Journal of Industrial Automation and Electrical Engineering
Vol. 02, No. 01, June 2025, pp. 1~9
ISSN: 3089-1159

IoT-based prototype for water quality monitoring and control

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Article Info

Article history:

Received February 10, 2025
Revised February 26, 2025
Accepted March 08, 2025

Keywords:

Clean water
pH sensor
TDS sensor
ESP32
Blynk

ABSTRACT

Clean water quality is an important factor for public health, but the problem of inconsistent PDAM water quality in Sijantang Koto village is still an obstacle. This research aims to design and build a prototype of an *Internet of Things* (IoT)-based water quality monitoring and control system. The system uses pH sensors and TDS sensors to measure water quality parameters in *real-time*. The data from the sensors is processed by the ESP32 microcontroller and displayed through LCD and Blynk application for remote monitoring. In addition to the monitoring function, the system is also equipped with an automatic control mechanism using a pump to add purifying agent (PAC) and pH neutralizer ($CaCo_3$) when the water parameters are outside the standard threshold. The results show that the system is able to detect changes in water quality and automatically control water parameters according to the set standards. The implementation of this system is expected to increase public awareness of the quality of water used and provide solutions in a more efficient and modern clean water management.

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1. INTRODUCTION

Clean water is a fundamental need for daily life. According to the Planning Criteria of the Directorate General of Human Settlements of the Department of Public Works in 1998, the clean water needs of rural communities are estimated at 80 liters per person per day, covering various household activities such as bathing, washing, and other sanitation needs [1]. However, the availability of quality clean water is still a challenge in many areas, including in Sijantang Koto Village, Talawi Sub-district, Sawahlunto City, West Sumatra. This village receives clean water supply from PDAM, but based on observations and interviews with residents, the quality of the water delivered is often inconsistent, with water conditions that are cloudy and contain soil sediment. This problem raises the need for a water quality monitoring system that can provide *real-time* information to the community.

The development of *Internet of Things* (IoT) technology provides new opportunities in water quality monitoring and control. Research by Yusri et al. [2] showed that an IoT-based monitoring system allows *real-time* monitoring of water quality parameters, providing early warning in the event of a decline in water quality. In addition, research by Mustamin et al. [3] revealed that the application of IoT in water quality monitoring can improve the efficiency and effectiveness of the monitoring system. By integrating pH and TDS (*Total Dissolved Solids*) sensors, this technology can provide accurate data related to water quality, enabling quick corrective action. The use of microcontroller technology in water quality monitoring systems has been widely developed. Wijaya & Sukarni [4] demonstrated the implementation of the Node-RED platform integrated with the SAW (*Simple Additive Weighting*) method to produce an accurate and easily accessible monitoring system. Meanwhile, Putra & Rosano [5] developed an IoT-based water quality monitoring system using the Blynk platform and *Google Sheet*, which allows *real-time* monitoring and more efficient data storage.

Based on previous research, Setiawan [6] has designed an IoT-based water quality monitoring system with a cloud-based system, while Ramadhan [7] implemented IoT sensors for river water quality monitoring with a focus on identifying water pollution. Therefore, this research aims to develop an IoT-based water quality monitoring system that not only monitors water quality, but also provides feedback on the monitoring results. The system will be able to provide information directly to the user as well as activate pumps to deliver corrective materials to solve water quality problems.

This research focuses on developing a system that integrates pH and TDS sensors with NodeMCU ESP32 microcontroller to monitor PDAM water quality parameters in *real-time.* The data obtained will be displayed through LCD for direct monitoring and Blynk *platform* for remote control for pump activation that can manage the provision of corrective materials such as PAC (*Poly Aluminum Chloride*) and CaCO3 (*Calcium Carbonate*) if the water quality parameters are outside the set threshold. With this system, it is hoped that the community in Sijantang Koto Village can gain access to clean water that is more guaranteed in quality. In addition, this system can also be a reference in the development of IoT-based water quality monitoring technology in the future.

2. METHOD

The waterfall method is a method that uses a systematic and sequential approach to system development [8]. Figure 1 shows the stage of waterfall methods.

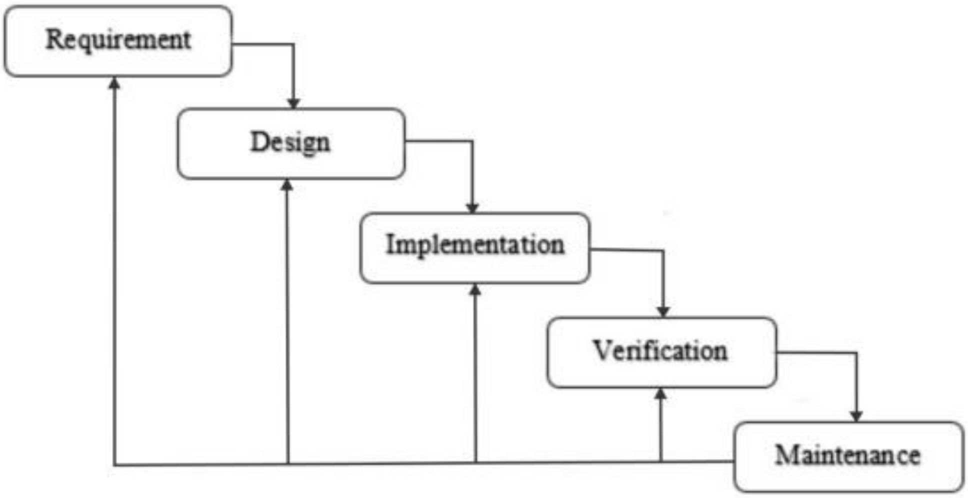


Figure 1. Stages of the waterfall method

The waterfall method consists of five stages. The first stage is Requirement (Needs Analysis), which involves determining water quality parameters, sensor specifications, and the necessary devices and components. The second stage is Design, where the IoT system architecture, electronic schematics, user interface, flowchart, and component layout are created. The third stage is Implementation, which includes assembling the device, programming the ESP32, developing a monitoring dashboard, and integrating all system components. The fourth stage is Verification, involving sensor accuracy testing, Wi-Fi connectivity checks, IoT data communication validation, and ensuring accurate data display on the Blynk dashboard and LCD. The final stage is Maintenance, which consists of periodic sensor calibration, system performance monitoring, cleaning, and replacing damaged components.

A block diagram is a system representation that displays the main parts or main functions of a system in the form of boxes connected by lines [9]. Block diagrams are used to describe the relationship between parts in a system. Block diagrams allow users to understand how the whole system works. Its main function is as a guide in arranging and connecting components in electronic circuits. The block diagram consists of three main parts: 1) Input Block - Consists of pH and TDS sensors that measure water quality parameters in the form of pH levels and the amount of dissolved particles, then send the data to the ESP32, 2) Processing Block - The ESP32 processes the data to determine if the water parameters meet the set thresholds. 3) Output Block - The processing results are displayed on the Blynk app and LCD. If the parameter value does not match the threshold then the relay will activate the pump to add correction solution into the water.

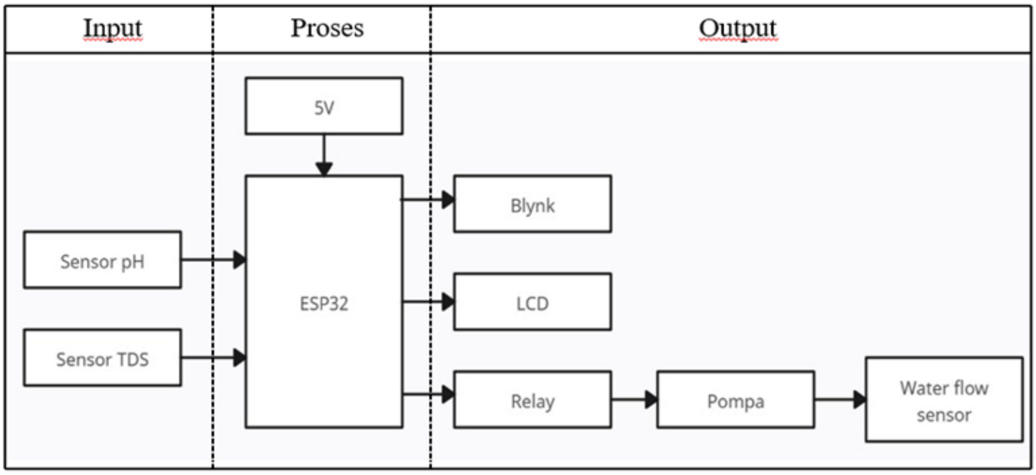


Figure 2. Block Diagram

The circuit scheme ensures that each component is connected to each other so that the system can work according to its respective functions. In depicting the circuit scheme, each component can be depicted in its own form or represented with symbols. Figure 3 shows the circuit scheme of proposed system

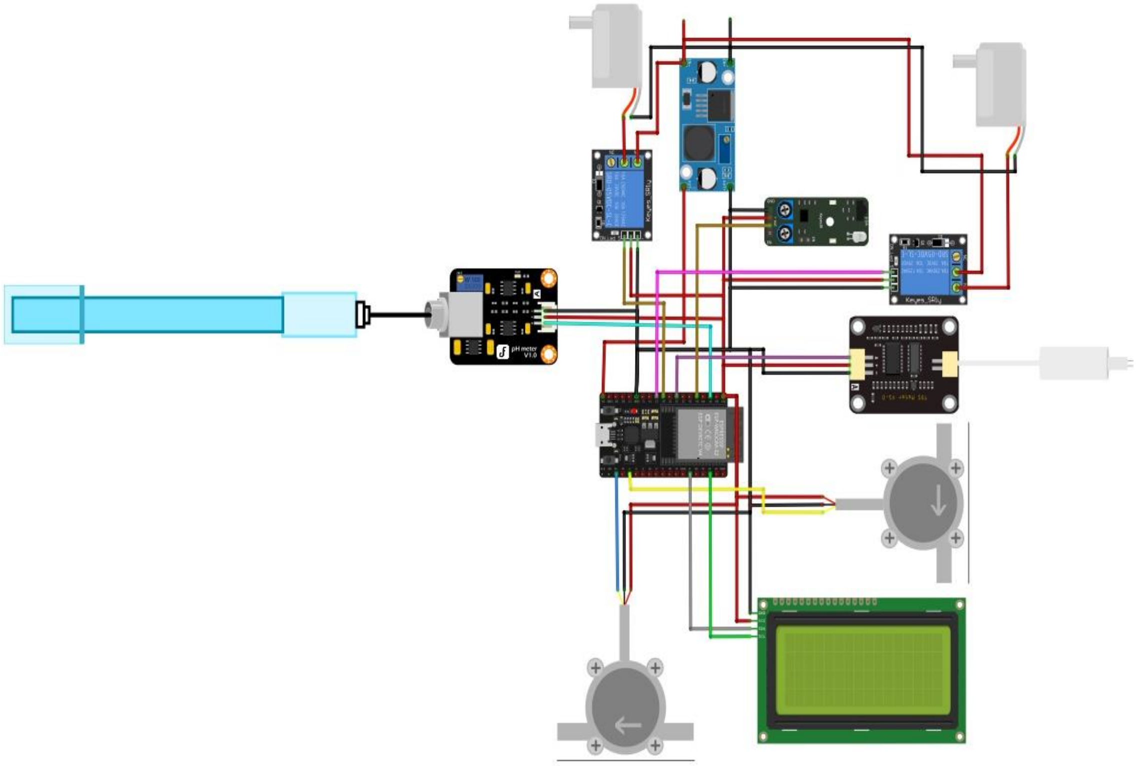


Figure 3. circuit Schematic

Flowchart is a diagram or chart that describes the flow of processes or steps in a program, including the relationship between processes and statements involved in it [10]. Flowchart consists of several symbols connected by lines, with each symbol having its own meaning. Flowcharts are also used to represent the conceptual structure of complex software systems, serving as design documents used by system analysts to communicate, negotiate and represent the complexity of a process [11]. Figure 4 shows the flowchart of system.

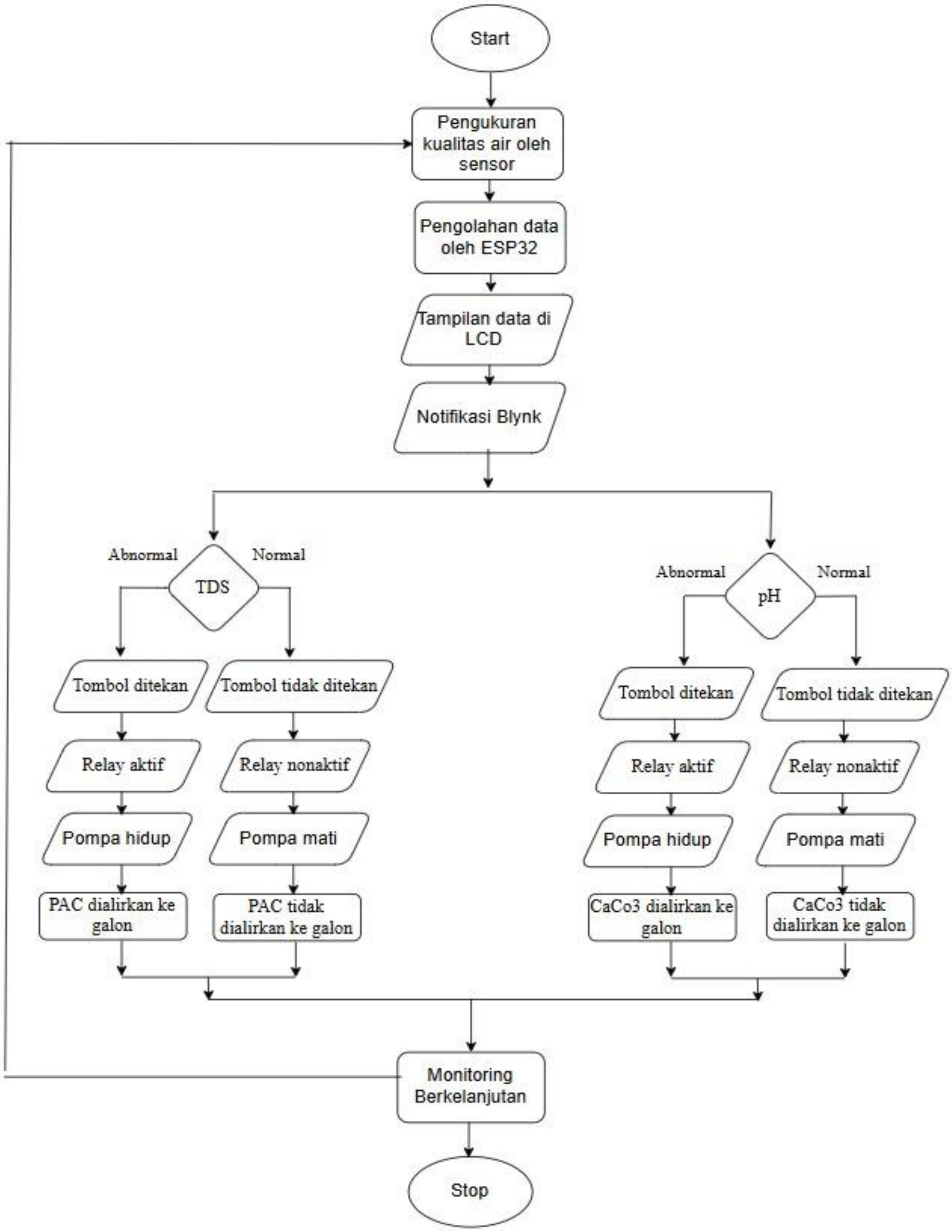


Figure 4. Flowchart

Hardware design is the process of designing, planning and developing the physical form of a system, including architectural design, component selection and technical specifications of the device to be made. The prototype water quality monitoring and control system above is designed using the Autocad 3D design application with a scale of 1:10. Figure 5 shows the hardware design of proposed system.

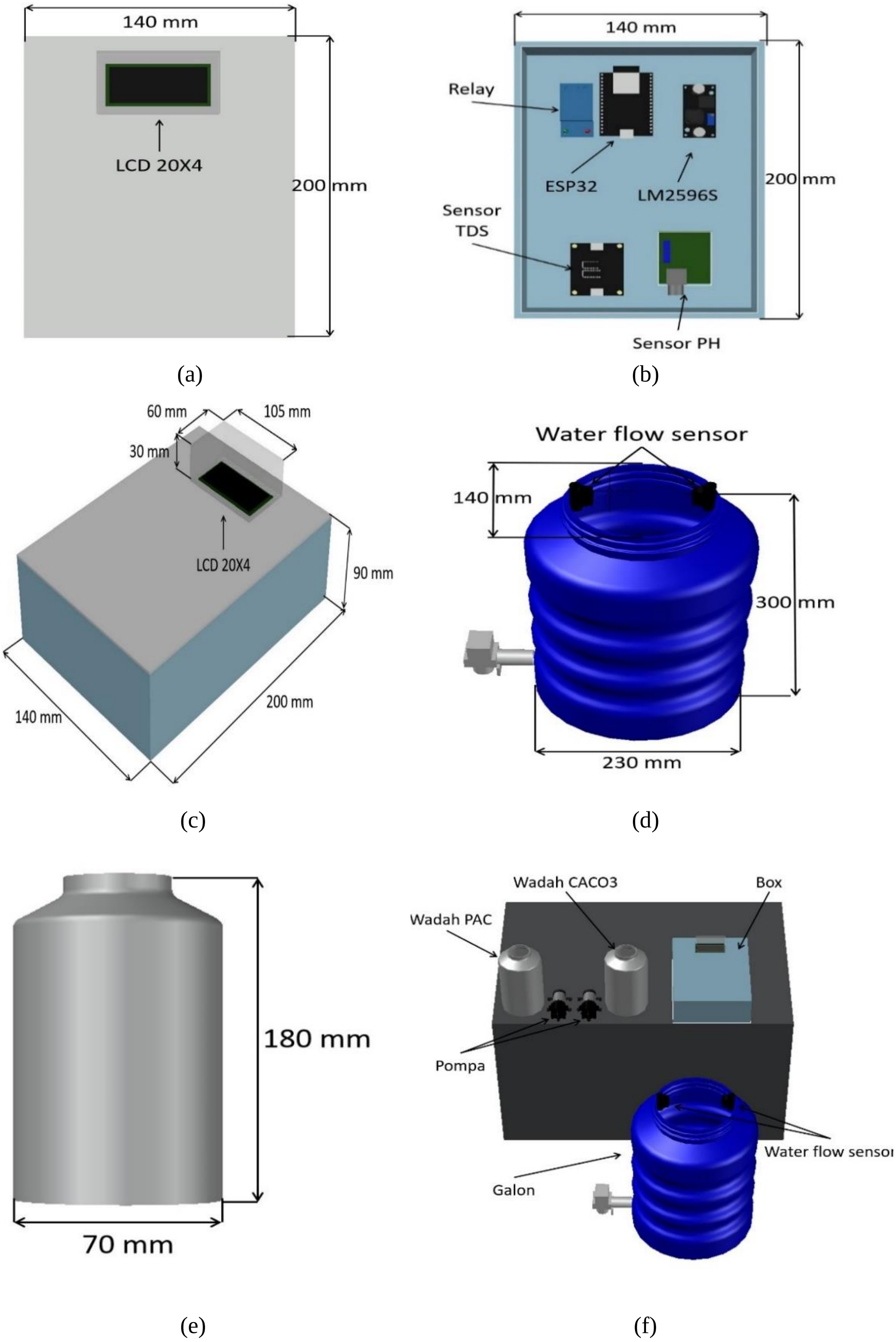
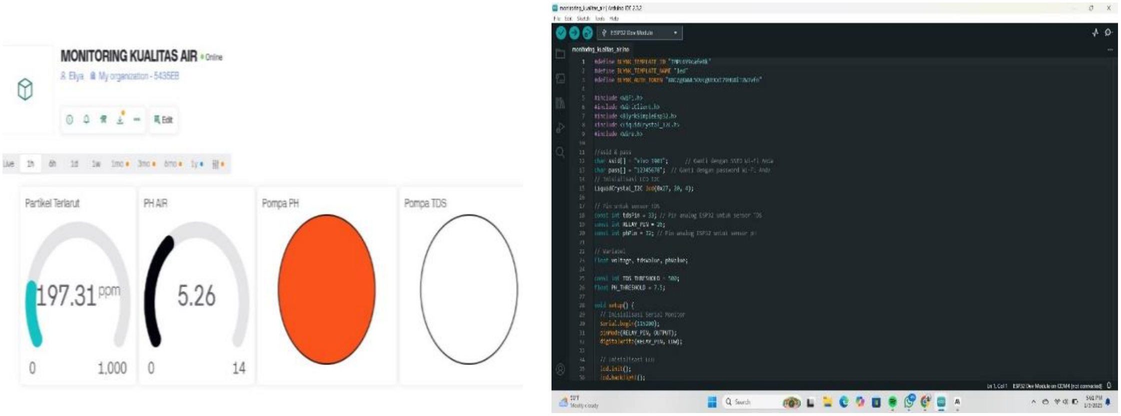


Figure 5. Hardware design (a) Component box top view, (b) Component box inside view, (c) Component box exterior view, (d) Water storage container, (e) PAC and $CaCo_3$ solution container and (f) Overall device design

Software design is a process that involves planning a software system that creates a framework to meet user needs [12]. Figure 6 shows the software design. The design of water quality monitoring and control tools based on the Internet of Things uses ESP32 as a controller, with Arduino IDE as the programming platform. The working principle of this tool is as follows : 1) Measurement of Water Quality Parameters, The measurement of PDAM water quality parameters is carried out using 2 types of sensors: pH sensors to measure the acidity of water and TDS sensors to measure the amount of dissolved particles in the water. Measurement data from these sensors will be processed by the ESP32 to obtain water quality parameter values. 2) Data Delivery, After processing and obtaining the water quality parameter values, the ESP32 will send the data via Wi-Fi connection or IoT network to be displayed on the LCD or blynk platform. 3) Data Reception and Display, The water quality data sent by ESP32 will be displayed on the LCD and blynk platform with Wi-Fi connection. The data will be displayed in the form of the number of dissolved particles and the pH of the water. The data display makes it easy to monitor water quality in real-time. 4) Pump Control, Based on the monitored water quality values, the ESP32 will control the 12V pump through a relay. If one of the water quality parameters is at a reasonable threshold, the pump will regulate the influx of materials that can control the water quality parameters, so that the water becomes normal.



(a) (b)

Figure 6. Software design (a) Data display on blynk and (b) Program view on arduino IDE

In this final project research, the research instruments used are pH sensors and TDS sensors. The pH sensor (potential of Hydrogen) is a sensor used to measure the acidity of water. The output form of the pH sensor is an analog voltage so that the output on the module can be read using the microcontroller ADC input [13]. Table 1 present the classification of water pH.

Table 1. Classification of water pH

pH	Classification	Example of a water source
< 3.0	Very acidic	Industrial wastewater, sulfuric acid, acid mine water
3.0-5.5	Acid	Polluted rainwater, peat water
5.6-6.5	Slightly acidic	Normal rainwater, groundwater in acidic areas
6.6-7.5	Neutral	Standard drinking water, PDAM water, clean river water
7.6-8.5	Slightly alkaline	Well water, lake water with algae
8.6-10.0	Basa	Soapy water, household wastewater
> 10.0	Very alkaline	Alkaline industrial wastewater, strong cleaning solution

According to Permenkes No.492/MENKES/PER/IV/2010, the acidity or pH level of PDAM water ranges from 6.5 to 8.5 which is allowed to be used for household purposes [14]. To ensure the correctness of the value of water quality measurement results by the pH sensor, a conventional pH meter will be used. The measurement results from these two tools will be compared to get the percentage error of the pH sensor. The formula to be used is:

$$\text{Error (\%)} = \frac{\text{Nilai pH meter} - \text{Nilai sensor pH}}{\text{Nilai pH meter}} \text{ X } 100 \tag{1}$$

Based on observations and preliminary research, it was found that the pH level of PDAM water in Sijantang Koto village ranged from 4 to 8. To neutralize the pH of the water, $CaCO_3$ with a concentration of 200 mg/L was used, according to the maximum limit of 500 mg/L allowed in water reservoirs according to the

Minister of Health Regulation. The TDS (Total Dissolved Solids) sensor is a sensor used to indicate the amount of dissolved solids in milligrams dissolved in one liter of water. In general, the higher the TDS value, the easier it is to dissolve solids in water and the dirtier the water. Therefore, the TDS value can be used as a reference to measure water cleanliness [15]. Table 2 describes the drinking water TDS

Table 2. Classification of drinking water TDS

TDS (ppm)	Classification
<300	Very good for drinking
300-600	Good to drink
600-900	Good enough to drink
900-1.200	Not good for drinking
>1.200	Not suitable for drinking

According to Permenkes No.492/MENKES/PER/IV/2010, the level of turbidity and the number of dissolved particles in water allowed is a maximum of 500 mg/L or 500 ppm. To ensure the correctness of the value of the water quality measurement results by the TDS sensor, a conventional water turbidity measuring device in the form of a TDS meter will be used. The measurement results from these two tools will be compared to get the percentage error of the TDS sensor. Based on observations and preliminary research, it was found that TDS levels in PDAM water in Sijantang Koto village ranged from 100ppm to 600ppm which is included in the low turbidity category. To reduce the TDS of the water, PAC is used with a concentration of 20 mg/L, according to the maximum limit of 50 mg/L allowed in water reservoirs according to the Minister of Health Regulation.

3. RESULTS AND DISCUSSION

Testing of PDAM water in Sijantang Koto Village was carried out every day for a week at 12.00 WIB to monitor water quality. Parameters tested include Ph and the amount of dissolved particles. If a water quality problem is found, the pump will be activated to deliver PAC or $CaCO_3$ as a solution to the problem. Table 3 describes the experimental results.

Table 3. Water quality testing data

No.	Day/Date	pH	Pump 1 ($CaCo_3$)	TDS (ppm)	Pump 2 (PAC)
1	Monday/ 20-01-2025	6.53	Disable	367.71	Disabled
2	Tuesday/21-01-2025	7.30	Disabled	350.13	Disabled
3	Wednesday/22-01-2025	7.87	Disabled	341.60	Disabled
4	Thursday/23-01-2025	5.26	On	197.31	Disabled
5	Friday/24-01-2025	7.76	Disabled	635.55	On
6	Saturday/25-01-2025	4.38	On	314.64	Disabled
7	Sunday/26-01-2025	5.32	On	418.42	Disabled

It can be seen in the table that the water quality testing data for one week shows that the pH value of the water varies between 4.38 to 7.87 with the most acidic condition occurring on Saturday (4.38). As for the TDS value in testing for one week shows an average normal value. Water turbidity conditions that exceeded the standard only occurred on Friday (635.55 ppm). From the pump activity, it can be seen that Pump 1 ($CaCO_3$) which aims to increase pH is activated on Thursday, Saturday and Sunday. Meanwhile, it can be seen that Pump 2 (PAC) which is active on Friday serves to reduce water turbidity due to high TDS values. Water quality monitoring data for one week is not only stored in tabular form, but also in graphical form to facilitate analysis. On the graph, the blue bar shows the data from the water pH test. Meanwhile, the red bar shows the data from the water TDS test. The highest water TDS value was recorded on Friday, January 24, while on other days it remained in the normal category. Meanwhile, the most acidic water pH value occurred on Saturday, January 25. Figure 7 shows the experimenntal results.

PDAM water quality in the form of pH and TDS levels that do not meet the threshold are most likely influenced by the surrounding environmental conditions, especially since the Sijantang Koto area is located close to the mine and uses the Ombilin River as the PDAM's raw water source. Mining activities can contribute to water quality degradation, especially with the introduction of mine waste containing heavy metals, particulate solids and acidic compounds that can lower the pH of the water and make the water cloudy.

A monitoring system is needed to monitor the quality of PDAM water in this area. With a water quality monitoring and control system in place, this PDAM water quality problem can be addressed. When the probes of the pH sensor and TDS sensor are inserted into the water reservoir, the data will be displayed on the LCD and blynk. People as users will know the quality of PDAM water they receive on that day based on the monitoring data. If the water quality is not in accordance with the threshold, the user can activate the pump through blynk to drain the corrective material. As shown in the table, when the pH or TDS levels do not meet the threshold, the pump will be activated to deliver PAC and CaCo3 into the reservoir. These corrective materials serve to address the PDAM's ongoing water quality problems, so that the water received by the community can still be used for household purposes.

This monitoring data will be displayed on LCD for direct monitoring and Blynk platform for real-time monitoring via smartphone and stored automatically through google sheet. The data stored on google sheets can be converted into a graphical form so as to facilitate the analysis of water quality that occurs during one week.

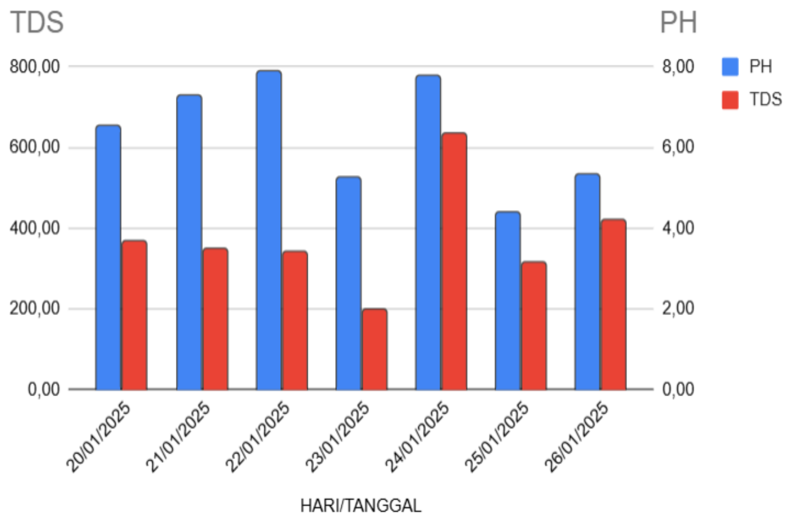


Figure 7. Quality graph

4. CONCLUSION

After designing, observing, testing, and collecting data from each trial conducted on the water quality monitoring and control system, several conclusions were drawn. The developed tool can accurately measure water pH after calibration according to the datasheet and comparison with conventional pH meters, with an error rate of 2.78%. It can also measure dissolved solids (TDS) in water after calibration, with an error rate of 3.47% compared to conventional TDS meters. The Internet of Things (IoT)-based monitoring system is successfully implemented, as evidenced by the real-time transmission of water quality data to the Blynk application, which can be accessed via the user's smartphone or PC when the system is turned on. Additionally, the water quality control function operates effectively by activating pumps that dispense the corrective substances PAC and $CaCO_3$ in appropriate doses whenever the pH or TDS parameters exceed the acceptable threshold. Some suggestions to improve tool performance and develop innovations in future research include adding an alkaline water neutralizing corrective agent to maintain pH balance more effectively. Additionally, using pH and TDS sensors with higher accuracy and resolution can help reduce measurement errors. Regular calibration of measuring instruments is also recommended to ensure the accuracy of monitoring results.

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