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AUTOMATIC *POLYALUMINIUM CHLORIDE* (PAC) DOSING CONTROL SYSTEM FOR WATER PURIFICATION USING NODEMCU-ESP32

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Abstract. This study discusses the design and implementation of a control system for a water pump used to inject PAC solution into raw water, thereby producing treated water that meets quality standards. The pump's operating duration is adaptively controlled based on the turbidity level of the water to be clarified. The system employs a turbidity sensor as the input signal, which generates data to be processed by a NodeMCU-ESP32 device serving as the central controller. Subsequently, the controller issues commands to the water pump, functioning as the actuator, to perform the PAC injection process. Experiments were conducted on three types of water sources, namely river water, paddy field water, and groundwater, with initial turbidity levels of 29, 35, and 64 NTU, respectively. The results showed that all water samples were successfully clarified to a turbidity value of 0 NTU within 47, 120, and 137 minutes, respectively. At the beginning of the treatment process, turbidity value readings exhibited fluctuations due to the initial mixing of PAC solution with raw water. However, the turbidity values steadily decreased once the PAC and suspended particles were fully settled. To facilitate monitoring, the system is equipped with an IoT feature via the Firebase platform, which displays numerical indicators including water volume, turbidity level, pump speed, pump operating duration, and water status classified according to clarity. This innovation is expected to contribute as an effective water purification automation technology, expecially for small- and medium-scale clean water treatment facilities.

Keywords : Water pump, Polyalumunium Chloride (PAC), turbidity sensor, NodeMCU-ESP32, IoT

1. INTRODUCTION

The availability of clean water is a fundamental requirement for human life and public health [1], [2]. Clean water services are delivered through a series of raw water treatment processes designed to ensure water quality and safety [3]. One of the most crucial stages in this process is coagulation and flocculation, which aim to remove suspended particles and colloids responsible for water turbidity [4], [5]. At this stage, Polyaluminium Chloride (PAC) chemical is widely used as a coagulant due to its several advantages, including high effectiveness in precipitating contaminants, good flocculation and sedimentation capabilities, and a wide operational range of pH and temperature, while requiring only relatively low dosages [1], [6], [7].

The determination of PAC dosage in water treatment is generally carried out manually or semi-automatically through estimation or laboratory tests, such as the Jar Test [8], [9], [10], [11], [12]. Although effective, this method has several limitations, including low responsiveness to fluctuations in raw water quality, the risk of overdosing or underdosing that may affect both water quality and operational costs, as well as the absence of comprehensive and real-time data for optimal decision-making [12], [13]. Bello and Owoeye modeled the dosing pump control using Proportional Integral (PI), Proportional Integral Derivative (PID), and Model Predictive Control (MPC) techniques. The results indicated that MPC outperformed the other methods in both servo-control and regulatory-control responses, exhibiting faster rise time, shorter settling time, absence of overshoot, and superior set-point tracking capability compared to PI and PID [14]. In addition, Kurniawan *et al.*

conducted a study on the control of Palm Oil Mill Effluent (POME) quality using a PAC solution, processed through a fuzzy logic algorithm embedded in an Arduino Mega 2560. The findings demonstrated that the turbidity sensor effectively detected a reduction in wastewater turbidity from 160 to 138 Nephelometric Turbidity Units (NTU) within 12 minutes, with the results satisfying the regulatory standards for wastewater discharge [15]. Despite achieving turbidity levels below 150 NTU, the effluent turbidity remained relatively high, suggesting that further optimization of the treatment process is necessary to enhance effluent quality and ensure greater environmental protection prior to discharge. Fadliondi and Purwanto also constructed a motor pump control system for PAC dosing using a Programmable Logic Controller (PLC). The study demonstrated that the motor speed was adjusted according to the turbidity level of the raw water, enabling the PAC solution to be injected based on the required dosage. However, the experiment was limited to a single turbidity condition of 50 NTU with a motor speed of 375.36 rpm [16]. The absence of testing across multiple turbidity levels limits the comprehensiveness and generalizability of the research findings, as it does not provide sufficient evidence regarding the system's performance, stability, and responsiveness under varying raw water conditions that commonly occur in real operational environments.

Based on the aforementioned description, this study focuses on controlling pump operating duration according to raw water turbidity to adjust the PAC dosage required for the coagulation process. The system utilizes a turbidity sensor to measure water clarity and transmit data to a NodeMCU-ESP32 controller, which regulates pump activation and sends monitoring data to the Internet of Things (IoT) cloud platform for real-time display via Firebase. This approach is expected to enhance operational efficiency in the PAC dosing process and support the sustainable provision of clean water that meets regulatory standards [17].

2. METHODS

2.1 System Design

The water purification control system was designed using three main components: a turbidity sensor module to measure the turbidity level of raw water, a GP-129JXK Panasonic water pump to inject the PAC solution into the turbid water, and a NodeMCU-ESP32 serving as both the system controller and the internet interface. According to Figure 1(a), the turbidity sensor receives power from the 5V-GND pins, with its analog output routed to GPIO34 of the ESP32 through a resistor voltage divider circuit to ensure that the signal remains ≤ 3.3 V in accordance with the Analog-to-Digital Converter (ADC) operating limit. The ADC value represents digital data obtained from the conversion of the turbidity sensor's analog signal. The value then transforms into a voltage level for futher processing in the ESP32 [18], [19]. Subsequently, the module IR infrared obstacle sensor is connected to GPIO2 as a digital input. The relay is supplied from the 5V pin and controlled via GPIO23, functioning to connect or disconnect the current to the water pump. The primary power source is a 12 V adapter, which is converted to 5 V DC via a step-down module to supply the entire circuit. The overall system is illustrated in the form of a block diagram, as displayed in Figure 1(b).

Following the proper connection of all component pins as shown in Figure 1(a), the system was programmed using Arduino IDE 1.8.19, with the code shown in Figure 1(c). This sketch employs an ESP32 to monitor water quality using a turbidity sensor, an infrared sensor, and a relay module, with the acquired data transmitted to Firebase via WiFi. Sensor readings are processed using a median filter to reduce noise, while an interrupt routine is utilized to count RPM pulses, and the water status is classified based on NTU values. In summary, the program is designed to acquire sensor data with improved accuracy, control the pump, and present real-time water quality conditions through Firebase.

Real-time data display and internet connectivity were implemented through the Firebase platform, with the program code presented in Figure 1(d). The code from lines 1 to 139 represents a web-based water monitoring dashboard that integrates Bootstrap for layout design, Chart.js for data visualization, and the Firebase Realtime Database for real-time sensor data storage. The initial section defines the HTML structure, CSS styling, and sidebar navigation, followed by information cards displaying water volume, turbidity (NTU), RPM, pump operating duration, and water status, along with corresponding graphical visualizations. The final section contains the Firebase configuration, the *updateGauge* function for dynamically updating values and indicators, and the initialization of the RPM chart. Overall, this code constructs a monitoring interface that presents real-time sensor data in the form of numerical values, indicators, and graphical charts.

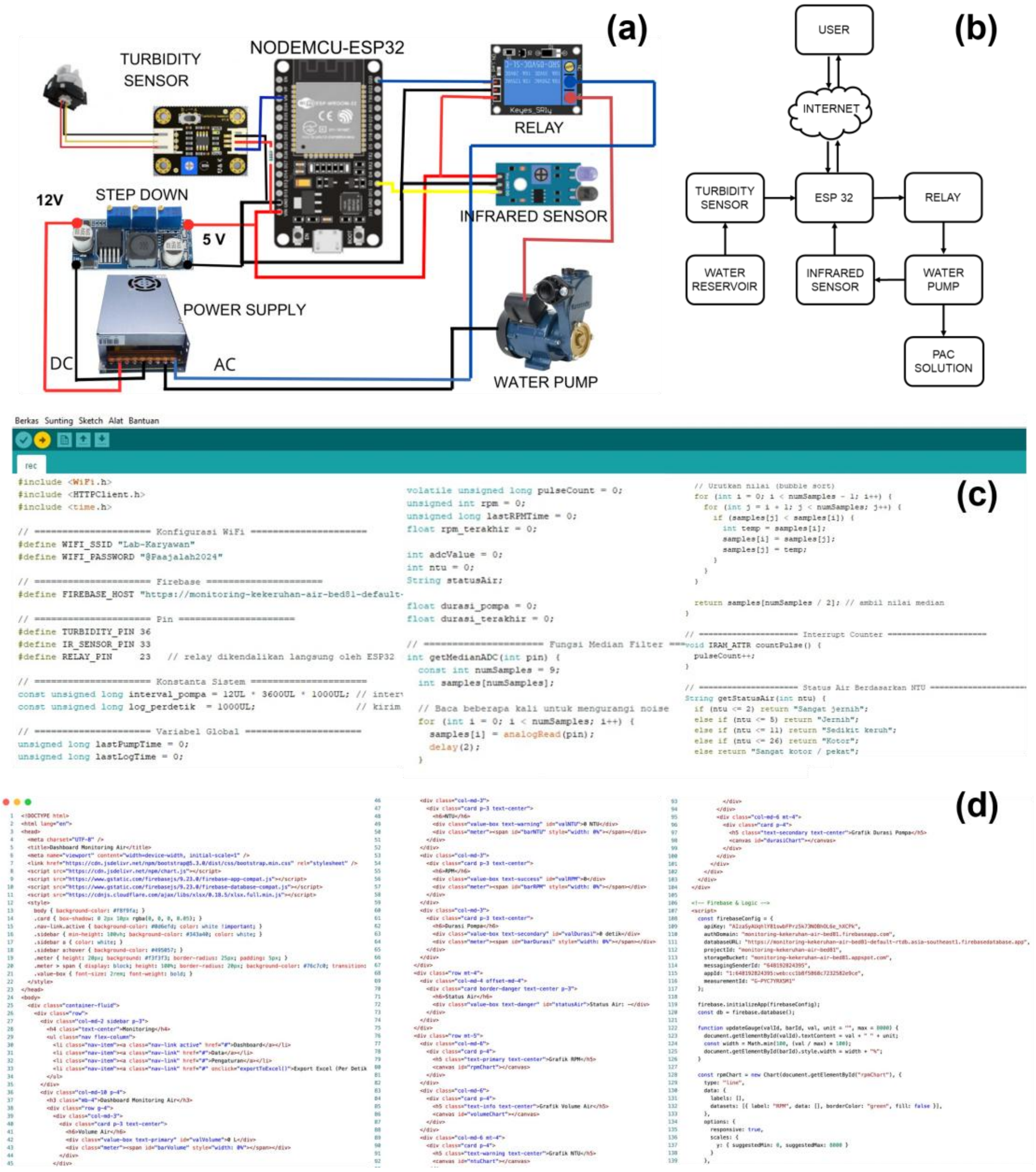

Figure 1. System architecture. (a) wiring diagram, (b) block diagram, (c) controller program code, and (d) firebase program code of the system.

2.2 Working Principle of System

The system operates by utilizing a turbidity sensor as an input device to measure the turbidity level of raw water. The measurement data are transmitted to the ESP32 microcontroller, which activates a relay to drive a water pump that injects PAC solution into the raw water reservoir. The water pump operation is adjusted according to the turbidity level, as presented in Table 1. An infrared sensor is installed on the water pump to measure its rotational speed. After the PAC solution is injected, the mixing process is performed conventionally for 15 minutes. Subsequently, turbidity measurements are performed in real-time and connected to the internet to facilitate remote monitoring. The water generally becomes clear within 47 to 137 minutes after the addition of the PAC solution. In this study, three types of raw water with different turbidity levels were examined, namely river water, rice field water, and ground water.

Table 1. The Pump Operating Duration Based on Water Turbidity

Turbidity Range (NTU)	Pump Operating Duration (second)
4 – 30	9.4
31 – 60	16.5

> 60	28.5

2.3 PAC Dosage and Turbidity Measurement

To clarify water using PAC chemical, a dosage of 13–130 ppm is required depending on the turbidity level of the raw water [20], [21], [22]. In this study, an 82.5 ppm PAC solution was applied to treat 5 liters of turbid water. The operating time of the water pump was regulated according to the measured turbidity level. The turbidity value of the raw water was calculated using Eq. (1), where T denotes the turbidity (NTU), a represents the slope of the linear relationship between turbidity variation and voltage, V is the output voltage of the turbidity sensor obtained from ADC-to-voltage conversion, and b indicates the intercept of the linear relationship [23].

$$T = a.V + b \tag{1}$$

The calibration process of the turbidity sensor is performed using standard solutions with known turbidity values, such as 0 NTU (distilled water) and several reference points (e.g., 50 and 100 NTU). The sensor is immersed in each solution, and the corresponding analog output voltage is recorded through a ESP32 microcontroller. The collected data are plotted to establish the relationship between output voltage and NTU value, from which a calibration equation—typically linear within a specific measurement range—is derived. Based on this calibration, the control system operates according to the predetermined threshold values obtained during the calibration stage. Measurement accuracy is evaluated by comparing sensor readings with the reference standards and calculating the percentage error. Under stable testing conditions, the sensor turbidity generally provides an accuracy of approximately ±5–10%, depending on calibration quality, optical cleanliness, and ambient lighting conditions.

3. RESULTS AND DISCUSSION

3.1 Water Purification Data

The designed system successfully operated in accordance with the implemented program. The system could clarify three types of water, with varying treatment durations depending on the initial turbidity level. Measurement data were recorded every 2.5 minutes through the Firebase platform and systematically stored in a digital dataset.

As shown in Figure 2(a), river water with an initial turbidity of 29 NTU was successfully clarified through the injection of a PAC solution using a water pump, resulting in a turbidity reduction to 0 NTU within 47 minutes. The turbidity sensor effectively detected changes in turbidity throughout the treatment period. However, the sensor readings exhibited fluctuations due to instability of the sensing device. This phenomenon is caused by the temporary stickiness of some PACs and suspended particles to the sensor probe, which reduces the light intensity received by the photodiode and results in elevated turbidity readings. After the particles settle, the light intensity received by the photodiode increases, and the turbidity readings decrease in accordance with the actual water clarity [24], [25]. A consistent decrease in turbidity values was observed during the last seven minutes prior to complete purification. Figure 2(b) shows the purification process of paddy field water with an initial turbidity of 35 NTU. A similar pattern was observed in the sensor readings, where turbidity values fluctuated during the early stages of measurement. However, a more consistent decline in turbidity was recorded, with minor noise detected within the first ten minutes. Figure 2(c) presents the turbidity data of ground water over time, with an initial value of 64 NTU. The purification process lasted for 137 minutes, during which turbidity readings were unstable and showed significant fluctuations at the 32nd and 60th minutes. Nevertheless, a consistent decrease in turbidity with minor noise occurred from the 65th minute until the final stage of purification. Furthermore, Figure 2(d) presents the pump operating duration based on the turbidity level of the water. The higher the turbidity, the longer the pump operating time required.

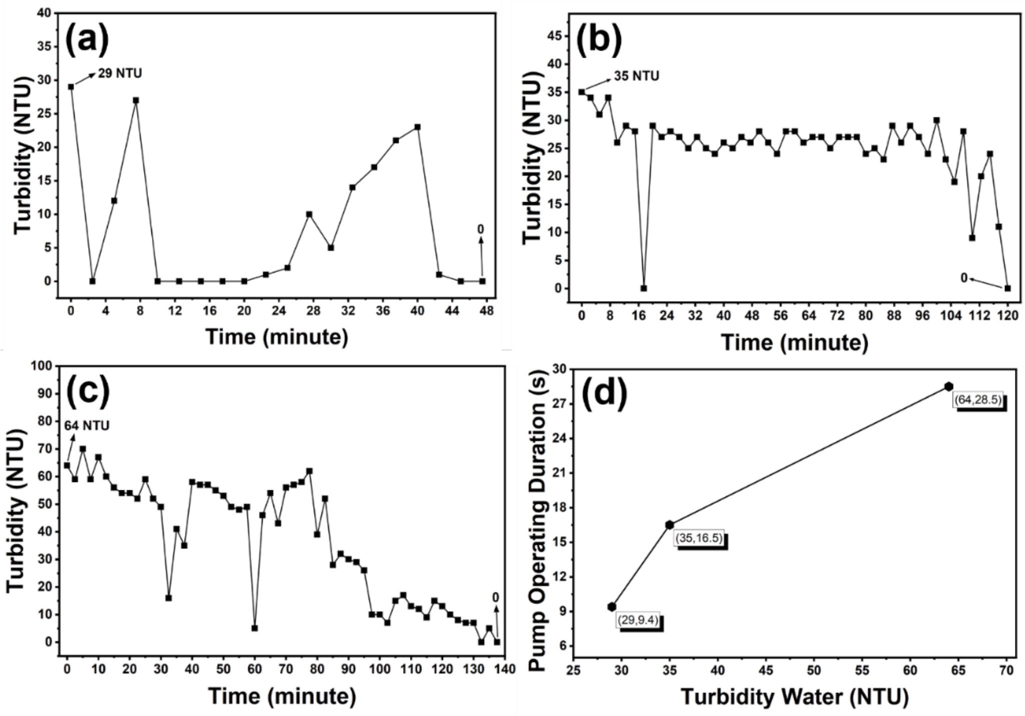

Figure 2. Experimental Data of Water Purification for Various Water. (a) River Water, (b) Rice Field Water, (c) Ground Water, and (d) Pump Operation Duration against Water Turbidity Level

The detailed experimental results of the clarification process for three types of raw water are presented in Table 2. It is observed that higher initial turbidity levels require longer treatment durations to achieve complete clarification (0 NTU). The 0 NTU value represents the actual measured turbidity for each sample and corresponds to the minimum detection limit of the turbidity sensor employed. The final outcome of the purification process is illustrated in Figure 3, demonstrating that within a specified time frame, all three types of raw water were successfully clarified automatically by the proposed system.

The experiments were conducted repeatedly to ensure system reliability and data consistency. Although minor variations were observed among the recorded results, these differences were not significant and did not affect the overall trend of the findings. Overall, the system exhibited stable performance and consistent responsiveness in regulating the pump operating duration according to the detected turbidity level. The water pump effectively injected the PAC solution into the raw water based on the measured turbidity value. The implementation of this prototype is expected to enhance the efficiency of PAC utilization, particularly in small- to medium-scale clean water treatment facilities.

Table 2. Results of Water Purification

Water Type	Initial Turbidity (NTU)	Final Turbidity (NTU)	Purification Duration (min)
River Water	29	0	47
Rice Field Water	35	0	120
Ground Water	64	0	137

Figure 3. Visual Comparison of Various Types of Water Prior to and Following Treatment

3.2 Website Dashboard Interface

The website provides a real-time dashboard for monitoring water quality. Numerical indicators include water volume (L), turbidity (NTU), pump speed (RPM), pump operating time (s), and water status categorized according to clarity (see Figure 4). Graphs of these parameters facilitate effective tracking of changes, while a side navigation panel offers system settings, Excel data export, and main page access. Integration with Firebase ensures real-time data storage and updates via the internet.

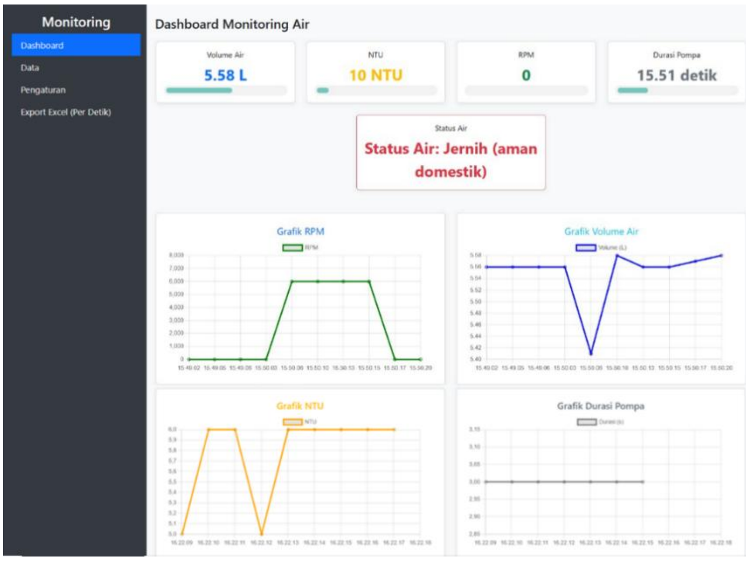

Figure 4. Website Dashboard Interface

4. CONCLUSION

This work successfully clarified various types of water automatically through the injection of a PAC solution into raw water. Three water sources with initial turbidity levels of 29, 35, and 64 NTU were clarified to a final turbidity of 0 NTU within 47, 120, and 137 minutes, respectively. At the beginning stage of the purification process, turbidity readings exhibited fluctuations caused by the stickiness of some PACs and suspended particles to the sensor probe, which affected the intensity of light captured by the photodiode. However, once these particles settled, turbidity readings decreased consistently. Overall, the turbidity sensor proved effective in detecting changes in the turbidity levels of the samples during the treatment process. For monitoring purposes, the system integrates an IoT feature through the Firebase platform, providing numerical indicators such as water volume, turbidity level, pump speed, pump operating time, and water status categorized by clarity.

5. ACKNOWLEDGEMENT

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