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Non-Linear Modelling and Performance Analysis of Robotic Arm using Fuzzy based Control System

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ABSTRACT: Modelling and control of 6 degree of freedom (DOF) robot arm is the aim. The main objective of this is in presence of uncertainties, FLC controller is used to control of highly nonlinear systems especially for multi degrees of freedom (DOF) serial links robot manipulator and control a robot arm using fuzzy logic controller (FLC) to acquire the desired position. The performance of FLC is then compared with well known conventional controller, Proportional integral derivative (PID). The comparison between the PID controller and FLC results in terms of overshoot, time response and steady-state error specifications. Based on simulation results, FLC gives better results than classical PID controller in terms of overshoot, time response and steady-state error. Through this study it is proved that the FLC is more efficient in the time response behavior than the PID controller.

KEYWORDS: Degree of Freedom (DOF), Fuzzy Logic Controller(FLC), PI controller

I. INTRODUCTION

Industrial robot manipulator field is one of the interesting fields in industrial, educational and medical applications. Research in control the motion and movement of industrial robot was the most concentrate field during recent year. Due to advance computer and visualization technology, robotic manipulator study is divided in two categories, mathematical modelling and computer modelling of the manipulator and the actuators, which includes an analysis for the forward kinematic, the inverse kinematic and modelling the direct current motor.

This study is focus on modelling an industrial robot manipulator and designing controller for the motion of the industrial robot manipulator meet the requirement of the desired trajectory or desired angle.

Robot manipulator is classified as a complex system due to nonlinear systems. Proportional Integral Derivative (PID) controller may be the most widely used controller in the industrial and commercial applications for the early decades, however, PID does not give optimal performance due to the nonlinear elements. Fuzzy logic controller (FLC) was found to be an efficient tool to control nonlinear systems.

Study of robot manipulators is classified into two main subjects: kinematics and dynamics. The study between rigid bodies and end-effector without any forces is called Robot manipulator Kinematics. Study of this part is very important to design controller and in practical applications. The study of motion without regard to the forces (manipulator kinematics) is divided into two main subjects: forward and inverse kinematics. Forward kinematics is a transformation matrix to calculate the relationship between position and orientation (pose) of task (end-effector) frame and joint variables. This part is very important to calculate the position and/or orientation error to calculate the controller's qualify.

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II. LITERATURE SURVEY

Fuzzy logic was first proposed by Lotfi A. Zadeh of the University of California at Berkeley in a 1965 paper. He elaborated on his ideas in a 1973 paper that introduced the concept of "linguistic variables", which in this article equates to a variable defined as a fuzzy set Other research followed, with the first industrial application, a cement kiln built in Denmark, coming on line in 1975. Interest in fuzzy systems was sparked by Seiji Yasunobu and Soji Miyamoto of Hitachi, who in 1985 provided simulations that demonstrated the feasibility of fuzzy control systems for the Sendai railway. Their ideas were adopted, and fuzzy systems were used to control accelerating, braking, and stopping when the line opened in 1987.

III. RELATED WORK

Research and development is also continuing on fuzzy applications in software, as opposed to firmware, design, including fuzzy expert systems and integration of fuzzy logic with neural-network and so-called adaptive "genetic" software systems, with the ultimate goal of building "self-learning" fuzzy-control systems.These systems can be employed to control complex, nonlinear dynamic plants, for example, human body.

IV. PROBLEM STATEMENT

Motion control is fundamental to many robotics applications, and is known to be a difficult problem. Execution in real world environments is confounded by noisy sensors, approximate world models and action execution uncertainty. A practical and mathematical model of industrial robot required many equations and consumed much time when it comes to design and experiment a real model. It has been proved that the benefit of design an industrial model in computer simulation had reduced the cost and time in designing and simulates an industrial robot. The complexity of the robotic tasks is getting more and more advanced, so an intelligent, robust, computationally simple and easy to implement controller must be designed and analysed to optimize and maximize the performance of industrial robot.

The problem statements of this study are:

i. Robot system and its mathematical modeling is very complex system, a computer software simulation is the easiest method to model a real robot without writing a code/programming and derive mathematical equation.
ii. Performing an experiment, a behavior and mechanism of a real robot may damage the robot and required lot of money, a robot modeling and computer simulation required to reduce the cost and time to study a robot system.
iii. PID controller is not sufficient to obtain the desired tracking control performance because of the nonlinearity of the robot manipulator, so nonlinear controller such as Fuzzy Logic is required to minimize and counter the nonlinearity issue.
iv. Conventional controller has issued in handling the time response, overshoot and steady-state error of a robot manipulator, this issue can be mitigate using nonlinear controller.

V. METHODOLOGY

One of the drawbacks for using the PID control techniques is that, they are not sufficient to obtain the desired tracking control performance because of the nonlinearity of the robot manipulator. Hence, a lot of time is required to tune the PID parameters. On the other hand, other techniques are used to overcome the previous problem, such as fuzzy controller that emulates human operation.

FLC is an emerging technique in control systems. It is considered as intelligent controller. Many studies show that the fuzzy controller (FC) performs superior to conventional controller algorithms. Zadeh did the main idea of FLC and fuzzy set theory. Mamdani and his colleagues have done a pioneering research work on FLC in the for engine steam boiler. The benefit of FLC is obvious when the controlled process is too complicated to be analysed using PID controller or when the information about the controlled system does not exist.

FLC is classified into two categories: the first, involves the fuzzy logic system based on a rule based on expert system, to determine the control action. The second used FL to provide online adjustment for the parameters of the conventional controller such as the PID control. This method attempts to combine the merits of FL with those control

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techniques to expand the capability of linear control technique to handle the nonlinearity in the physical system. Fuzzy supervisory is used to reduce the amount of tuning the PID controller with a fuzzy system. It is considered as an attractive method to solve the nonlinear control problems, one of the advantages of fuzzy supervisory that the control parameters changed rapidly with respect to the variation of the system response.

The fuzzy supervisor operates in a manner similar to that of the FLC and adds a higher level of control to the existing system. Fuzzy supervisory is hybrid between the PID controller and FLC that designed to overcome the problem of tuning PID in nonlinear systems using FLC as an adaptive controller. The basic structure of FC resembles the structure of PID controller, but the controlled parameter of PID controller depends on the output of the fuzzy controller.

VI. SYSTEM SETUP

The servomotor was controlled using an PIC microcontroller board. The microcontroller was used to interface the servomotor with Matlab / Simulink environment.

The microcontroller utilizes a series of square pulses to control the position of the servomotor. The width of the pulses corresponds to the reference angle of the servomotor. When the reference angle is input into the servomotor, the embedded servo controller computes the control input needed to track the reference angle, and applies the appropriate voltage to the motor.

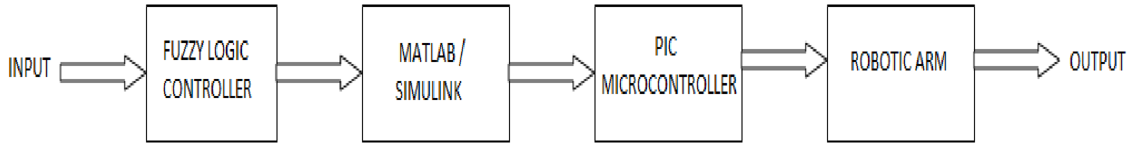

Fig. 1: The block diagram of the entire system

The first step to analyse forward kinematics is link descriptions. This item must to describe and analyse four link and joint parameters. The link description parameters are; link length, twist angle, link offset and joint angle. The second step to compute Forward Kinematics (F.K) of robot manipulator is finding the standard D-H parameters. The Denavit-Hartenberg (D-H) convention is a method of drawing robot manipulators free body diagrams. Denvit-Hartenberg (D-H) convention study is compulsory to calculate forward kinematics in robot manipulator.

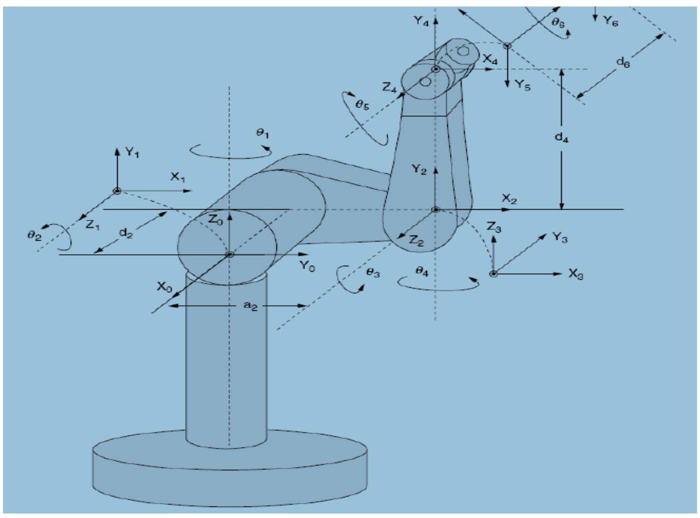

Fig.2: Modelling of Robotic Arm

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Automatic control has played an important role in advance science and engineering and its extreme importance in many industrial applications, i.e., aerospace, mechanical engineering and robotic systems Fuzzy controller (FC) is robust nonlinear intelligent controller. In this methodology the main controller is sliding mode controller and fuzzy logic controller is applied to it to estimate the nonlinear dynamic formulation in presence of uncertainty and external disturbance. '**Wu et al'** have proposed a PI sliding mode controller with fuzzy logic tuning controller for Electro-Hydraulic Driving. In this research authors first of all design PI sliding mode controller based on switching function and equivalent dynamic equations and after that design fuzzy logic estimator that design parallel with PI sliding mode controller to estimate the nonlinear equivalent functions.

Fig.3: Hardware Set-up

Fuzzy Controller Operation: A robot manipulator considers as a nonlinear and MIMO system with outputs available measurement and possibility to input change. According to design sliding mode controller, this controller can be used as a controller when it has a satisfying result and system is easy to implement but if some information about robot manipulator operation or controller is available and it can be formulated as a set of rules and fuzzy controller is used to control of robot manipulator. However, the application of fuzzy logic controller is really wide, all types of fuzzy logic controllers consist of the following parts:

- Choosing inputs
- Scaling inputs
- Input fuzzification (binary-to-fuzzy[B/F] conversion)
- Fuzzy rule base (knowledge base)
- Inference engine
- Output defuzzificat ion (fuzzy-to-binary[F/B] conversion)
- Scaling output

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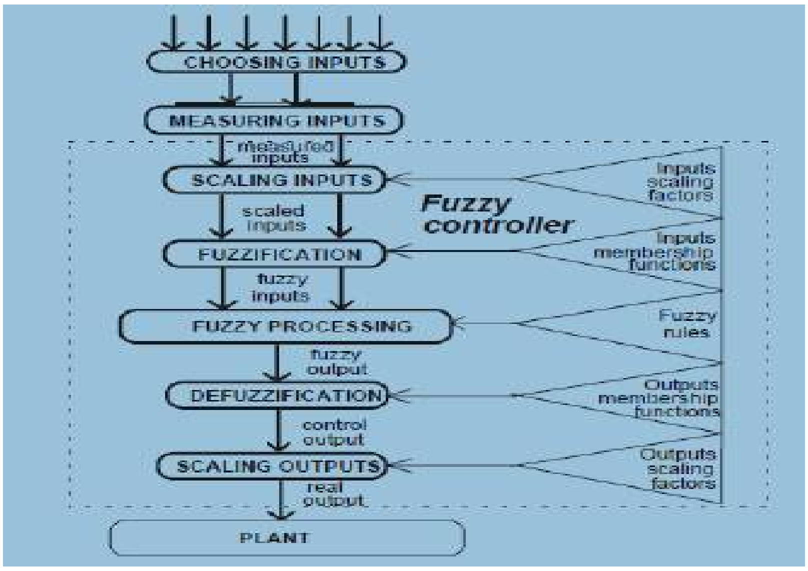

Fig.4: Fuzzy Logic Controller Design

Mamdani fuzzy inference system based on 49 rule bases was design and analyzed. This controller was nonlinear model free and the main challenges in this design is reliability and this item is one of the most important part to select the best method of control design. The Rule Viewer displays a roadmap of the whole fuzzy inference process. It's based on the fuzzy inference diagram, each rule is a row of plots, and each column is a variable. The first two columns of plots show the membership functions referenced by the antecedent, or the if-part of each rule. The third column of plots shows the membership functions referenced by the consequent, or the then-part of each rule.

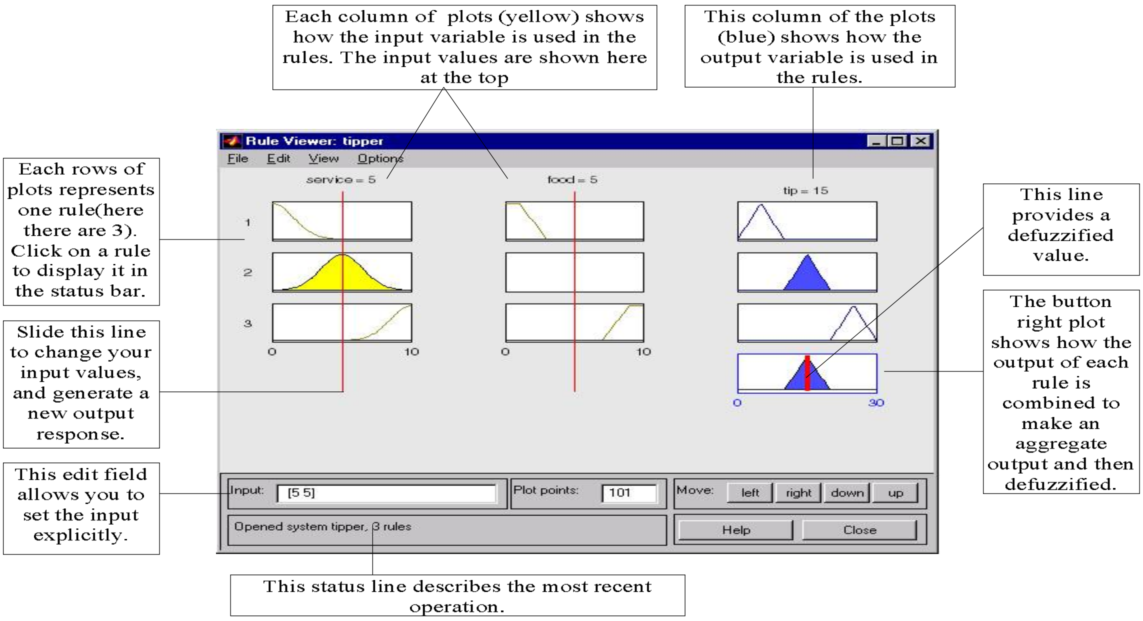

Fig.5: Output of Fuzzy Logic Controller

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De-fuzzification is the process of producing a quantifiable result in Crisp logic, given fuzzy sets and corresponding membership degrees. It is typically needed in fuzzy control systems. These will have a number of rules that transform a number of variables into a fuzzy result, that is, the result is described in terms of membership in fuzzy sets. A common and useful defuzzification technique is center of gravity.

De-fuzzification methods used in this are:-

1. Centroid
2. Center of sums
3. Height
4. Center of sets.

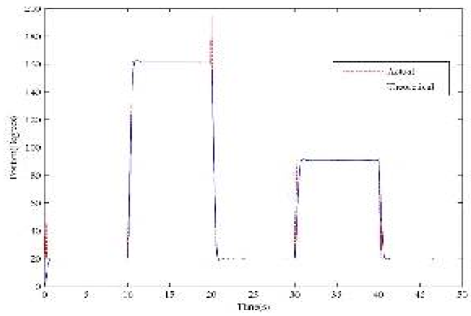

Fig.6: Actual measured output vs theoretical estimated response

VII. RESULTS AND DISCUSSION

A closed loop PI-controlled system was set up and the PI controller was tuned using the Ziegler-Nichols method followed by hand tuning. The tuned gains were:

$$Kp = 1, Ki = 1.5$$

The result of these studies has shown that fuzzy logic is indeed a powerful control tool, when it comes to control system or process. Some studies have also shown that fuzzy logic performs better when compared to conventional control PI. There are specific components characteristic of a fuzzy controller to support a design procedure. The controller is between a pre-processing block and a post-processing block.The tuned gains of the PI controller were then used to compute the gains of the fuzzy logic controller. The execution time of each defuzzification method was recorded as well. The execution time is the average total amount of time taken by the controller to compute the output at a single point. Table I : Depicts the IAE, as well as the execution time for each defuzzification method. The performances of all the methods are plotted.

Defuzzifcation Method	IAE	Execution Time
Centroid	381.0	0.00703 s
Center of Sums	402.35	0.00683 s
Height	387.4	0.00553 s
Center of Sets	382.65	0.00829 s

Table I : IAE & Execution time of different defuzzification methods

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VIII. CONCLUSION

Real-time implementation of the FLPIC to control the position of a DC servomotor, which controls a robotic arm was successfully done. Different de-fuzzification methods were tested. The tests revealed the superiority of the Centroid method over the other methods. Overall, FLPIC showed much improved performance over the conventional PI controller, as well as the PID controller. This improvement is evident when handling uncertainty and impression induced in the system by means of noise and sudden disturbances.

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