Monitoring and Controlling of a Real-Time Ball Beam Fuzzy Predicting Based on PLC Network and Information Technologies

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***Abstract*—Information and communication technology are essential for infrastructure development. Therefore, control communication plays an essential role in enabling control in changing working conditions such as environment and target position values directly affecting quality and efficiency. This research presents the application of information technology to display and control the position of Ball Beam that easily detestably. Fuzzy logic controller estimation when changing target position compared to calculating the PID controller gain using mathematical equations. This research uses a Programmable Logic Controller (PLC) employing communication (M2M) network communication technology using the MQTT protocol to display real-time control results. Based on the MATLAB control simulation and experimental results demonstrating the efficacy of the control signal using fuzzy logic, the control result was better at start-up and steady-state than using the display and control with PID controller. MQTT from the test results of PLC network communication and MQTT use found that it can be applied to control applications very well.**

***Index Terms*—MQTT, automation, programmable logic controller, fuzzy logic, ball beam**

I. Introduction

Control system and automation are the turnkey solution to increase the productivity and quality, or to reduce the cost. In particular, the system has to process in real-time for monitoring and operating, in order to prevent the damage or increasing of the working cost. The first priority to solve the problem and improve is how to communicate the information among the devices in automation system: sensors, controllers and actuators under the security. In addition, the use of intelligence for.

The first consideration to solve and optimize such problems is the communication in the automation system. In particular, the connection from the source device, the controller, to the terminal power equipment must be considered safe, and That must work following the same approach. In addition, the use of intelligence from optimization or artificial intelligence applies to the maximum benefit.

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Several works have been developed to optimize all systems that need and impact living at the lowest cost with an intelligent system. The work in [1] proposed the using of Fuzzy logic for heart disease symptoms monitoring system. This system can monitor and tracking the patients at home with alert and advise functions. The research in [2] proposed the use of IIoT for baggage handling systems. By deploying IIoT devices, it can infuse the intelligence for adjusting configuration of the subsystem according to operating conditions to achieve optimized performance. The research work in [3] presented a study on the development of commercial robots to facilitate the development of medical robots for newcomers, emphasizing security and communication techniques to analyze data for use.

A. Monitoring and Communication Signal

Nowadays, Information technology is more popular to apply information technology in various forms on control devices such as microcontroller PLC by applying the architecture close to the communication network of computers. Fig. 1 shows the industrial network that is commonly used in factories and industrial production systems. PLC communication networks can divide into three primary levels: device level, controller level and supervisory level.

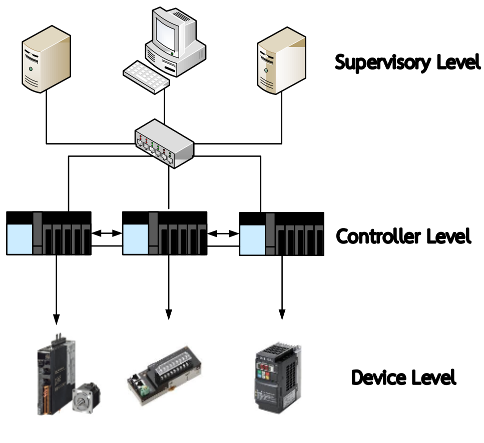

Figure 1. Industrial controller network.

Device-level has PLC communicating with control devices such as servo motors, I/O remote, and inverter.

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Controller level is responsible for connecting PLCs in industrial networks to communicate data. Lastly, supervisory level is responsible for displaying or monitoring the data from the Information Technology system.

B. Industrial Internet of Thing

Parameters displaying which is required for analysis and obtained from industrial systems or processes is a crucial factor to develop the intelligent efficiency and the optimized management. This real-time data can be used for forecasting, planning or making the appropriate decision. Therefore, there several researches were proposed the using the information technology to improve the industrial process. For example, the research [4] presents robust and lightweight protocols to deal with command and display errors or insecurity, Internet of Things to protect the privacy of patient data in healthcare systems that need confidentiality. The research [5] presents a remote issue management system for industrial automation in combination with functions that can be used to remotely monitor and manage issues from accessing vendor databases and obtain problem management functions through processing. The research [6] presents a comparative measure of cloud security. Trusted for those who want to opt for cloud computing, the research [7] proposes a real-world network scenario compression method to optimize wireless network data compression to reduce the reception, transmit data in the network, and obtain better data efficiency by using preprocessing and regulating the frequency of sequencing. The research [8] propose an object-based image classification model. Based on measurements and decision-making for high-resolution remote sensing in the field of use, the research [9] proposes an automated weather monitoring system of dynamic real-time local weather data. It is designated by using Internet of Things technology and embedded systems with sensors and wireless technologies. The research example shows that communication and the Internet are beneficial in the application for further development.

C. PLC Network and Information Technology

Programmable Logic Controllers (PLC) is widely used in industrial processes and automated production systems. It also applies in engineering process control because it has functions supporting widely application including digital and analog signal processing and communication. PLC programming language is implemented under IEC 61131-3 in order to support the high complexity task, increase the reliability and supporting. Many previous researches have shown how to enhance the security of PLC networks used in information technology systems. For example, research [10] discusses the pros and cons of implementing Programmable Logic Controllers in Industry 4.0. Furthermore, it introduces programming models for complex tasks. The work in [11] presented data communication security in PLC automation using a modified open-source PLC to encrypt all data sent via the network. Communication is protocol provides a mechanism that is safe from network attacks. Research in [12] provided the guidelines for secure controller analysis for production systems controlled by programmable logic controllers to a safety filter and prevent control errors.

PLCs are used in research to communicate and control. For example, in the research [13], the sequence and state generation of automation from PLC controllers was presented with response and trace and trace that reduce errors and operation of the device network in the control system. Research [14] A PLC is applied to control the direction of the production line with a fuzzy controller to reduce errors and make self-determination. Research [15] PLC is possible to operate network communications in industries that support complex operations using industrial IoT protocols. Research [16] has applied model predictive control to write control programs in programmable logic controllers. The IEC 61131 standard PLC programming language is used to solve the problem for conditions in process system.

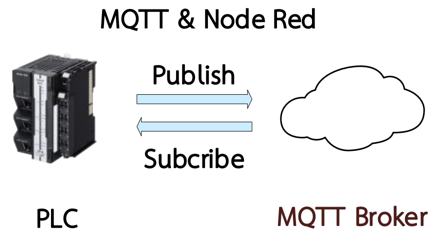


Figure 2. Programmable logic controller factory automation network.

Research and development control for industrial production systems more flexible by adjusting the appropriate parameters to the environment variables, resulting in high efficiency and lower costs. Finding the optimal parameters in a real-time environment is one of the most popular areas of development and research. The applying optimization and artificial intelligence to prediction and implementation, for example, research [17] presented a PSO design technique to optimize the adaptive neuro-fuzzy controller for the system. LQR controller controls the car's suspension. The PSO algorithm is used to determine the optimal radius for ANFIS operation, resulting in improved driving comfort and good road grip. [18] the proposed method of using fuzzy in combination with neural network and parameter optimization with PSO based on the proposed techniques, efficiency can be achieved. Research [19] presents a control design. inverted pendulum stabilization with LQR control using PSO function parameters. Research [20] presents a development of a hospital information system with a deep neural network to predict scheduled drug demand. By applying PHP code to a demand prediction module that implements a deep neural network model using a python library, research [21] proposes an exemplary implementation of fuzzy logic to optimize energy efficiency. Even more with bright street lighting with IoT. Fig. 2 illustrates the use of protocol MQTT to communicate with the PLC by biological or environmental data that affects quality and efficiency factors for use in the control work.

II. Methodology

A. PLC Network Communication with Information Technology

Communication data into controllers and display devices the use of IoT or Internet-enabled platforms is widely used. For example, the research in [22] presented Machine to Machine (M2M) data exchange. Implemented over HTTP, constrained application Protocol, and Message Queuing Telemetry Transport (MQTT) to help deliver data more efficiently in low-power networks. Research at [23] presents resource allocation with the MQTT model of intelligent buildings on-demand with energy supply and storage systems intending to reduce grid demand. Research [24] has been presented to teach MQTT protocol communication systems using Node-RED to weather stations in a low-cost design and construction. It can be displayed through an online platform designed for laboratories and teaching IoT-related subjects. This research aims to develop communication and signal processing of commands and decision-making with an embedded Fuzzy logic controller in PLC to control ball beam with MQTT real-time signal communication technology.

Control studies to improve efficiency and enhance the quality of the target signal. Researchers and developers prefer to study processes that are modeled or simulated using actual conditions by quickly selecting from the destabilization factor high nonlinearity. Several studies have opted for ball beam stabilization processes, such as research [25], which proposes the development of variable design frequency and position models of ball beam based on the dynamics of the nonlinear mechanical system. Disturbance Load Mismatch and parameter uncertainty. Research [26] performed ball and beam stabilization control using variable linear parameterization techniques based on the development of slide mode control. Therefore, the study of control stability is an essential topic for improvement and optimization.

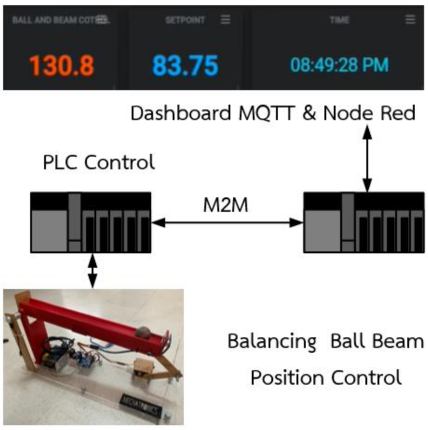


Figure 3. System architecture of balancing ball beam control.

In this research, the balancing ball beam system was built and conducted the experiment by applying the position control of ball on the balancing beam to the motor. As shown in Fig. 3, there are two PLCs used in the experiment where the first PLC is used for implementing the control algorithms such as Proportional Integral and Derivative (PID) controller and Fuzzy logic controller. The second PLC received the data from the main controller, then send the data to MQTT for displaying and command.

Fig. 4 shows wiring diagram of balancing ball beam control system. The system has two different models of PLC connecting together via industrial network. For controller unit, PLC OMRON NX1P2 model with analog to digital converter module can connect with two analog sensors and microcontroller for actuator interfacing. PLC OMRON NX102 model obtains the data from the controller unit, then displays real-time data on the Dashboard in the computer’s monitor or smartphone. The user can also adjust the set point value through the dashboard.

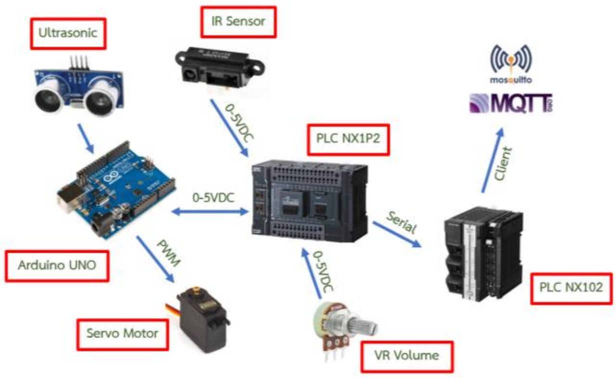


Figure 4. Wiring diagram of balancing ball beam control system and machine to machine.

B. PLC Networking with MQTT Protocal

Using of MQTT can be used with PLCs via OPCUA to enable quick and easy communication in the memory of the PLC to be displayed as shown in Fig. 5. The communication between PLC memory begins with the defining of the user variables, then apply the working variables to command control according to the control theory. Users can define the communication protocol by using functions block. Fig. 6 shows how to transfer control variables via MQTT to the server using PLC programming using Structure Text (ST) or Function Block (FB) in the section for inserting connection parameters, as shown in Table I.

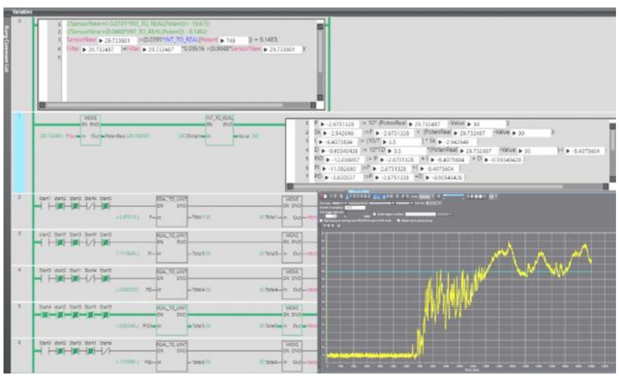


Figure 5. PLC parameter monitoring.

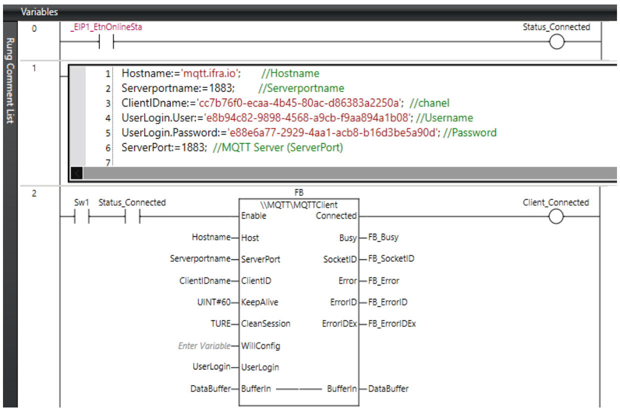
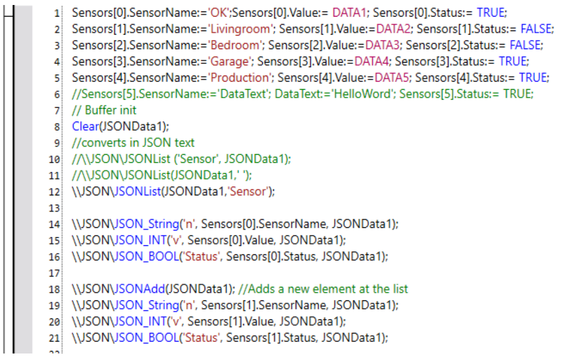


Figure 6. PLC function connecting MQTT.

TABLE I. CONNECTION SETTING OF PLC AND MQTT

No	Function parameter of connection	
	MQTT connection	Example
1	Host name	Mqtt.ifra.io
2	Sever port name	1833
3	Client ID name	Cc7b76f0-ecaa-4b45-80ac-d86383a2250a
4	User login user	E8b94c82-9898-4568-a9cb-f9aa894a1b08
5	User login password	E88e6a77-2929-4aa1-acb8-b16d3be5a90d
6	Service port	1833

The operation command can be programmed through the PLC by defining the data transmission sent to the PLC to the display device via the MQTT Protocol, allowing the control process data to be displayed through the Dashboard. Fig. 7 illustrates an example of these operation programs to define communication between each other.



```
Sensors[0].SensorName:='OK';Sensors[0].Value:= DATA1; Sensors[0].Status:= TRUE;
Sensors[1].SensorName:='Livingroom'; Sensors[1].Value:=DATA2; Sensors[1].Status:= FALSE;
Sensors[2].SensorName:='Bedroom'; Sensors[2].Value:=DATA3; Sensors[2].Status:= FALSE;
Sensors[3].SensorName:='Garage'; Sensors[3].Value:=DATA4; Sensors[3].Status:= TRUE;
Sensors[4].SensorName:='Production'; Sensors[4].Value:=DATA5; Sensors[4].Status:= TRUE;
//Sensors[5].SensorName:='DataText'; DataText:='HelloWord'; Sensors[5].Status:= TRUE;
// Buffer init
Clear(JSONData1);
//converts in JSON text
//\\JSON\JSONList ('Sensor', JSONData1);
//\\JSON\JSONList(JSONData1,' ');
\\JSON\JSONList(JSONData1,'Sensor');

\\JSON\JSON_String('n', Sensors[0].SensorName, JSONData1);
\\JSON\JSON_INT('v', Sensors[0].Value, JSONData1);
\\JSON\JSON_BOOL('Status', Sensors[0].Status, JSONData1);

\\JSON\JSONAdd(JSONData1); //Adds a new element at the list
\\JSON\JSON_String('n', Sensors[1].SensorName, JSONData1);
\\JSON\JSON_INT('v', Sensors[1].Value, JSONData1);
\\JSON\JSON_BOOL('Status', Sensors[1].Status, JSONData1);
```

Figure 7. PLC programming network.

C. Ball Beam Balancing Control

In order to learn control system engineering, the dynamic behavior and control of instability process should be studied. Ball beam system is the one of balancing and tracking control which the changing of beam angle is sensitive to the position of the ball. It is challenging work that stabilize the position of the ball on the beam. In this research, the motor position is used to adjust the beam angle that changing the ball's position according to the set point value.

Fig. 8 illustrates the prototype of ball beam balancing system. The pivot is at the right side of the beam which is revolution type. The RC servo motor is chosen to adjust the beam's position via the mechanical linkage; thus, the system is five-bar linkage mechanism. The ultrasonic sensor has been installed at the end of beam to detect the position of free moving ball.

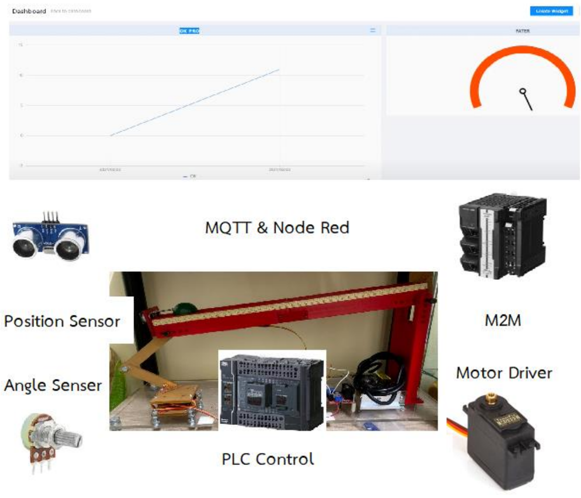


Figure 8. Monitoring and control structure of research.

Equation (1) represents the linearization of dynamic model which the relationship between the position of ball, r and beam angle α to the input torque u applied to the beam. Where M is mass of the ball, J is ball's moment of inertia, R_b is the ball's radius,

$$\begin{bmatrix} \dot{r} \\ \ddot{r} \\ \dot{\alpha} \\ \ddot{\alpha} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -\dfrac{Mg}{\left(\dfrac{Jb}{R_b 2}+M\right)} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} r \\ \dot{r} \\ \alpha \\ \dot{\alpha} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u \qquad (1)$$

This state-space equation can be used for designing the controller such as PID and Fuzzy Logic controller in computer simulation first. Then, the tuned controller parameters can be implemented in PLC controller. The motor can adjust the beam angle through the lever according to PLC's command which is obtained from the difference between the measured ball's position and the set point value.

D. Control Design by PID and Fuzzy Logic Controller

This section describes the controller design and implantation in PLC. The equation of PID (Proportional Integral Derivative) controller in time-domain can be expressed in Equation (2) where $u(t)$ is the motor command signal and $e(t)$ is the error between the desired output and the actual output. There are three parameters that need to adjust or tune properly: the proportional gain (K_p), the integral gain (K_i) and the derivative gain (K_d).

$$u(t) = K_p.e(t) + K_i \int_0^t e(\tau)d(\tau) + K_d \frac{d}{dt} e(t) \qquad (2)$$

Fig. 9 illustrates the simulation with MATLAB which the optimized tuned parameters gain can be obtained from the closed-loop response, and then writing the PID controller commands to the PLC.

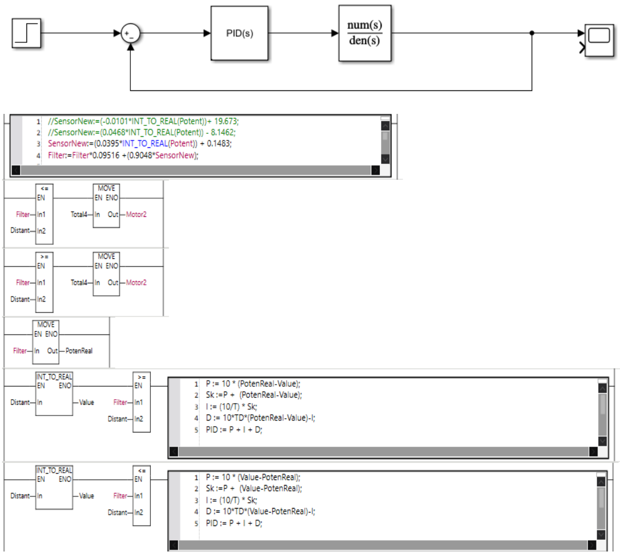


Figure 9. Block diagram PID controller and PLC programming.

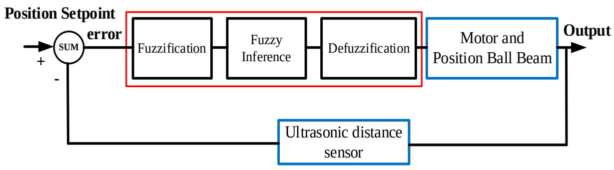


Figure 10. Block diagram of fuzzy controller process control.

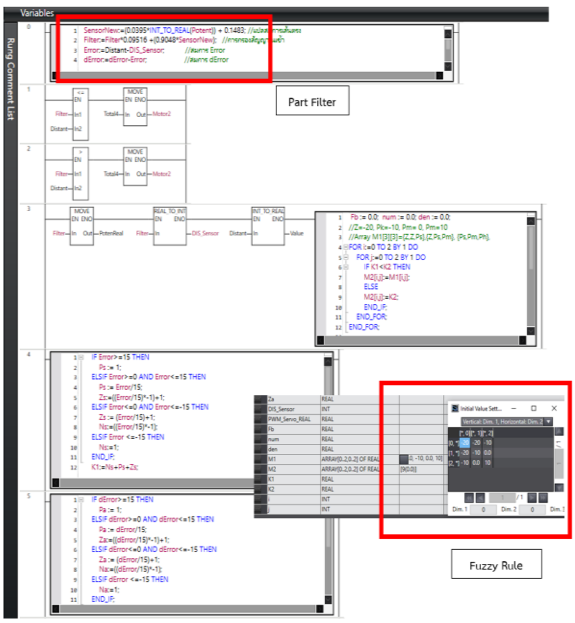


Figure 11. Fuzzy controller programming embedded PLC.

Fig. 10 presents the block diagram of Fuzzy logic controller for ball beam balancing system. To design Fuzzy logic control, there are three steps: fuzzification, fuzzy inference and defuzzification. The input of controller is error and rate of error signals fed to input membership function. In this work, zero-order Sugeno model has been used in which can be implemented by using a first order liner equation and slope. The position of ball is in range between 0.0-40.0cm. Fig. 11 shows the example of Fuzzy logic controller embedded into a PLC.

III. Result and Discussion

There are two sections of the experimental results. The first is the result of communication and transmitting the input-output data of the ball beam system. The data is received and transmitted between PLC and dashboard via MQTT Protocol. The second part of experiment is to simulate the results for designing the fuzzy rule, then applied and evaluate the performance comparing to PID controller. The set point values of ball's position are set at 15.0, 20.0 and 30.0 cm, respectively. The behavior of control system can be visualized through the Dashboard.

A. Monitoring and Controlling with MQTT Protocol

This section shows that time-history data on the Dashboard. It can display the online data and real-time control as shown in Fig. 12. Not only the position of the ball on the balancing beam has been updated, but also the angle of beam and motor command can be monitored and recorded.

Figure 12. Experimental control and monitoring result of ball beam with MQTT protocol.

B. Experimental Result

This section shows the performance of closed-loop system with a Fuzzy Logic controller and a PID controller. Both experiments have the same set point value and conditions. The controller parameters and rules can be expressed with the mathematical dynamic model. For Fuzzy Logic controller, MATLAB Fuzzy logic toolbox can be used for analyzing, designing and simulating systems as shown in Fig. 13 and Fig. 14.

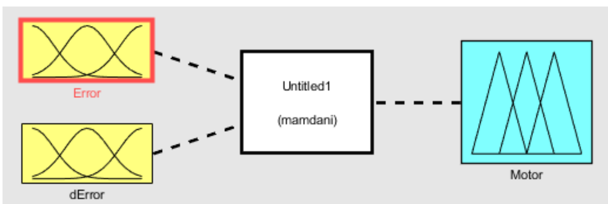


Figure 13. Diagram of the fuzzy logic controller.

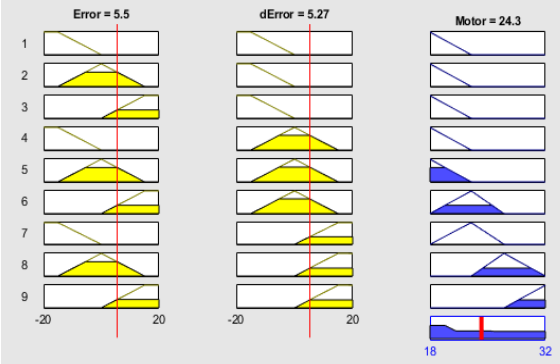


Figure 14. Simulation result of output control with fuzzy logic controller.

Fig. 15 presents the defuzzification result according to defined fuzzy rule. The motor command value depends on the error of the ball's position and its rate.

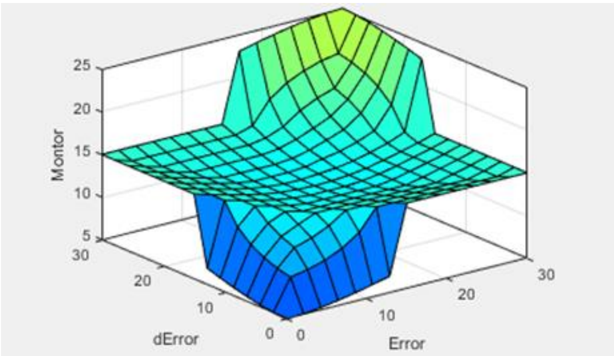


Figure 15. Simulation result of output control with the fuzzy logic controller.

After deploying both controllers into PLC, the control parameters can be updated that the ball's position has been stabilized in real-time. Moreover, the recorded data can be analyzed for evaluating the performance of controller or stabilized system. The experimental results of three different set point values of 15, 20, and 30cm with PID controller are shown in Fig. 16-Fig. 18, respectively.

Fig. 19-Fig. 21 shows the experimental results of the ball's position tracking with the Fuzzy logic controller at the target value at target values of 15, 20, and 30cm.

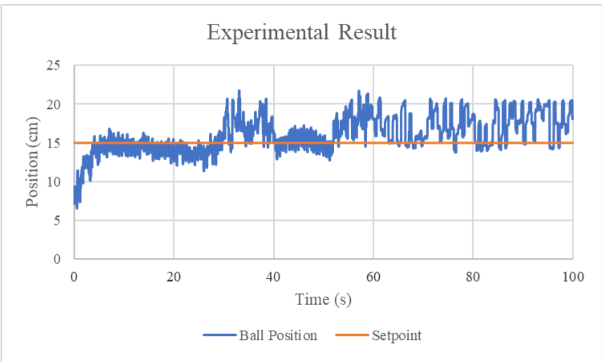


Figure 16. Experiment result PID controller of real time position control of the ball beam system setpoint 15cm.

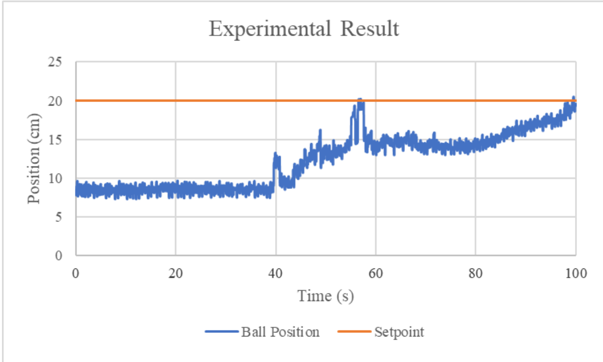


Figure 17. Experiment result PID controller of real time position control of the ball beam system set point 20cm.

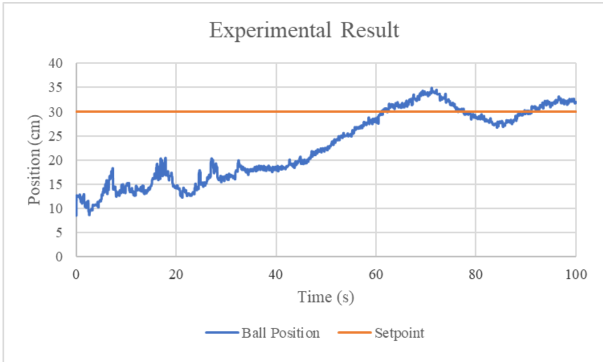


Figure 18. Experiment result PID controller of real time position control of the ball beam system set point 30cm.

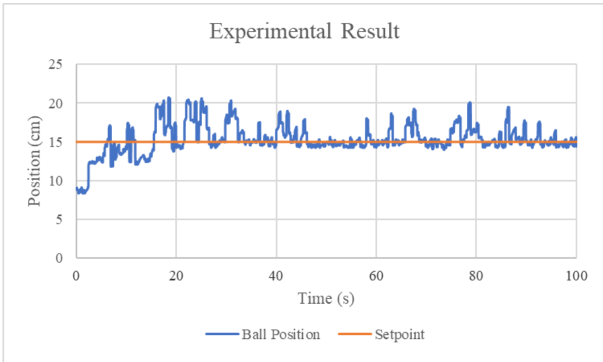


Figure 19. Experiment results fuzzy logic controller of real time position control of the ball beam system set point 15cm.

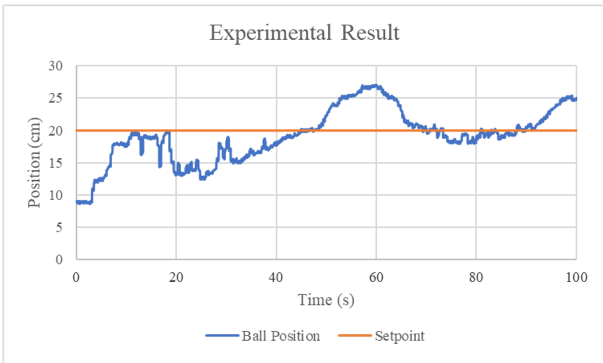


Figure 20. Experiment results fuzzy logic controller of real time position control of the ball beam system set point 20cm.

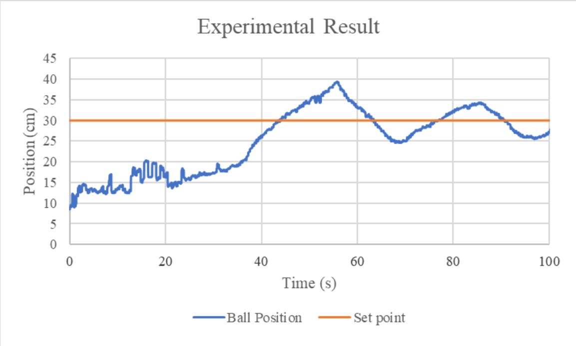


Figure 21. Experiment result fuzzy logic controller of real time position control of the ball beam system set point 30cm.

According to the experiment results, both controllers can stabilize the system to adjust the ball's position moving to the target position or set point. The system's behavior such as the oscillation can be visualized in real-time so that it is easy to evaluate the performance of both controllers. By using off-line data, it concluded that Fuzzy logic controller can stabilize the balancing ball beam system better than the traditional PID controller. For three set point, the responses of Fuzzy logic controller are able to reach within 40 second. During hold operation, the communication between PLC and dashboard works well.

IV. Conclusion

This research presents the application of information and communication technology to PLC which is the devices commonly used in industrial control. The performance of PID controller is compared with Fuzzy logic controller. The controller gains and fuzzy rules can be adjusted in the Dashboard to real-time update the operation of PLC through communication network with MQTT. The closed-loop control with either PID controller or Fuzzy logic controller are able to stabilize the ball's position on the beam to the target position. Comparing the steady-state response, the performance of Fuzzy logic controller is better than PID controller's, in which the control action is designed according to the Fuzzy rule. For the communication between two PLCs, the result shows that both of them can transfer the data for control and displaying on the Dashboard. The information can be utilized can be utilized properly, even though there may be a slight delay due to the internet speed.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

S. Howimanporn conducted the research. S. Chookaew and C. Silawatchananai analyzed the data and approved the final version. The authors were involved in the drafting of drafting of the manuscript and had approved the final version.

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