Design of 2-DOF Robot Manipulator

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Abstract— **This paper represents a two degree of freedom (DOF) Robot Manipulator that aims the quickest way to produce the very large drawings efficiently. The 2-DOF robot manipulator which is a Selective Compliance Assembly Robot Arm (SCARA) and its arm was rigid in the Z-axis and pliable in the XY-axis. The 2-DOF Robot Manipulator has a two axis control and a special mechanism to raise and lower the pen. A pen tool is fixed at the end-effector of the robotic arm and its control using a servo and SCARA which is an autonomous robotic arm with two Degree of Freedom (DOF). This system is experimented in drawing alphabets, for example "11 11". The input given from the computer using Arduino Uno which is an open-source physical computing platform on the drawing board. Some of the functions are controlled by a user is also designed to change necessary commands to the hardware system using serial communication code. The result shows that it has an advantage of this system is fast and easy to understand because of its structure and paths. It could be improved at drawing for complex images and many drawing in future.**

***Keywords*— 2-DOF, MATLAB, hardware design, kinematics**

I. INTRODUCTION

In the era of larger talent gaps and intelligent technologies, people are always wanted to manufacture new technology for various process in order to serve a purpose like solving problems or making there life comfortable and better. These technologies made them feel more secure with many areas in life for both personal and business reasons so people always searched different markets and people have entered the competition to manufacture their quality. That's why people are also needed automation systems. The most used components of automatic system are Robots, Mechatronics Engineering, Mechanical Engineering, Electrical Engineering and Computer Engineering has all worked together in this Robotic System. In this technology-driven economy, the demand for the robot is increasing rapidly and its application is widespread across all sectors. Recently, a robotic arm is an increasing links of either revolute or prismatic joints which form a kinematic chain. The end of the kinematic chain, termed the end-effector, is where the tool is located and is analogous to the human hand. Revolute joints allow rational motion about an axis, while prismatic joints allow linear translation along an axis. The kinematics is a fundamental part of the multidisciplinary research area of robotics. The position kinematics model relates the joints positions and the end-effector posture. The direct kinematics analysis is the process of calculating the end-effector posture from the joint positions given, while the inverse kinematics analysis is the process of obtaining the joint positions necessary to establish a desired end-effector posture. The inverse kinematics is an ill posed problem because of the problems such as multiply or even infinite solutions, nonlinearity, singularities and uncertainties. The ADM was first introduced by George Adomain at the beginning of the 1980's for solving a wide range of problems whose mathematical modes yield equation or system of equations involving algebraic, differential, integral and integro-diffrential terms. This method is simple and efficient for the solutions. Abbaui and Cherruault applied ADM to solve nonlinear algebraic equation f(x) =0 and proved the convergence of the series solution E. Babolian et al. applied the ADM to solve a system of nonlinear equations. A. R. Vahidi. et. al, used restarted ADM to improve the solutions of systems of nonlinear algebraic equations. A two degree of freedom (2-DOF) elbow manipulator consists primarily of two links which can take the form of a cylinder or a bar. The two links are connected together serially with a revolute joint called "elbow". The other revolute joint called the "shoulder" is used to connect the first link with the fixed part of the manipulator. A schematic diagram illustrating an upper view of the robotic manipulator is shown in figure 1.

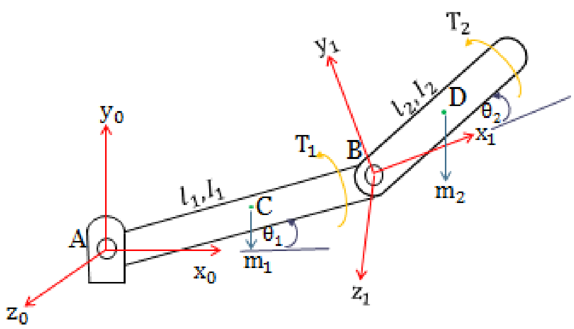

Fig. 1 Robot Arm (Hardware Implementation)

II. 2-DOF ROBOT MANIPULATOR MODELLING

A. 2-DOF Robot Manipulator

The 2-DOF robot 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 manipulator. 2-DOF robot manipulator is usually limited in the workspace; for instance, they generally cannot reach around obstacles. The calculations involved in performing a desired manipulation (inverse kinematics) are also usually more difficult and can lead to multiple solutions. [1]

B. Mechanism

Mechanisms are mechanical devices used to accomplish work [2]. 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 2-DOF robot manipulator mechanism.

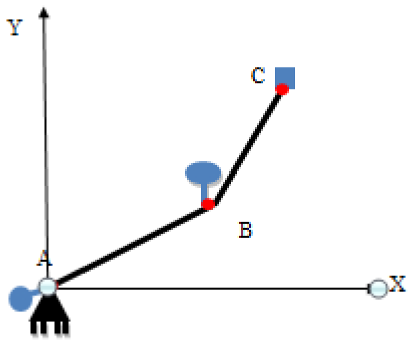

Fig. 2 2-DOF robot manipulator Mechanism Sketch

C. Linkages

Linkages with zero, or negative, degrees of freedom are termed locked mechanisms. These mechanisms are unable to move and from a structure. Linkages with multi-degrees-of-freedom need more than one driver to precisely operate them. Multi-degree-of-freedom mechanisms are open loop kinematics chains used for reaching and positioning, such as robotics arms and back hoes. In general, multi-degree-of-freedom linkages offer greater ability to precisely position a link. [2][3]

D. Degree of freedom

Degree of freedom for planar linkages joined with common joints can be calculated through Grubler's equation;[2]

M= degree of freedom= 3(n-1)-2jp-jh

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. 2-DOF Robot Manipulator Mechanism

A. Mechanical Part

A 2-DOF robot manipulator which can be written a set of number within "0 to 60" and also programmed for different pattern within workspace should move in a plane. The 2-DOF robot manipulator (figure 3) mechanism is made of aluminium 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 workplace than a slider mechanism but it is more efficient and fast. The end-effecter is the L_2 link. The input angles are Θ_1 and Θ_2. The actuators are two stepper motor. For supplying the motors with 12V and 0.5A. The two motors should have the parameters for and an easier control. TABLE1 with respect to the 2-DOF robot manipulator mechanism's specification data. The coordination of joint B can be denoted as follows,

$$p = L_1 \cos\theta_1 + L_2 \cos\theta_2, \tag{1}$$

$$q = L_1 \sin\theta_1 + L_2 \sin\theta_2, \tag{2}$$

TABLE1 2-DOF Robot Manipulator Mechanism's Specification Data

No.	Type	Length	Remark
1.	Flexible link- AB = L_1	0.254m	One stepper and Elbow joint
2.	Flexible Link- BC = L_2	0.254m	Elbow joint and end effecter
3.	Two Link Thickness (AB = BC)	0.0254m (hollow 0.0253m)	-
4.	Bush	0.003m	Joint of two link
5.	Washer	0.002m	-
6.	Width of each flexible link	0.0254m	-
7.	Height of Pencil/ Paint	0.035m	-
8.	Area of Workspace	0.22m*0.12m	L*H

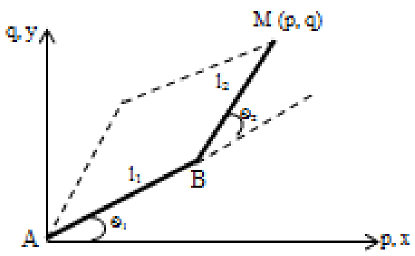

Fig.3 2-DOF robot manipulator Mechanism

$$\theta_2 = \cos^{-1}\frac{x^2+y^2-l_1^2-l_2^2}{2l_1l_2}, \tag{3}$$

$$\theta_1 = \tan^{-1}\frac{y}{x} - \tan^{-1}\frac{l_2\sin q_2}{l_1+l_2\cos q_2}, \tag{4}$$

$$x = p^2 - \frac{t^2}{2pt} + \frac{t}{2p}(x^2+y^2), \tag{5}$$

$$y = q^2 - \frac{t^2}{2qt} + \frac{t}{2q}(x^2+y^2), \tag{6}$$

B. Kinematics and Inverse Kinematics

Placing the robot base at its position depicted below simplifies in design of the system such that the arm will only ever be in the "elbow up" position and never in the "elbow down" position. To solve the angles the arms need to be at in order to achieve a desired location of the end effector (pen), inverse kinematics is used. Inverse kinematics calculates the required angles of the arms,θ_1 *and* θ_2, in order for the end effector to reach its desired coordinate point. A simple diagram for the robot arm is given below, where the end effector is represented by the orange circle. (x_0, y_0) is the coordinate frame for arm l_1, and (x_1, y_1) the coordinate frame for arm l_2.[4]

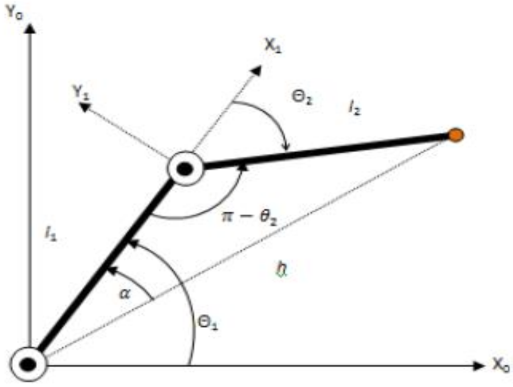

Fig. 4 Diagram of system

$$h = \sqrt{x_p^2 + y_p^2}, \tag{7}$$

Using the law of cosines

$$a^2 = b^2 + c^2 - 2bc \cos A, \tag{8}$$

Substituting a for h, b for l_2, c for l_1 and A for $(\pi - \theta_2)$ and solving for θ_2 yields,

$$h^2 = l_2^2 + l_1^2 - 2l_2 l_1 \cos(\pi - \theta_2), \tag{9}$$

$$\cos(\pi - \theta_2) = \frac{x_p^2 + y_p^2 - l_2^2 - l_1^2}{2l_2 l_1}, \tag{10}$$

$$\cos(\pi - \theta_2) = \frac{l_1^2 + l_2^2 - h^2}{2l_2 l_1}, \tag{11}$$

$$\pi - \theta_2 = \cos^{-1}\left(\frac{l_1^2 + l_2^2 - h^2}{2l_2 l_1}\right), \tag{12}$$

$$\theta_2 = \pi - \cos^{-1}\left(\frac{l_1^2 + l_2^2 - h^2}{2l_2 l_1}\right), \tag{13}$$

To find θ_p, atan of the new coordinate was calculated,

$$\theta_p = a\tan(x_p, y_p)$$

To solve for α, the law of cosine was again used. Substituting all the relevant variable and solving for a α yields,

$$l_2^2 = h^2 + l_1^2 - 2h^2 l_1^2 \cos(\alpha), \tag{14}$$

$$\cos(\alpha) = \frac{l_1^2 + h^2 - l_2^2}{2l_1 h}, \tag{15}$$

$$\alpha = \cos^{-1}\left(\frac{l_1^2 + h^2 - l_2^2}{2l_1 h}\right), \tag{16}$$

Nothing that θ_1 is simple the addition of θ_p and α, θ_1 is calculated by,

$$\theta_1 = \theta_p + \alpha, \tag{17}$$

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

IV. Hardware Design

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. [4]

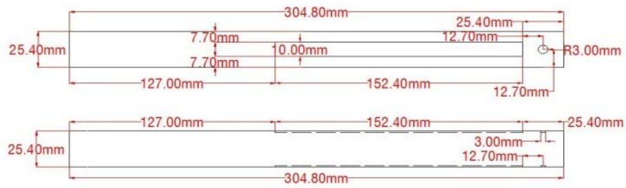

Fig. 5 Link-1 Top and Front View

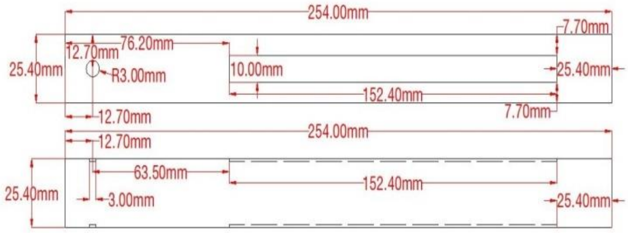

Fig. 6 Link-2 Top and Front View

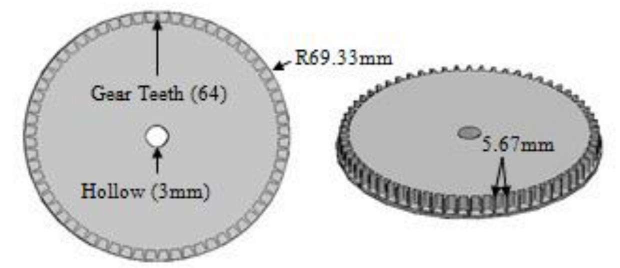

Fig. 7 Elbow Top and Front View

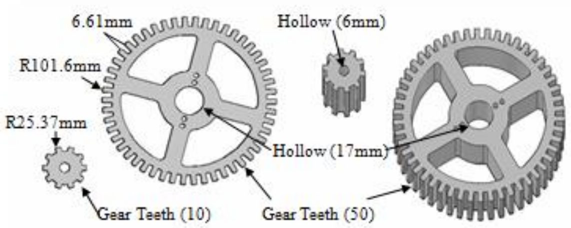

Fig. 8 Spur Couple Gear Top and Front View

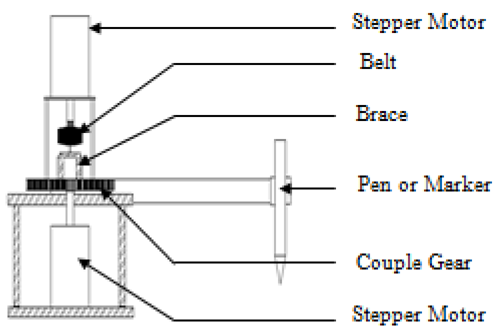

Fig. 9 Position of Components 2-DOF Robot Manipulator Front View

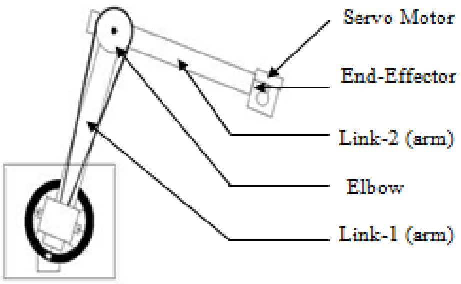

Fig. 10 Position of Components 2-DOF Robot Manipulator Top View

V. TEST AND RESULT

A. *Position Analysis Using CAD system*

A CAD system that supports the construction of lines and arcs, locates intersections of lines and arcs may be used. The construction is drawn at half-scale (127mm on the drawing corresponds to 254mm on the actual mechanism). The construction is shown in the position diagram in Fig. 11. A horizontal line representing the base link is drawn first, and two points bounding an interval of 127mm (half-scale of the actual length) are marked to represent A and B. Locate point B, which is where the driver link (L_1), is joined to the (L_2).A line through point A at angle of θ_1 = 190° to AB is drawn, and a point on that line at a distance of 125mm is marked to present point B.A line through point B at angle of θ_2 = 60° to BC is drawn, and a point on that line at a distance 207mm is marked to presented point C. Shows the result parameter with AutoCAD design in Fig. 12. The variable input angles at point A (θ_1), point B (θ_2) and (X_C, Y_C) values.

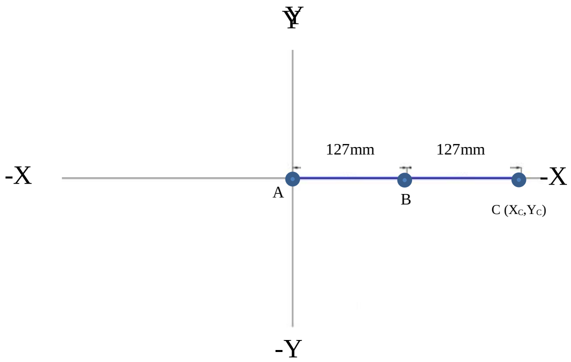

Fig. 11 Original Position of 2-DOF Robot Manipulator

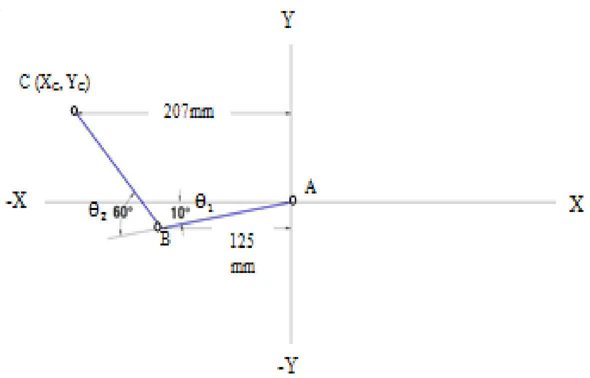

Fig. 12 Input Degree θ_1 and θ_2, Moving Robot Arm Position

B. *Hand Calculation Result and Test Program Result*

Table 2 shows the calculation results for 22 22 with are saved as array type and stored in C++ program as .csv file. Fig. 13 shows the program result of table 2.

Table 2 Array 2 Calculation Result

	X (inch)	Y (inch)	θ_1(Degree)	θ_2(Degree)
Array 2	-18	8	166	20
Array 2	-14	8	187	73
Array 2	-14	2	217	90
Array 2	-18	2	199	50
Array 2	-14	5	202	84
Array 2	-18	5	185	42
Array 2	-10	8	192	100
Array 2	-6	8	187	120
Array 2	-6	2	233	143
Array 2	-10	2	228	119
Array 2	-6	5	207	134
Array 2	-10	5	209	112
Array 2	6	8	353	120
Array 2	10	8	348	100
Array 2	10	2	312	119
Array 2	6	2	307	143
Array 2	10	5	331	112
Array 2	6	5	333	134
Array 2	14	8	353	73
Array 2	18	8	14	20
Array 2	18	2	341	50
Array 2	14	2	323	90
Array 2	18	5	355	42
Array 2	14	5	338	84

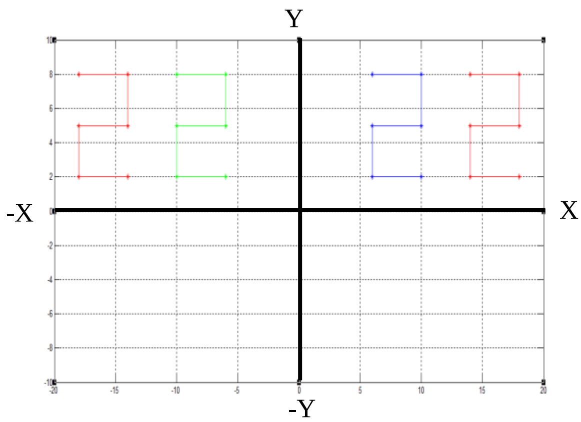

Fig. 13 Show the program results of table 2

C. *Workspace of the 2-DOF Robot Manipulator(MATLAB)*

One of the most important issues in the design process of 2-DOF robot manipulator is its workspace. For 2-DOF robot manipulator, this issue may be more critical since robot manipulator will sometimes have a rather limited workspace. The workspace of the 2-DOF robot 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. Fig. 14 shows the result simulation of maximum workspace for 2-DOF robot manipulator mechanism. The design result was obtained with respect to a given desired manipulator dimension.

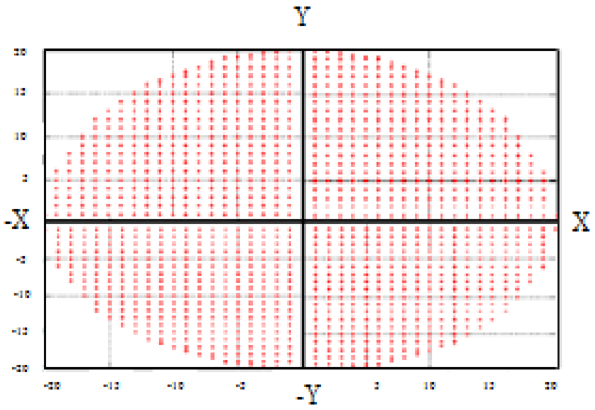

Fig. 14 Simulation of maximum workspace for 2-DOF robot manipulator

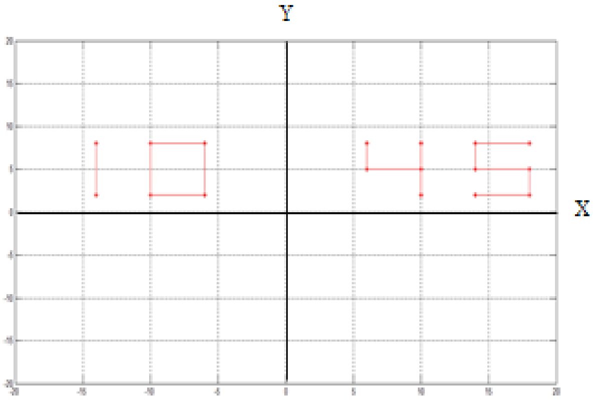

Fig. 15 Shows the MATLAB result for 2-DOF robot manipulator in written plane (10:45)

D. Mechanism of 2-DOF Robot Manipulator

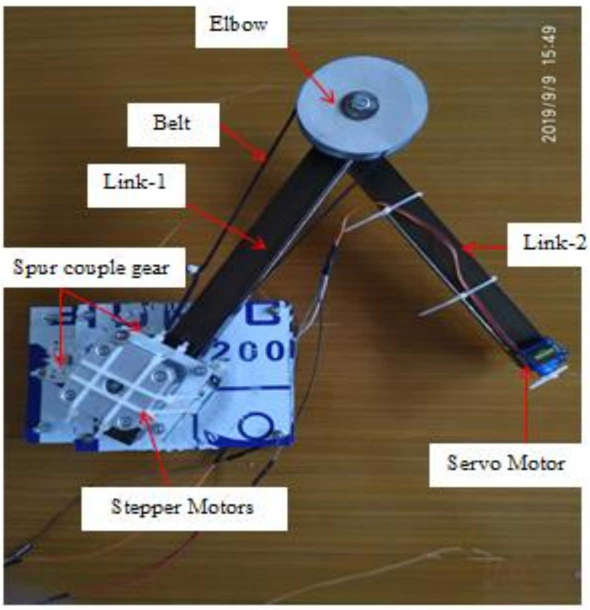

Fig. 16 Complete Mechanism of the 2-DOF Robot Manipulator (hardware)

VI. DISCUSSIONS

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.

VII. 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.

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