The Indonesian Journal of Computer Science
www.ijcs.net
Volume 13, Issue 4, August 2024
https://doi.org/10.33022/ijcs.v13i4.4127

Water Level Control in Coupled Tank System with PLC and IoT-Based PID Method

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Article Information

Received : 13 Jun 2024
Revised : 20 Jun 2024
Accepted : 1 Jul 2024

Keywords

Coupled Tank System, Water Level Control, PID Controller, PID Tuning Method, IoT

Abstract

There are many advanced technological discoveries in industry, including the coupled tank. Coupled tanks are several tanks connected to each other. One of the quantities that is often controlled in the industry is the control of water levels. Water level control in a PLC and IoT-based coupled tank system is a medium for controlling and monitoring water levels remotely in real-time. The sensor used is a Differential Pressure Transmitter (DPT) with a pump motor actuator which is connected to an Omron PLC using an inverter. There is a disturbance in the form of setting the control valve opening. The control method used is the PID method with Ziegler-Nichols tuning and trial and error. Both methods analyzed which performance of the system response characteristics was better. It is proven that PID tuning is suitable for water level control of coupled tank systems.

A. Introduction

Technological developments affect humans to work as effectively and efficiently as possible, which has led to many advanced technological inventions in the industry, one of which is coupled tanks [1]. Coupled tanks are multiple tanks that are interconnected. Through input manipulation and sectional valve areas, the coupled tank system can be configured as a Single Input Single Output (SISO) system and a Multi Input Multi Output (MIMO) system [2], [3], [4], [5]. In this study, the author will use the SISO system. The control system or control is the formation of system stability due to the arrangement of several physical components. One of the most common, simple structure, and easy implementation to achieve system stability is to use PID control. Some of the quantities that can be controlled are temperature, pressure, level, acidity level (pH), and many more [2][6]. One of the quantities that is often controlled in industry is the control of water levels, the system must be able to maintain according to the desired water level [7]. In this process, automatic control of control instrumentation is an important part. One of the devices that allows automatic control is a PLC (Programmable Logic Controller) [7]. The internet has also become a necessity for society and industry. With the internet, people can communicate with each other very easily and quickly. The internet not only connects people but things can also communicate with other things. This concept is called the Internet of Things (IoT) [8].

Previous research, by Siswoyo et al. conducted water level control in coupled tanks using the PLC-based PID method [7]. The results of the PID test were able to control the stability of the water level, with the parameters Kp = 6.25, Ti = 35, and Td = 8.75. Mohd Fua'ad Rahmat and Sahazati MD Rozali analyzed and compared the performance of PID and Fuzzy Logic controllers in controlling the water level of the coupled tank [9]. The author chose to use Fuzzy Logic because it is easy to apply to systems with multiple inputs multiple outputs (MIMO), while PID is suitable for single input single output (SISO) systems. Anisa Ulya Darajat and Swadexi Istiqphara made a simulation of a water level control system in a two-tank system or coupled tank using the adaptive integral proportional (PI) method [10]. The study succeeded in controlling 2 water tanks with an adaptive PI control system but there was a change in parameters when the process was running and this research was only a simulation. Another research by Dede Irawan Saputra et al. modeled and simulated the water volume control system in the process plant in the form of a tank with the state feedback method[11]. The results of the closed-loop control system test in Matlab obtained satisfactory results by using the pole placement equation with the state feedback gain value of the sensor which resulted in Td = 5 seconds, Ts = 237 seconds, Tr = 88 seconds, and overshoot of less than 10%. Akbar Hariputra and Puput Wanarti designed the PI-Fuzzy controller to control the fluid level in the coupled tank[12]. The equation of mass equilibrium and Bernoulli's law was carried out to obtain the equation of the mathematical model of the plant coupled tank by performing a linear model to obtain the transfer function value. Hazriq Izzuan Jaafar et al. developed a PID controller to control the water level in the coupled tank system [13]. It can be concluded that Ziegler-Nichols tuning requires a short turnaround time and is easier to use than other methods. In addition, ZN can also obtain Ti and Td in both closed and open-loop systems. Akram Muntaser and Nagi Buaossa control a system of paired tanks to keep the level of fluid in the tank constant when there is fluid ingress into the tank and/or fluid exiting the tank [14]. The PID control obtained an overshoot of 29%, a rise time of 3.72 seconds, and a settling time of 24.9 seconds. Ardilessi and Jaka Giwang Kara conducted research on tank volume control using Labview and Arduino UNO [15]. Researchers have succeeded in producing a faster rise time by using PID. Ibnu Hajar et al. made a simulation to control the water level using PLC and HMI [16]. PLC programming can control the water level well and HMI also runs well. There is another research in the form of designing a water level control system using PLC and HMI by Tri Wahyu Oktaviana Putri et al [17]. Researchers can control water levels with an error of 4% using the PID method and controllers in the form of PLCs. Dendin Supriadi designed a system that can control water levels using PLC-based ultrasonics [18]. Researchers have succeeded in controlling PLC-based water levels with errors between 0-5%. Another research on water level monitoring and sluice gate control is based on MCU node code microcontroller ESP8266 by Trian Fitra Ramadhan and Wahyu Triono[19]. The results of the study make it easier to control and monitor the water level and sluices. Annisa et al. designed a smart tank to control and monitor water levels based on IoT [20]. With IoT, it can be easier to control the filling of the tank remotely.

From several previous studies, the author developed the control and modeling of the water level of a coupled tank system using the PID method based on Omron PLC and IoT with the Ziegler-Nichols PID tuning method. The sensor used is a Differential Pressure transmitter with a pump motor actuator that is connected to an Omron PLC using an inverter. In the study, the author used the Ziegler-Nichols PID tuning method. Unlike previous studies that were only in the form of simulations using the Simulink and Labview applications, the author hopes to apply this control to real plants. In addition, the author added an IoT feature to remotely monitor the coupled tank plant in real-time. The application feature used for monitoring is using Node-RED. The author hopes that with this PID control, the output that corresponds to the set point can be achieved and the error is as small as possible.

B. Research Method

1. System Design

In this study, the author discusses water level control in PLC and IoT-based coupled tank systems. This IoT functions to remotely control and monitor this coupled tank system in real-time. The sensor used is a Differential Pressure transmitter with a pump motor actuator that is connected to an Omron PLC using an inverter. The control method used to control the water level in this coupled tank system is PID (Proportional, Integral, and Derivatives). The tuning used is Ziegler Nichols 1. The PID output controls the frequency of the inverter to power the pump. The following is an overview of this research system.

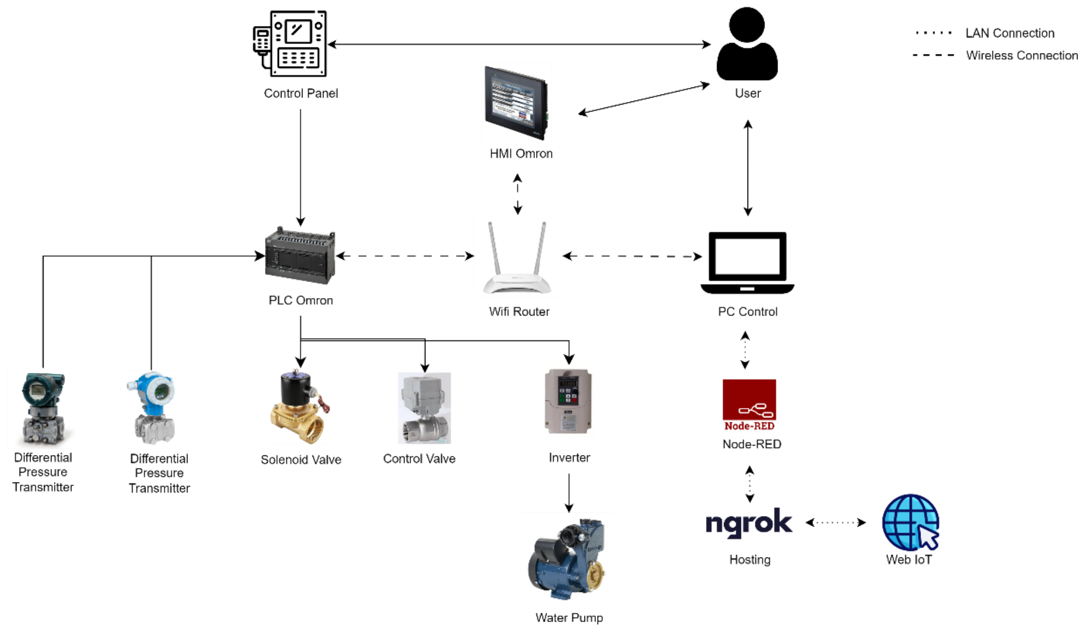

Figure 1. System General Picture

To be able to control and monitor the water level in the Coupled-Tank System plant in real-time through the control panel, Node-RED interface, and Omron HMI, it is necessary to involve several components. Omron's PLC functions to connect sensors and actuators with interfaces. The Differential Pressure Transmitter is used to measure the water level using water pressure. The actuators used are solenoid valves, control valves, and inverters. The inverter gets an analog signal from the PLC to control the frequency of the AC pump. The control panel can control the plant, which consists of start, stop, drain, emergency, and 3 selector switches. In addition, there are also indicators in the form of run lights (green), standby and drain (yellow), stop (red), and emergency lights. The Node-Red interface serves as parameter setting and monitoring. The parameter setting is to enter the value of the set point, Kp, Ki, Kd, and inverter frequency. For HMI, Omron has the same function as Node-RED, only adding buttons. This plant is also equipped with IoT-based remote control and monitoring functions. Ngrok serves to expose local hosts in the form of Node-RED to the internet through a secure tunnel.

Based on previous references, there are 2 ways coupled tanks work, SISO (Single Input Single Output) and MIMO (Multi Input Multi Output). In this research, the author will use a SISO coupled tank system with a controller in the form of an Omron CP1H PLC. This coupled tank system with one input and one output can include two water tanks connected by pipes, where one pump regulates the rate of water flow into the system. The water level in a tank is measured by a sensor in the form of feedback, and the controller uses this information to regulate the input (set the pump speed) to keep the water level at the desired value. The following is a P&ID image of the SISO system on a coupled tank.

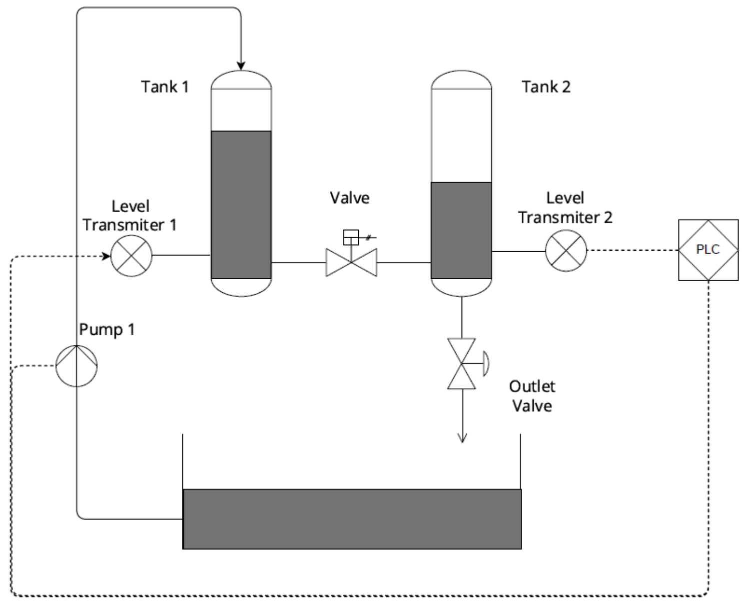

Figure 2. P&ID SISO (Single Input Single Output)

2. Block Diagram

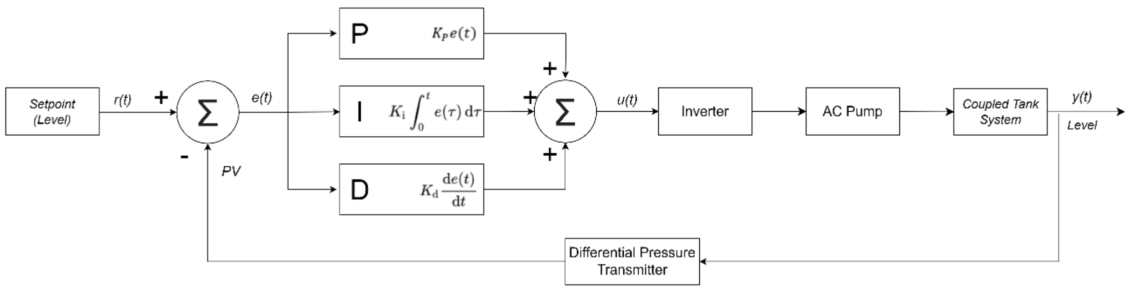

Figure 3. PID Control System Block Diagram

The water level control in the coupled tank system uses PID. The user enters the setpoint value in the form of the desired water level. PV (Process Variable) is a measurable quantity, in this study the PV value is measured by DPT. The error is the difference between the setpoint and the PV. The difference value is entered into the PID system. Manipulated Variable(MV) is the output of the PID calculation. The output will emit an inverter frequency signal that will control the pump speed and fill the tank to reach the desired height.

3. PID Tuning

In this study, the researcher will conduct PID tuning experimentally using the Ziegler Nichols 1 method. The Ziegler-Nichols method is one of the most well-known methods of tuning PID. ZN is also an automated PID method that is widely used in industrial fields [21]. Ziegler-Nichols tuning requires a short turnaround time and is easier to use than other methods [13]. In addition, ZN can also obtain Ti and Td in both closed and open-loop systems.

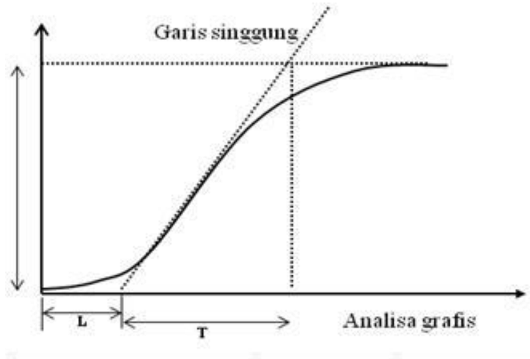

Figure 4. S Curve Ziegler-Nichols Graphical Analysis[22]

The delay time L and the time constant T are the two parameters that determine the curve S. To get both parameters, we can draw a tangential line at the inflection point of the curve S to get the intersection of the tangential line with the timeline and the line c(t) = K, as shown in Figure 4. After that, using the formula contained in Table 1, we can determine the values of the parameters Kp, Ti, and Td by entering the values L and T into the formula.

Table 1. Formula Ziegler-Nichols

Controller Type	Kp	Ti	Td
P	$\frac{T}{L}$	∞	0
PI	$0.9\ \frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\ \frac{T}{L}$	2L	0.5L

C. Result and Discussion

1. Mechanical Implementation

The following are the results of mechanical implementation. This plant has dimensions of 2m long, 1m wide, and 2m high. It has two acrylic tubes. The tube size is 190mm inner diameter, 200mm outer diameter, and 960mm high.

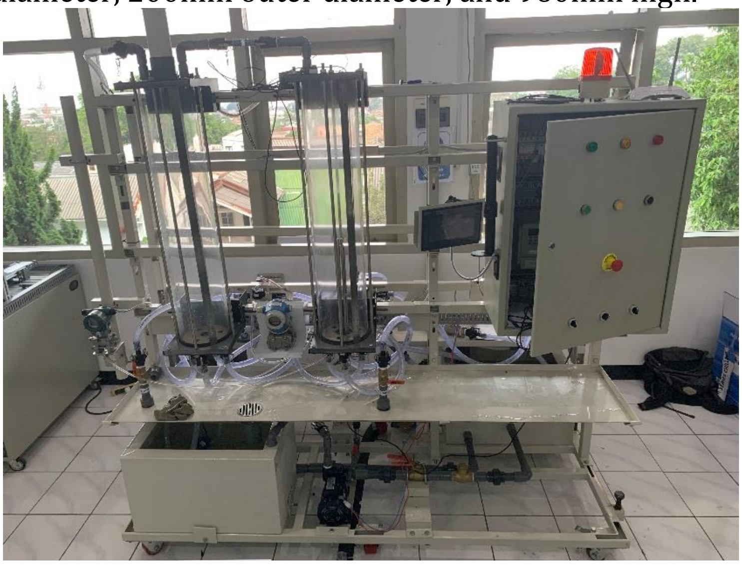

Figure 5. Coupled Tank Plant

2. Sensor Testing

2.1 Differential Pressure Transmitter PMD 75 Endress Hauser

This test is carried out to ensure the performance and reliability of the resulting altitude sensor. In this study, measurements were made at a height of 0-90cm.

Table 2. DPT EJX 110A Yokogawa Sensor Reading Test

NO	Actual			Sensor		PLC Scaling	
	%	Input mmH2O	Input cm	mmH2O	Error %	%	Error %
1	0	0	0	5	0.556	0	0.000
2	11.1	100	10	95	0.556	8	3.100
3	22.2	200	20	194	0.667	21	1.200
4	33.3	300	30	292	0.889	34	0.700
5	44.4	400	40	392	0.889	41	3.400
6	55.5	500	50	490	1.111	54	1.500
7	66.6	600	60	589.00	1.222	67	0.400
8	77.7	700	70	689	1.222	80	2.300
9	88.8	800	80	785	1.667	87	1.800
10	100	900	90	885	1.667	100	0.000
Average Error (%)				**1.044**		**1.440**	

As can be seen in Table 2, the average error comparing the actual value with the sensor is 1.044%, while the average error in the use of scaling in the PLC program compared to the actual value is relatively large, which is 1.440%. Therefore, researchers use linear regression to reduce errors. This method is done by looking at the relationship between the digital value read on the PLC and the actual value measured on the acrylic tube. The following is a table and equation of linear regression of DPT PMD75 Endress Hauser.

Table 3. Linear Regression DPT PMD75 Endress Hauser

Digital Value	**Actual Value(mm)**
12	0
335	100
708	200
1078	300
1454	400
1824	500
2200	600
2575	700
2948	800
3321	900

The data from Table 3 is processed into a graph to know the linear regression value as shown in the figure below.

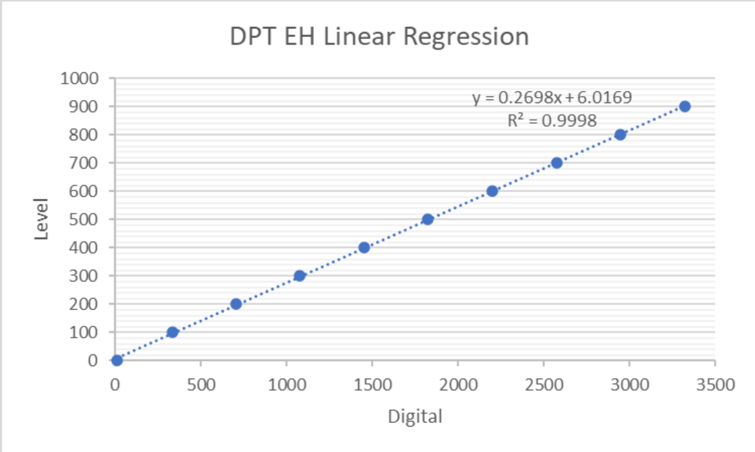

Figure 6. Linear Regression DPT PMD75 Endress Hauser

It can be seen in Figure 6 that there is a linear regression equation, that is: $y = 0.2698x - 6.0169$, the equation is then inserted into the PLC program so that the level of sensor accuracy with the actual value is higher. The following are the test results after linear regression.

Table 4. DPT PMD75 Endress Hauser Linear Regression Testing

No.	Actual	PLC Linear Regression	
	Input cm	cm	Error (%)
1	0	0	0.000
2	10	9	1.111
3	20	19	1.111
4	30	29	1.111
5	40	39	1.111
6	50	50	0.000
7	60	60	0.000
8	70	70	0.000
9	80	80	0.000
10	90	90	0.000
Average Error (%)			**0.444**

The average value of the actual accuracy with the PLC reading after linear regression is 0.444% as can be seen in Table 4.

2.2 Differential Pressure Transmitter EJX 110A Yokogawa

Just like before, this test is carried out to ensure the performance and reliability of the resulting altitude sensor. In this study, measurements were made at a height of 0-90cm.

Table 5. DPT EJX 110A Yokogawa Sensor Reading Test

NO	Actual			Sensor		PLC Scaling	
	%	Input mmH2O	Input cm	mmH2O	Error %	%	Error %
1	0	0	0	8.88	0.987	0	0.000
2	11.1	100	10	100.2	0.022	3	8.100
3	22.2	200	20	199.9	0.011	17	5.200

4	33.3	300	30	298.3	0.189	24	9.300
5	44.4	400	40	397.82	0.242	38	6.400
6	55.5	500	50	497.62	0.264	52	3.500
7	66.6	600	60	595.84	0.462	65	1.600
8	77.7	700	70	695.32	0.520	72	5.700
9	88.8	800	80	793.21	0.754	86	2.800
10	100	900	90	892.74	0.807	100	0.000
Average Error (%)				**0.426**		**4.260**	

As can be seen in Table 5, the average error in The comparison of the actual value with the sensor is 0.426 %, while the average error on use Scaling in the PLC program which is compared to the actual value is relatively large, which is 4.260%. Therefore, researchers use linear regression to reduce error. This method is done by looking at the relationship between the digital value read on the PLC and the actual value measured on the acrylic tube. The following is a table and equation of linear regression of DPT EJX 110A Yokogawa.

Table 6. DPT EJX 110A Yokogawa Linear Regression

Digital Value	Actual Value(mm)
61	0
671	100
1330	200
1999	300
2656	400
3323	500
3978	600
4642	700
5296	800
5960	900

The data from Table 6 is processed into a graph to know the linear regression value as shown in the figure below.

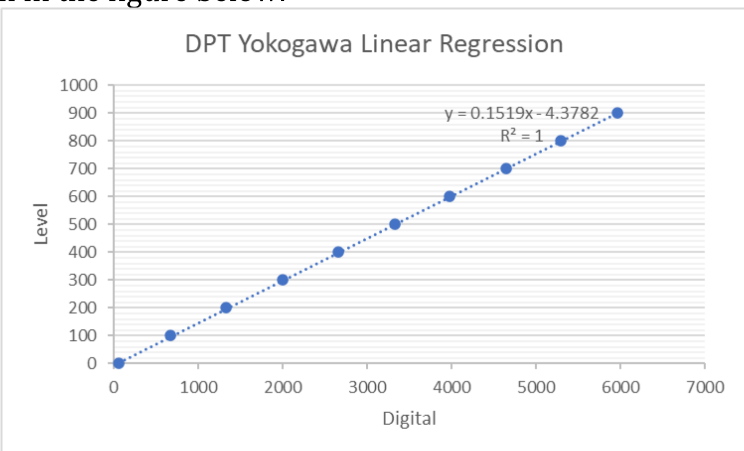

Figure 7. DPT EJX 110A Yokogawa Linear Regression

It can be seen in Figure 7 that there is a linear regression equation, that is: $y = 0,1519x - 4,3782$, the equation is then entered into the PLC program so that the level of accuracy of the sensor with the actual value is higher. The following are the test results after linear regression.

Table 7. DPT EJX 110A Yokogawa Linear Regression Testing

No	Actual	PLC Linear Regression	
	Input cm	cm	Error (%)
1	0	0	0.000
2	10	10	0.000
3	20	20	0.000
4	30	30	0.000
5	40	40	0.000
6	50	50	0.000
7	60	60	0.000
8	70	70	0.000
9	80	80	0.000
10	90	90	0.000
Average Error (%)			**0**

The average value of the actual accuracy with the PLC reading after linear regression is 0% as can be seen in Table 7.

3. System Testing

Node-RED hosting which is a local host is assisted by using Ngrok. The following are signs of active ngrok.

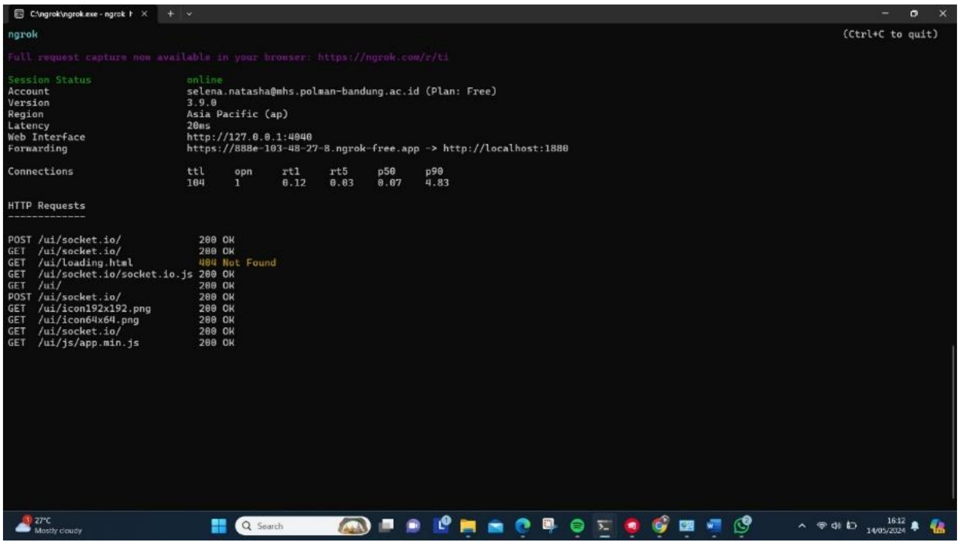

Figure 8. Ngrok Active

There is a link that has been hosted by ngrok. The link can be accessed on other devices. This test it was carried out with a laptop server in a control lab, the links that had been hosted were accessed on other computers using different internet.

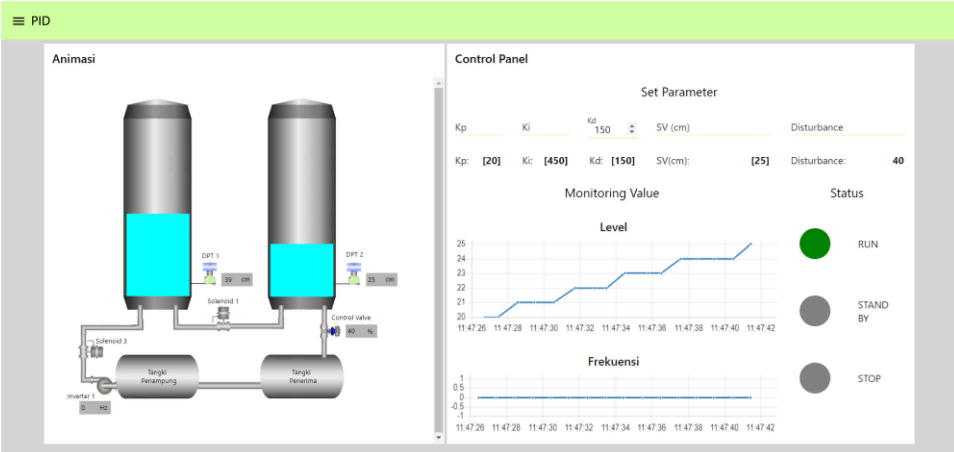

Figure 9. Node-RED Interface Design

Figure 9 is the Node-RED interface. On this page, users can monitor and set parameters like in Omron HMI. For monitoring, it shows sensor and actuator data as well as graphs. There are also run, standby, and stop-light indicators. Users can set parameters Kp, Ki, Kd, Setpoint (SV), and also disturbances in the form of control valve openings.

In Table 8, this test is to find out whether the communication between the PLC and Node-RED by IoT is connected or not and whether the performance is good enough or not. The following are the test results.

Table 8. IoT Node-RED Testing

No.	Feature		Input/Output	Address	Working/Not Working
1	Indicators	Green Light (Run)	Output	CIO 100.00	☑
		Yellow Light (Standby)		CIO 100.01	☑
		Red Light (Stop)		CIO 100.02	☑
2	Monitoring Value	Inverter 1	Output	D750	☑
		DPT 1		D440	☑
		DPT 2		D650	☑
		Kp		D4	☑
		Ki		D11	☑
		Kd		D300	☑
		SV(cm)		D6	☑
		Disturbance		D13	☑
3	Setting Parameters	Kp	Input	D4	☑
		Ki		D52	☑
		Kd		D53	☑
		SV(cm)		D6	☑
		Disturbance		D13	☑

Information: ☑ Working
☒ Not Working

Control and monitoring have been successful with IoT, but it requires a stable internet network.

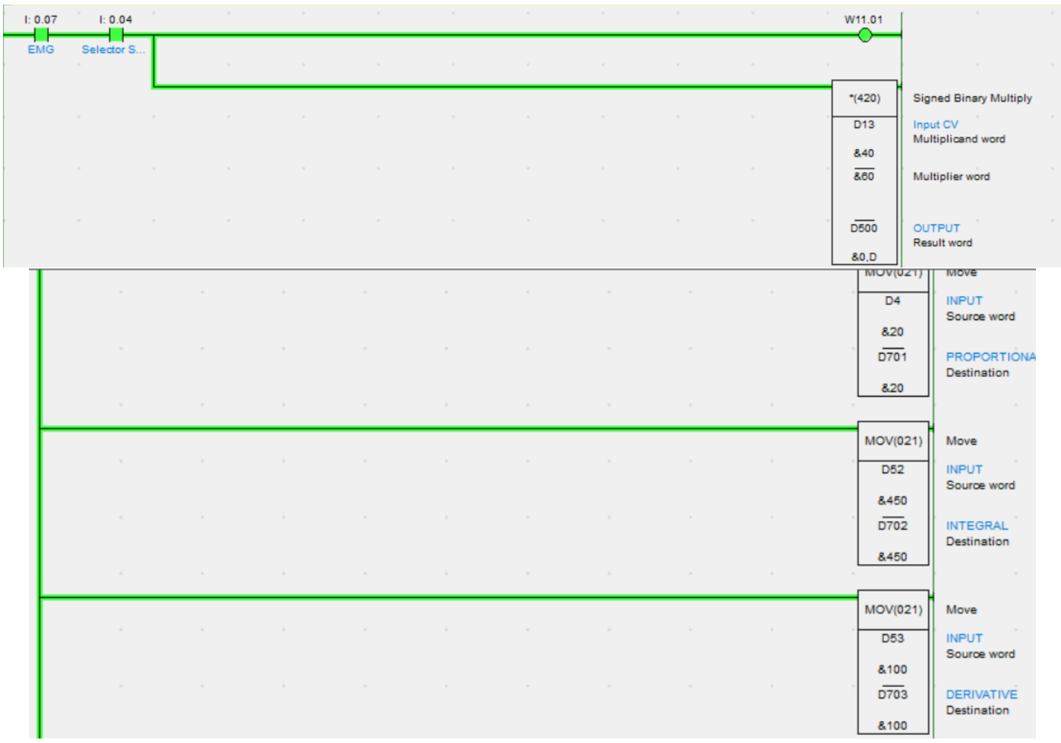

Figure 10. Setting Parameters Can Be Connected

With the help of Wireshark software, the average delay or delay time required to send and receive data packets on this IoT system is obtained, as can be seen in Table 9.

Table 9. Data Communication Testing

No.	Feature		Input/Output	Address	Delay (ms)
1	Indicator	Green Light (Run)	Output	CIO 100.00	0.0000
					0.0196
					0.4208
					0.0018
					0.5030
					0.0020
					0.4255
					0.0022
					0.5058
					0.0522
Delay Average (ms)					**0.1933**
2	Monitoring Value	DPT 2	Output	D650	0.0584
					0.0639
					0.0574
					0.0589
					0.0606
					0.0597
					0.0541
					0.0543
					0.0517
					0.0439

Delay Average (ms)					**0.0563**
3	Setting Parameter	Kp	Input	D4	0.4841
					0.0274
					0.1602
					0.1324
					0.1568
					0.4652
					0.1195
					0.1789
					0.2370
					0.2088
Delay Average (ms)					**0.2170**

As can be seen in Table 9, the data communication speed can be said to be fast and has a very small delay. The process of receiving data has an average delay of 0.1933ms on the indicator feature and 0.0563ms on the monitoring value feature. Meanwhile, the process of sending data has an average delay of 0.2190ms.

4. PID Testing

Starting with the collection of data on the time and water level until it reaches the setpoint using the inverter on-off program with the maximum frequency with the condition that the drain control valve on tank 2 is opened by 50%. From this data, an S curve is made. The delay time L and the time constant T are obtained by drawing the tangent as shown in Figure 11.

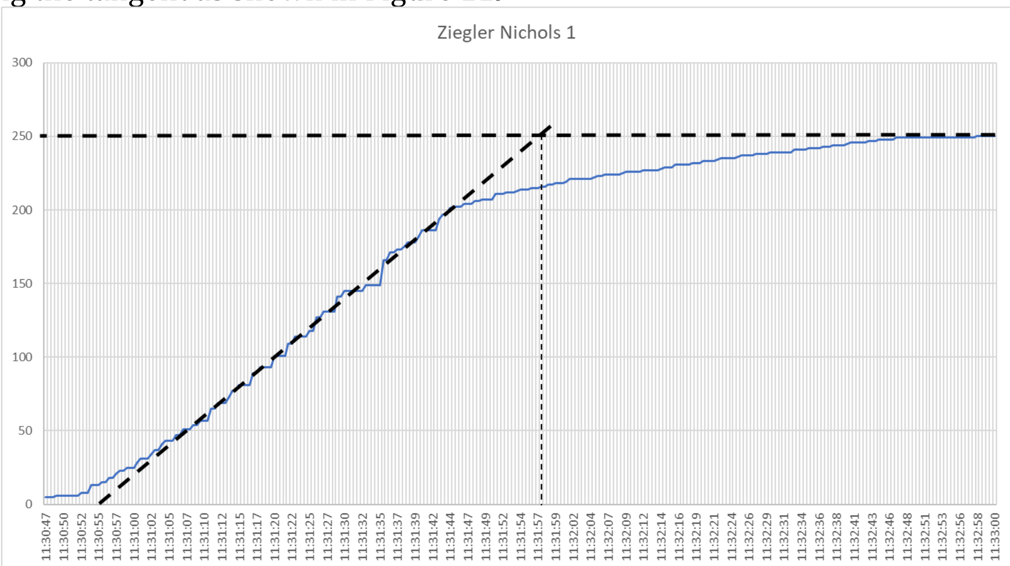

Figure 11. S Curve DPT 2

T was obtained in 62 seconds and L in 8 seconds. From this data, the values of Kp, Ti, and Td are obtained by entering them into Table 10. The following are the results of Kp, Ti, and Td from Ziegler Nichols 1.

Table 10. ZN-1 Tuning Results

Controller Type	Kp	Ti	Td
P	7.75	∞	0
PI	8.975	26.666	0

PID	9.3	16	4

The first test uses the results of PID tuning Ziegler Nichols 1 in Table 10, with Kp = 9, Ti = 16, and Td = 4. From these parameters, a graph is obtained as shown in Figure 12.

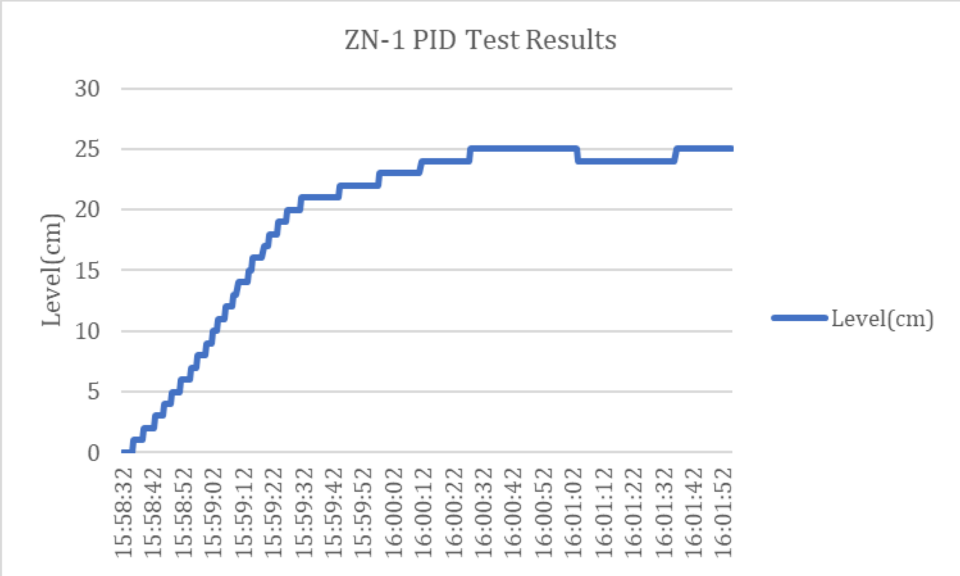

Figure 12. ZN-1 PID Test Results

The graph in Figure 12 has a settling time (T_s) of 116 seconds, a rise time (T_r) of 69 seconds, a percent overshoot (OS%) of 0%, and an error steady state (SSE) of ±0.7cm.

Other tests use the results of PID tuning with the trial and error method. Kp, Ti, and Td are obtained as shown in Table 11.

Table 11. Result Tuning PID Method Trial and Error

Controller Type	Kp	Ti	Td
PID	20	425	100

From the parameters that have been obtained in Table 11, a graph is made as shown in Figure 13.

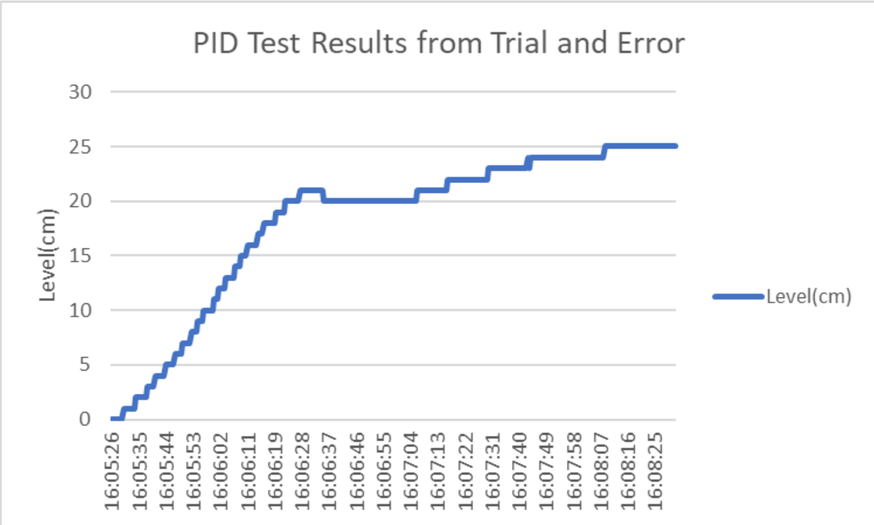

Figure13. PID Test Results from Trial and Error

The graph in Figure 13 has the settling time (T_s) of 162 seconds, the rise time (T_r) of 107 seconds, an overshoot percent (OS%) of 0%, and an error steady state (SSE) of 0cm.

The system response characteristics of the two methods are included in Table 12 to make it easier to compare them.

Table 12. System Response Characteristics

Method	Settling Time (s)	Rise Time (s)	Overshoot (%)	Error Steady State (cm)
ZN-1	116	69	0	±0.7
Trial & Error	162	107	0	0

As can be seen in Table 12, it can be concluded that the ZN-1 method has a faster time to reach a stable state on the system to survive at ±2% of the final value than the trial and error method. In addition, the time required for a change from 10-90% of the final value of the ZN-1 method can be said to be faster than with the trial and error method. However, by using the trial and error method, the resulting SSE (Error Steady State) is 0cm, which is better than the ZN-1 method.

D. Conclusion

From the results of this study, all design results in the form of electrical, mechanical, informatics, and control have been successfully carried out or implemented.

The results of the PID tuning control test of ZN-1 on the coupled tank system with the condition that the exhaust control valve in tank 2 was opened by 50% can be said to be quite good with Kp=9, Ti=16, and Td=4. The set point can be reached at 25cm, but there is still an oscillation of about ±0.7cm. The results of the PID control test using the trial and error method, obtained a steady state error result of 0% but the settling time and rise time were quite high, namely 162 seconds and 107 seconds.

The ZN-1 method has a faster time to reach a stable state on the system to survive at ±2% of the final value than the trial and error method. In addition, the time required for a change from 10-90% of the final value of the ZN-1 method can be said to be faster than with the trial and error method. However, by using the trial and error method, the resulting SSE (Error Steady State) is 0cm, which is better than the ZN-1 method.

The implementation of IoT control and parameter setting was successfully carried out with the help of Ngrok hosting. Data communication has an average error of 1,555ms.

E. References

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