Vol. 7, No. 2, August 2025, pp. 177~194, p-ISSN 2685-2381, e-ISSN 2715-2626
http://dx.doi.org/10.28989/avitec.v7i2.3066

Feedforward–Feedback Fuzzy-PID Water Level Control using PLC and Node-RED IoT

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Article Info

Article history:
Submitted June 11, 2025
Accepted June 26, 2025
Published July 2, 2025

ABSTRACT

Water level control is vital in industrial processes to maintain operational stability and efficiency, especially against varying disturbances like changes in water inflow and outflow. This research proposes a combined feedforward–feedback control system using a Fuzzy-PID algorithm implemented on an Omron CP1H PLC, integrated with an IoT-based Node-RED monitoring interface. The system is designed to improve response accuracy and disturbance recovery in water level control applications. An experimental method was used to evaluate the performance of the proposed control system against conventional single-feedback control under varied disturbance scenarios. The results indicate that the combined control achieved a lower average steady-state error (0.67%) compared to feedback-only control (1.12%), faster recovery time (3 seconds vs. 6.3 seconds), and no overshoot. The integration of flow sensors as feedforward inputs enabled earlier detection and correction of disturbances before they impacted the water level. Additionally, the Node-RED interface allowed real-time monitoring and remote control, enhancing usability and supporting Industry 4.0 standards. While the system demonstrated improved stability and responsiveness, some oscillations remained due to sensor signal noise, suggesting a need for improved filtering techniques. This study contributes a practical and scalable solution for adaptive water level control, combining intelligent control strategies with IoT capabilities. It offers a foundation for future implementations in dynamic industrial environments that demand high reliability and remote accessibility.

Keywords:
PLC;
Fuzzy-PID;
Node-RED;
Water Level Control;
Feedforward-Feedback.

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1. INTRODUCTION

In process control industries such as water treatment plants, water level control systems are used to control and process water flow. The water level control system is an important factor affecting production quality and yield [1]. This water level control aims to maintain operational stability and efficiency [2]. However, in maintaining the stability of process control, disturbance is a problem that is found in many industrial environments [3]. The disturbance can be caused by changes in inflow, changes in water discharge rate. Varied disturbances can easily affect the system response, causing control errors and instability in the system [4][5]. Therefore, it is necessary and important to conduct research that focuses on developing efficient and effective controls to overcome the varying disturbances in the control of water control systems [6].

Industrial processes often require control systems to maintain variables such as water, temperature and concentration at desired values for reasons of process safety and product quality [7]. One of the control systems that is familiar in the industrial world to maintain these variables is using Feedback control [8]. Feedback control is a control system that will correct errors to return the output to the desired condition / setpoint. This means, when there is a disturbance in the system, Feedback control will work when the Process Variable (PV) value moves away from the setpoint. Meanwhile, to keep the main variable such as water from disturbance, an extra controller is needed whose job is to push the Process Variable (PV) value back to the setpoint. In this condition, Feedforward control is a control that can overcome the measured disturbance before the PV value moves away from the setpoint. Thus, the disturbance will be corrected more quickly before heading to the Water Level Plant.

By combining the two controls above, it can anticipate problems and improve overall performance as in previous research [9][10]. Previously unknown disturbances with this combination of controls can improve performance faster to return to set point and can reduce the use of AC motors as actuators to work more effectively [11].

In controlling a system process, the internet is often used for the needs of society or industry. With the internet, people can communicate with each other very easily and quickly [12]. In this research, the IoT system used is hosting-based with the help of Ngrok software and the Node-RED dashboard as an interface. In a previous journal, it was concluded that the use of IoT in a manufacturing process can reduce Not Good or unfit products and the consistency of the quality of products produced by remotely monitoring and predicting what will happen [13].

In previous research, the control system used was Feedback control and Level Transmitter sensor as Input to determine the PV value and using programmable logic control, namely Programmable Logic Controller (PLC). The study used Fuzzy Logic Tuning control as a Proportional, Integral, Derivative (PID) controller and the Ziegler-Nichols PID Tuning method as a control with a disturbance variation in the form of a DC pump output that can be adjusted from the DA PLC output of 0-6000 resolution which is converted to 0-100%. The result is that Fuzzy-PID is better at responding with minimal overshoot, shorter settling time on average 17.23 seconds while PID averages 78.4 seconds and there is overshoot. However, Fuzzy-PID tends to have a slower rise time of 1-2 seconds than PID control [14].

Based on previous literature studies, the purpose of this research is to present the novelty of Feedforward-Feedback combination system control with the addition of flow sensors as Feedforward control and modeling of water level plants with a system identification approach using PLC as IoT SCADA-based control with Node-RED [15]. Based on previous journals, PID control is more suitable for Single Input Single Output (SISO) systems [12] and this research will use Fuzzy-PID because it refers to previous research. This research is expected to overcome process control problems such as rise time, stability of the control system process against changes in disturbances and the addition of a Human Machine Interface (HMI) as an interface with tool operation. Using Node-RED as a dashboard makes it easy for users to monitor remotely. Although feedback control has been widely used, this research adds a new approach by incorporating feedforward control, which allows the system to respond to disturbances faster before they affect the setpoint and tuning from Fuzzy-PID. By installing a flow sensor on the output pipe will calculate the amount of flow discharge that was previously unaccounted for making the response faster back to the desired value.

2. RESEARCH METHODS

2.1 Study Design

The research method used in this research is the experimental method. The experimental research method is one of the quantitative methods, used when researchers want to conduct experiments to find the effect of independent variables (effectors) on dependent variables (variables that are affected) under controlled conditions [16]. The stages of the experimental method can be seen in Figure 1.

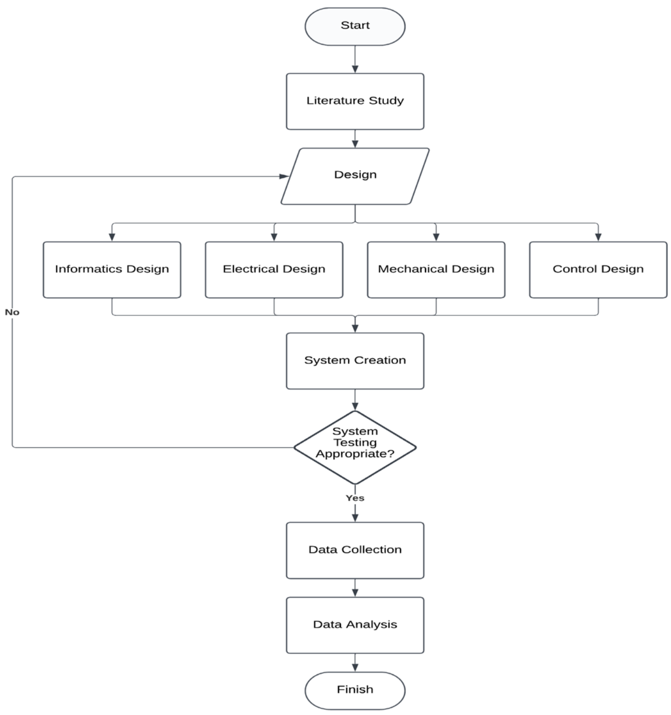

Figure 1. Study design

Figure 1 shows the study design. This research begins with finding information about previous research that is relevant to the current research. This information can come from books, journals, proceedings, or the internet. After getting some research journals, the results are analyzed, recorded, and studied. Conclusions from previous research will be used as a background for current research. Then, make a design from mechanical, electrical, informatics and control. Electrical design includes panel design and electrical wiring diagrams, mechanics including Water Level Plant frame design, informatics including SCADA Interface design and control, namely making a control design system that will be implemented in the Water Level Plant. Furthermore, system manufacturing, assembly or assembly of the results of all completed designs. Then, system testing is carried out after all is assembled, such as testing sensors, actuators, Omron PLC controllers, Control and SCADA so that it can be seen which ones can work and cannot work. Before analyzing the data, if the test is appropriate, the next process is data collection. If there is a mismatch during testing, there will be a review from the start of the design. After all systems work properly and data has been collected, the last stage is data analysis and conclusions.

2.2 System Overview

Figure 2 shows an overview of the entire system. The working principle of several components that enable the use of the Node-RED SCADA dashboard to control and monitor water levels. The level sensor is a sensor that measures the water level using the water pressure in the tank [17]. Pressure transmitter functions as a pump pressure gauge. Flow Meter serves to measure flow using the turbine principle. This flow meter measures the disturbance flow at the inlet and outlet of the Plant. Node-RED can also be used for data loggers to Excel. In addition, the user can control the plant through the control panel, but only for start, stop, drain, and emergency. There are several lights shown on the panel: green for start, yellow for standby and drain, and red for emergency. Ngrok serves as a hosting service, so client PCs can access the Node-RED dashboard through a link that has been hosted by Ngrok. The DC motor functions for disturbances that can be adjusted. The inverter regulates the frequency of the AC Pump so that the speed can be adjusted.

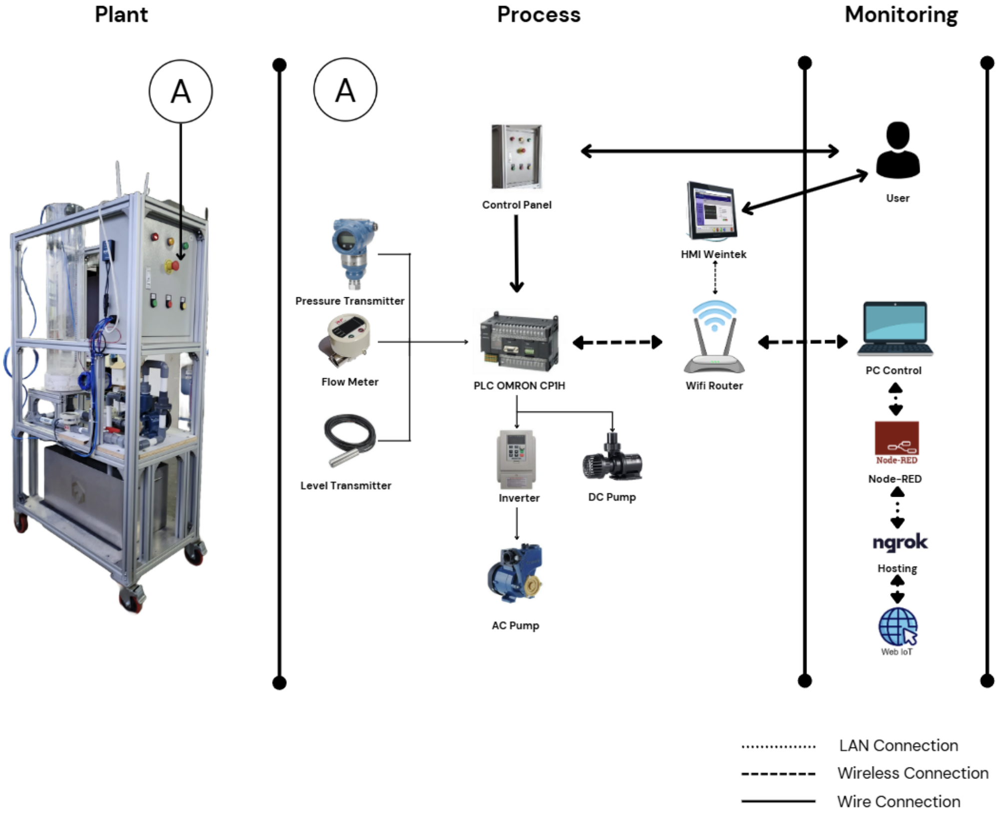

Figure 2. System overview

Software used such as MATLAB version 2021 as a calculator to calculate the rules of the Fuzzy Logic Controller. The latest version of Node-RED Dashboard, namely 4.0.8 as a visual-based programming tool for connecting and automating data flows visually and Node.js version 22.13.1 as the basic foundation for being able to run Node-RED.

The Omron CP1H PLC was selected due to its robust support for high-speed I/O, analog input sensor and output analog sensor, compatibility with Modbus and FINS protocols, and proven industrial-grade reliability. It provides precise signal control and is well-suited for real-time control applications [18].

Node-RED was chosen for its visual programming capabilities, rapid deployment for IoT dashboards, and seamless integration with cloud/hosted services through tools such as Ngrok. Its web-based UI enables easy monitoring and remote parameter control, flexible data logging capabilities, in line with Industry 4.0 requirements. This combination enables cost-effective, scalable, and industry-ready implementation of SCADA-like monitoring systems. [19][20].

2.3 Statistical Analysis

Measure Absolute Percentage Error (MAPE) is one of the commonly used metrics in statistics and forecasting to measure the accuracy of a forecasting model. It expresses the absolute average of the percentage error between the actual (true) value and the forecasted (predicted) value [21] as Equation (1).

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{At-Ft}{At}\right| \times 100\% \quad (1)$$

with: A_t : the actual value in period t

F_t : the forecast value in period t

n : the number of periods or observations

$|cdot|$: the absolute value

2.4 Mechanical Design

Figure 3 is the mechanical design of the plant. There are 3 levels starting from level 1, which is the water storage tank, then level 2 is the sensor storage and level 3 is the control panel.

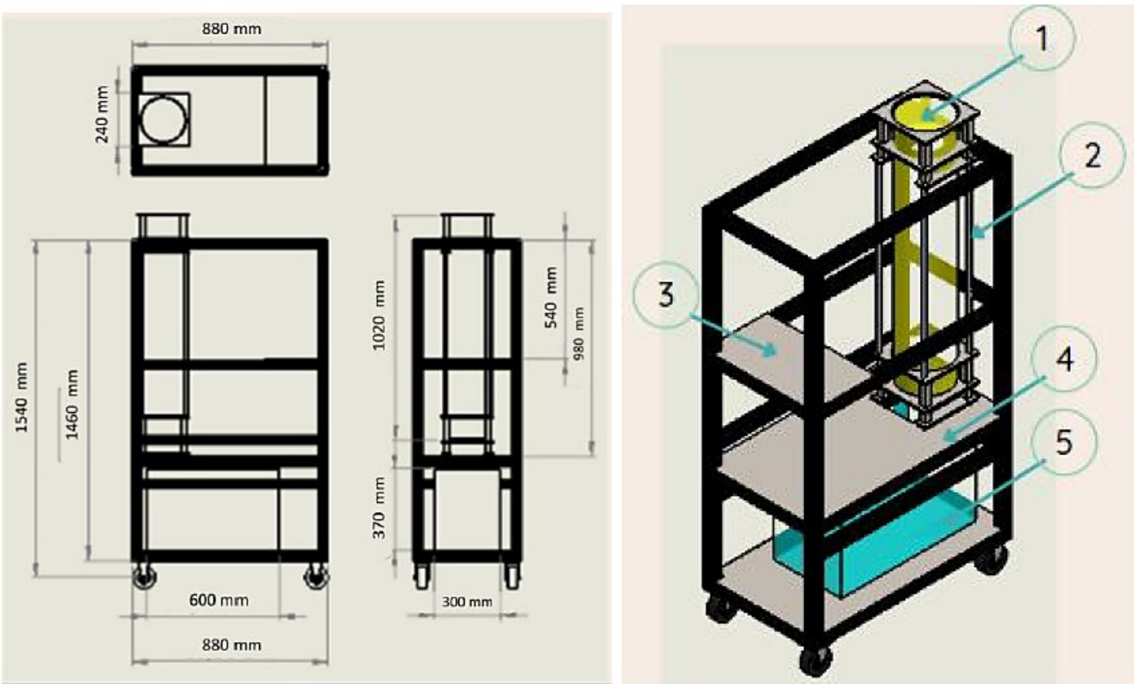

Figure 3. Mechanical Design of Water Level Plant

Figure 4 The media used to measure the water level in this tool is a tank that can be changed in height through the Level Transmitter sensor. In this research, actuators namely AC (Alternating Current) and DC (Direct Current) pumps are used to fill the Water Level Tank. The AC pump speed can be adjusted using an inverter, then the DC pump is used as a disturbance, simulating a leaking tank. The water that comes out of the DC pump then enters the Water Storage tank again. The flow meter measures the water discharge then if the incoming and outgoing water discharge changes it will send a signal to the PLC to immediately adjust the actuator. Pressure sensor as an indicator of water flow pressure.

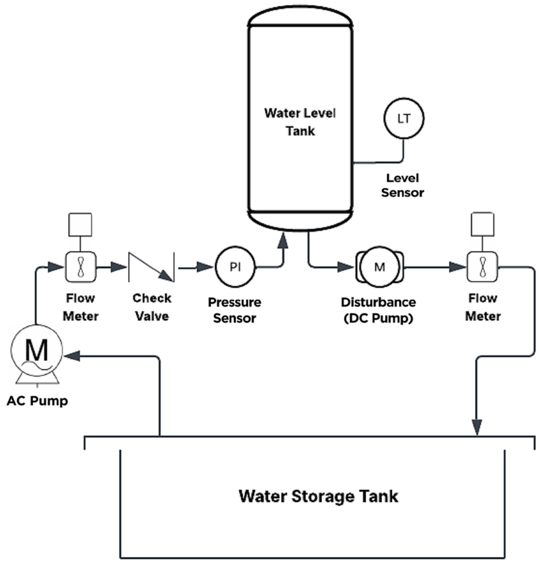

Figure 4. P&ID Water Level Plant

2.5 Electrical Design

Figure 5 shows the design of the electrical panel in terms of external front view and internal layout. This panel is designed for automation systems that are controlled using a Programmable Logic Controller (PLC), Inverter as a motor regulator, MCB for overcurrent safety and terminal blocks as a link between cables.

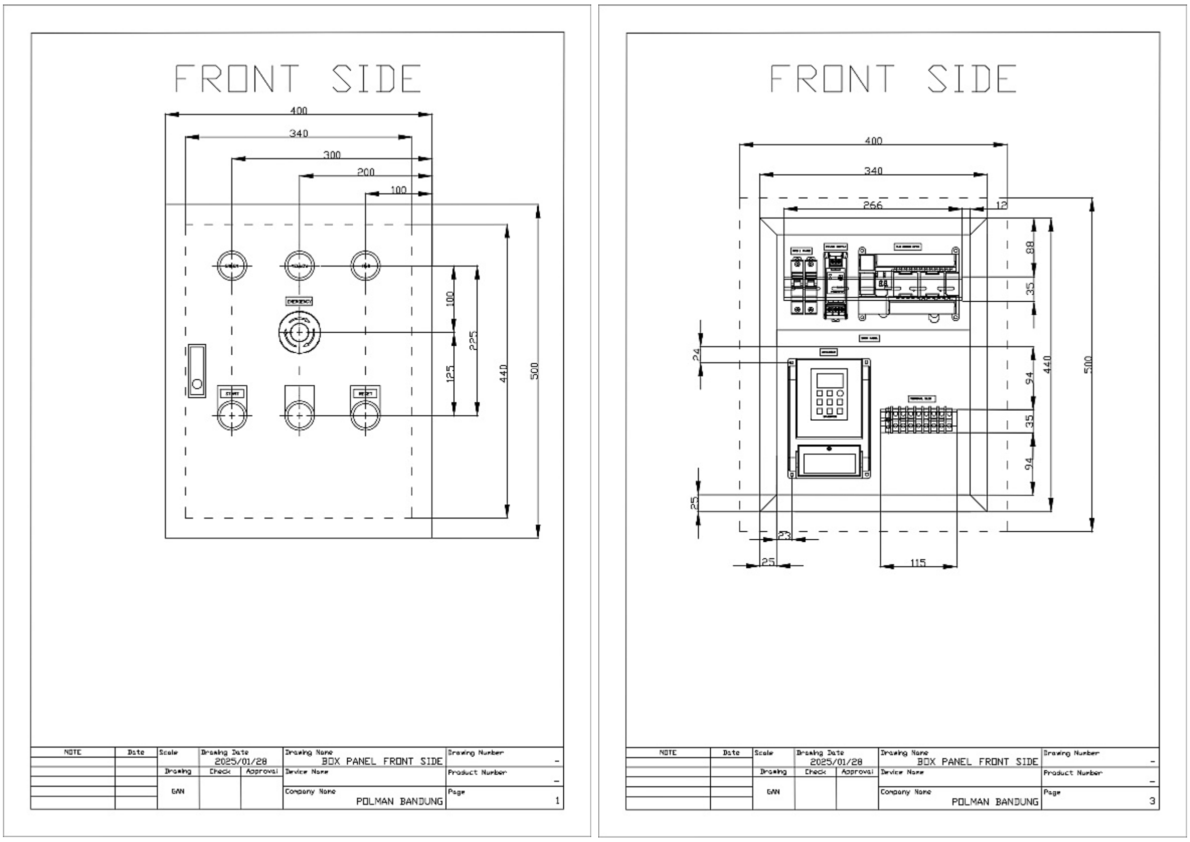

Figure 5. Control Panel Design

2.6 Control Design

In Figure 6, the initial process begins by entering the desired setpoint value, then the setpoint will be entered into the Fuzzy system. Then the flow meter will detect interference along with the previously inputted PID value. The inverter speed will turn on the pump and fill the tank to get the error and delta error values. The output of the Fuzzy system will produce Kp, Ki and Kd values for the PID parameters, then the inverter speed will adjust to the new PID parameters.

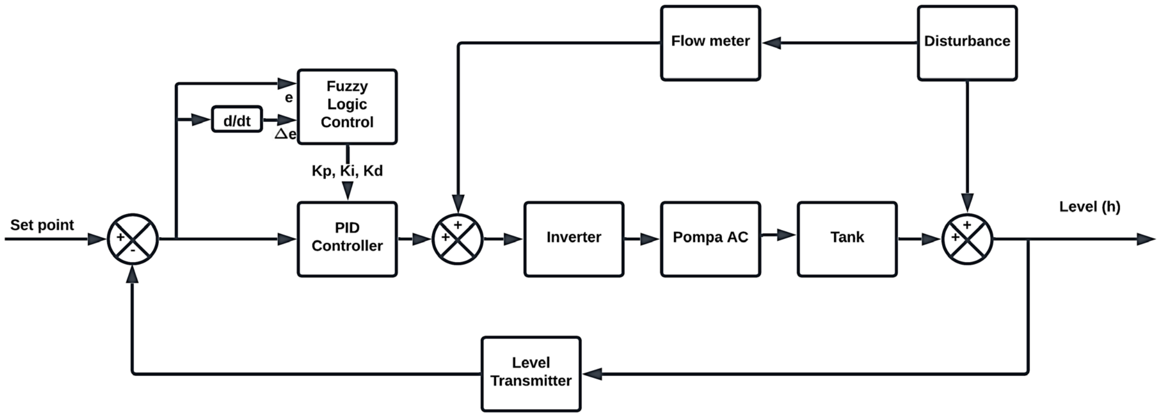

Figure 6. System Block Diagram

Figure 7 shows the MATLAB Fuzzy-PID design block. This design is used to determine whether the fuzzy results produced are in accordance with expectations before being implemented on the PLC. This block has three outputs, namely pb, ti, and td. Fuzzification, Inference, and Defuzzification are the steps in the fuzzy generation process.

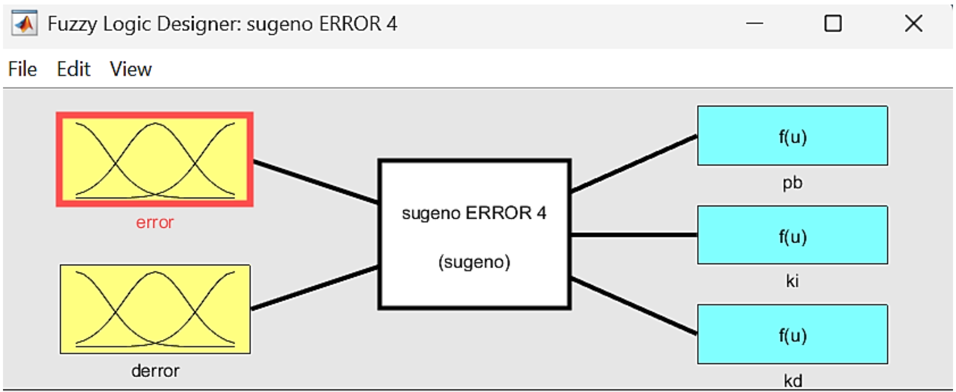

Figure 7. Fuzzy PID Block in MATLAB

Fuzzification is the process of transforming numerical variables into linguistic variables The normalized error (e) and delta error (Δe) values of the variables (-600) - (600) into linguistic variables which are labeled as the basic range of each linguistic variable and five Fuzzy subsets namely: NB (Large Negative), NS (Small Negative), ZE (Zero), PS (Small Positive), PB (Large Positive) in order to cover the basic range of each linguistic variable.

Fuzzy Inference System, Figures 8 and 9 show the decision matrix used (Fuzzy inference system) in the Fuzzy-PID self-tuning.

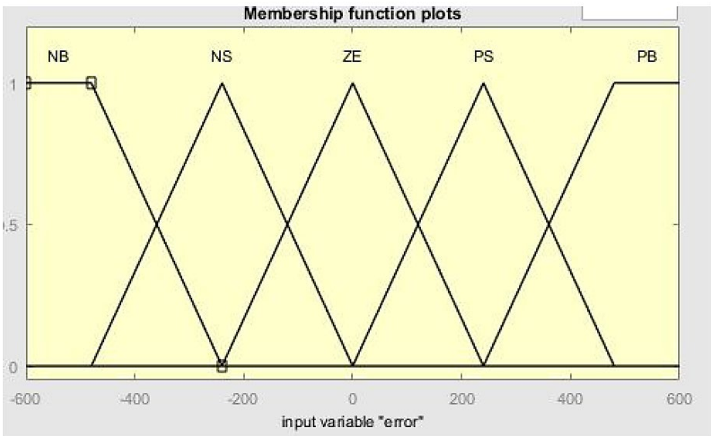

Figure 8. Membership Function Input Error

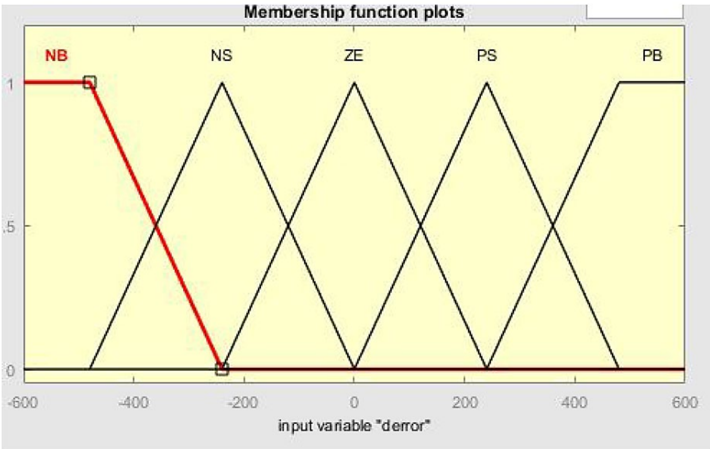

Figure 9. Membership Function Input Delta Error

Figure 10 explains table rules of fuzzy logic control which output value is Kp, Ki and Kd. The rules to be the next process into defuzzification. Defuzzification is a method used in the system to find the weighted average value on Fuzzy. The formula used to find the output is using Equation (2).

$$Zk = \frac{\sum_{i=1}^{n} \alpha i Zi}{\sum_{i=1}^{n} \alpha i} \quad (2)$$

with: αi : the α i-th predicate
Zi : the i-th rules of output antesden
n : the number of rules used

dKp dKi dKd		**dError**				
		NB	**NS**	**ZE**	**PS**	**PB**
Error	**NB**	S B B	B S ZE	B S ZE	B S ZE	B ZE B
	NS	S B ZE	B S ZE	B S ZE	B ZE B	B S B
	ZE	S S ZE	B B ZE	ZE ZE ZE	B B ZE	B S ZE
	PS	S S B	B ZE ZE	ZE S ZE	B S B	B B ZE
	PB	S ZE B	B S ZE	ZE S B	B S ZE	B B ZE

Figure 10. Rules of Fuzzy Kp, Ki and Kd

2.7 Informatic Design

Figure 11 shows the display of the system design. This interface is designed to provide PID (proportional integral derivative) control operation and monitoring through an interactive interface. The user can view the main diagram in different tabs, "Menu" to view the graph of the system cost. This diagram helps the user visually understand the performance of the system, especially when the system reacts to changes in setpoint values.

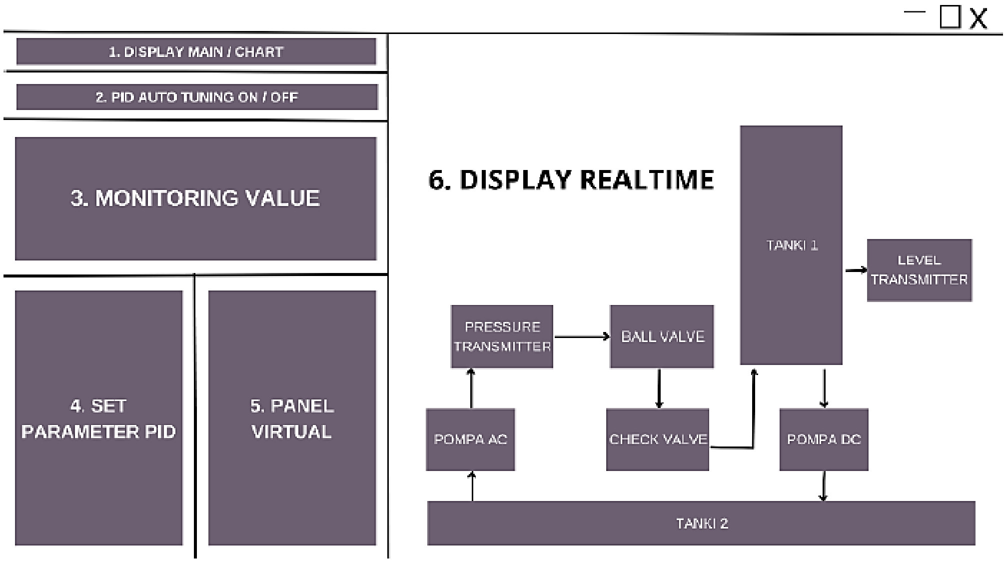

Figure 11. Node-RED Interface Design

3. RESULTS AND DISCUSSION

3.1 Mechanical Implementation Results

The water level plant was successfully made with a length of 880 mm, a width of 240 mm and a height of 1540 mm. Divided into several levels starting from level 1 for water storage then level 2 is like a sensor and actuator then level 3 is the control panel. Figure 12 is the result of mechanical implementation.

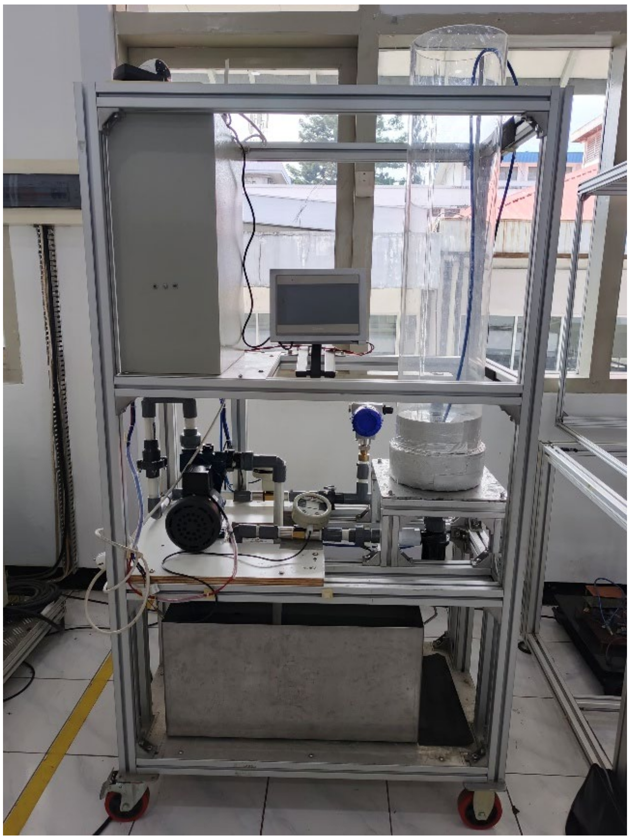

Figure 12. Side view of Water Level Plant

3.2 Sensor Testing Result

3.2.1 Level Sensor

Table 1 shows the digital value of the level sensor on the tank.

Table 1. Digital value of the level sensor on the tank

Digital value	Actual Value (mm)
157	0
272	100
390	200
509	300
623	400
742	500
857	600

From Table 1, there are digital and actual values (mm) in the water level tank which will be converted into a linear regression as shown in Figure 13.

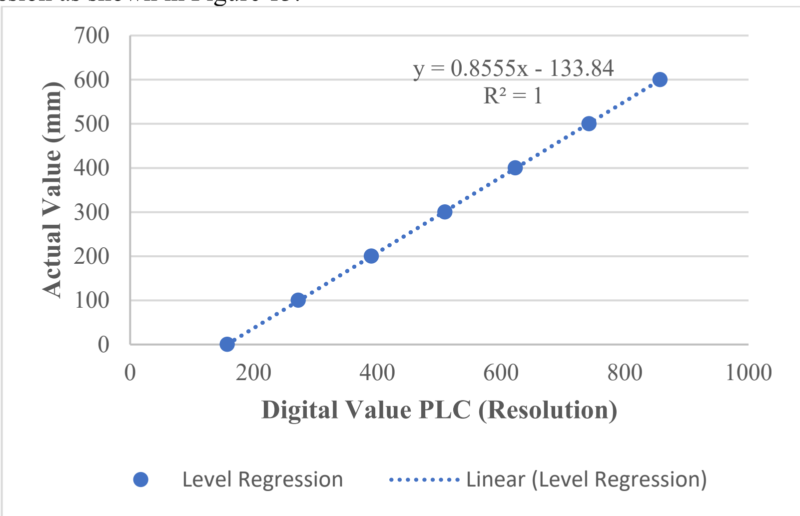

Figure 13. Linear Regression of Level Sensor

Figure 13 produces a linear equation, namely $y = 0.8555x - 133.84$, then the results of the equation are entered into the PLC program with the level sensor test shown in Table 2.

Table 2. Level Sensor Testing

REAL (cm)	PLC		Average	Error Absolut (%)
	Min Value	Max Value		
10	10.5	10.7	10.60	6.0
20	20.6	20.8	20.70	3.5
30	30.5	30.7	30.60	2.0
40	40.7	40.9	40.80	2.0
50	50.7	50.9	50.80	1.6
60	60.7	61.0	60.85	1.4
MAPE (Mean Absolute Percentage Error)				**2.75**

Table 2 is a test of the level sensor by comparing REAL measurements and the results obtained from the PLC system for several distance values in centimeters. The PLC measurement values are recorded in the form of minimum and maximum values, then the average of the two values is calculated. Furthermore, the absolute error for each measurement was also calculated. The Mean Absolute Percentage Error (MAPE) value obtained is 2.75%, which indicates that the PLC is able to produce distance measurements with good accuracy, where the error rate is relatively low.

3.2.2 Flow Out Sensor

Table 3 show the digital value of the flow out sensor.

Table 3. Digital Value of the Flow Out Sensor

Digital Value	Flow rate Value
9	0
691	1
1050	2
1315	3
1637	4
1908	5
2198	6
2472	7
2703	8
2951	9
3162	10
3387	11
3602	12
3762	13
3959	14
4127	15
4302	16
4322	16.5

From Table 3, there are digital and actual values (mm) in the water level tank that will be converted into a linear regression as shown in Figure 14.

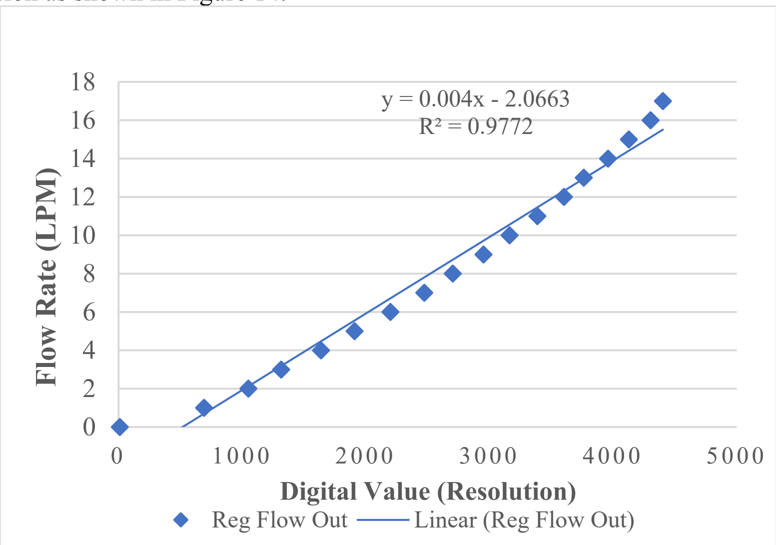

Figure 14. Linear Regression of Flow Out Sensor

Figure 14 produces a linear equation, namely y = 0.004x - 2.0663, then the results of the equation are entered into the PLC program by testing the flow out sensor shown in Table 4.

Table 4. Flow Out of sensor testing

REAL (LPM)	PLC		Average	Error Absolut (%)
	Min Value	Max Value		
5	5	5	5.0	0.00
10	10	10	10.0	0.00
15	14	15	14.5	3.33
16	15	16	15.5	3.13
MAPE (Mean Absolute Percentage Error)				**1.61**

Table 4 is a test of the Flow in sensor showing the comparison between the REAL value of flow in units of liters per minute (LPM) and the results obtained from the PLC system. The Mean Absolute Percentage Error (MAPE) value obtained is 1.61%, which indicates that the PLC system has very good accuracy with an error of less than 2% and is classified as low.

3.3 Control System Testing Result

Control testing is carried out with 2 controls, namely single control (Feedback and Fuzzy-PID) and combination control (Feedforward and Feedback with Fuzzy-PID). This test is carried out with the same Kp, Ki and Kd values and is carried out for 2 minutes given different disturbances in the 1st minute (first 60 seconds) from 50% to 100% with the aim of knowing stability if given different disturbances. PID parameters can be seen in Table 5.

Table 5. Parameter of Tuning Fuzzy-PID

Controller Type	Kp	Ti	Td
Fuzzy-PID	6	40	8

In testing the control response, the constants in the combination control, namely Feedforward and Feedback with Fuzzy-PID, are determined based on trial & error as in the book [22]. That is by determining the constant value based on trial & error. The book states that if the constant value causes overshoot in the system response then reduce the value but if the value is less in the system response then add the value little by little. In this study, using a constant with a value of constant of feedforward by trial & error value (*Kff*) = 12.5, then the value as a multiplier for the Flow In and Flow out sensor values. The value is entered into the Omron PLC program so as to produce additional values for the Fuzzy-PID output. In Figure 15, the D801 data is the inverter output after adding the constant from the feedforward. From the beginning without feedforward, the output value of the inverter resolution is +2787 after being combined to +2887. This means that the feedback and feedforward combination has been included in the PLC program.

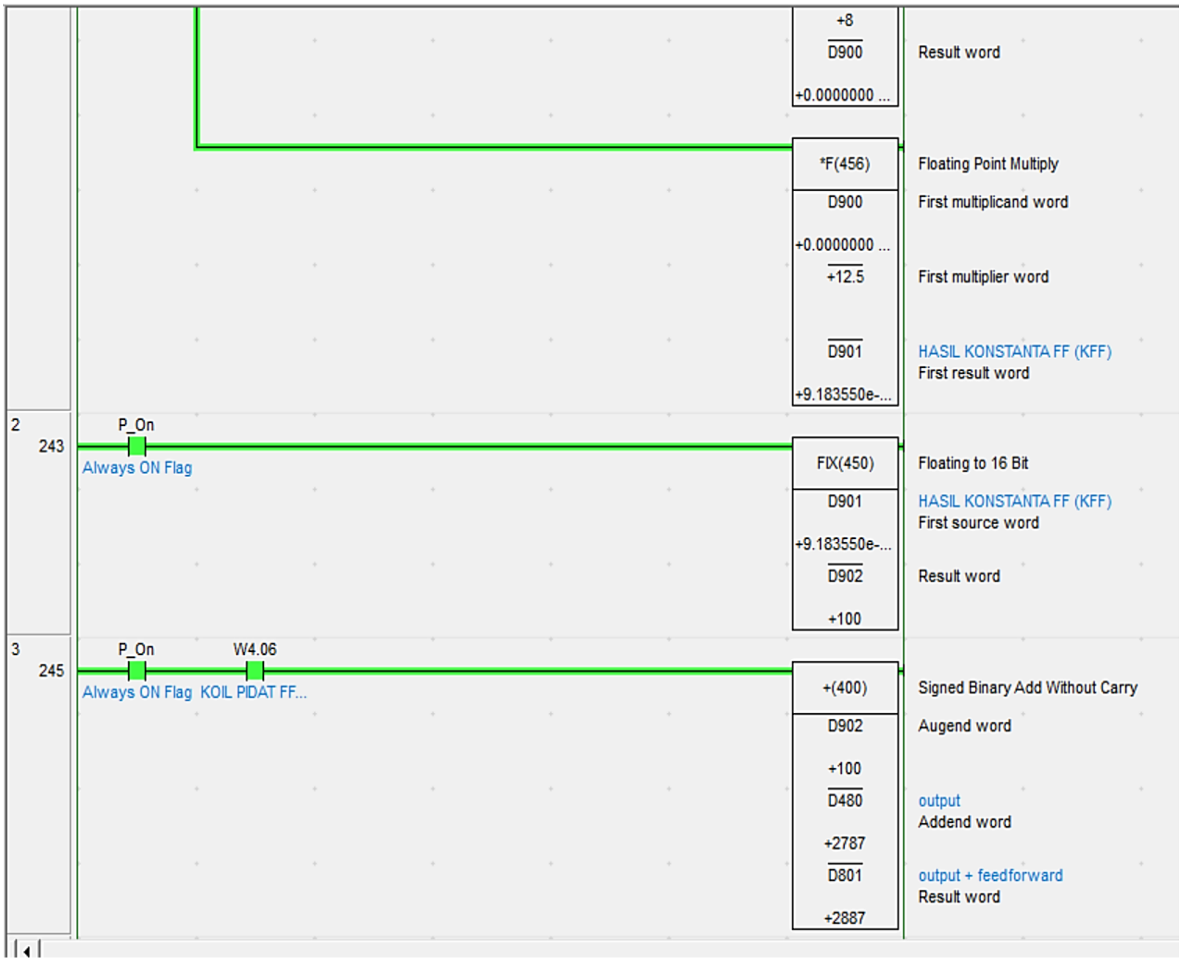

Figure 15. Feedback and Feedforward Combination Program on a PLC

Figure 16 is the result of the test response between the two controls, namely Fuzzy-PID with Feedback (Single Control) and Fuzzy-PID with Feedforward and Feedback (Combination Control). The graph of disturbance flow to system response. The graph visualizes how the flow out of a system changes over time under the control of two different control configurations: "single control" (represented by the blue line) and "combination control" (represented by the orange line). Outflow is measured in Liters per Minute (LPM) on the vertical axis, while time is measured in seconds (s) on the horizontal axis. This graph presents the dynamic response of both systems to changes in the requested flow setpoint. Discussion of Figure 16 can be seen in Table 6 and Table 7.

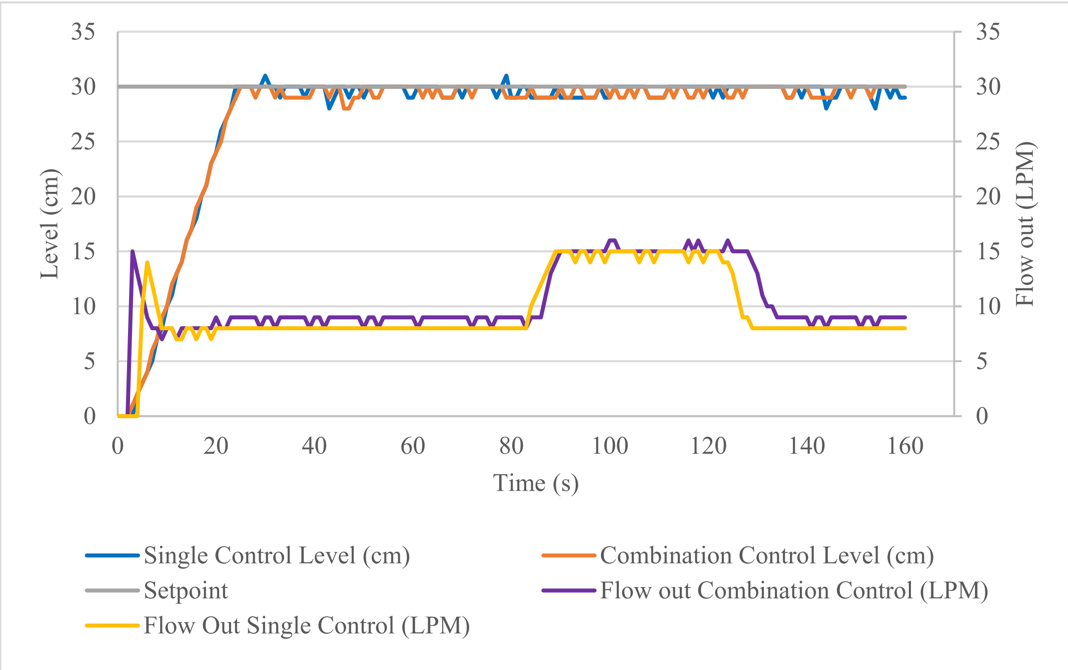

Figure 16. Comparison Response Testing

Table 6. System response characteristics of single control

Test	Self Tuning Fuzzy PID Single Control				
	Error steady state (%)	Rise Time (s)	Settling time (s)	Overshoot	Oscillation
1	1.02	17	28	No	Yes
2	1.01	18	30	No	Yes
3	1.35	18	28	No	Yes
Average	**1.12**	**17.6**	**28.6**	**No**	**Yes**

Table 7. System response characteristics of combination control

Test	Self Tuning Fuzzy PID Combination Control				
	Error steady state (%)	Rise Time (s)	Settling time (s)	Overshoot	Oscillation
1	1.01	18	29	No	Yes
2	0.00	17	29	No	Yes
3	1.01	17	28	No	Yes
Average	**0.67**	**17.3**	**28.6**	**No**	**Yes**

In Table 6 and Table 7, the analysis shows that the Combination Control configuration provides superior performance compared to the Single Control, especially in the aspect of accuracy. The significant decrease in the average steady state error of 0.67% in Combination Control is a clear evidence of higher efficiency in achieving precision. Although the difference in rise time and settling time is not very large, the consistency in avoiding overshoot in both configurations is a noteworthy achievement. The remaining challenge for both systems is to overcome the remaining oscillations, which if eliminated, will further improve the overall response quality of the system.

Figure 17 presents the results of the "Test-1 Disturbance Test" which compares the performance of two control system configurations: "Single Control" and "Combination Control". The objective is to analyze how these two systems respond to changes and disturbances in managing the water level (Level) in the tank and the flow out.

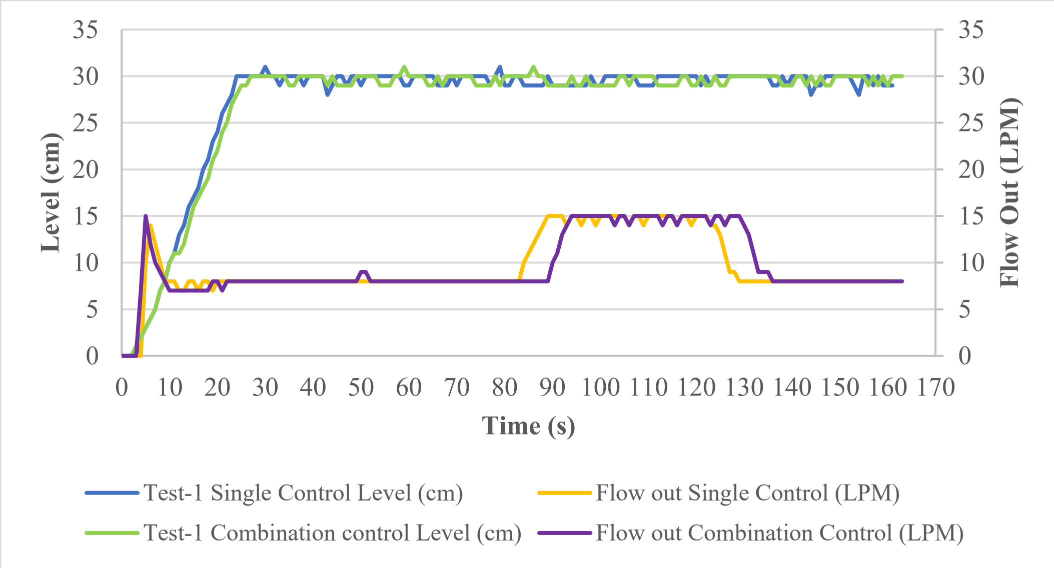

Figure 17. Analysis on Disturbance Test-1

In Table 8 and Table 9, present are comparison tables between Feedback and Feedforward systems against disturbances. The Single Control system reacting to disturbances is a reflection of its robustness. The disturbance is applied according to the condition when the outflow has reached 100%. Once a disturbance occurs, the system takes between 5 to 9 seconds of recovery time to return to a stable state. This time range shows that Single Control is indeed capable of recovering, but the process can vary slightly. As for the fault survival time, which is how long the system can maintain its performance before being significantly affected, it ranges from 4 to 6 seconds. This shows that there is a short period where the system can "fight" the disturbance before the full effect is felt.

Table 8. Analysis of System Response to Single Control Disturbance

Test	Single Control Disturbance Analysis		
	Disturbance Time (s)	Recovery Time (s)	Disturbance Resistance Time (s)
1	89	9	6
2	86	5	5
3	87	5	4
Average		**6.3**	**5**

Table 9. Analysis of System Response to Combination Control Disturbance

Test	Combination Control Disturbance Analysis		
	Disturbance Time (s)	Recovery Time (s)	Disturbance Resistance Time (s)
1	94	2	2
2	90	3	8
3	89	4	2
Average		**3**	**4**

When it comes to fault handling, Combination Control clearly excels, especially in recovery speed. The ability of a system to quickly regain stability after a disturbance is a crucial feature for applications in dynamic and unpredictable environments. Although the fault survival time shows little variation, the Combination Control's potential to significantly delay the effects of a fault (as seen in Test 2) is a great indicator of its strength.

In the test, the average comparison between the two controls, namely single control and combination control. The single control was only able to recover the set point from the disturbance for 6.3 seconds and the survival time of the set point for 5 seconds was 1 second longer than the combination control. The Combination control is able to recover the disturbance by 3 seconds faster than 3.3 seconds from the single control even though it has a difference in survival time from the disturbance of only 1 second from the single control. This shows that combination control can be an option when a system has a disturbance that cannot be measured.

3.4 Informatic Testing Result

3.4.1 Node-RED with PLC Interface Testing

Figure 18 shows the test between the Node-RED dashboard and the PLC program. Users can monitor the water level through the level sensor, know the input and output flow through flow in, flow out, know the pressure in the tank with gauge value pressure and can know the speed of the AC motor inflow through the frequency on the inverter.

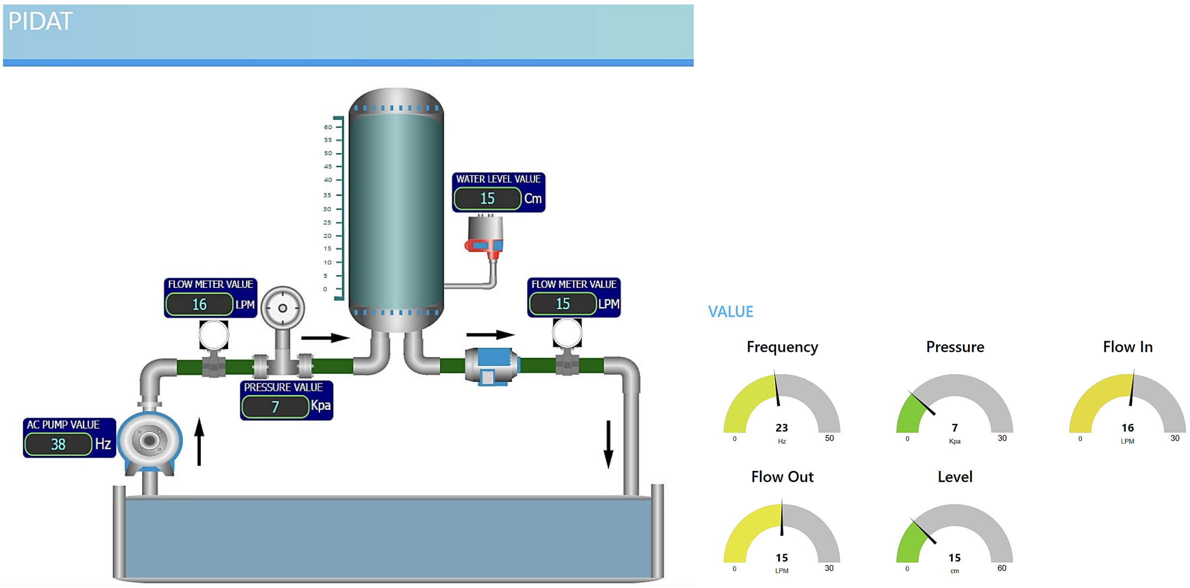

Figure 18. Node-RED Dashboard Testing

3.4.2 PC-PLC Data Transfer Speed Testing with TCP Fins

In this speed test, Wireshark software is used to calculate the difference between the sender's address, 192.168.10.6 to 192.168.10.16 as the Omron PLC address using the Fins TCP protocol. Table 7 shows the average transfer speed.

Table 10 shows that the average speed of the level sensor reading input is 0.027621 ms, then at setting the input value of the Proportional Constant (Kp), the average range is 0.156153 ms and the reading of the light indicator output is 0.253308.

Table 10. Transfer speed data

No	Features		Input/ Output	Address	Delay (ms)
1	Sensor	Level	Input	D701	0.000864; 0.010942; 0.030609; 0.069359; 0.031187; 0.000611; 0.070653; 0.010702; 0.020569; 0.030717
Average (ms)					**0.027621**
2	Setting Parameter	Kp	Input	D411	0.053796; 0.464394; 0.062664; 0.268633; 0.242599; 0.252450; 0.023951; 0.051414; 0.128076; 0.013556
Average (ms)					**0.156153**
3	Indicator	Green Lamp (Run)	Output	W3.08	0.223512; 0.283305; 0.254409; 0.179058; 0.258269; 0.294168; 0.274062; 0.172690; 0.279798; 0.313811
Average (ms)					**0.253308**

3.5 IoT Testing of Node-RED

In testing the SCADA Node-RED in IoT, testing was carried out with the help of a hosting platform, namely Ngrok, because Node-RED is still based on localhost. Figure 19 shows the Ngrok shortcut that is already active and hosted, in Session Status, namely the Web Interface http://127.0.0.1; 1880 is the Node-RED dashboard address which is then hosted by Ngrok to produce a new address, namely in Forwarding to https://29f7-103-48-27-8.ngrok-free.app. After getting a new address, this new address will be tested on another device, here I use a cellphone with its own cellular network. HTTP Request is a request sent by a client, such as a browser or application, to a server to retrieve various resources, such as HTML files, images, or JavaScript scripts. There are several processes such as 304 Not modified which means that there are no changes to the /ui settings parameters on Node-RED made on other devices. This test can be seen in Figure 20.

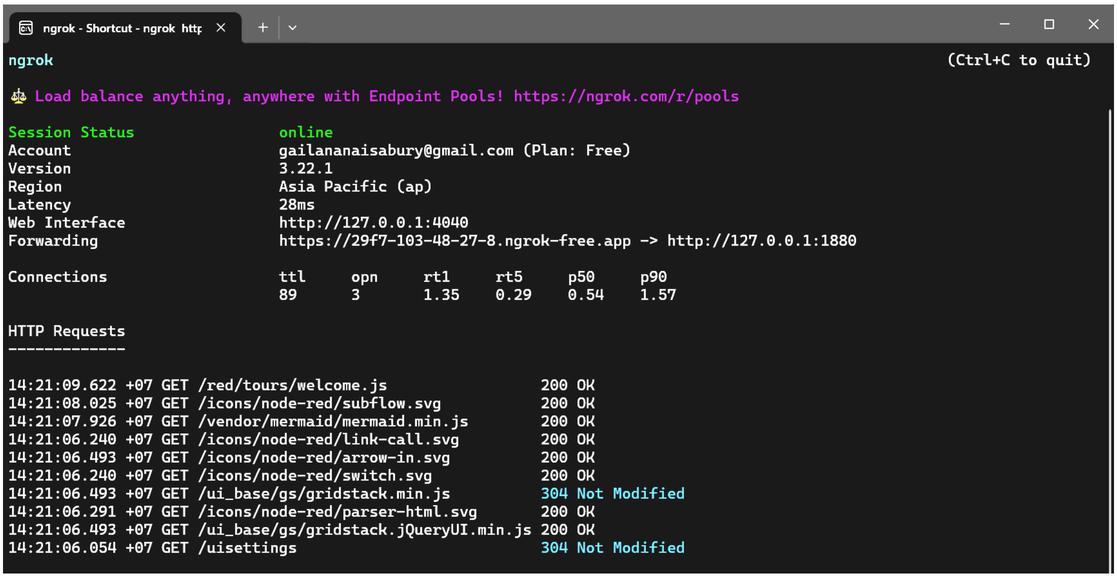

Figure 19. Active Ngrok Command

Figure 20 is an IoT hosting test using another device or mobile phone with a cellular network. Users can set parameters on the plant using a different internet (using their own cellular network data). This means the system is already online and can be controlled remotely. Signaling the Water Level Plant is integrated with the Internet of Things.

Figure 20. IoT Water Level Plant Hosting Testing

3.6 Discussion

Our results show that the Fuzzy-PID Feedforward-Feedback combined control system provides a more stable response (average steady state error 0.67%) than the single feedback control of 1.12% and a faster recovery time of 3 seconds than the single of 6.3 seconds. These performance improvements are consistent with the findings in previous studies which underscore the effectiveness of combined control in reducing the impact of disturbances on process systems.

While this study has successfully designed stable feedback and feedforward controllers for WWTP aeration systems, challenges in addressing time delays and oscillations due to disturbance characteristics persist. As a step forward in overcoming these limitations and exploring more practical implementations, our subsequent research by Sunarya et al. proposes a feedforward-feedback water level control system utilizing Fuzzy-PID on an Omron CP1H PLC, complemented by an IoT-based Node-RED monitoring interface [9]. Our approach shows significant performance improvement: our combined control system can recover the disturbance time more robustly as long as 3 seconds and the average steady state error becomes 0.67% compared to the single feedback control. In addition, we managed to eliminate the overshoot observed in the single feedback control, which is critical for system stability. A major novelty in our research is the utilization of flow sensors as feedforward inputs, enabling more proactive fault detection and correction compared to the previously discussed time-delay constraints.

These results are in line with the findings in previous research [23] which shows that the use of Fuzzy-PID is able to produce faster settling time and less overshoot than conventional PID, although it has a slightly slower rise time of about 1-2 seconds of optimization. The research focused on optimizing Fuzzy-PID as a single controller with varied disturbances, while this research develops further by adding feedforward control that uses a flow sensor as an additional input, so that disturbances can be detected and corrected more quickly before affecting the water level. The integration of IoT SCADA through Node-RED in this research adds innovation value by providing real-time remote monitoring and control capabilities, which have not been explained in detail in previous studies.

Understanding these strengths and limitations is essential for future deployment and scalability of the control system, especially in real industrial environments. The strengths and limitations of the proposed design are summarized in Table 11 for further clarity and evaluation.

Table 11. Strengths and Limitations of the Proposed Control Design

Strengths	Limitations
1. Enables faster and more stable system response under disturbances. 2. Effectively integrates proactive and reactive control strategies through feedforward-feedback combination. 3. Suitable for nonlinear processes and systems with time delays.	1. Requires higher computational effort and tuning complexity compared to single PID. 2. System oscillation still persists due to raw sensor fluctuations. 3. Implementation on low-spec PLCs may face performance bottlenecks.

3.7 Implications and Contributions.

This research offers practical and academic contributions. From an industrial perspective, the control system can be implemented in water treatment plants, manufacturing systems, and other process industries requiring adaptive level control [24]. The integration of IoT allows remote diagnostics, predictive maintenance, and enhanced safety through real-time alerts [20].

From a scientific standpoint, this study advances the field by validating a hybrid Fuzzy-PID controller enhanced by feedforward action on a real-time PLC-based platform. The integration with Node-RED provides a scalable, user-friendly HMI solution rarely explored in past research. This reinforces the importance of combining smart control techniques with accessible monitoring tools for broader industrial adoption.

The main contribution of this research lies in the integration of flow sensors as feedforward inputs, which enables more proactive fault detection and correction than traditional feedback approaches [23]. Adding control from previous research that has not used feedforward. This research uses a flow sensor so that the system response will be faster.

4. CONCLUSION

Well-written, but needs a clear link to hypothesis/objective from the Introduction. Please summarize contributions more explicitly. Recommendations for future work should be more concise. This research aimed to address the challenges of water level control in dynamic industrial environments, particularly those affected by unpredictable disturbances such as fluctuating inflow and outflow. By integrating a feedforward–feedback control system using a Fuzzy-PID approach implemented on an Omron CP1H PLC and complemented with an IoT-based Node-RED interface, the study successfully achieved its objective of enhancing control accuracy and system responsiveness. The results demonstrated that the proposed control system outperformed conventional feedback-only control, achieving a lower steady-state error (0.67% vs. 1.12%), faster disturbance recovery (3 seconds vs. 6.3 seconds), and eliminating overshoot entirely. These findings validate the hypothesis that combining feedforward and feedback mechanisms leads to more robust performance, especially when dealing with unmeasurable disturbances. This study contributes to both practical and academic fields in several key ways. First, it introduces the novel use of flow sensors as feedforward inputs, allowing proactive disturbance detection and correction before the water level is affected. Second, it provides a real-world implementation of a Fuzzy-PID controller within an industrial-grade PLC, showcasing its effectiveness in nonlinear and time-sensitive systems. Third, the incorporation of Node-RED as a web-based SCADA platform enables real-time, remote monitoring and control, promoting accessibility, scalability, and readiness for Industry 4.0 applications. Despite its promising results, the system still exhibits oscillations caused by raw sensor signal fluctuations, and the tuning complexity of Fuzzy-PID requires additional computational overhead. These issues highlight opportunities for further refinement. Future work should focus on enhancing sensor signal filtering to minimize oscillations and testing the control system in more complex, real-world industrial scenarios to evaluate its robustness and adaptability on a larger scale.

ACKNOWLEDGMENT

Thanks are given to the Center for Development, Research and Community Service (P3M) of Bandung Manufacturing Polytechnic for funding this research. And to the Control System Laboratory Team, Department of Manufacturing Automation and Mechatronics, Bandung Manufacturing Polytechnic, who have provided very meaningful facilities and technical assistance.

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