# Design of 2-DOF Parallel Manipulator



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*Abstract*— **This thesis mainly highlights on the design of 2-DOF parallel manipulator. It describes the parallel mechanism with five-bar configuration. Manipulators are composed of five rigid links. This manipulator dedicated to fast and accurate parallel operation possess higher average stiffness characteristics through their workspace. This proposes a new method of modeling and simulation of 2-DOF (degree-of-freedom) parallel manipulator with flexible link base on MATLAB/SimMechanics. The controller also designed under the environment of Simulink and SimMechanics to satisfy the performance requirement for making the end-effector track of the reference trajectory. The simulation result shows that the controller can control the movement of the robot effectively. It also have greater rigidity and superior positioning capability. This research is a first trend of parallel robot in our university.**

***Keywords*— 2-DOF, parallel operation, controller, five-bar, MATLAB**

## I. Introduction

Parallel Manipulators with 2 or 3 translational DOFs play important roles in industry and can be applied in parallel kinematics machines, parallel applications, and other fields. Most existing 2-DOF parallel manipulators are the well-known five-bar mechanism with prismatic actuators or revolute actuators. First, the robot architecture is introduced. [1] Then, its actuation singularities and constraint singularities are analysed. Finally, a design methodology is proposed to determine the set of design parameters associated with the proximal modules for this manipulator to be assembled and free of parallel singularity. The research work is concern with the design of 2-DOF parallel manipulator, mainly the five-bar mechanism. The motor control will be leading to the movement of five bars system on detail. It is dependent on the movement of each linkage, which are attached with each other parallel to the workspace. In order to move of the each linkage (forwards, backwards) the mechanism are moved causing the control of motor or calculating workspace within calibration. The movement of linkages are activated with the microcontroller using the designated controller Mikro C language. [2] The movement is changed by the actuation on the programming sequence in Microchip PIC microcontroller. The actual parameter to be calculated by the software's result is sent to the PC to generate the signals to activate the control motor for actual movement. Figure-1 shows the proposed block diagram of the 2-DOF parallel manipulator. There are three portions to implement the research work.

(1) Software simulation (calculating workspace, SolidWorks design)
(2) Practical motor control portion
(3) Framework portion

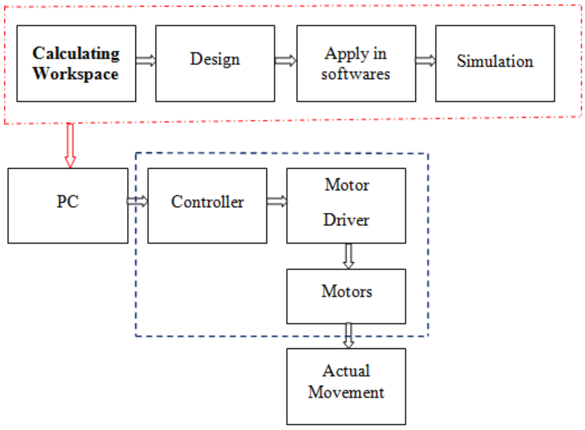


Fig. 1 Implemented Block Diagram

## II. Parallel Manipulator

### A. Parallel Manipulator

A parallel manipulator is a mechanical system that uses several computer-controller serial chains to support a single platform, or end-effector. It becomes progressively less rigid with more components. They can be first acting in comparison to serial manipulators. Parallel robots are usually limited in the workspace; for instance, they generally cannot reach around obstacles. The calculations involved in performing a desired manipulation (forward kinematics) are also usually more difficult and can lead to multiple solutions. [3]

### B. Mechanism

Mechanisms are mechanical devices used to accomplish work [4]. A mechanism is a heart of a machine. It is the mechanical portion of the machine that has the function of transferring motion and forces from a power source to an output. Mechanism is a system of rigid elements (linkages) arranged and connected to transmit motion in a predetermined function. Mechanism consists of linkages and joints. Figure-2 shows the sketch of five-bar mechanism. [5]

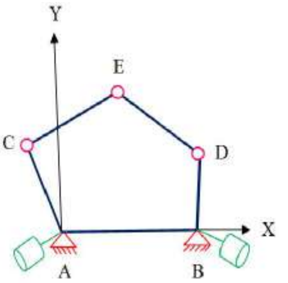


Fig. 2 Five-bar Mechanism Sketch

### C. *Linkages*

Linkages with zero, or negative, degrees of freedom are termed locked mechanisms. These mechanisms are unable to move and form a structure. Linkages with multiple degrees of freedom need more than one driver to precisely operate them. Common multi-degree-of-freedom mechanisms are open-loop kinematics chains used for reaching and positioning, such as robotic arms and back hoes. In general, multi-degree-of-freedom linkages offer greater ability to precisely positioning a link. [4][10]

### D. *Degrees of freedom*

Degrees of freedom for planar linkages joined with common joints can be calculated through Grubler's equation: [4]

M= degree of freedom= $3(n-1)-2j_p-j_h$

where n = total number of links in the mechanism

$j_p$ = total number of primary joints (pins or sliding joints)

$j_h$ = total number of higher-order joints (cam or gear joints)

## III. Five-Bar Mechanisim

### A. *Mechanical Part*

A 2-DOF parallel manipulator which can be written a set of letters within "A, a to Z, z" and also programmed for different pattern within workspace, should move in a plane. The five-bar (Figure-3) mechanism is made of fibreglass links, because is a light material and it is placed on a plate which provide a good stability to the system. It has a smaller workspace than a slider mechanism but it is more efficient and fast. The end-effector is the $L_2$ link. In my design, all links are equal. The links $L_5$ is the distance between the actuators. The input angles are $\theta_1$ and $\theta_2$. The actuators are two stepper motors; they have 4° displacement for one-step. For supplying the motors with 12V and 0.5A. [9] The two motors should have the same parameters for an easier control. Table-1 with respect to the five-bar mechanism's specification data. The coordinates of joint C and D can be denoted as follows,

$X_C = L_1 \cos\theta_1$ (1)

$Y_C = L_1 \sin\theta_1$ (2)

$X_D = L_5 + L_4 \cos\theta_2$ (3)

$Y_D = L_5 + L_4 \sin\theta_2$ (4)

TABLE1
Five-Bar Mechanism's Specification Data

| No. | Type | Length | Remark |
|---|---|---|---|
| 1. | Flexible Link- AB=$L_5$ | 0.22m | Two motors distance |
| 2. | Flexible Link- AC=$L_1$ | 0.15m | Centre-to-centre distance |
| 3. | Flexible Link- CE=$L_2$ | 0.15m | |
| 4. | Flexible Link- ED=$L_3$ | 0.15m | |
| 5. | Flexible Link- DB=$L_4$ | 0.15m | Centre-to-centre distance |
| 6. | Four Links Thickness (AC=CE=ED=BD) | 0.01m | - |
| 7. | Bush | 0.014m | Joint of two links |
| 8. | Washers | 0.005m &0.002m | - |
| 9. | Width of each flexible link | 0.025m | - |
| 10. | Height of Pencil /Paint | 0.035m | - |
| 11. | Height of Workspace | 0.075m | - |
| 12. | Area of Workspace | 0.6m*0.6m | L*H |

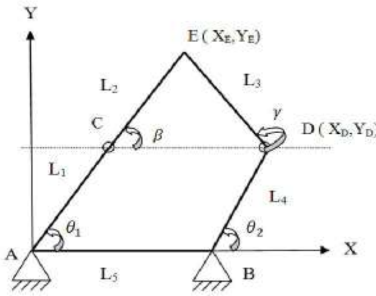


Fig. 3 Five-bar Mechanism

$$BC = \sqrt{L_5^2 + L_1^2 - 2\,(L_1)(L_5)\cos\theta_1} \quad (5)$$

$$\theta_1 = \cos^{-1}\left[\frac{(L_1^2)+(L_5^2)-(BC)^2}{2\,(L_1)(L_5)}\right] \quad (6)$$

$\theta_2 = \cos^{-1}( X_E - L_1 \cos\theta_1 ) / L_2;$ (7)

$\theta_3 = \cos^{-1}( X_E - (L_5 + L_4 \cos\theta_4 ) / L_3;$ (8)

### B. *Kinematics and Inverse Kinematics*

The position vector E, which defines the location of E at the centre of the revolute joint that connects the two links, describes the unknown position of the end-effector. The Cartesian coordinates of the point E ($X_E$,$Y_E$ ) can be found as two solutions because of quadratic equation nature. [7] The inverse kinematic problem can be written as

$$q_1 = \sqrt{L_2^2 - (x - \tfrac{L_5}{2})^2} \quad (9)$$

$$q_2 = \sqrt{L_3^2 - (x + \tfrac{L_5}{2})^2} \quad (10)$$

From eq(9) and eq(10), the solutions for the direct kinematics of the manipulator can be expressed as

$x = ey + f$ (11)

$$e = \frac{q_2 - q_1}{L_2} \quad (12)$$

$$f = \frac{q_1^2 + q_2^2}{L_2 L_5} \quad (13)$$

$a = e^2 + 1$ (14)

$b = 2e\,( f - L_2) - 2q_1$ (15)

$$c = (f - R)^2 + q_1^2 - \frac{L_5}{2} \quad (16)$$

where $R = L_2 = L_3$

$$Y_E = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{17}$$

$$X_E = \frac{(Y_C - Y_D)}{(X_D - X_C)} Y_E + \frac{(X_D{}^2 + Y_D{}^2) - (X_C{}^2 + Y_C{}^2)}{2(X_D - X_C)} \tag{18}$$

From the above equations we can see that the direct and inverse kinematics of the manipulator can be described in closed form.[8]

### C. *Workspace of the Parallel Manipulator*

One of the most important issues in the design process of a parallel manipulator is its workspace. For parallel manipulators, this issue may be more critical since parallel manipulators will sometimes have a rather limited workspace. The workspace of the 2-DOF parallel manipulator is often represented as a region in the plane. The simulation analysis will also be carried out using MATLAB, where a code is written as m-file. Figure-4 shows the simulation of maximum workspace for five-bar mechanism. The design result was obtained with respect to a given desired manipulator dimension.[7]

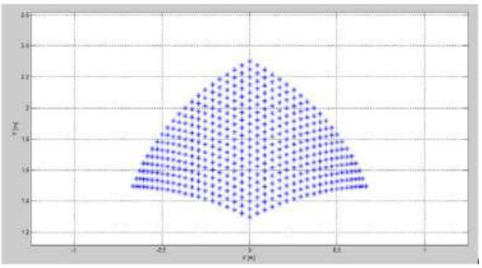

Fig. 4 Simulation of Maximum Workspace for 2-DOF

## IV. CAD PROGRAM SOLIDWORKS

The mechanical construction is performed with the CAD program SolidWorks for parallel manipulator and the data export to SimMechanics, a simulation tool for mechanical. Figure-5 to 10 shows the different views of five-bar mechanism's SolidWorks design. Figure -11 and 12 show the isometric view and wire frame. The structure of this manipulator design to cover a large workspace.

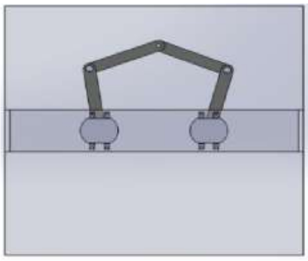

Fig. 5 Top View

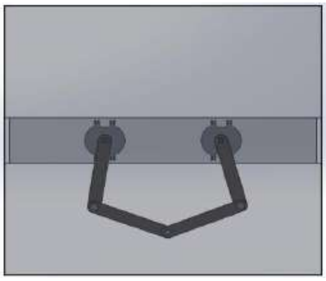

Fig. 6 Bottom View

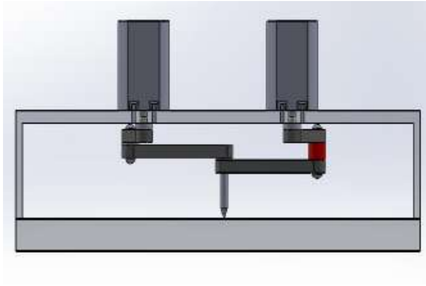

Fig. 7 Front View

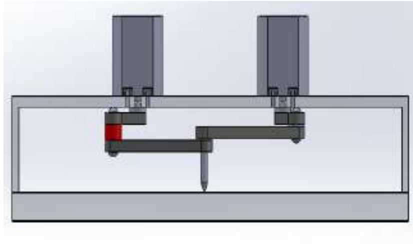

Fig. 8 Back View

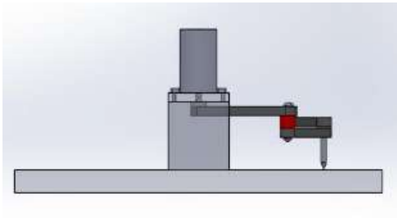

Fig. 9 Right View

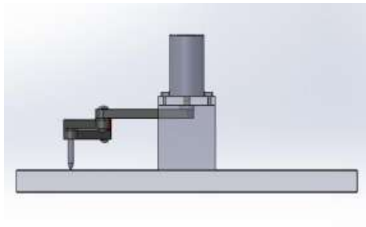

Fig. 10 Left View

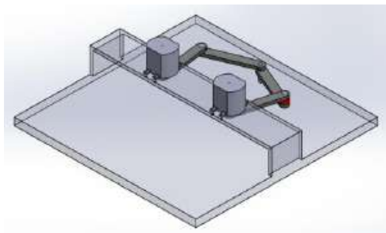

Fig. 11 Isometric View

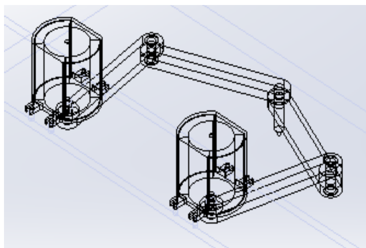

Fig. 12 Wire Frame

## V. DISCUSSION

I desire to construct like this above simulation software design. I try the best for actual movement. Software implementation and calculation are already perfect but design and construction can get error. My future plans need more effort to construct the mechanism for getting result with the best accuracy and precision. So, I need more emphasize to study about the hardware components such as electric motors, actuators, drivers and controllers environment in detail.

## VI. CONCLUSION

The design and calculation of this mechanism is based on own parameters and only tend to 2-DOF so that the required degree of freedom of different kinds of parameters can be designed and improved according to these mechanism's different characteristics. The control system has been designed with computer for input data angles instead of thinking load and it's used simple kinematics equations.

## VII. RECOMMENDATION

This paper has demonstrated that low-cost components can be used to create a control system that will allow automatic writing alphabets and drawing different patterns to increase the precision. This allows high precision and high speed of movements. Although the equation augmentation has been completed in this paper with own parameters, more complete system will be constructed with hardware components and creates the actual movements in the future work.

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