DC Motor Control using Fuzzy Logic Controller for Input to Five Bar Planar Mechanism

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Abstract*—DC motor speed and position control finds various applications in Robotics, Material handling, Industrial drives and Automation. In this paper, a control of Five Bar Mechanism Motion is obtained by DC motor position and speed control using Fuzzy rule-based system. The Five Bar Mechanism has second degree of freedom. The second degree of freedom is very difficult to handle as for the deterministic positions there can be multiple orientations. By providing the restriction of the input links and controlling the positions of the input links the degree of freedom is reduced to one. Mechanically such a restriction is possible through the use of gears which have the limitation due to gear ratio. With rule based system it is possible to achieve desired orientation of path by controlling speeds of the two DC motors. Using DC motors instead of gears one can achieve various deterministic orientations of mechanism. The dimensions of the mechanism may introduce the locking conditions. The locking condition means the two input links have the restriction of position with respect to other. The rule base system also detects the locking position and resets the system. The system is simulated using Software developed for Five Bar Planar Mechanism. The coordinates for the motion path or locus are obtained through the software. The fuzzy rule based system controls the motion of motor, such that the desired coordinates are travelled using a smooth curve. The five bar mechanism can trace the desired path with an accuracy of ±2.5%.

***Keywords* — DC Motor control, FBPM, PID, FLC.**

I. INTRODUCTION

The use of DC motor is very popular in Robotics, Automation, Industrial Drives systems, Material Handling etc. In these entire systems closed loop control of motor is required. The advantages to use DC motors in such systems are constant speed torque (Liner) characteristics, accurate and high control of torque, better dynamic response, high speed and simple control methods. There are many traditional methods are available to control position and speed of DC motor. In this project new control method of Fuzzy Logic Controller is designed for speed and position control of DC motor. Where DC motors will act as a drive for application of Five Bar Planar Mechanism. In the proposed system two DC motors are used as input to the first two links of Five Bar Planar Mechanism. The Five Bar Mechanism is basically used for required curve (path) tracing. The required cure can be traced by controlling speed and position of DC motor accurately.

The Most popular and conventional method of close loop control is PID controller. PID controller is useful for both, speed and position control of system. PID controller needs proper tuning of controller parameters for accurate control. PID controller cannot work properly when dynamic conditions like Maximum Overshoot, Response action time. In case of Five Bar Mechanism real time conditions like mechanical locking, occurrence of unknown dynamics as friction may cause damage to the proposed system. Due to these drawbacks of PID controller, the design and implementation of new controller is discussed in this project for application of Five Bar Planar. The Fuzzy Logic Controller will be useful in real operating conditions mentioned above. Most importantly it will avoid mechanical locking of mechanism for particular curves of Mechanism by controlling speed and position of DC motors.

II. PROPOSED SYSTEM

A. Five bar planar mechanism (FBPM)

Fig. 2.1: FBPM

The Prototype of Five bar planer mechanism is shown in above Fig.2.1 FBPM has second DOF. One link is always fixed which is link 1-3 in above fig. When the input link connected to it, is set to a predefined position, it is not possible to deterministically find the positions of other three links. Where as in four-bar mechanism there is a unique position of remaining two links. Hence it is the most popularly used mechanism. The mechanism has wide number of applications in the field of Material handling, Robotics and applications where coupler curve is very important. The five bar mechanism with rotation constraint reduces the DOF to one. The mechanism uses two input links connected to the fixed link. These input links have initial positional relation among themselves mentioned as $\theta_2 = f(\theta_1)$. Further there is a relation in the speeds of input links as $\omega_2 = g(\omega_1)$. Thus the constraints are specified in terms of angular positions and angular velocity

B. Block diagram of system

The block diagram gives a brief idea about the working of whole system. The two DC motors have operating voltage of 24 volts. On the each shaft of the two motors link 1 and link 2 of mechanism is attached respectively. The Arduino UNO (AT-mega 328) controller used for driving two DC motors based on Fuzzy Rule-base. Arduino has output voltage level 5 volts and the operating voltage of DC motors are 24 volts each. Arduino cannot provide that much voltage to drive the motor therefore there is need of the Driver Circuit which is L298n duel dc motor driver.

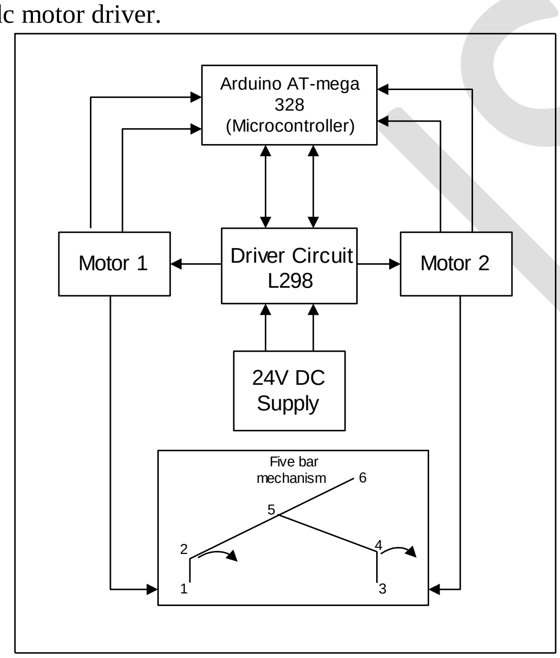


Fig. 2.2: Block diagram of proposed system.

C. Functional Flowchart

The input coordinates of the curve will be given as input to the Arduino program. The Arduino program will select the required speed and positions of the two motors based on Fuzzy Rule-base. Arduino and the motors are interfaced using the driver circuit. The output from the arduino is given to the driver circuit speed pin i.e. encoder pin and direction pin i.e. input pin. The driver circuit has two output channels where the two motors are connected. Input voltage i.e. 24V for the DC motor is given to the input pin of driver circuit. Driver circuit needs 5V logic supply for itself which will be given by external 5V supply. The Five Bar Mechanism will be mounted on the two motors. The feedback pins i.e. encoder output of position and speed is again connected back to the Arduino controller's digital pins. Those pins will read actual position and speed of motor. At last stage DC motor drive mechanism with such speed and positions that it will trace desired curve at locking and unlocking conditions.

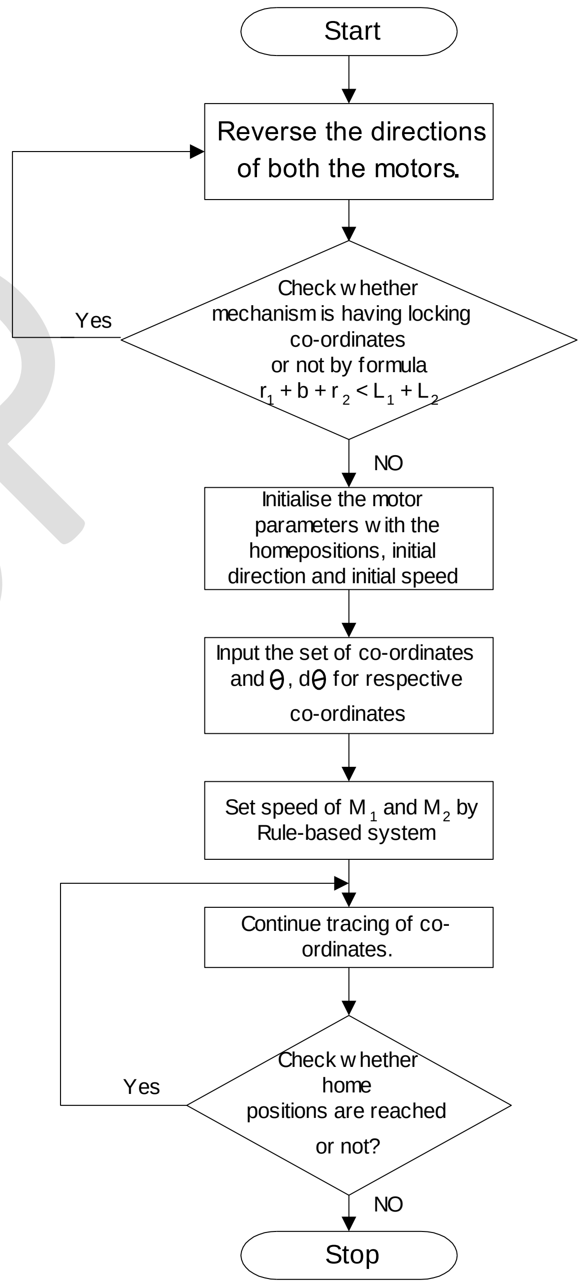


Fig. 2.3: Functional Flowchart of proposed system.

III. SIMULATION

The existing software for Five Bar Mechanism developed in C++ and CG is very useful for this scope. The Software can give the different curves or path drawn by Five Bar Mechanism with set home positions. Therefore with the help of this software the co-ordinates of desired can be calculated very easily just by simulating the Five Bar Mechanism. Simulation software helps also for constructing the Fuzzy Rule Base Table. The collection of data can be done which will be used as different inputs for Fuzzy Set operations. Based on these data collection and using proper Fuzzy Inference the Fuzzy Rules can be formed. Next step will be to calculate input Speeds, Positions and Directions for desired curve using Fuzzy Rule Base table. The system is simulated in both C++ and CG as well as in MATLAB. First part will describe study of existing software used and some changes done according to DC motor position and speed control, second part will describe formulation of fuzzy rule-base system for speed and position control of motor using MATLAB.

A. Simulation using existing software

The Simulation for two DC motors as input to the Five Bar Mechanism is done using C++ and CG. In the simulation the Graphical User Interface (GUI) is designed. In this Project scope first using Simulation of Five Bar Mechanism the desired curves and co-ordinates on those curves are finalized. The desired curves and co-ordinates are finalized for both, Locking and Unlocking conditions. The simulation software has provision of setting the different directions, speeds and angular positions of motors to trace different co-ordinates.

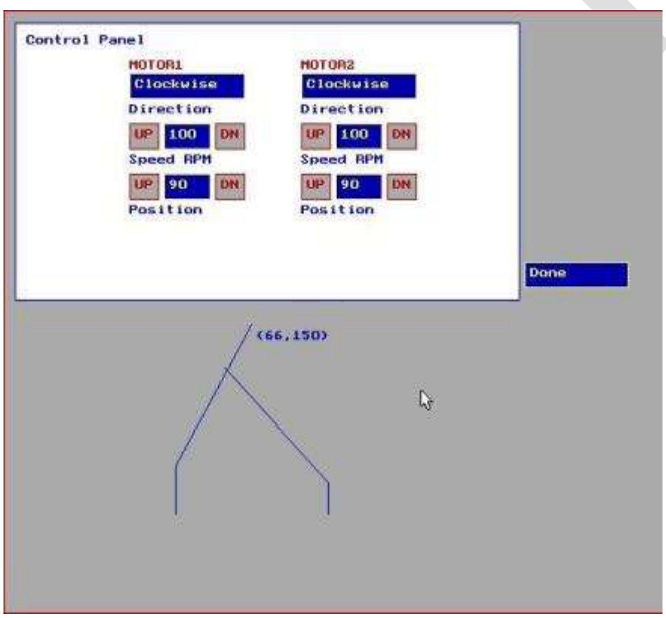


Fig. 3.1: Simulation using Existing Software

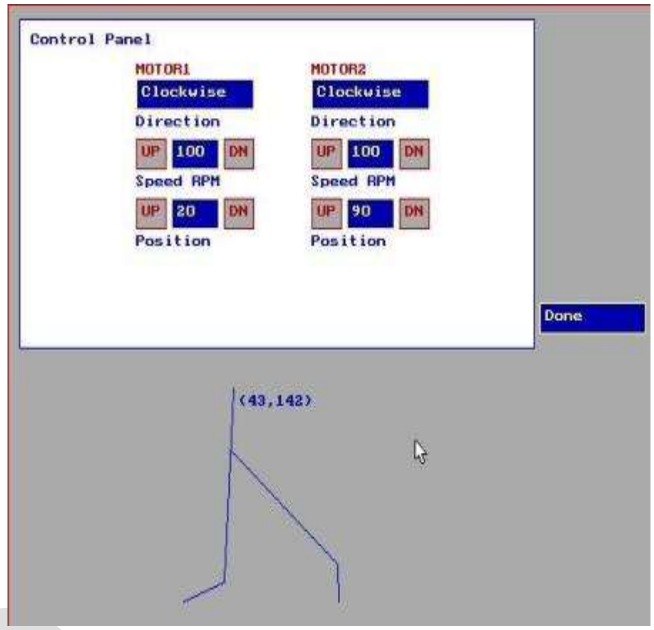


Fig. 3.2: Parametric values for motors given by Software for required co-ordinate tracing.

Above figures shows an example of two co-ordinates from the set of curve, and required direction, speed, and angular position for reaching that co-ordinate.

B. Simulation using MATLAB for Fuzzy Expert system.

The coordinates, to be traced, are translated into the positions of the input links. The scope of the project work is related to the position and speed control of the input links. From current angular positions of the input links to the next angular positions, the motors should be rotated. It is necessary that the motors reach the angular destinations in the same amount of time. This requires the speed control of the motor during this traversal. Thus the fuzzy system will take the current position and the next position as the input. But instead of increasing the input parameters, we input the next change in the angles of the input links. Development of Fuzzy system requires defining linguistic variables and specifying problem statement so that a controller can be designed. Mamdani controller is used in this scope.

- **Steps for designing Mamdani Controller using MATLAB software**.

Step 1 Defining Linguistic variables

1. Theta θ (Angle to be reached)
2. Difference between theta dθ (Difference between Theta and Current angle)
3. Speed S (Output)

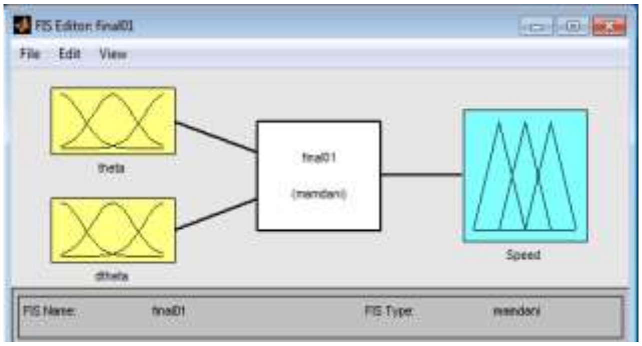


Fig. 3.3: Selection of Linguistic inputs and outputs in MATLAB

Step 2

TABLE I
LINGUISTIC VARIABLE THETA θ

Linguistic variable Theta θ		
Linguistic Value	Notion	Numerical Range
Small	S	[0 15 30]
Medium	M	[30 55 80]
Large	L	[80 110 140]
Huge	H	[140 160 180]

Step 3

TABLE II
RANGES LINGUISTIC VARIABLE dθ

Linguistic variable Difference between Theta, dθ (Actual angle –Current angle)		
Linguistic Value	Notion	Numerical Range
Small	S	[0 0.125 0.25]
Medium	M	[0.25 0.375 0.5]
Large	L	[0.5 0.625 0.75]
Huge	H	[0.747 0.872 0.997]

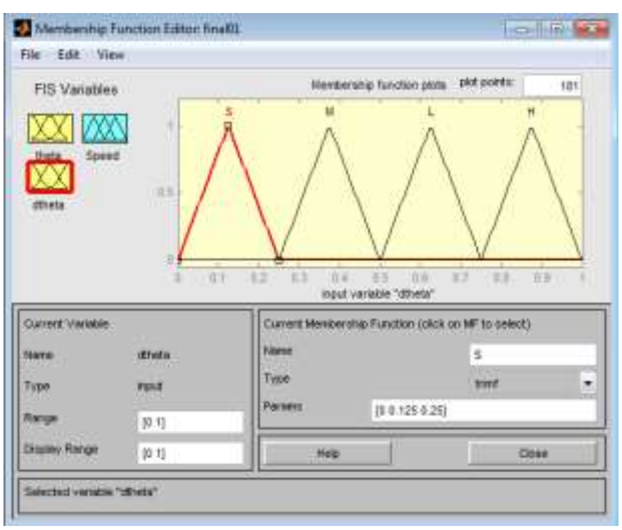


Fig. 3.4: Ranges for variable dθ in MATLAB

Step 4

TABLE III
RANGES LINGUISTIC VARIABLE S

Linguistic variable Speed S		
Linguistic Value	Notion	Numerical Range
Small	S	[40 50 60]
Medium	M	[60 70 80]
Large	L	[80 90 100]

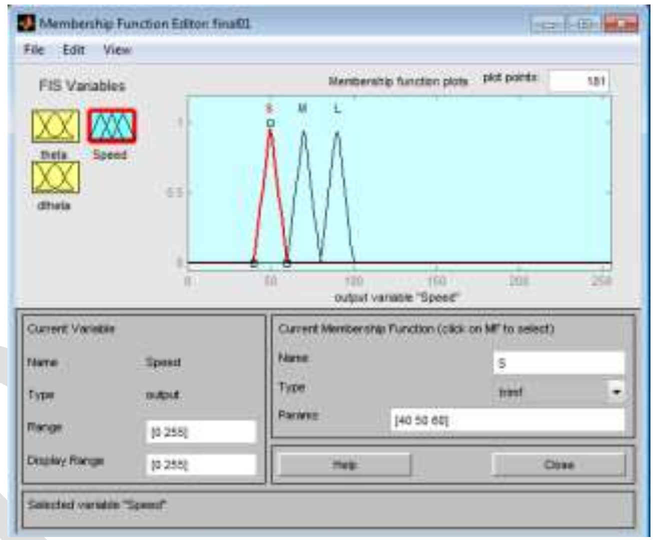


Fig. 3.5: Ranges for variable S in MATLAB

Step 5

Inputs are two which are Theta θ and Difference between Theta θ Linguistic values are four which are small Medium, Large and Huge.

The formula for calculating the no. of rules is as follows

$$Number\ of\ Rules = (\text{Total number of inputs})^{(Total\ linguistic\ values)} = (2)^4 = 16$$

TABLE IV
FUZZY RULE-BASE TABLE

	Difference between Theta θ (Actual angle –Current angle)				
Theta θ	Speed(Output)	S	M	L	H
	S	S	-	-	-
	M	S	S	-	-
	L	S	M	M	
	H	S	M	H	H

As observed in the table IV,there are 6 positions which can not be reached and hence show -.The reason behind this is we perform the direction change based on the next angular position so that the difference always remains less than 180 degrees. 180 degrees in clockwise and anticlockwise direction allow us to cover all the angular positions of the input links.

The change in the direction is not considered as output for Fuzzy system. Rules in matlab from above table 5.10

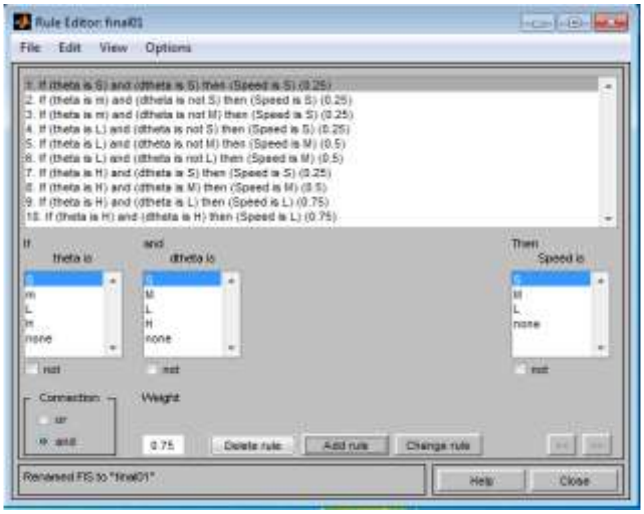


Fig. 3.6: Constructing Fuzzy Rules in MATLAB

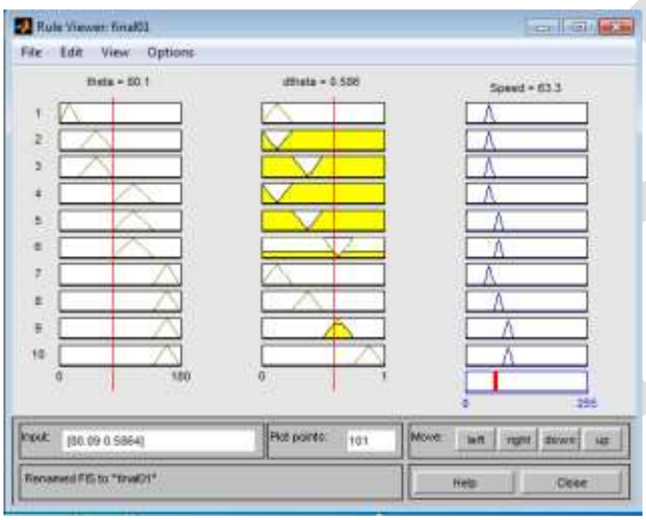
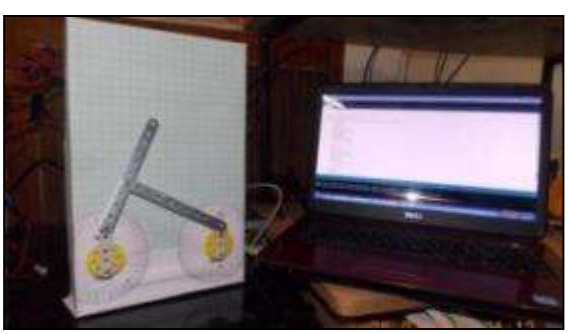


Fig. 3.7: Rule Viewer in MATLAB

IV. TESTING

A. Hardware Setup:



a)

b)

Fig. 4.1 Complete Hardware Setup

B. Testing of Five Bar Mechanism for given curves tracing:

Five bar mechanism can trace 'n' no. of paths or coordinates. In this scope for testing purpose three sets of co-ordinates with unlocking mechanism and one set with locking condition. For testing purpose coordinates to be traced are taken from existing simulation software mentioned in section III Simulation.

Testing procedure for set 1 co-ordinate tracing is given in following section.

1) The X-Y Co-ordinates with respect to desired Curve are taken as inputs to the system.
2) The system is set to home position which has X-Y coordinates as X= 66 and Y = 150, angular position $\theta_1 = 90^0$ and $\theta_2 = 90^0$, speeds are zero for both motor.
3) The Fuzzy system decides speed of two motors to trace desired co-ordinates.
4) The co-ordinates traced during travel are tabulated in table 6.3.

TABLE V
INPUT CO-ORDINATES OF SET - 1

Set 1							
X	Y	Theta1	Theta2	Dth1	Dth2	Dir1	Dir2
66	150	90	90	-70	0	-1	1
43	142	20	90	55	-55	1	-1
90	138	75	35	-25	-35	-1	-1
102	132	50	0	80	40	1	1
76	111	130	40	50	20	1	1
53	92	180	60	-90	30	-1	1
66	150	90	90				

5) The results are compared with the results obtained in software.
6) The system tested for desired curve with respect to 5 co-ordinates in table 6.3. The co-ordinates traced by system are illustrated in fig 4.3 to 4.7.

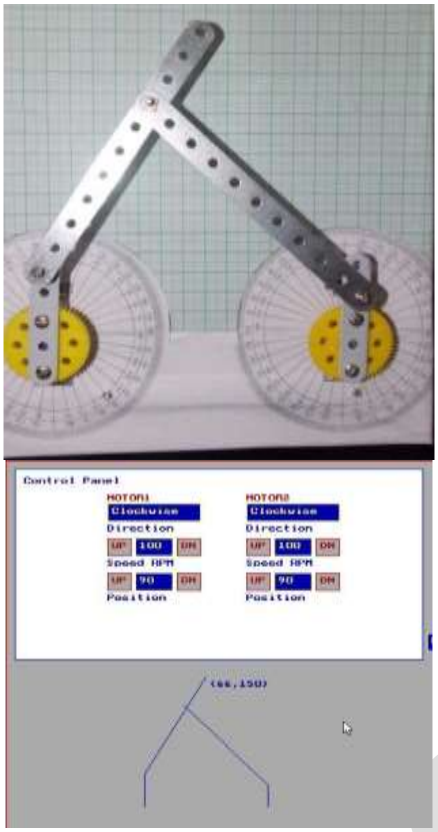


Fig. 4.2: Home positions of set 1 of the two motors

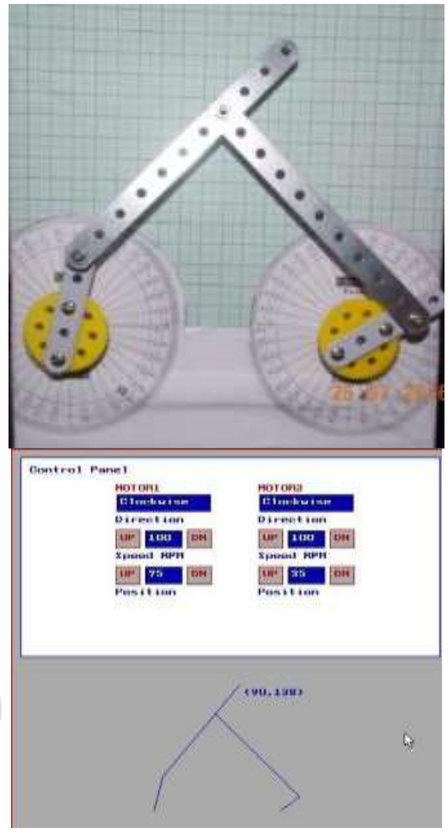


Fig. 4.4: Position 2 of set 1 of the two motors

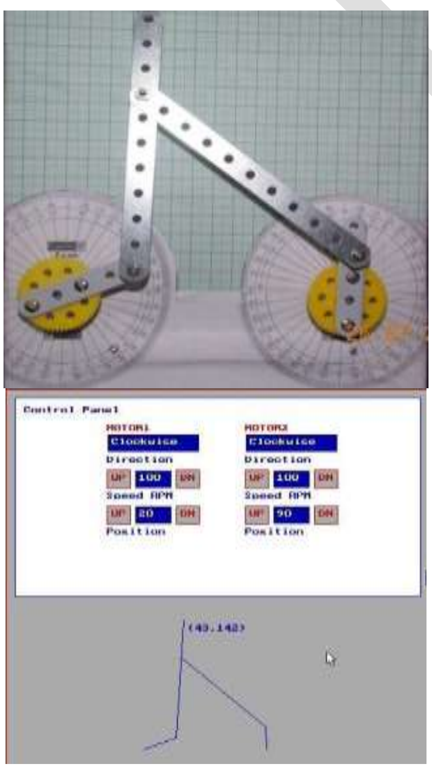


Fig. 4.3: Position 1 of set 1 of the two motors

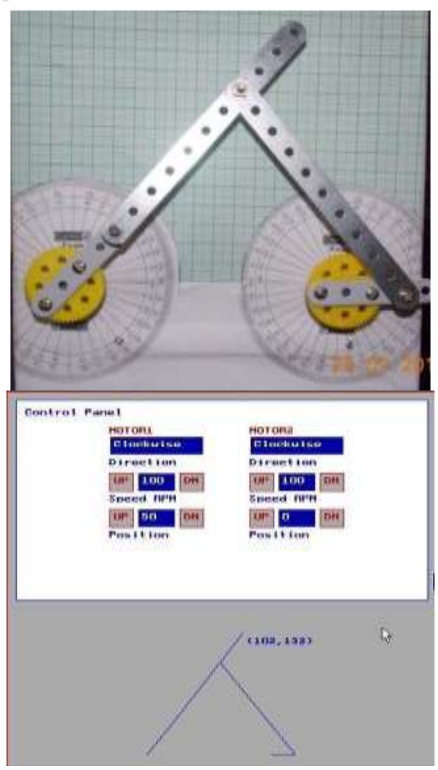


Fig. 4.5: Position 3 of set 1 of the two motors

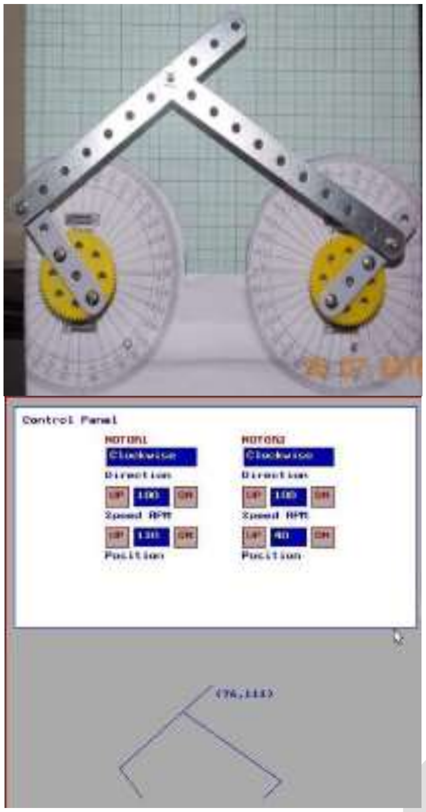


Fig. 4.6: Position 4 of set 1 of the two motors

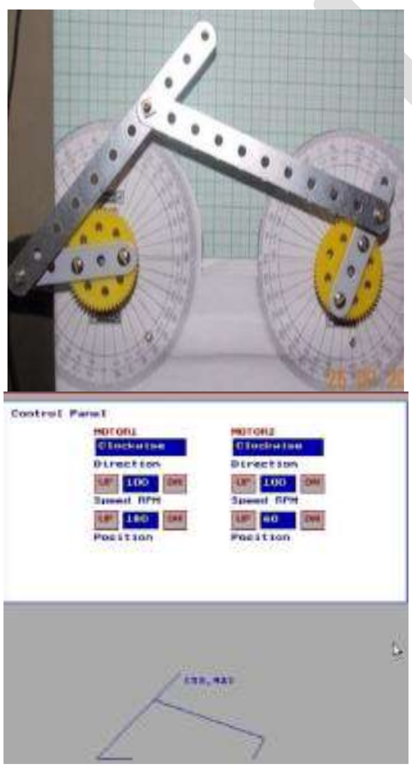


Fig. 4.7: Position 5 of set 1 of the two motors

Following figures show the hardware results achieved same as the software results.

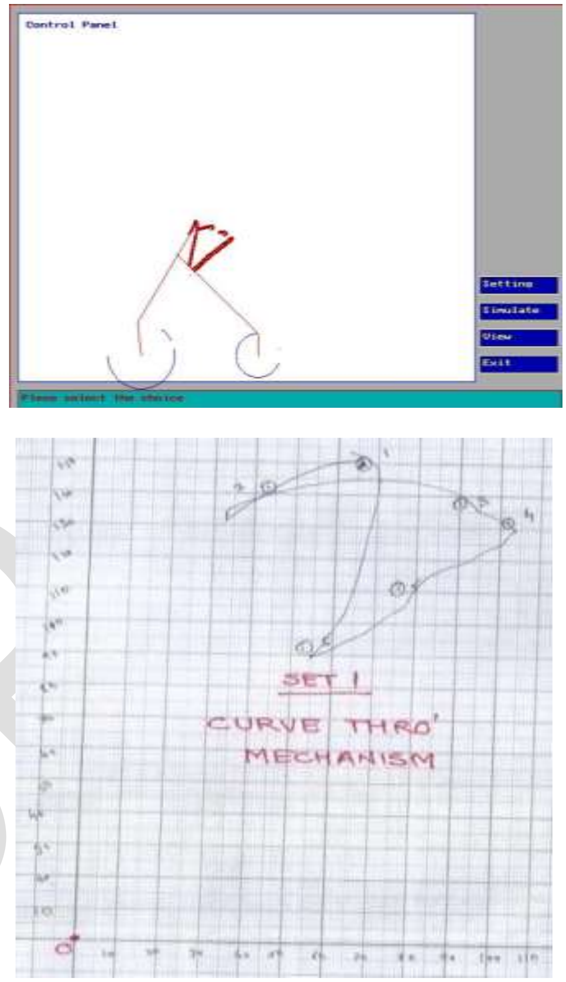
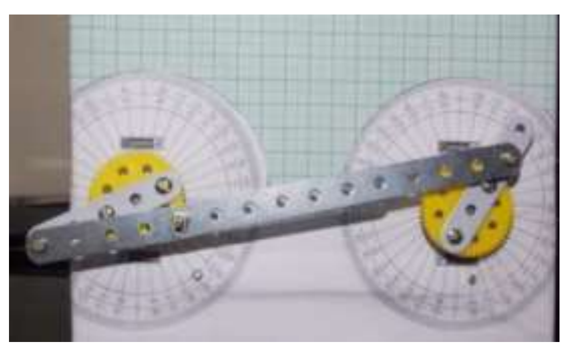
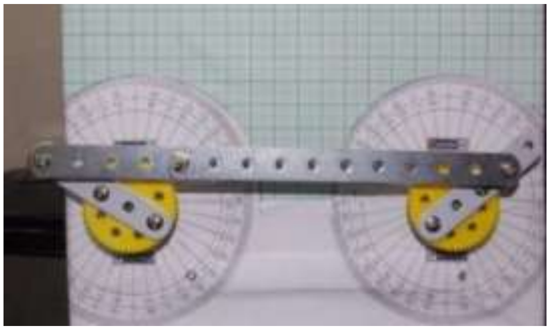


Fig. 4.8: Comparison of Simulation with Actual Curve

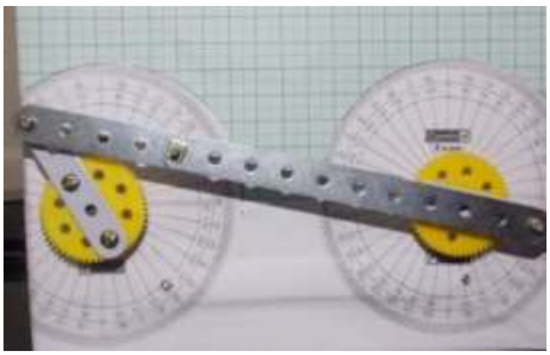
Similarly for set two and set three of co-ordinates the above procedure is repeated. Only when locking of mechanism will occur, procedure will be different. First of all the locking condition of mechanism should be studied. Following fig shows example of locking conditions and how the mechanism will get locked.



a) Locking condition 1



b) Locking condition 2



c) Locking condition 3

Fig. 4.9: Locking conditions of mechanism

At locking conditions the speed rules will remain the same but as the locking angles are known namely the range –LTH1 to + LTH1 for theta 1 and –LTH 2 to + LTH 2 for theta 2 the fuzzy logic gives 0 speed to the first length which reaches the locking range the second link will continue to pass the locking range and then link 1 continues the movement. The locking range indicates that simultaneously theta 1 and theta 2 cannot be in locking range.

V. RESULTS

TABLE VI
OBSERVATIONS OF 4 SETS

Sr. No.	Input		Output		% Error
	X	Y	X	Y	
	Set 1 Co-ordinates : No dimensional locking				
1.	66	150	66	150	0
2.	43	142	40	141	3.16
3.	90	138	91	140	2.23
4.	102	132	103	130	2.23
5.	76	111	77	110	1.41
6.	53	92	54	92	1.0
7.	66	150	66	151	1.0
	Set 2 Co-ordinates : No dimensional locking				
1.	66	150	66	150	0
2.	76	148	77	147	1.41
3.	93	120	94	122	2.23
4.	40	133	41	134	1.41
5.	55	138	56	139	1.41
6.	66	150	66	151	1.0
	Set 3 Co-ordinates : Dimensional locking : Safe				
1.	54	163	54	163	0
2.	82	109	83	111	2.23
3.	67	120	69	121	2.23
4.	94	135	96	137	2.82
5.	54	163	53	162	1.41
	Set 4 Co-ordinates : Dimensional locking : Locked				
1.	54	163	54	163	0
2.	82	109	83	111	2.23
3.	88	88	-	-	-
4.	37	146	-	-	-
5.	40	123	-	-	-
6.	54	163	-	-	-

Observe that in set 4, when the locking mechanism is connected, the first reading is correct but for the next point given, the point is not reachable/ the mechanism goes through the locking step. As the fuzzy logic avoids the locking by stopping the motor and reversing the direction, the next points cannot be reached. The basic purpose of the fuzzy logic is also to avoid the damage to the mechanism. The locking may occur due to dimensional limitations or the construction limitations as the screws connected, may result in locking. The particular point set is chosen to indicate the locking during the traversal. If the points are given without the locking the mechanism performs correctly. The motors can stop after locking but, in the code we have implementing the recovery from locking,

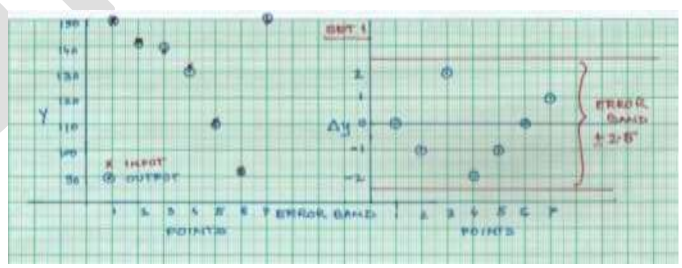


Fig. 5.1: Error Band

VI. CONCLUSION

A five bar mechanism control system, using DC motor, controlled by Fuzzy Logic Controller is design and fabricated in this project. The DC motor's speed is controlled using fuzzy logic for reaching the desired positions of mechanism. The Fuzzy logic is selected because it needs minimum speed changes to achieve desired co-ordinate position without overshoot i.e. retracing of the path. PID controller cannot avoid oscillations and response time is more than Fuzzy Logic Controller. In fuzzy we can define the rules to avoid particular angular positions in combination but in PID it will be a difficult task because in critical situation the overshoot will lock the system. The Fuzzy logic controller used will avoid locking of mechanism and will trace the desired co-ordinates.

The simulation for tracing desired coordinates is done the software. Hardware is simulated and tested for set of co-ordinates of locking and unlocking positions. It is observed that system traces path with an accuracy of ±2.5% but largely dependent on the mechanical system as the play in the links will increase the error. System will trace the path successfully avoiding locking conditions.

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