_4 \qquad \text{Eq(6)}$$

$$- 2L_1 L_5 \cos \theta_1 + 2L_4 L_5 \cos \theta_4 - 2 L_1L_4 \cos \theta_1 \cos \theta_4$$

$$\theta_2 = \sin^{-1} \left[\frac{L_3 \sin\theta_3 + L_4 \sin\theta_4 - L_1 \sin\theta_1}{L_2}\right] \qquad \text{Eq (7)}$$

Table 2. Input degrees and position point of end-effector for drawing alphabet MTU

No.	θ_1	θ_2	X_C (cm)	Y_C (cm)
1.	116	100	9.6	23.6
2.	106	114	9.9	28.2
3.	106	104	10.8	27.2
4.	104	97	12.5	28.9
5.	107	90	12.7	23.8
6.	100	83	14.8	23.9
7.	88	95	18.2	29.15
8.	93	100	13.7	29.1
9.	83	90	16.5	29
10.	95	78	16.6	24
11.	86	72	19.1	24.8
12.	74	84	18.5	29.2

2.1.2 Position Point of End-effector for MTU Alphabet

Calculating with above eq (1) to eq (6) can get the output of the system (or) position point of C (X_C, Y_C). The output of the system must situate within the workspace moreover the plot of the point can simulate with software. According to Case II, I have chosen the input angles degree to satisfy within the workspace and summarized in Table 2 and also shows the position point of end-effector.

2.2 Construction of PM Apply in SolidWorks for Optimal Design

The design of the system is drawn by CAD (Computer Aided Design) apply is SolidWorks. Additionally, the constraint-based sketching mode in solid modeling system, such as SolidWorks can be extremely useful for planar kinematic analysis. Geometric constraints, such as length, perpendicularity, and parallelism, need to be enforced when performing kinematic analysis. This SolidWorks software supports the system to see clearly the dimensions, parts and easily understand. Also, check the system error between software and hardware by using these tools. Fig. 2 to 8 show the sketch of the PM. [1][5]

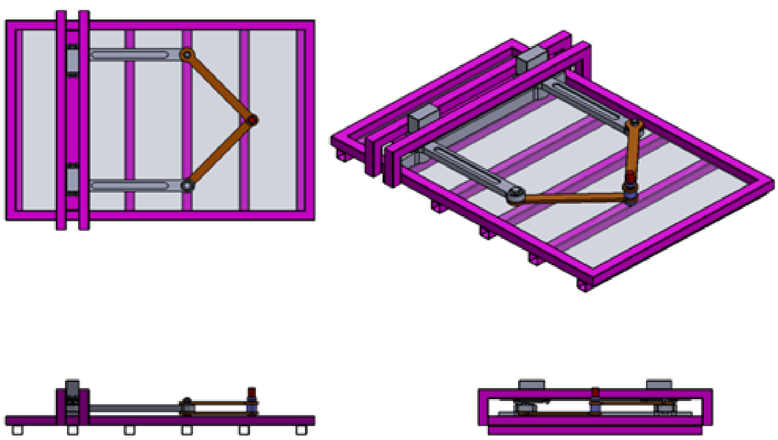


Fig. 2. Parallel Manipulator with different views

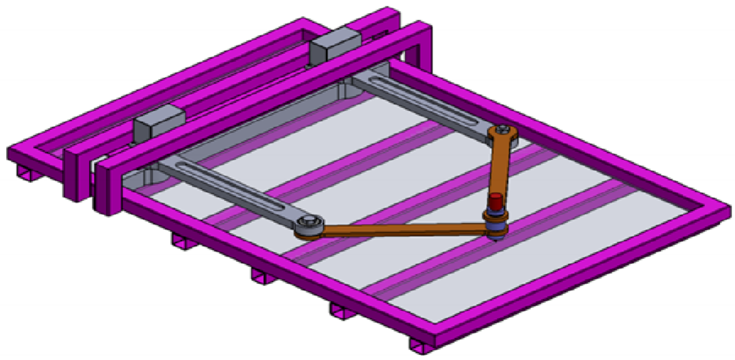
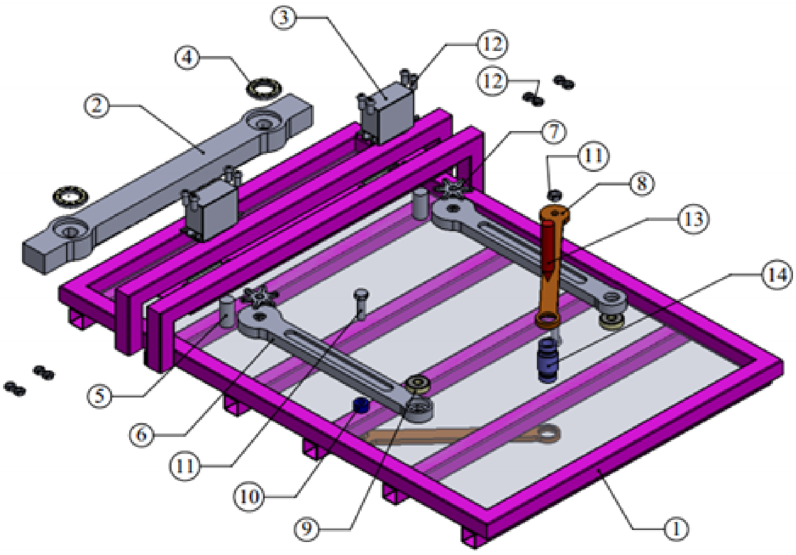


Fig. 3. Parallel Manipulator of Top View



Exploded View of Parallel Manipulator

List of Items

NO.	Names	Quantities
1.	Light Weight Frame	1
2.	Link Supportor	1
3.	Servo Motor (5V)	2
4.	Split Bearing	2
5.	Link Aligned Rod	2
6.	Link (18cm)	2
7.	Coupler	2
8.	Link (15cm)	2
9.	Ball Bearing	2
10.	Adaptor	2
11.	Bolt and Nut (6M)	2
12.	Screw and Nut (5M)	8
13.	Pencil	1
14.	Pencil Holder	1

Fig.4. Exploded View of Five-bar Mechanism and list of item

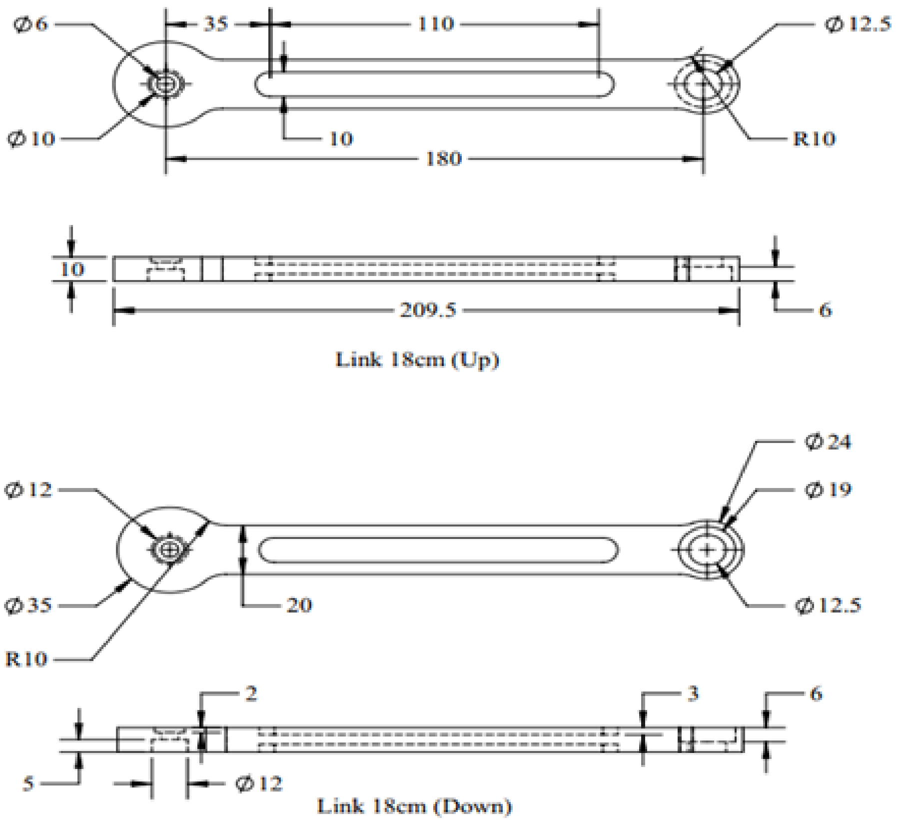


Fig. 5. Length parameter of Links L_1 and L_4

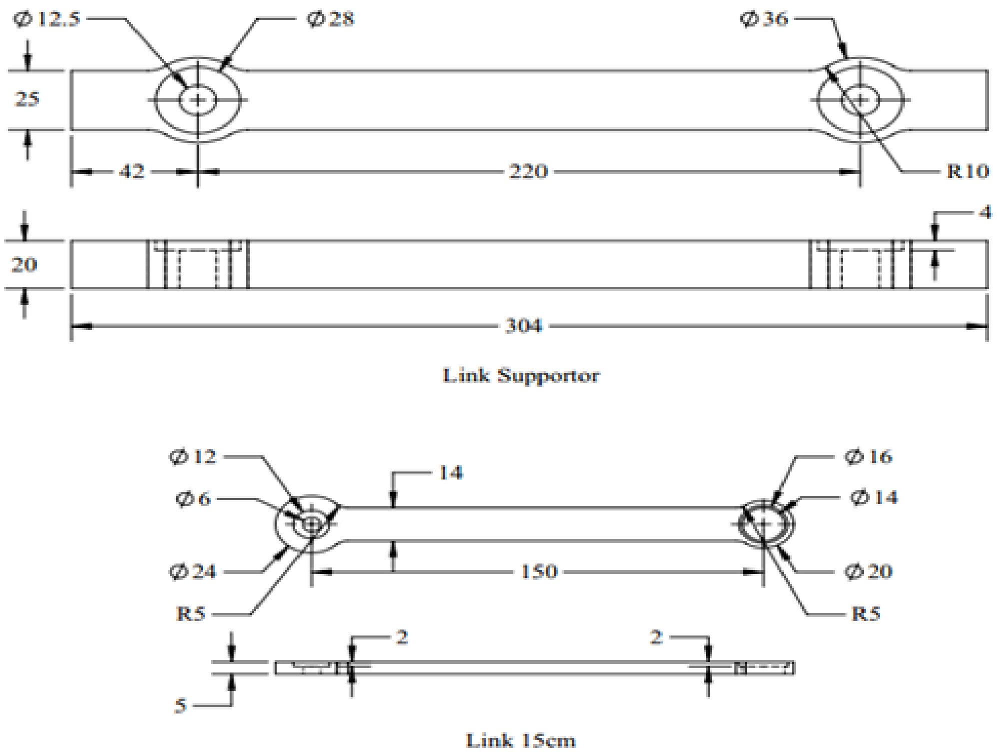


Fig. 6. Length parameter of Links L_2, $L_3$and L_5

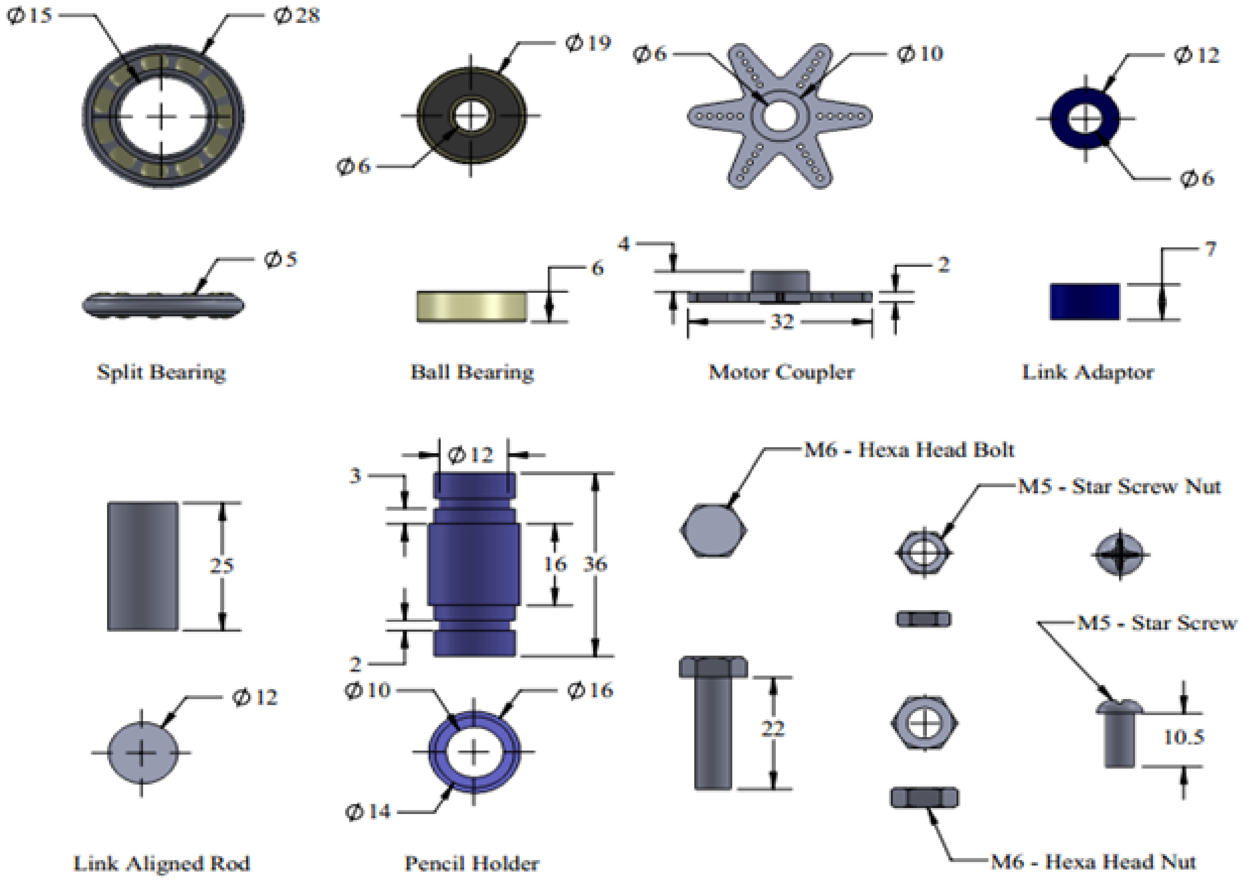


Fig. 7. Parts of the Five-bar mechanism

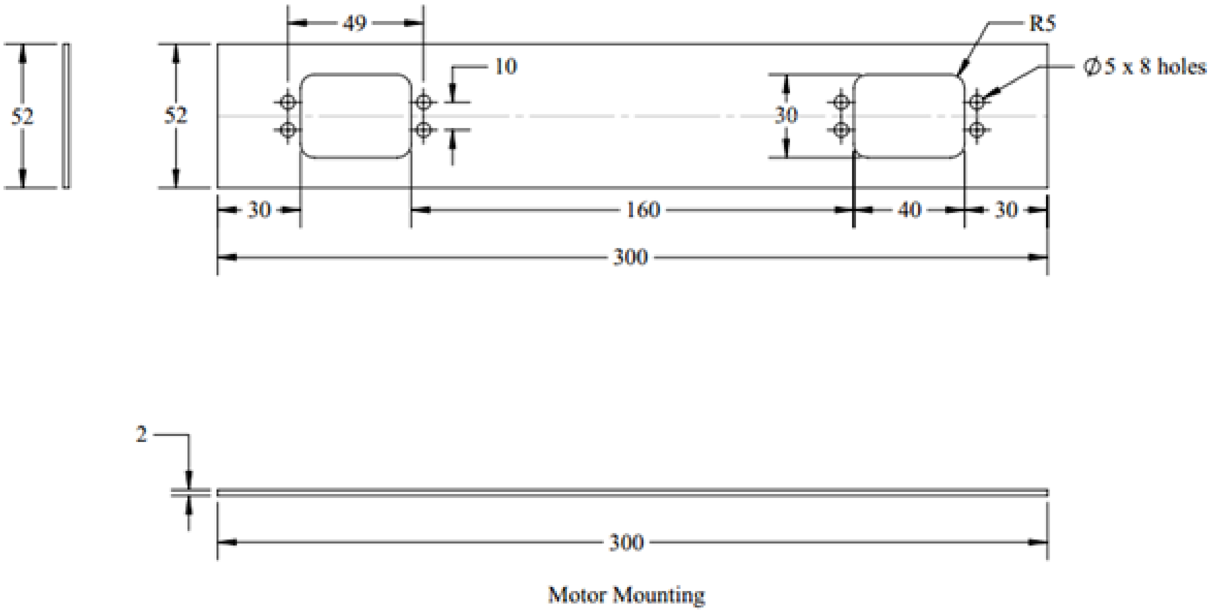


Fig. 8. Design of motor mounting with dimension

2.3 Hardware Components of the PM

2.3.1 Servo Motor (Futaba- S3003)

The following type of two servo motors uses to control the optimal design of 2-DOF PM. These two motors situate at left and right of the PM that are controlled by Arduino Pro-mini via RS-232 from Personal Computer (PC). [6] [9]

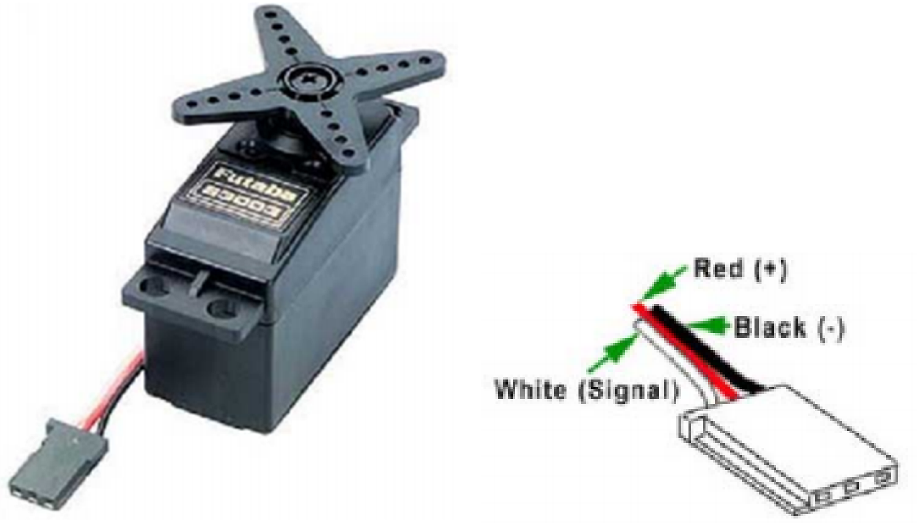


Fig. 9. Futaba-S3003

2.3.2 Optimal Design of PM

This construction of PM is optimal design because it has cost effective solution, not only to control but also to monitor the robot in real-time and realized with the simulation of the system. Also, the selected links parameters are very satisfactory for the movement within the calculated workspace.[6]

Fig. 10. Top View of the Optimal Design of the PM

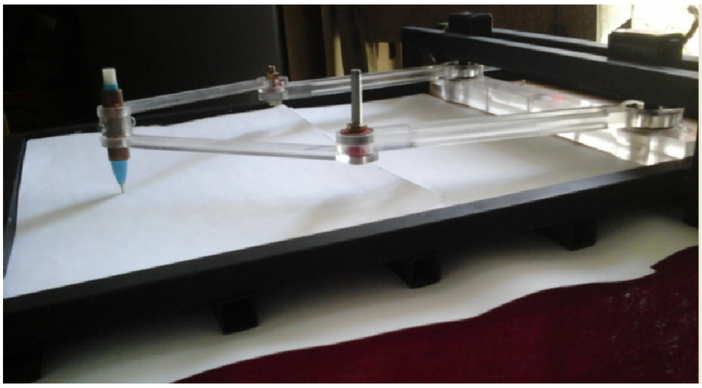


Fig. 11. Side View of the Optimal Design of the PM

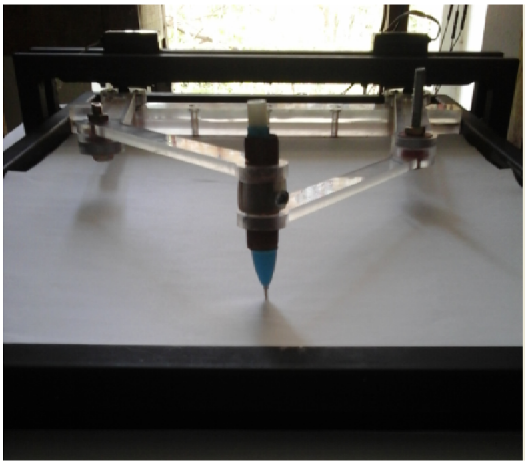


Fig. 12. Front View of the Optimal Design of the PM

2.3.3 WORKSPACE AREA OF 2-DOF PM

Fig. 13 shows the overall workspace of the PM with input angles increment 0:5:360 degree. After constructing the mechanism, it cannot get this workspace area. Fig. 14 is the optimal workspace of 2-DOF PM. The marked * is the border lines of the workspace and also inside marked * can reach this design of PM. [2] [8]

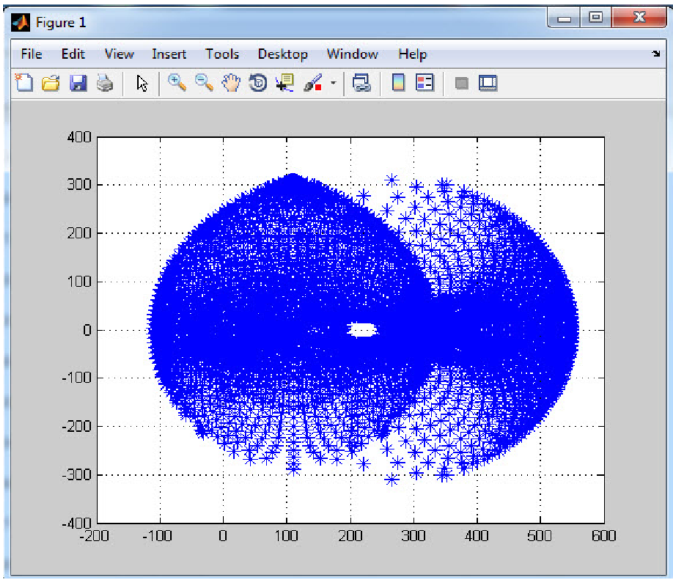


Fig. 13. Overall Workspace of the PM

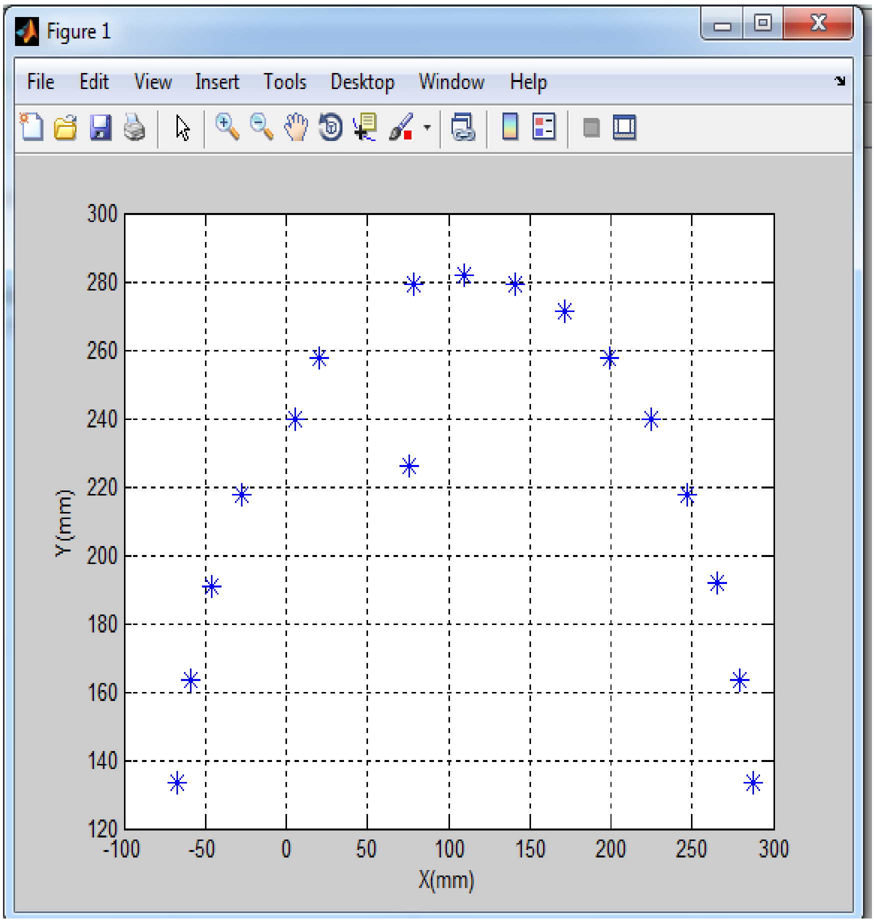


Fig. 14. Optimal Workspace of PM

3 CONTROL FOR MOTOR WITH VISUAL C#

To move the PM is firstly giving the input angles of θ_1 & θ_4. And calculating end-effector point C then using the C# programming language via the Arduino Pro-mini (motor driver) controller. Also sending this data to 5V servo motor (Futaba-S3003). Finally, fig.15 is the control tool for optimal movement of PM.

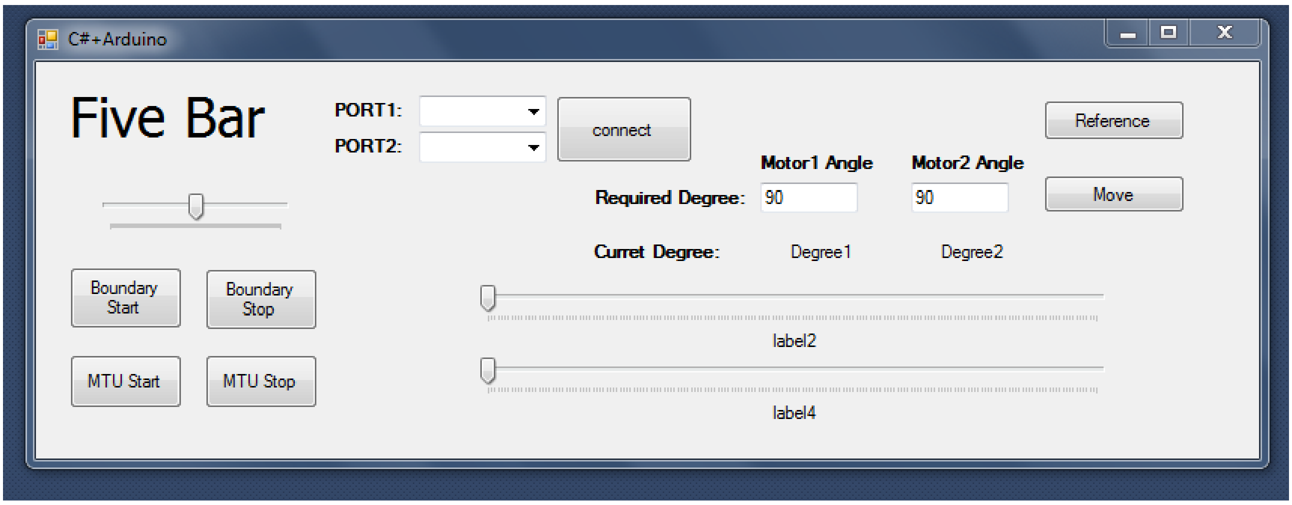


Fig. 15.Visual C# Programming Language for PM

Fig. 16 shows the trajectories planning of MTU (end-effector path of PM) by calculation apply in MATLAB software and plot the end-effector points of table 2.

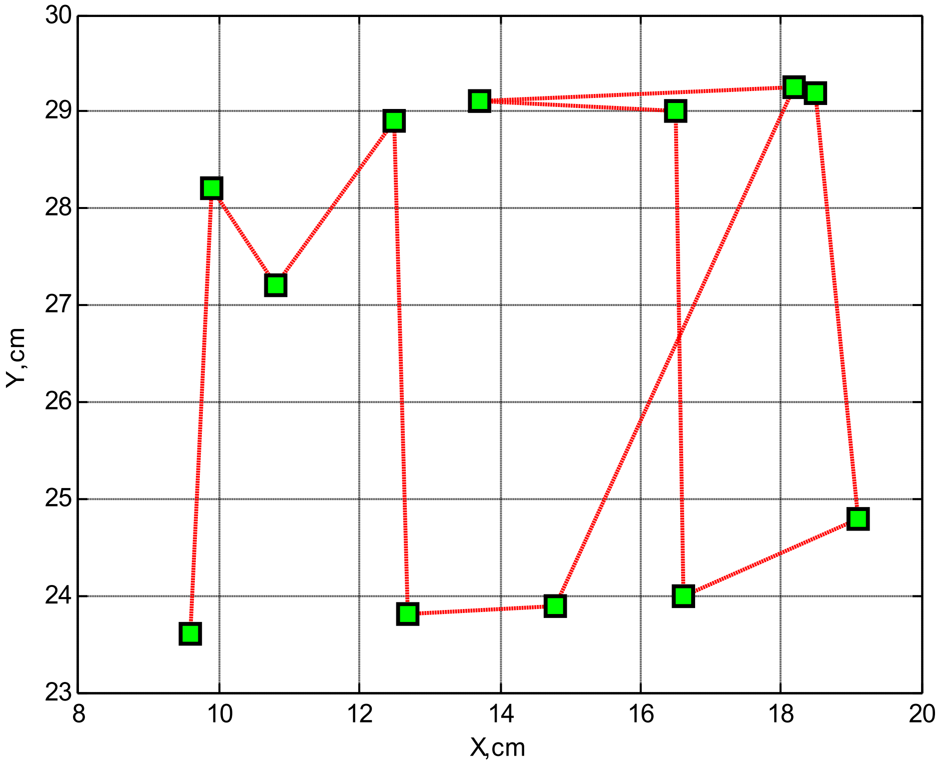


Fig. 16. Trajectory Planning of MTU

Fig. 17. Actual 2-DOF PM's Trajectory Planning of MTU

The accuracy different between calculation and actual mechanism of 2-DOF PM has 1.8cm error in end-effector path X_C. That error can get from testing of only two points and shows in Fig. 18. This error occur in this system because of the motor movement in reverse position has the dynamic effect. In my design does not consider the dynamic behavior and only consider the kinematic approach.

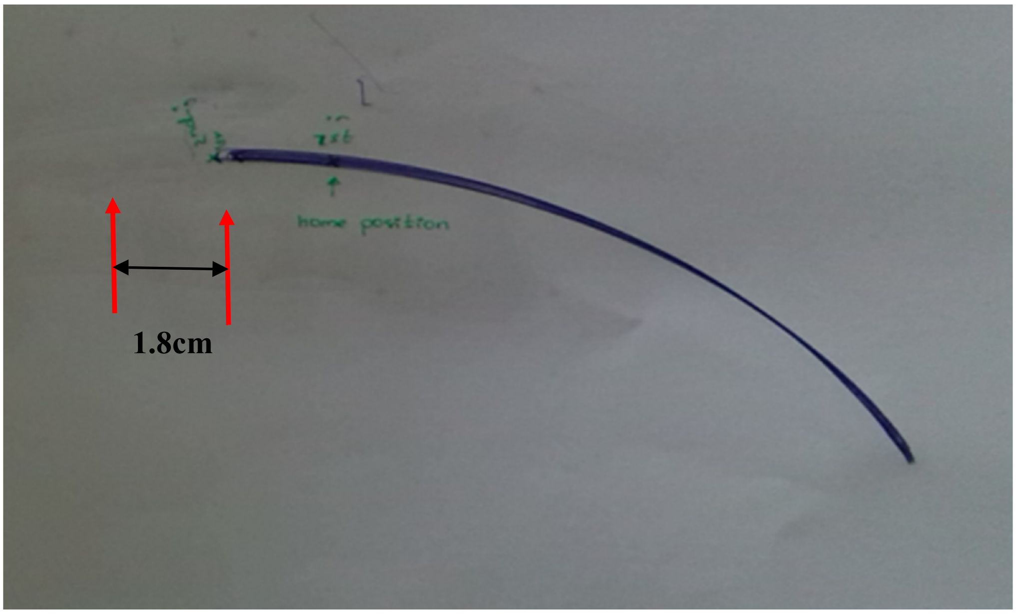


Fig. 18. Error Movement of X_C= 1.8cm

4 Conclusions

According to the design, the mechanism can move exactly point-to-point but in the reverse direction it has a little changes in the way as first way. Therefore, the motor reverse speed is very important for system stability. The natures of a power supply for forward and reverse position are always same at all the time and the control system used in same delay time, if we built additional controller for reverse position of motor, it can get more definite way of back condition. But, the basic concept of control system and programming languages are the same. The control approach presented in this paper can also be applied to other parallel manipulators with different links length and workspace.

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