Design Planning of Raw Water Turbidity and Temperature Monitoring Circuit Using PLC Outseal and ESP32

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ARTICLE INFO

Article history:
Received 9 May 2026
Received in revised form
June 8, 2026
Accepted 28 June 2026
Available online 30 June 2026

Keywords:
Monitoring
Raw Water
PLC Outseal
Turbidity
Temperature.

ABSTRACT

Monitoring the quality of raw water at the intake of the Jakarta Canal Flood Water Treatment Plant currently still relies on manual methods in laboratories which have limited time efficiency and are susceptible to human error. This research aims to design and build a prototype of an automatically integrated raw water quality monitoring system. The research methods used include problem identification, literature study, mechanical/electronic design, hardware assembly, functional testing of equipment, and data calibration using standard laboratory instruments (turbidity meters and thermometers). This system uses an PLC Outseal as the main data acquisition unit, ESP32, a SEN-0175 turbidity sensor, and a DS18B20 temperature sensor. The physical data that is read is then transmitted via an RS-485 converter and visualized in real-time via HMI (Human Machine Interface). Based on the results of prototype testing and calibration on five types of water condition samples, turbidity sensor testing showed a valid non-linear response compared to laboratory equipment on clean water samples reading a turbidity value of 18 NTU at a voltage of 4,962 V compared to the actual data of 10 NTU, up to very turbid samples reading 545 NTU at a voltage of 3,966 V compared to the actual data of 500 NTU. Meanwhile, testing of the DS18B20 temperature sensor shows a positive linear relationship with very high precision without significant deviation in the range of 20 °C to 55 °C, where the temperature reading results on the PLC show exactly the same value as a laboratory thermometer at every test point (for example, it reads exactly 20 °C at a sensor output of 829 mV and 55 °C at 2,260 mV). This prototype has proven reliable in processing, displaying and archiving raw water parameter data efficiently and economically.

1 Introduction

The quality of river water as a source of raw water currently tends to be very fluctuating and is vulnerable to decline due to contamination from liquid waste resulting from human activities [1]. This condition can affect its use, it can have negative impacts, especially if it contains chemical compounds that are harmful to living things, especially humans [2]. Based on the Regulation of the Indonesian Minister of Health No. 492/MENKES/PER/IV/2010, the physical standards for safe water set a maximum limit for turbidity levels of 5 NTU with an ideal temperature tolerance range of ± 3 °C from the surrounding air temperature [3].

However, water quality monitoring at several facilities, such as the Jakarta Flood Canal intake, still relies on manual methods. Operators must periodically take samples for analysis using turbidity meters and thermometers in the laboratory. The limitations of this method create a significant gap between actual data requirements and the slow testing process, making it difficult to ensure consistent raw water quality. To address this issue, the implementation of automated monitoring using a Programmable Logic Controller (PLC) presents a reliable strategic solution to provide crucial parameter data and serve as an early warning system [4].

The problem of increasingly high PLC prices has encouraged research on other types of PLC. In this study, the PLC Outseal was chosen because it has various functional advantages compared to conventional PLCs in general [5]. PLC Outseal is specifically designed with modular capabilities and high flexibility for industrial application development, thus enabling more efficient integration with analog and digital sensors required in water quality monitoring [6]. The main difference between PLC Outseal and other commercial PLC lies in their cost-effective development and high-speed data processing capabilities, resulting in faster system response. Furthermore, their modular architecture also simplifies maintenance and allows for future system scalability [7]. Therefore, this study utilizes the advantages of the PLC Outseal to design a prototype of an automatic monitoring system for turbidity and raw water temperature at the intake of the Water Treatment Plant, to replace the manual monitoring method which is inefficient and prone to human error.

Several previous studies have explored the application of IoT and embedded systems for water quality monitoring. Research by Maknunah et al. [14] demonstrated that PLC Outseal combined with SCADA can achieve a pH sensor accuracy of 94.99% and temperature sensor accuracy of 98.32% in a water treatment plant prototype, with a system response time of less than 2 seconds. Similarly, Wirandi et al. [4] succesfully implemented a PLC-based water tank level monitoring system with real-time HMI visualization at both laboratory and industrial scales, confirming the effectiveness of PLC systems for automated water infrastructure management. These findings support he feasibility of the approach adopted in this tsudy, where the PLC Outseal serves as the central controller for multiparameter raw water quality monitoring. The novelty of this research lies in the simultaneous integration of turbidity and temperature monitoring with RS-485 communication protocol and cloud-based SCADA visualization, targeting an application environement that has not been previosly adressed in the published literature.

2 Literature Study

2.1 Raw water standards

Based on Government Regulation (PP) No. 82 of 2001, the physical parameters of raw water suitable for consumption are

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Doi : 10.30996/elsains.v8i1.133516

determined by temperature, visual aspects, and concentration of solids [8]. In addition, water must meet the visual criteria of being clear, colorless, odorless, and tasteless and must have a total dissolved solids (TDS) level below 1000 mg/L [9].

2.2 Turbidity Sensor Sen-0175

The turbidity sensor works by measuring the light scattered by particles in the water. This sensor uses a laser diode (with a wavelength of 650 nm) to emit light and a TSL 250 photodiode as a detector when the light passes through turbid water [10].

Figure 1. Turbidity Sensor Sen-0175

2.3 DS18B20 Temperature Sensor

The DS18B20 is a digital temperature sensor with a configurable output resolution ranging from 9-bit to 12-bit for Celsius measurements. This sensor is equipped with a nonvolatile temperature alarm feature that can be flexibly programmed by the user [11]. In its communication system, the DS18B20 uses the 1-Wire Bus protocol, which allows data exchange with the central microprocessor via only one main data line and ground [12].

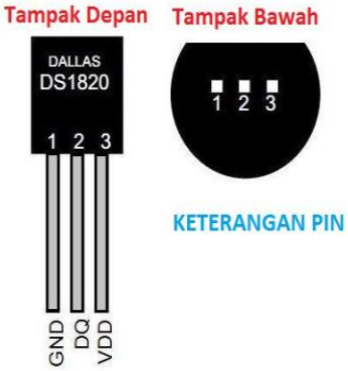

Figure 2. DS18B20 Temperature Sensor

2.4 PLC Outseal

PLC Outseal have excellent compatibility with Supervisory Control and Data Acquisition (SCADA) systems [13]. This combination facilitates real-time monitoring data storage and allows access for direct data visualization. The use of ladder diagrams in PLC Outseal also provides flexibility in adjusting signals from sensors, which ultimately contributes to increasing overall system accuracy. The combination of Outseal PLCs and SCADA makes it a more stable platform and is suitable for automation monitoring and control applications [14].

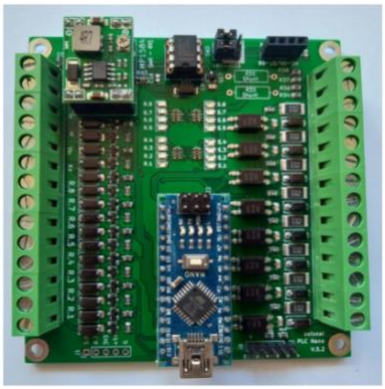

Figure 3. PLC Outseal

2.5 ESP32

The ESP32 is a compact and easy-to-program prototyping board using the Arduino IDE. It features 2.4GHz dual-mode WiFi and BT wireless connectivity. It also integrates 512kB of SRAM and 4MB of memory, 2x DACs, 15x ADCs, 1x SPI, 1x I2C, and 2x UARTs. PWM is enabled on all digital pins [15].

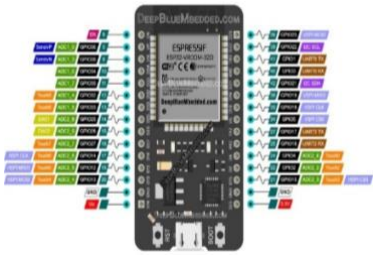

Figure 4. ESP32

3 Methodology

3.1 Research Flowchart

This research method consists of several stages, namely problem identification, literature study, and system design planning, followed by component preparation and physical assembly of the tool. Next, the tool is tested. If an error is found, the system will be re-evaluated to the design stage. However, if successful, the tool will enter the calibration stage by comparing sensor values with standard laboratory tools with turbidity meters and thermometers. Valid data is presented and analyzed to draw conclusions and is completed.

The research begins with problem identification, analyzing the limitations of manual monitoring at the Jakarta Canal Flood intake. A literature review then identifies appropriate sensor technologies and communication protocols. In the system design phase, the mechanical enclosure layout and electronic circuit schematic are developed, covering sensor placement, power supply distribution, RS-485 wiring, and PLC I/O configuration. Component procurement follows, after which physical assembly is performed including mounting of the PLC Outseal, ESP32 DevKit, sensors, and power supply within a protective casing.

Once assembled, the prototype undergoes functional testing to verify all components operate correctly. If errors are detected, the system returns to the design phase for correction.

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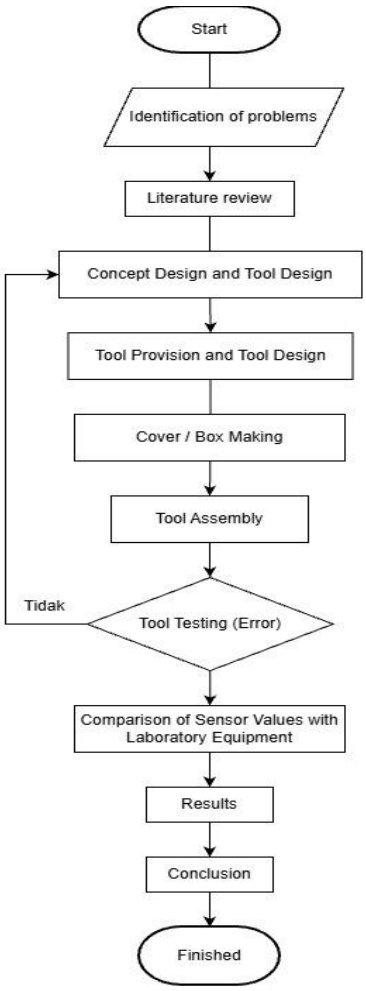

Figure 5. Research Flowchart

Upon successful testing, calibration begins by comparing prototype sensor readings against certified laboratory instruments: a digital turbidity meter for the SEN-0175 and a precision digital thermometer for the DS18B20. Five water samples of varying turbidity are prepared and measured simultaneously with both systems. Data meeting the acceptable error threshold are retained for analysis. The research concludes with a summary of findings and recommendations for future development.

4 Discussion

In designing and implementing a raw water turbidity and temperature monitoring system based on the PLC Outseal, one crucial factor that must be considered is the stability of the electrical power supply to all components to ensure optimal and sustainable system performance. Various core components in this device including the PLC Outseal, ESP32 DevKit, turbidity sensor, DS18B20 temperature sensor, RS-485 converter, and power supply unit are highly dependent on a constant voltage supply without any noise. Therefore, before thorough testing it is very important to ensure that all grounding paths are integrated and connected together (common ground) correctly. This preventive step is mandatory to eliminate any potential differences between components that risk triggering leakage currents, short circuits, or fatal damage when the device is started.

In the testing method on this tool, a series of procedures are carried out through two main stages to ensure the validity and accuracy of the resulting data. This process begins with the process of collecting and recording the analog output voltage values issued by the turbidity sensor and temperature sensor on the prototype system in real time. Next comparative measurements (initial calibration) are carried out on the same raw water sample using standard laboratory instruments, namely a turbidity meter and a digital thermometer.

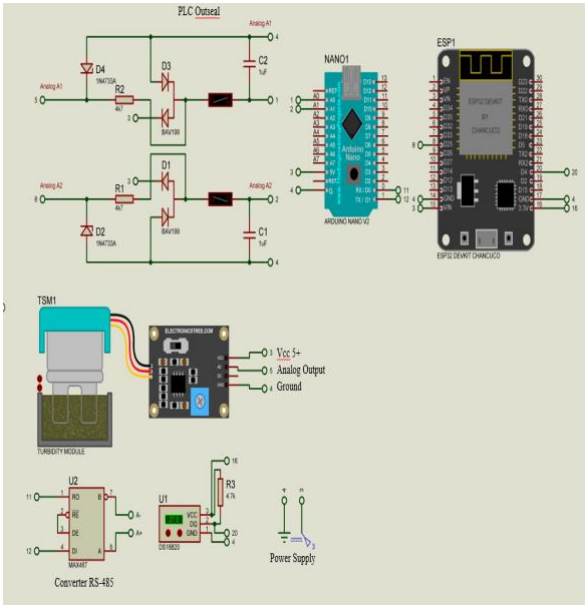

Figure 3. Monitoring Tool Wiring Design

Table 1. Test Results Using Turbidity Meter

No	Water Sample	TurbidityMeter (NTU)	Turbidity Sensor Voltage Output (V)
1	Clean Water	10	4,977
2	Slightly Cloudy	50	4,924
3	A bit murky	100	4,856
4	Cloudy	200	4,719
5	Very Cloudy	500	4,304

Table 2. Prototype Test Results

No	Water Sample	NTU PLC	Turbidity Sensor Voltage Output (V)
1	Clean Water	18	4,962
2	Slightly Cloudy	75	4,889
3	A bit murky	135	4,881
4	Cloudy	238	4,668
5	Very Cloudy	545	3,966

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Doi : 10.30996/elsains.v8i1.133516

Elsains: Journal of Electrical Engineering | 8(1) June 2026: 29-34
p-ISSN: 2527-6336 | e-ISSN: 2656-7075

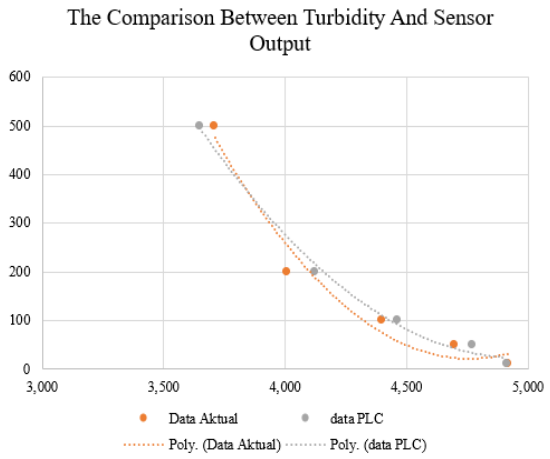

Figure 4. Comparison Chart of Turbiditymeters and Turbidity Sensors

From the graph in Figure 7, the test results between the turbidity meter measuring instrument as actual data and the results of the conversion of readings by the turbidity sensor through the PLC system are visible. The linearity response of both data is mapped based on the sensor output voltage value in millivolts (mV). The curve shows that an increase in voltage from 4,000 mV to nearly 5,000 mV represents a non-linear decrease in turbidity levels. The high agreement between the polynomial regression trend (Poly.) of the actual data and the PLC data proves that the sensor calibration in the control system has a good level of accuracy.

Table 3. Test Results Using a Thermometer

No	Water Sample	Termometer (°C)	DS18B20 Temperature Sensor Output (mV)
1	Very Cold Water	20	829
2	Cold Water	26	1,075
3	Normal Water	30	1,240
4	Hot Water	40	1,655
5	Very Hot Water	55	2,260

Table 4. Prototype Test Results

No	Water Sample	PLC Temperature (°C)	DS18B20 Temperature Sensor Output (mV)
1	Very Cold Water	20	829
2	Cold Water	26	1,075
3	Normal Water	30	1,240
4	Hot Water	40	1,655
5	Very Hot Water	55	2,260

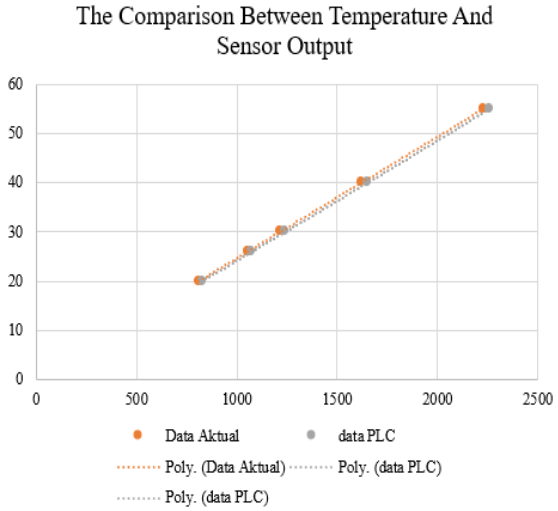

Figure 5. Comparison Chart of Thermometer and Temperature Sensor

From the graph in Figure 8, the test results between the thermometer measuring instrument as actual data and the temperature value converted from the reading by the DS18B20 temperature sensor via the PLC system are visible. Based on the graph, a positive linear relationship is seen where the increase in sensor output (in mV units on the X-axis) is directly proportional to the increase in temperature value in ℃ on the Y-axis in the range of 20 ℃ to 55 ℃. The polynomial regression trend curve of both data shows a very high level of precision without any significant deviation, proving the reliability of the temperature sensor reading system on the PLC.

5 Conclusion

The prototype of the PLC Outseal based raw water monitoring system has been successfully implemented with a high level of accuracy, where the turbidity sensor readings are proven to be non-linearly valid against a laboratory turbidity meter, and the DS18B20 temperature sensor shows a highly precise linear response over the range of 20 ℃ to 55 ℃. The main advantages of this system lie in the efficiency of economical development costs and reliable data processing speed thanks to its modular architecture. However, this system still has limitations in terms of automatic early mitigation so that further development needs to be focused on adding an automatic Early Warning System (EWS) feature and optimizing the HMI platform.

In terms of system performance evaluation, the turbidity monitoring results indicate that the SEN-0175 sensor exhibits a non-linear voltage-to-NTU conversion characteristic, which necessitates the use of polynomial regression for accurate reading interpretation. The average deviation between the PLC-converted turbidity values and the laboratory turbidity meter readings ranged from approximately 8 NTU to 45 NTU across the five tested water conditions. This level of deviation, while acceptable for a prototype early-warning application, suggests that further sensor calibration using a higher-order polynomial fitting curve could significantly improve measurement accuracy. Future work should also consider integrating an ambient light shielding enclosure around the SEN-0175 sensor to minimize optical noise interference, which is one of the identified contributing factors to measurement inconsistency in field conditions.

In contrast, the DS18B20 temperature sensor demonstrated near-perfect linearity with zero deviation from the laboratory

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thermometer across all five test points (20 to 55 degrees Celsius). This performance is attributed to the digital 1-Wire communication protocol of the DS18B20, which eliminates analog signal degradation and noise that commonly affects resistive temperature sensors. The PLC Outseal successfully processed both analog and digital sensor inputs in real time, with a scan cycle time estimated at under 10 milliseconds, confirming its suitability for continuous monitoring applications at water treatment intake facilities. The Haiwell Cloud SCADA integration further enabled remote visualization and data logging, reducing the need for on-site operator presence during routine monitoring cycles.

From a comparative perspective, this system offers a more cost-effective alternative to conventional industrial water quality monitoring solutions, primarily due to the use of the PLC Outseal platform rather than branded PLCs from major manufacturers. The total component cost of the prototype is estimated to be significantly lower than equivalent commercial systems, while maintaining acceptable measurement reliability for early-warning purposes. This cost advantage makes the proposed system particularly suitable for deployment in developing regions or community-scale water treatment facilities where budget constraints often limit the adoption of automated monitoring technologies. The modular design also allows for future sensor expansion, such as the addition of pH, dissolved oxygen, or conductivity sensors, without requiring a complete system redesign.

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