Parameter Estimate PID Controller for Multi-position Control of Servo Drive System with Fuzzy Self-Tuning

Pantawong Visavapiwong *, Sasithorn Chookaew, and Suppachai Howimanporn

Department of Teacher Training in Mechanical Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand
Email: s6302017810041@email.kmutnb.ac.th (R.V.); sasithorn.c@fte.kmutnb.ac.th (S.C.); suppachai.h@fte.kmutnb.ac.th (S.H.)
*Corresponding author

***Abstract*—This research aims to study the application of fuzzy logic to optimize parameter values for adjusting the control parameters in the servo drive that uses the movement of the servo motor. Process automation requires the convenient and quick control of distance, speed, and acceleration by using a Programmable Logic Controller (PLC) to command, display, and control as accurately and thoroughly as possible significantly reducing the tolerances to a minimum. This research compares the experimental results between manual tuning parameter settings and parameter adjustment using the proposed fuzzy logic system. It also collects movement speed and position with different loads. The experimental results are different weights that compare and find efficiency values and tolerances. The fuzzy logic results are more satisfactory than using the original in all cases.**

***Keywords*—servo drive, fuzzy logic controller, programmable logic controller, Proportional Integral and Derivative (PID) controller**

I. INTRODUCTION

Nowadays, servo systems play a considerable role in the industry such as mechanical arms for picking up workpieces, metal welding robots, and cargo delivery robots. They all have a servo system as a component because they have constant torque. They are accurate in position and have high efficiency [1]. The AC servo system consists of a processor frequency conversion unit and an AC servo motor with an encoder. The frequency converter unit supplies electricity to the rectifier unit, which sends electricity to the AC servo motor. The type of AC servo motor is a synchronous brushless motor. The core is a permanent magnet surrounded by copper coils, and at the end of the AC servo motor is an encoder. The feedback signal for the position of the motor shaft back to the processing unit [2]. In the AC servo system, in position control mode, when the load weight changes it is necessary to adjust various parameters to maintain the stability of the system. The suitable adjusting of the system parameters will result in stable system stability and increased efficiency. However, it takes work to adjust the servo drive parameters to perfection. Most users need to use the user's experience to set it up. The current use of fuzzy logic was invented by L.A. Zadeh in 1965 as a doctoral dissertation. Fuzzy logic is logic based on the fact that many events occur similarly. It is impermanent and creates uncertainty. It is ambiguous for example, the set of ages might be divided into infancy, childhood, adolescence, middle age, and old age [3].

The Programmable Logic Controller: PLC is a device like the human brain commonly used in industry to control engineering work. It is a device that consists of an embedded system to control process data and has a system that can communicate with various industrial equipment such as metal detection sensors, weight sensors, limit switches, relays, etc. In addition, the ability to connect to wireless IoT systems to transmit data, import data, perform wireless commands, and check various statuses through the IoT system. Therefore, PLCs are widely used in industrial processes in automated production lines for quality control. Increase system reliability increase production quality reduce production costs [4] PLCs are used for engineering control. Because the PLC system has functions to support a variety of applications. Both in terms of processing receiving values from digital sensors analog readings Programmable Logic Controller (PLC) programming is under the IEC 61131-3 standard and can support highly complex systems and can send various values through the IoT system for use in industry 4.0 especially mathematical processing capabilities to store data [5]. PLC also has mathematical processing capabilities for data collection. Everyone likes to apply PLC for processing. PLC is widely used for control in industry, and there is also research into fuzzy logic control. Simulating the experiment within computer software shows that the fuzzy Proportional Integral and Derivative (PID) system adjustment has a fast response and good efficiency [6]. Lian *et al.* [7] investigated the self-

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adjustment of a Permanent Magnet Synchronous Motor (PMSM) system using a fuzzy logic system to adjust the PID parameters by simulating computer software experiments. The experimental results show that using a fuzzy logic system for adjustment gives a good response. Alzarok [8] researched speed control of DC motors with fuzzy logic systems using theory Ziegler-Nichols and simulated experiments through the computer system. Jin *et al.* [9] used fuzzy logic theory to study the high-resolution control of brushless DC motors (BLDC) and PID self-tuning. From the literature the researcher has reviewed, most of the research is simulated within a computer through the MATLAB program. Therefore, the researcher has an idea to create an experimental set to be tested for this research to compare the experimental results with existing literature.

II. Methodology

AC servo systems are widely used in manufacturing engineering. Automation manufacturing wants to control products efficiently and precisely to meet standards. Especially in industrial production, controlling the position for product line movement speed is necessary. Adopting a motor with position control capability to speed easily and quickly is the AC servo motor system. It provides precise control of position, speed, and torque. The servo system consists of a servo motor and a servo driver. Signals from PLC control the servo driver. Generally used include position, speed, torque, and position control loops. Many studies have focused on maximizing efficiency. They significantly reduce mistakes that will cause product loss. In addition, adjusting the parameters of the AC servo system to work with the appropriate position, speed, and torque control loops is necessary. Ali *et al.* [10] applied a Proportional Integral (PI) controller with an AC servo system, which gave satisfactory experimental results. However, external loads are changed or disturbed when the system operates. The changes in system parameters will affect system stability. Therefore, to stabilize the movement it is necessary to adjust various parameters in real-time [11]. PLC and AC servo motors as shown in Fig. 1(a) and (b).

(a) (b)

Fig. 1. (a) Programmable Logic Controller (PLC) (b) Servo Motor and Driver.

The fuzzy logic theory is proposed to solve problems with uncertain decision systems. There is ambiguity or complicated [12]. Fuzzy logic refers to the logic of approximation that allows different levels of truth, such as very cool, cool, hot, and very hot [13]. The fuzzy logic theory has been widely applied using processing from embedded coding controller systems such as robots and image processing security systems and telecommunications for decision systems. The fuzzy logic has the following processes fuzzification is converting input values into fuzzy system definitions. The rule gives weight to values obtained from membership functions in the input for the clarity value of the fuzzy set. Defuzzification is converting data into precise consistent results [14]. The fuzzy logic theory is applied to adjust the gain parameters of Proportional Integral and Derivative (PID) system controllers. Many researchers have calculated data using fuzzy logic controllers. The fuzzy logic theory is applied to adjust the gain parameters of PID controllers. The fuzzy logic theory is applied to adjust the gain parameters of PID controllers. Research has calculated data using fuzzy logic controllers. The calculated results adjust the PID controller gain value, K_P, K_I, K_D. A system adjusting PID gain with fuzzy can improve the optimization efficiency [15]. The fuzzy logic theory diagram is shown in Fig. 2.

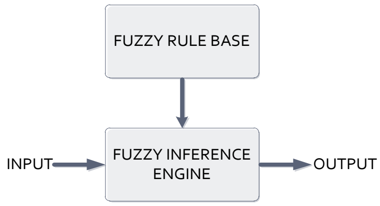


Fig. 2. Inference in fuzzy logic application.

Hardware systems can perform fuzzy logic processing, but there will be some limitations such as making system changes difficult. There are difficulties in the design. If the system is complex, the design will be complicated and there is a high cost. Therefore, someone invented a computer system to perform mathematical calculations instead of a hardware system [16]. Fuzzy logic can be applied to modify the servo system's PID parameters by processing various values or data in the fuzzy logic system and using the calculated results to alter the parameters of the servo system. Servo system for maximum efficiency [17]. Fuzzy Logic can use the LabView software to analyze inputs and create outputs from this article can concluded that the LabView software can be connected to a PLC through an Open Platform Communications (OPC) server to read data from the PLC and analyze it using the fuzzy logic process [18].

PID fuzzy control system is a type of control system that is designed by combining PID control system and fuzzy control. PID control is controlling the entry of a target with a probability algorithm reliable but also depends on the model parameters. Fuzzy control can be adjusted manually to achieve the system's best results as shown in Fig. 3.

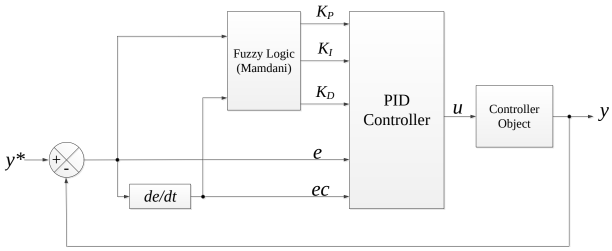


Fig. 3. PID tuning with fuzzy logic control.

$$e(k) = y^{*}(k) - y(k-1) \quad (1)$$

$$\dot{e}(k) = \frac{e(k)-e(k-1)}{T} \quad (2)$$

$$u(k) = K_P \left[e + \frac{1}{T_1} \int_0^t e(t)dt + T_D \frac{de(t)}{dt} \right] \quad (3)$$

$$u(k) = K_P e(k) + K_I \sum_{i=0}^{k} e(i) + K_D \left[e(k) - e(k-1)\right] \quad (4)$$

where y^{*} is the system input signal. $y(k-1)$ is the system feedback signal. $e(k)$ is deviation of the system input signal and feedback signal. $\dot{e}(k)$ is the rate of change of deviation signal. T is the sampling period. K_P is proportional gain. K_I is integral gain. K_D is derivative gain. The PID system consists of the following parameters: K_P, K_I, K_D These three parameters all affect the system performance as shown in Fig. 4.

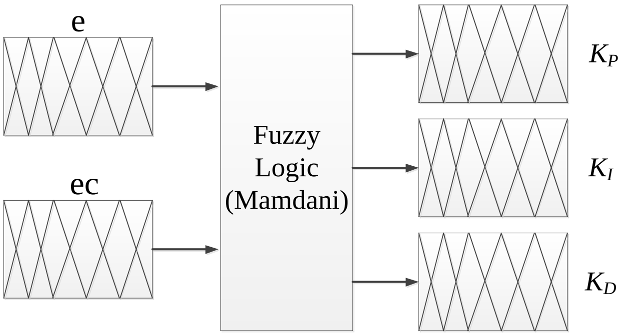


Fig. 4. Fuzzy logic PID controller model.

A. PLC and Servo Driver Communication

The Mitsubishi AC servo set model MR-J3-10B was chosen for this research. It has a QD77MS16 module that communicates, controls, and adjusts various servo drive parameters set by contact. The communication is fiber optic as shown in Fig. 5.

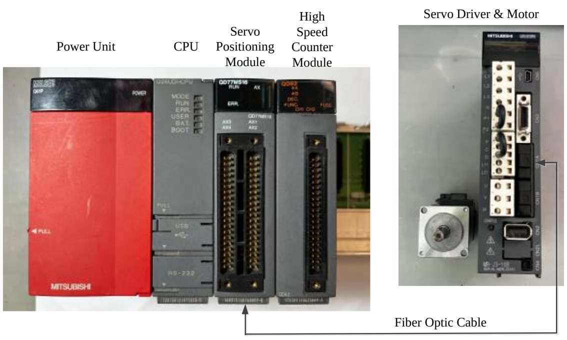


Fig. 5. PLC and servo drive communications.

In this research, it is necessary to adjust the parameters of the servo drive in real-time. This requires the properties of the module to transmit the parameters obtained from the calculation of fuzzy logic theory or manual adjustment to the servo drive. The module commands the servo drive to move to a position at a specified speed and reads various data values from the servo drive unit to forward to the CPU for data analysis based on the experimental hypothesis the researcher designed the experimental diagram as shown in Fig. 6.

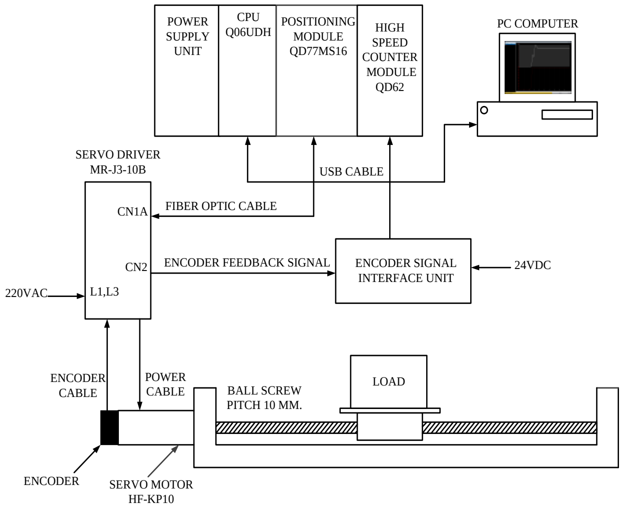


Fig. 6. Block diagram.

Fig. 7 shows the experimental set produced according to the design diagram in Fig. 6 to collect data and use it to analyze the experimental results in this research.

Fig. 7. Experimental set created for this research.

B. GT Designer 3 and SoftGOT 2000 Software

The research experiment uses a unit to process, configure, and display system signal values. Mitsubishi Company has the GT Designer 3 software that can write a program to bring deals from variables in the PLC to display. The user can operate through various control buttons on the display screen. Set different variable values and send values to the PLC program from the computer screen as shown in Fig. 8.

Fig. 8. GT Designer 3 program.

The SoftGOT 2000 software is software used for connecting programs designed by GT Designer 3 and the PLC ladder program inside PLC unit. The PLC model and communication channels between the SoftGOT 2000 software and the PLC must be specified correctly. Many communication channels can be identified, and this research will use the USB port communication channel as shown in Fig. 9.

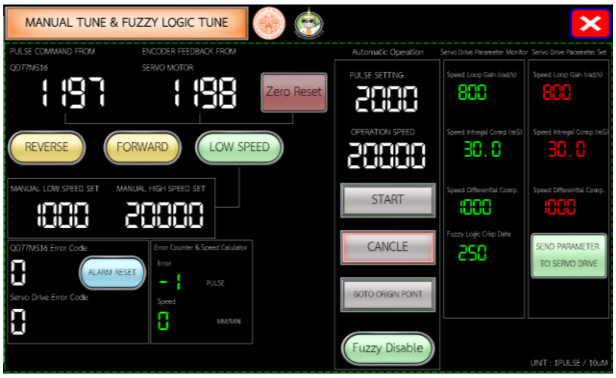


Fig. 9. GT SoftGot 2000 software running.

C. Fuzzy Logic Design

In this research, the MATLAB 2022b program designs and calculates values in the fuzzy logic system with the following members. The speed of movement (Speed) and the difference between the movement command and the distance measured from the direction of the ball screw (Error) are calculated. The output values obtained from the calculation are sent for adjustment. Servo drives parameters through the QD77MS16 module while moving in real-time. The adjustment frequency period is 10 ms as shown in Fig. 10.

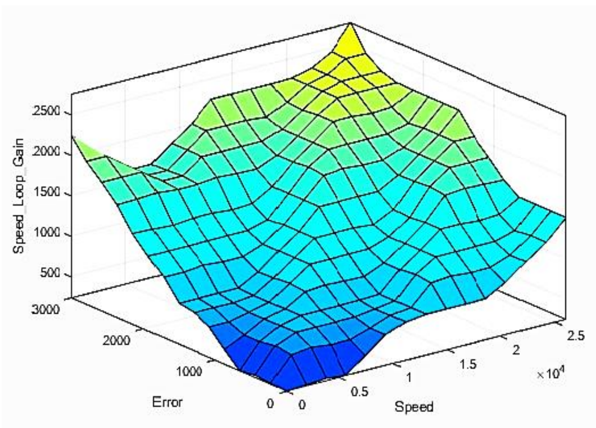


Fig. 10. Simulation result of output control with the fuzzy logic controller in MATLAB 2022b.

Fig. 11 shows the experimental simulation results using the MATLAB 2022b program setting the speed at 4200 mm/min and the difference between the movement command and the distance measured from the movement is equal to 799 the result shown 700.

Fig. 12 shows the values calculated with the PLC program by setting the speed the difference between the movement command and the value measured from the movement (Error) and the values that the MATLAB 2022b simulation software will produce. The resulting value is 671.

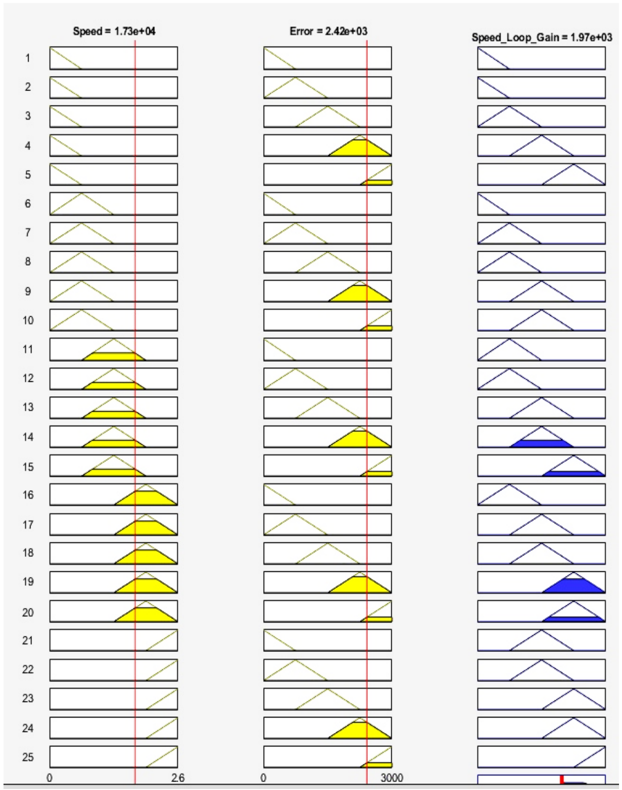


Fig. 11. Simulation data result of output control with the fuzzy logic controller in MATLAB 2022b.

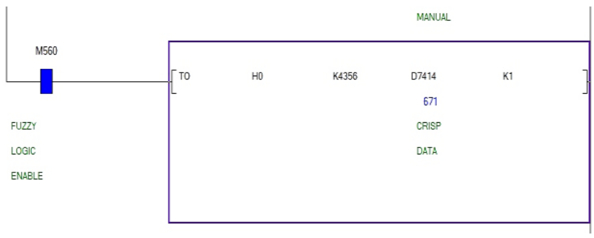


Fig. 12. CRISP data calculate from PLC program.

III. Experimental Result

Table I shows the manual adjustment of the speed loop gain parameter using random values with a set point of 90.00 mm. a travel speed 10,000 mm/min and no payload. When the parameters are not appropriate it will affect the system's movement causing vibrations when starting to move. The system vibrates while approaching the set point and the stopping distance error value is lower than the set point as shown in Fig. 13. Randomly adjusting the parameters can make the system move more efficiently but it is necessary to experiment with the adjustments many times. If the system changes, such as the speed of movement stiffness of the mechanical system and the payload it will immediately affect the system's efficiency movement of the system as shown in Fig. 14.

TABLE I. PARAMETER TUNING BY MANUAL METHOD NO LOAD AND SET POINT 90.00 MM

No.	Speed (mm /min)	Speed Loop Gain	Speed Integral Compensation	Speed Differential Compensation
1	10000	30	33.7	980
2	10000	40	33.7	980
3	10000	50	33.7	980
4	10000	60	33.7	980
5	10000	100	33.7	980
6	10000	200	33.7	980

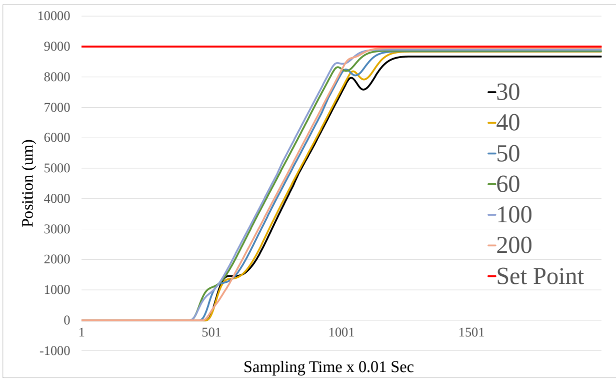


Fig. 13. Experimental result of parameter tuning by manual method.

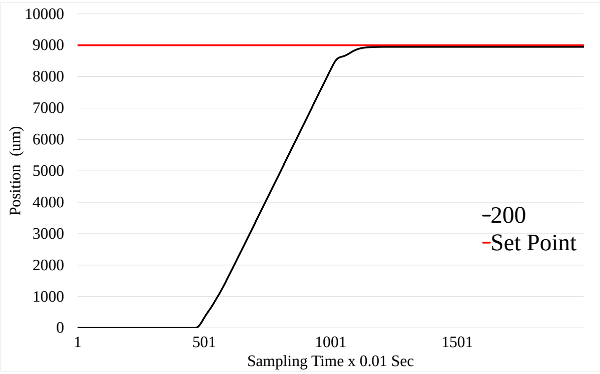


Fig. 14. Experimental result of parameter tuning by manual method speed loop gain 200 rad/s.

Table II is the experiment of changing the payload without changing the servo drive parameters.

TABLE II. PARAMETER TUNING BY MANUAL METHOD AND DIFFERENCE LOAD CHANGE LOAD SPEED 10,000 MM/MIN

No.	Load (g)	Speed Loop Gain	Speed Integral Compensation	Speed Differential Compensation
1	1,000	200	33.7	980
2	3,300	200	33.7	980

The Table II shows the experimental system movement with change a pick-up load between 1000 g and 3,300 g. In Fig. 15 shows a result when difference pick-up load. At the beginning of the movement there is a jerk. When moving closer to the set point there was an overshoot of approximately 2% and it returned to the set point a short time later. When comparing the movement between a loading weight of 1000 g and a weight of 3300 g as the load weight increases the time to start moving and reach the set point takes longer.

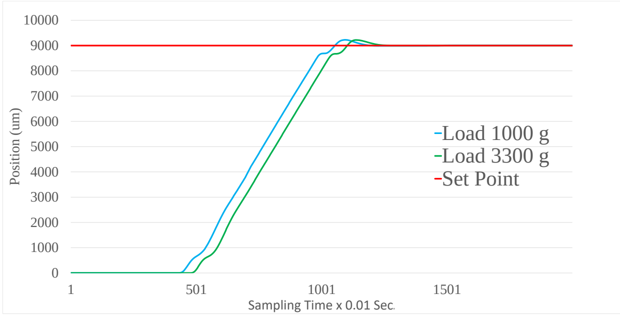
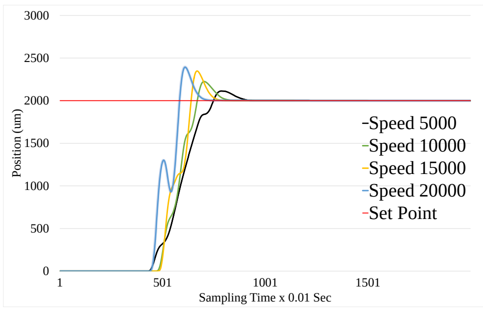


Fig. 15. Experimental result of parameter tuning by manual method difference load.

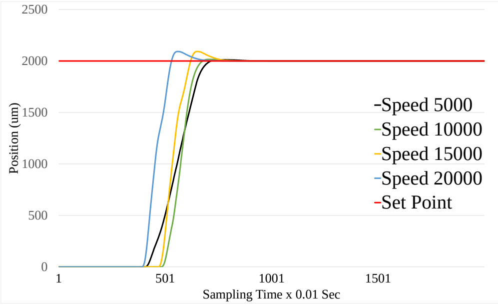
The data in Table III shows the movement of the system with the movement speed adjusted. The experiments in topics 1–4 don't change system parameters. The experimental results show that when the movement speed is low when the system starts moving the jerk will be less than when driving at high speed. When moving closer to the set point the overshoot rate will be less than when moving at high speed. The graph experimental results shows that when the movement is set to a very high speed, such as 20,000 mm/min the movement takes less time to reach the set point than when moving at a low speed, but the system will experience severe jerking. The overshoot rate before the set point is very high as shown in Fig. 16(a). The experiments in topics 5–8 use a fuzzy logic system to adjust real-time parameters. The results show that when the system moves smoothly there are no vibrations or jitters and at a speed of 5000–10,000 mm/min it shows no overshoot and can move entirely to the set point. However, a slight overshoot was detected when the movement speed was increased to more than 10,000 mm/min. It took less time to reach the set point at higher movement speeds as shown in Fig. 16(b).

TABLE III. PARAMETER TUNING BY MANUAL METHOD AND NO LOAD AND DIFFERENCE SPEED SET POINT 20.00 MM

NO.	Speed (mm/min)	Speed Loop Gain	Speed Integral Compensation	Speed Differential Compensation
1	5000	200	33.7	980
2	10000	200	33.7	980
3	15000	200	33.7	980
4	20000	200	33.7	980
5	5000	Fuzzy	Fuzzy	Fuzzy
6	10000	Fuzzy	Fuzzy	Fuzzy
7	15000	Fuzzy	Fuzzy	Fuzzy
8	20000	Fuzzy	Fuzzy	Fuzzy



(a)

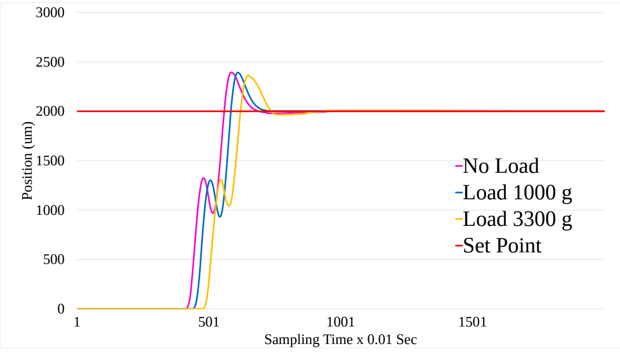


(b)

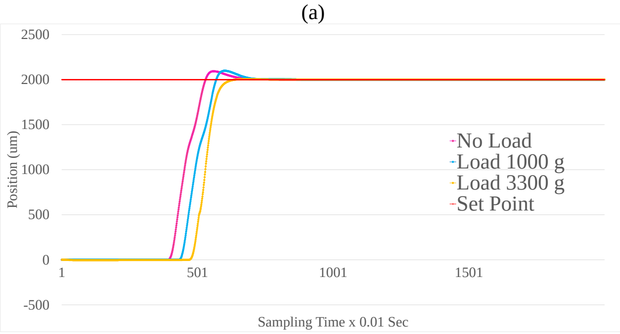
Fig. 16. Experimental result of parameter tuning (a) by manual method difference speed; (b) by fuzzy logic method difference speed.

TABLE IV. PARAMETER TUNING BY MANUAL AND FUZZY LOGIC DIFFERENCE LOAD AND SET POINT 20.00 MM. SPEED 10,000 MM/MIN

No.	**Load (g)**	**Speed Loop Gain**	**Speed Integral Compensation**	**Speed Differential Compensation**
1	No Load	200	33.7	980
2	1000	200	33.7	980
3	3300	200	33.7	980
4	No Load	Fuzzy	Fuzzy	Fuzzy
5	1000	Fuzzy	Fuzzy	Fuzzy
6	3300	Fuzzy	Fuzzy	Fuzzy



(a)



(b)

Fig. 17. Experimental result of parameter tuning by (a) manual method difference load; (b) fuzzy logic method difference load.

The data in Table IV shows the experimental movement of the system with the load adjusted. It has a constant moving speed 10,000 mm/min. The experiments in topics 1–3 use the system parameters according to the information in Table II settings are manual. Perform a movement test with no payload with a load of 1000 g and 3300 grams. The results of the experiment show that while there is no load the moving system has a jerk and a high overshoot rate when a load of 1000 g and 3300 g is applied respectively the system still has a jerk and the overshoot rate is high as is the low payload. The steady state time to reach the set point is longer as shown in Fig. 17(a). Experiments in topics 4–6 use a fuzzy logic system to adjust real-time parameters. The results show that when the system moves smoothly, there are no vibrations or jerks and an overshoot rate, only slightly as shown in Fig. 17(b).

The fuzzy logic system to help decide on parameters and send those parameters to the servo drive to adjust in real-time makes the system very stable both in terms of changing the speed of movement and in terms of changing the payload value, as can be seen from past experiments, it can be concluded that using the fuzzy logic system to automatic adjusting the parameters of the servo system makes the system very efficient.

IV. CONCLUSION

A Mamdani fuzzy logic system is used in this research to adjust the parameters of the servo system in real-time. The fuzzy logic system can adjust the PID parameters of the servo system making the servo system more efficient while changing speed or load compared to manual adjustments. This method can be concluded that using fuzzy logic to adjust the PID parameters of the servo system is more efficient than manual adjustment. Future research development guidelines should use the neuron fuzzy system instead of the traditional fuzzy logic system to compare the performance of the two fuzzy logic systems.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHOR CONTRIBUTIONS

R.V. conducted the research. S.H. and C.S. analyzed the data, all authors had approved the final version.

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