Robust Altitude Control of a Quadrotor with Self Tuning via Embedded PLC and Dashboard

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***Abstract*—Robust performance improvements useful in engineering to achieve the best quality of produce popular development focus on applying control and communication technology to achieve greater efficiency. In addition, stability is essential in engineering as it must be resistant to environmental or changing conditions. This research presents an improvement in the control performance of the quadrotor position output signal by adopting an industrially popular Programmable Logic Controller (PLC) to demonstrate the ability to control and communicate in display and control via OPC-UA communication. The experimental present can be applied to control applications very well. The operation data can be transmitted in real-time satisfactorily. Control research has focused on improving the durability of the quadrotor's control at different target levels by using the fuzzy controller to determine the optimal amount of feedback signal region over time and to compares with the design of the PID controller by the mathematical model with the fuzzy controller design presented in this study can change the control value according to the target signal at different levels. The experimental results found that could optimize fuzzy controller embedded PLC could have the reasonable control of keeping the target position even changing the target altitude to other functions.**

***Index Terms*— self tuning, quadrotor, fuzzy controller, PID controller, programmable logic controller**

I. INTRODUCTION

Improving and optimizing the output signal before it is used in engineering is very important and necessary; due to the desired target signal, it changes according to the conditions of the design of the work to be appropriate. In addition, the incoming call interferes with the system that often occurs. The result for control signal does not meet the target signal that has been set. Therefore, ensuring the quality of the control signal matches the target signal in its initial and steady state is a critical requirement in control engineering. In a closed-loop automatic control system, the signal pattern changes oscillation. Process control starts by measuring the parameters to be controlled, such as position, speed, heat, strength, and converts the parameters into electrical signals to be received into the control device. Nowadays, digital control devices are commonly used for a transformation of signal to control parameter signal from convert an analog signal to digital signal by conversion board. The parameters are received into the controller's memory, conditions can be created and solved by programming or entering controller theory or a programmable system that can intelligently analyze the optimal output quantity and send it to the process for maximum efficiency. Many research focuses on maximizing efficiency using intelligent systems. For example, Research [1] proposes a fault-tolerant control design by applying feedback delay and slide-mode feedback (SMC) feedback techniques to the quadrotor to provide higher durability. Research [2] proposes linear feedback control using metric function estimation techniques to control the piezoelectrical by adjusting parameter to improve performance. In research [3] proposes improvements to fog node devices used in automated production systems. Ethics to be more efficient by setting according to the nature of the space-time to be suitable for the working conditions, the research [4] presents an analysis of the reliability of the smart grid system in the electrical network from renewable energy sources ensuring user confidence. In research at [5] proposes improvements in the efficiency and solutions of the control of electrical power applications through communication with the internet of things controllers, enabling intelligent power management. Research [6] has proposed a novel control application method for compensating internal feedback and setting point error control of a conveyor system to makes the signal received from the control more increasing efficient. Research [7] offers an impression of the effectiveness of the electrocardiogram device mechanism to monitor the heartbeat to monitors performance degradation in real-time and improves performance. The research collected detailed data over the device's entire lifespan. Study [8] proposes an algorithm using hybrid fuzzy-PID controllers to control a quadrotor to moves 6 degrees of freedom for control position stability in various situations. The research [9] presents the use of IoT to design and implement a real-time monitoring system for farming in the mekong delta. to improve reliability and reduce maintenance costs. From the research above, it can be seen that increasing intelligence and the use of IoT systems brings benefits to a wide range of tasks, focusing on improving efficiency, reducing costs, and self-making decisions.

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A. Signals Processing and Control

Improving target parameter signals to be as accurate and complete as possible is a trend of research because the target parameter signal is often derived from a transformation from the original signal to a new signal that is ready for further use. In control system engineering, how to control the signal according to the target signal is the most important thing. The control signal needs to be durable. The high stability, low noise, and the value are closest to the target signal. An automation or intelligent system is essential to employ the principle of a closed-loop control system to compare the target and feedback signal to improve quality. Fig. 1 shows that the quadrotor's altitude control position is controlled according to the set positions 15 cm, and 20 cm, respectively. A sudden change in height will cause the control signal to have an error. Therefore, it is interesting to calculate the appropriate gain by self-tunning to the controller.

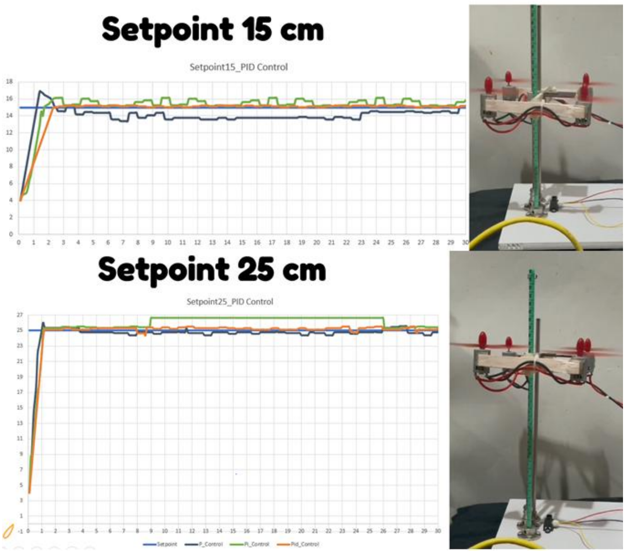

Figure 1. Real-time control.

B. Programmable Logic Controller Technology

The controller's device of processing and control is used, a programmable logic controller come to use it to be able to set conditions and increase intelligence. functions using communication networks database system within the control device, currently works requiring high stability use programmable logic controllers. Numerous studies have used programmable logic controllers to optimize intelligence, such as research at [10] provides an overview of the state of operations why industrial technology has developed programmable logic controller technology, presenting a critical analysis of the strengths and weaknesses of prominent programming styles for the automation systems used. at present. Research [11] proposes an automation analysis method that can learn the behavior of PLCs and develop a state that can combine with function blocks for use in industrial 4.0 systems. In research [12] used a PLC to control the position of a directional wheel conveyor, decides the output signal according to the size of the fault signal with a fuzzy logic controller. Study [13] proposes the use of PLCs to automatically code the PLC programming language according to IEC 61131–3, it is used to determine the parameters suitable for use in real industrial environments and is presented. The results of applications to control multivariate chemical plants on hardware in the loop. In research [14] presents the use of fuzzy to optimize parameters of multi-point data routing used in vehicle ad hoc networks with the proposed protocol. It looks at the common problem of end-to-end packet transmission ratio and end-to-end latency. The research [15] presents the use of a fuzzy controller to determine the suitability of an energy storage system in conjunction with other energy sources to minimize fuel consumption. In study at [16] the optimum parameterization is presented to make the mechanical system more environmentally resistant by a fuzzy regulator with the control rules adjusted to suit the status quo. The research [17] proposes using neuro-fuzzy to control the power capacity of solar panels connected to a grid connect system and increases efficiency and prevents damage caused by abnormal power system conditions. Research [18] proposes self-adjusting fuzzy control values in closed-loop control systems based on the results to provide results. reach the goal with high efficiency.

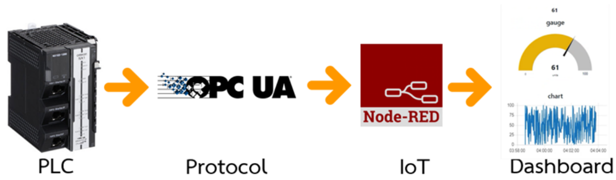

Figure 2. Smart factory automation using programmable logic controller.

Nowadays a PLCs have the potential to implement functionality-based control. It can also be connected to a network in a variety of ways, including Protocol enabled communications. Fig. 2 illustrates the potential of PLCs to be able to communicate to display enabled communication networks.

C. OPCUA Communication

Control applications are widely used in control and communications because makes it easy to use and manage to increase the efficiency of work processes. A development of control devices, including PLCs, to support communication function systems and increase communication systems at various levels to support more applications. In addition, protocols have been developed to support them, such as the research [19] presenting communication between machines using the MQTT protocol, enabling data exchange in the form of IoT using the standard internet. In addition, the research at [20] proposes the application of various forms of OPC standards to industrial measurement and control applications. The test focuses on communication efficiency.

Figure 3. OPCUA setting in Programmable logic controller network.

Fig. 3 illustrates the basic setup required to connect to an OPC-UA network to communicate internal PLC data to an external display in the form of information technology. TCP/IP communication settings and OPC-UA function selection. However, it is necessary to control the quadrotor for different altitude positions and achieve the lowest altitude error due to some missions. The quadrotor's balancing control is highly weak to faults if the position changes target altitude, resulting in reduced control efficiency. In research [21] presents an enhancement of control with quadrotor parameter estimation by using a simple error diagnosing algorithm to analyze abnormalities that occur due to nonlinear system lines to optimize control. A study [22] proposes servo control used with the quadrotor to withstand outdoor use in changing environmental conditions. The experimental control of the quadrotor's position relative to ground targets. Research [23] proposes quadrotor control by estimating uncertainty and noise to improve the independent tracing control efficiency.

II. Methodology

In the design of the method of operation, there are two parts: the first part is controlled by the PID controller and the fuzzy so that the output signal is best matched with the target signal. This section introduces the most widely used controller, the PID controller, designed the controller gain based on the mathematical equations of the quadrotor. The controller gain values can be obtained from the MATLAB software when The PID controller gain is obtained from offline computation and is used to program the PLC control device. In this paper, an embedded PLC for real-time online of the control signal with the fuzzy controller is proposed. The second part is to bring the parameters inside the PLC to display in the dashboard using information technology.

A. Monitoring with OPC UA Protocol

Display or command to control operations from source data to control calculate and process the signals within the PLC control device. Protocols can be used to directly communicate the PLC control device to the service in various forms and the management system to bring the data into a system that supports with node-red.

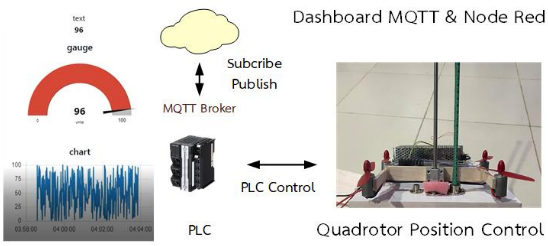

Figure 4. Communication structure of quadrotor control.

Fig. 4 show that the working principle starts from using the sensor to measure the altitude of the quadrotor position. It sends the signal back to the PLC control device by converting the signal from analog signal to digital signal sent to the memory unit to process error signals. The feedback signal will send to meet the needs of keeping the position matching the target signal. The parameters stored in the PLC's memory, such as the target signal, come from the measured sensor, the calculated parameter value of the controller it can be delivered to a display that is compatible with communication systems. This study also demonstrated the connection between a PLC and a dashboard device displayed on a web browser using node red communication. An OPC-UA can display real-time data from Dashboard on a computer or smartphone connected to the network.

B. Experimental Setup

The use of embedded programmable control devices PLC is widely used in industry because it is resistant to the environment. The user can change the conditions of the embedded program as needed, convenient and fast. Both digital and analog sensor connections are now accepted. In addition, programming can also be selected as appropriate, such as function block, ladder, and structure text in the IEC 61131 standard. In addition, can use communication with support standards such as Ethernet, OPC-UA can be used with PLC via OPC-UA to communicate with IT devices easily.

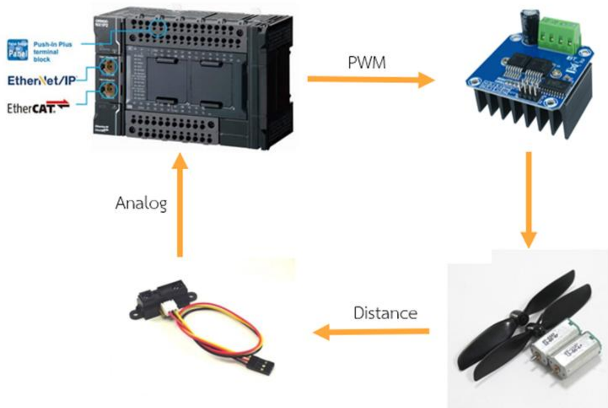

Figure 5. PLC and Experimental set up.

Fig. 5 illustrates the use of a PLC to program commands to control the rotors of the quadrotor system with the controller and send the parameters in the PLC memory.

C. Quadrotor

The quadrotor is susceptible to loss of stability. It is necessary to maintain the quality of the altitude position signal under tasks such as recording and spraying pesticides. The assembly and installation in the air maintaining the altitude level of the target signal are challenging, when there is interference or changes in the target signal, there is a high chance of error. Therefore, this research focusses to maintaining the height of the quadrotor by controlling the speed of the motor to generate lift from the propeller to maintain the balancing position in the air to reach the specified target position. The study controllers to optimize performance or improve operational decision-making in real-time operating conditions is a key focus for control system engineering. It mainly determines the quality of the output signal is received. Especially for systems that require high performance and noise or the effect of the conversion and processing of the signal learning in control system engineering is therefore popular to simulate engineering processes that can be exploited and have low stability. From the past to the present, quadrotor has been used to study control engineering situations.

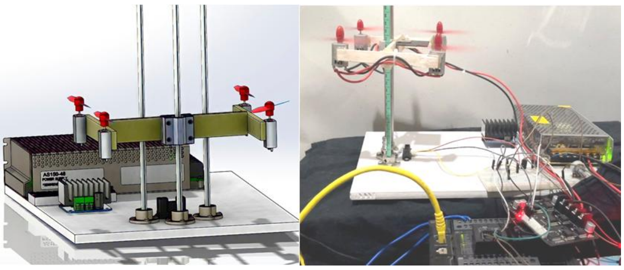

Figure 6. Quadrotor prototype of research.

Fig. 6 illustrates the prototype quadrotor's altitude stabilization process used to test, control, and communicate with the dashboard. The installing a sensor to measure the height between the floor to the level of the quadrotor. The amount of signal received from the sensor changes; it is digitized with the signal conversion module in the PLC device. The operator can then set the target signal to use in calculations with the PID controller and applied a fuzzy controller to determine the optimal control value automatically. The results are obtained from the processing and transmitted in the form of a control signal. The PLC to control speed of the four propellers for the lift and can be adjusted up and down to altitude control.

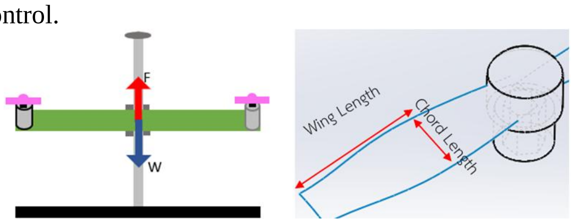

Figure 7. The architecture of the quadrotor.

$$\sum F = 0 \tag{1}$$

$$\sum_{i=1}^{4} k_F \omega_i^2 + mg = 0 \tag{2}$$

$$\sum_{i=1}^{4} k_F \omega_i^2 + mg = ma \tag{3}$$

$$A \;=\; Chord\ Length\ x\ Wing\ Length \tag{4}$$

The functional relationship of the quadrotor can be seen in Fig. 7, where the target position of the float is calculated based on the error. The equations of move up and down can be expressed in Equations (1)-(3). Equation (4) shows the calculation of the area of the impeller. In Table I, the definition of the parameters used in the calculations is shown in equation (5) shows the relationship of the transfer function used in the PID control.

TABLE I. PARAMETER OF QUADROTOR

Symbol	Description
F_L	Lifting Force
C_L	Life Coefficient
A	Area of Propeller
d	Density of Air
v	Air velocity
w	Weight
m	Mass
g	Gravity
ω	Rotor speed

$$F_L(S) = \frac{C_L \cdot d \cdot \frac{V^2}{2} \cdot A}{S} \tag{5}$$

D. Robust Self Tuning Design

This research presents a control with a fuzzy controller to quantify the control output without the need for mathematical modeling and control parameter gain. However, it requires the rules to set up work. Therefore, rule setting is important, starting from simulation through MATLAB to compare with packing embedded program into PLC.

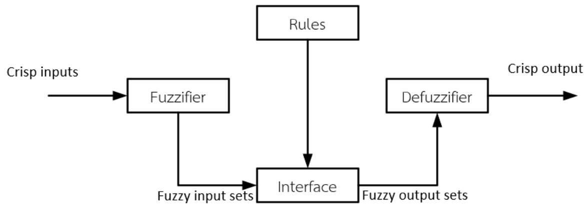

Figure 8. Fuzzy controller is designed to process control.

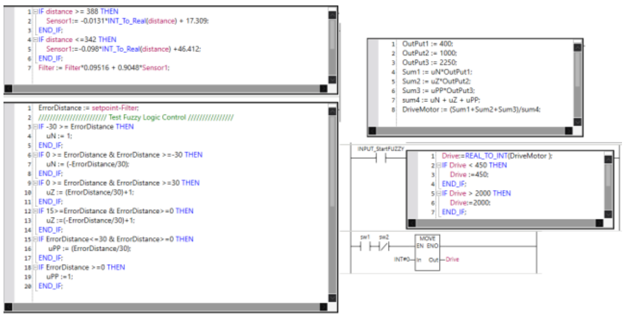

Figure 9. Fuzzy controller programming embedded PLC.

Fuzzy logic control, there are components of the procedure, as shown in Fig. 8 that illustrates the process of design a fuzzy control. The model can be simulated with MATLAB and write conditions for the fuzzy controller sugeno. Fig. 9 shows programming a fuzzy controller embedded into a PLC where the fuzzy logic input value is the error value. The fuzzy controller can adjust speed in the control position programming error by using the straight-line point and slope equation Input to determine the height of the quadrotor from the ground about 0 - 35 cm. A PID controllers in control system engineering is preferred, however since using PID controllers, it is necessary to find the optimal gain parameter in different conditions by mathematical modeling. One disadvantage is that when environmental changes occur. The parameter gain must also change according to the behavior of the environment. In this study, the close loop system used a quadrotor PID controller to compare with the proposed fuzzy controller. The PID controller equation can be represented as equation 6, with the system error variable between the target signal output and the actual signal (e), input control force (u), proportional gain controller (K_p), integral gain controller (K_i) derivative gain controller (K_d).

$$u(t) = K_p.e(t) + K_i\int_0^t e(\tau)d(\tau) + K_d\frac{d}{dt}e(t) \qquad (6)$$

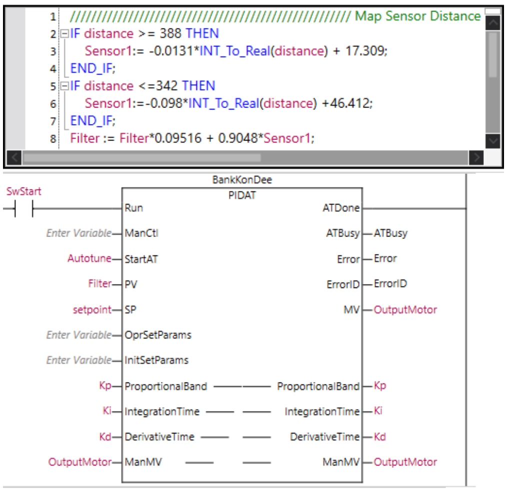

Figure 10. Block diagram PLC programming of PID Controller.

Fig. 10 shows the programming of a PID controller. Programming a controller can be programing by using a function block programmed into a PLC.

III. Experimental Result

The experimental results can be divided into two parts: the results obtained from MATLAB simulations and the results of the experiments from the embedded program within the PLC and the results obtained from the dashboard display in real-time. A comparing the experimental results to determine the output values for the automatic position control with the fuzzy controller will be compared with the P, PI, PID controllers. The experimental data obtained was used to control the Fuzzy and PID controllers by setting the position values. The four targets level 10, 15, 20, and 25 cm, respectively are used to test the behavior of the output signal and connect the display to the dashboard.

A. Simulation Result

This research uses a closed-loop control system with a fuzzy controller with two inputs consisting of the position error and the speed of the quadrotor position from the ground. The fuzzy rules are set to Fig. 11, Fig. 12, and Fig. 13, showing the output applied to the control. Therefore, to ensure that before implementation in the PLC for control and processing the desired target signal is sampled. The output value is calculated from MATLAB and the embedded program into the PLC.

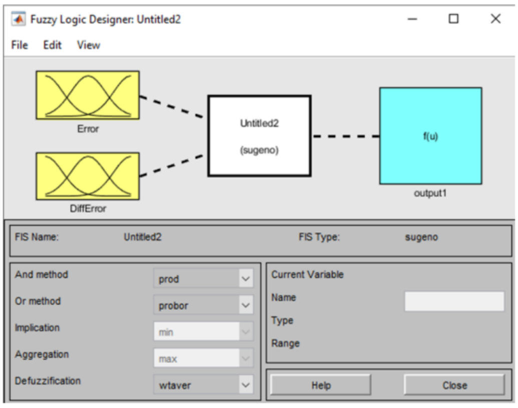

Figure 11. Diagram of the fuzzy logic designer.

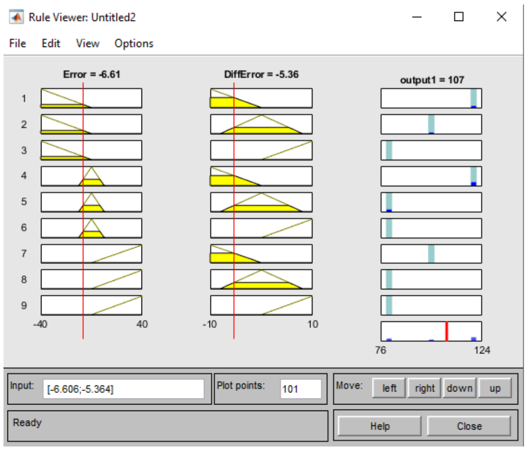

Figure 12. Rule base of the fuzzy logic controller.

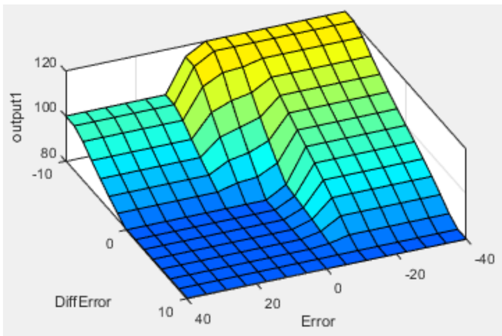

Figure 13. Simulation result of output control with the fuzzy logic controller.

B. *Experimental Result*

The experiment to collect data by using the control parameters calculated from the written program. It can be demonstrated online and real-time control. Fig. 14 shows the height position of the quadrotor level position and shows the signal received from the PLC control to show the results that are compatible with use and display platform.

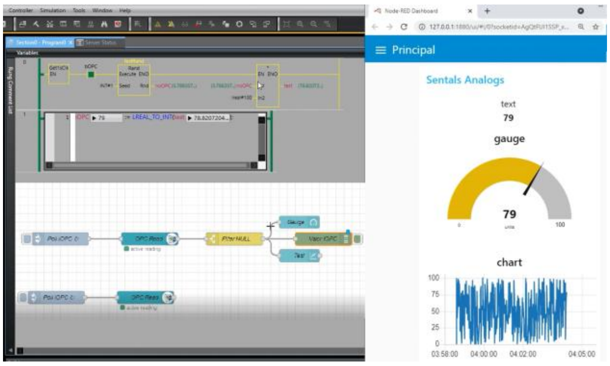

Figure 14. Communication between PLC and dashboard.

Embedded control experiment with PLC processing of parameter output signal values from quadrotor controls the working height position in real-time. The results of maintaining the altitude position according to four target values were at target values of 10, 15, 20, and 25 cm with P, PI, PID controls, as shown in Figs. 15-18, respectively.

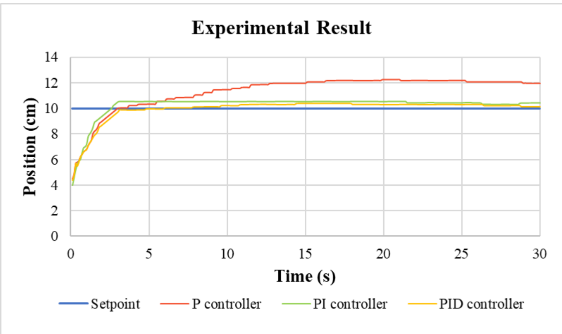

Figure 15. Experiment result P, PI and PID controller of real time position control of the quadrotor system setpoint 10 cm.

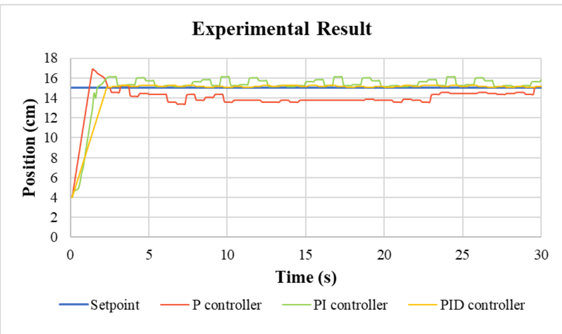

Figure 16. Experiment result P, PI and PID controller of real time position control of the quadrotor system setpoint 15 cm.

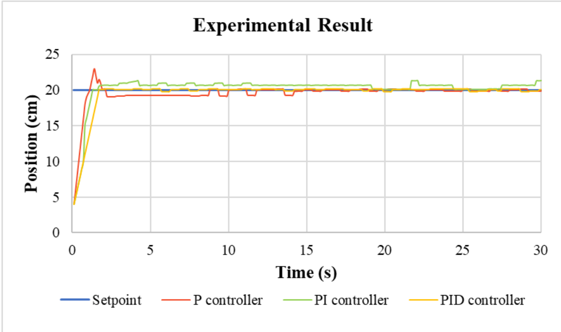

Figure 17. Experiment result P, PI and PID controller of real time position control of the quadrotor system setpoint 20 cm.

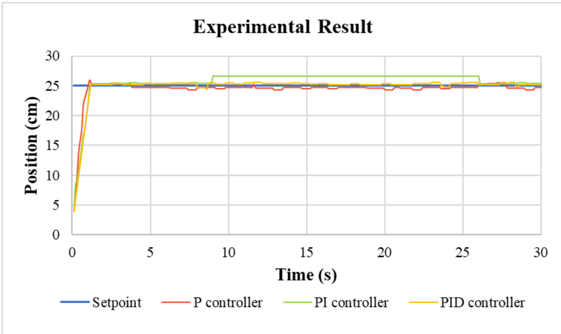

Figure 18. Experiment result P, PI and PID controller of real time position control of the quadrotor system setpoint 25 cm.

Figs. 19-22 shows the experiment results controlling the quadrotor's height position in real-time embedded in the PLC using a fuzzy controller at target values of 10, 15, 20, and 25 cm. Experiment with the same conditions as P, PI and PID controller.

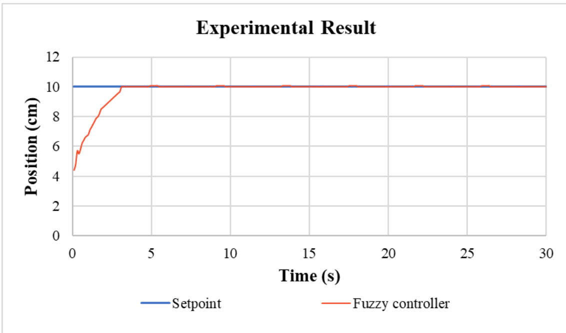

Figure 19. Experiment results fuzzy logic controller of real time position control of the quadrotor system setpoint 10 cm.

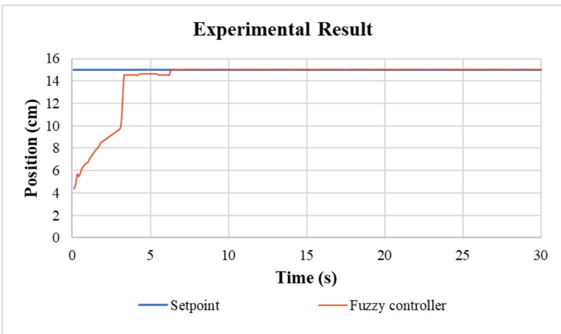

Figure 20. Experiment results fuzzy logic controller of real time position control of the quadrotor system setpoint 15 cm.

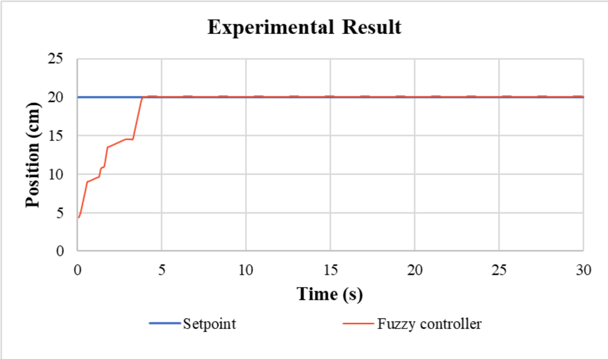

Figure 21. Experiment result fuzzy logic controller of real time position control of the quadrotor system setpoint 20 cm.

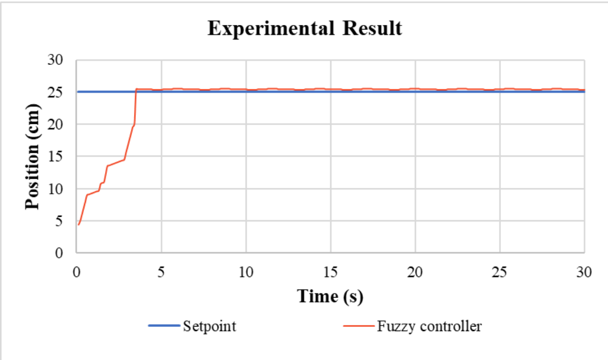

Figure 22. Experiment result fuzzy logic controller of real time position control of the quadrotor system setpoint 25 cm.

The quadrotor altitude control experiments show that both controllers can maintain target altitude and show results in real-time effectively, but PID control has a higher signal oscillation than fuzzy control. A fuzzy controller also has the advantage of manually adjusting the output when the target signal changes. The experimental results graph found that the fuzzy control was more responsive to the user's needs, adjusting from the control rules that differ from the PID controller.

IV. Conclusion

This research presents the altitude control of the quadrotor using a fuzzy controller for self-tuning that can adjust the output signal when the control target signal is changed. High stability is required by designing the controller to be embedded in the PLC. In addition, the processing values can be displayed through the communication model with OPCUA on a web browser with Node-Red in real-time. The fuzzy controller can use designed for robust balancing and can be used properly because the amount of control can be decided by itself according to the set control rules. The experimental results of monitoring and communication with OPC-UA and node-red between the PLC and dashboard could properly communicate data.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

SH conducted the research, SC and CS analyzed the data and approved the final version. The authors were involved in the drafting of the manuscript and had approved the final version.

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