SCADA system in water storage tanks with NI vision LabVIEW

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ABSTRACT

Advances in technology have driven the need for efficient water management systems. This study presents a SCADA-based water management system that integrates LabVIEW and Arduino to monitor and regulate water levels and flow rates in a storage tank. The system uses an HC-SRF04 ultrasonic sensor for water level measurement with 99.77% accuracy and an HX710 pressure sensor, which achieves 98.54% accuracy. The LabVIEW interface displays real-time data, giving users an intuitive view of system performance. A proportional integral derivative (PID) algorithm optimizes the water pump through pulse width modulation (PWM), achieving water flow rate control. The Ziegler-Nichols method tunes the PID parameters to Kp = 16.59, Ti = 1.102, and Td = 0.2755. This tuning ensures the system maintains a consistent target flow rate of 4 liters per minute (L/min) with minimal variation. Initial testing showed a 2.5% overshoot but stabilized at the desired flow rate within 10 seconds, indicating effective control. This SCADA system reduces water and energy waste by enabling continuous real-time monitoring and control. The system provides accurate data through a LabVIEW interface, ensuring effective and informed operational decisions. This robust solution supports efficient water management for industrial and environmental applications, contributing to sustainability and resource optimization.

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1. INTRODUCTION

Water is vital for various human activities, including drinking, bathing, washing, and industrial processes [1]. However, ensuring its availability to meet these demands often poses challenges [2]. To address this, water is typically stored in tanks and pumped through electricity-powered pipes using pumps [3], [4]. Manual filling of reservoirs, however, can lead to waste when tanks are left unchecked, resulting in unnecessary water and electricity consumption if pumps are not turned off once the tank is full [5], [6]. Proper water conservation is achieved through regulated usage, ensuring taps are turned off when not in use [7]. Maintaining the correct liquid level in industrial settings is critical for meeting production demands [8]. Insufficient real-time monitoring and control may result in manual operation, which, while cost-effective, presents challenges, particularly when accessing water reservoirs located remotely or at elevated positions [9], [10].

Effective water level control in storage tanks is essential for proper distribution [11]. A well-designed control system prevents overflow during tank filling, ensuring a consistent water supply [12] while enabling real-time monitoring and control [13]. Control techniques range from basic on/off systems to more advanced methods like proportional integral derivative (PID) control [14], which is commonly used for regulating induction motor speeds [15]. However, determining the correct gain values for Kp, Ki, and Kd can be challenging [16]. In water level control, PID systems regulate the speed of water pumps, controlling the flow into storage tanks while monitoring the water level [17]. This requires an integrated system with a human-machine interface (HMI), which facilitates communication between the user and machine [18]. The HMI displays system status, enhancing usability and ensuring efficient interaction through intuitive controls and status information [19].

HMIs enable real-time monitoring, direct control, and alarm notifications for hazardous conditions [20]. Integrating data acquisition, monitoring, and control, SCADA systems are widely used to address water level monitoring challenges, providing an easy-to-use interface for remote real-time observation [21]. SCADA enhances efficiency by delivering real-time data and automating water tank management, including monitoring and controlling water parameters [22], [23]. Effective system control, however, requires the right software and actuators. LabVIEW facilitates rapid measurement, monitoring, and data storage, while microcontrollers like Arduino are necessary for implementing control settings [24].

This study focuses on developing a water level control and monitoring system for tanks using an HMI-based SCADA system. The system aims to automate water filling and distribution to prevent waste and optimize electricity use [25]. The HMI interface enables real-time monitoring, while SCADA integrates tracking, control, and data collection. Users can view water levels on an intuitive display, with alarms for abnormal conditions. Integrating LabVIEW with an Arduino microcontroller improves performance visualization. This research is significant for advancing efficient water management solutions, especially in industrial environments where managing tank liquid levels is crucial.

2. METHOD

The flowchart facilitates the analysis and implementation of the designed tool, namely the SCADA system on the water storage tank, with NI-VISA LABVIEW. The research flow can be seen in Figure 1. The flowchart serves as a valuable tool for analyzing and implementing the SCADA system on the water storage tank, which is designed using NI-VISA LABVIEW. It provides a clear overview of the necessary steps and processes involved in developing and executing the system. The research flow, illustrating each stage of the project, is depicted in Figure 1 for better visualization and understanding.

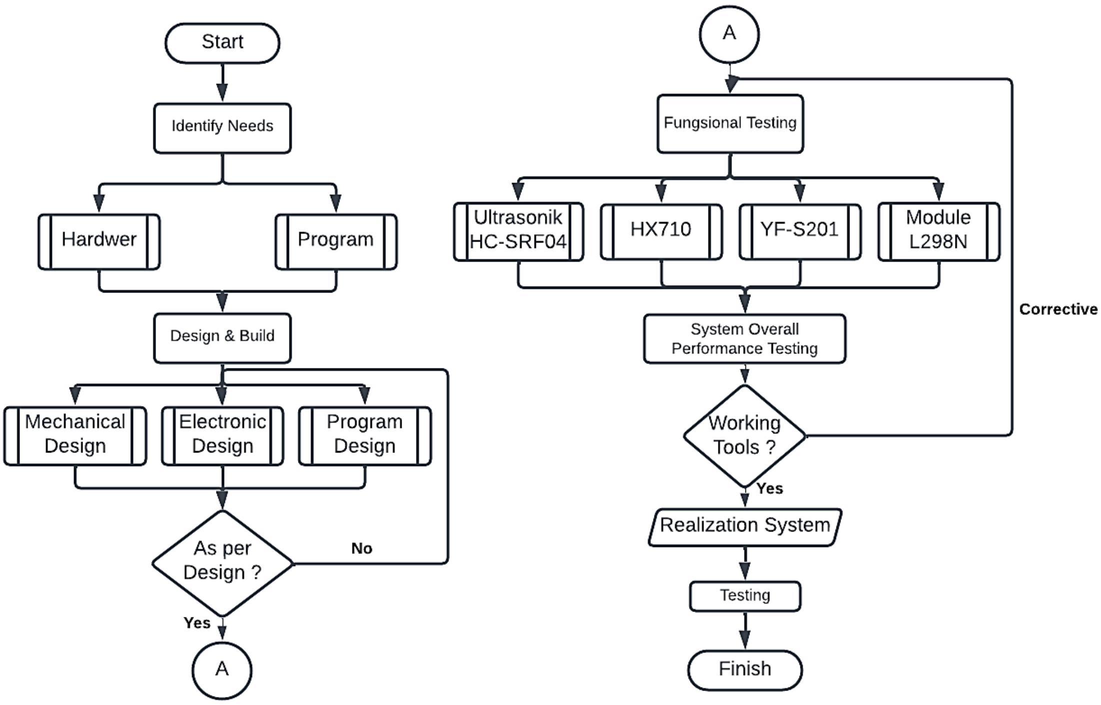


Figure 1. Research flow chart

2.1. Tool working system

Figure 2 illustrates the water flow monitoring and control system, which integrates LabVIEW, Arduino R3, the L298N driver module, relay, and several sensors, including the HC-SR04 ultrasonic sensor, HX710 pressure sensor, and YF-S201 flow sensor. LabVIEW commands Arduino R3, the central controller, to manage the L298N driver module, which activates water pump 1 to transfer water to storage tank 1. The solenoid valve regulates the water flow from the pump to the tank. Once the water is stored in storage tank 1, the distribution water pump moves it to storage tank 2, the final storage location, with Solenoid valve 2 controlling the distribution flow. The sensors measure water level (HC-SR04), pressure (HX710), and flow (YF-S201), sending data back to Arduino R3. LabVIEW continuously monitors and adjusts the system to maintain the water flow at the setpoint.

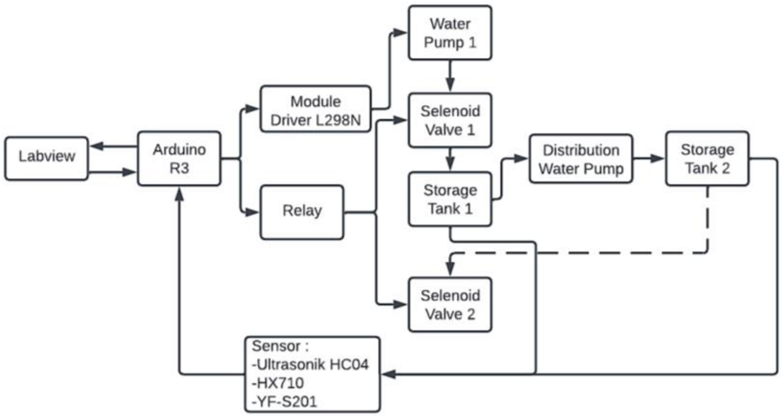
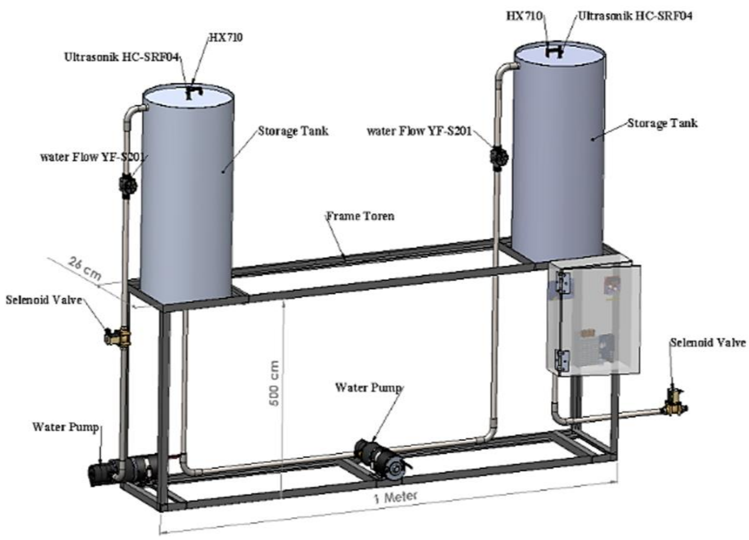


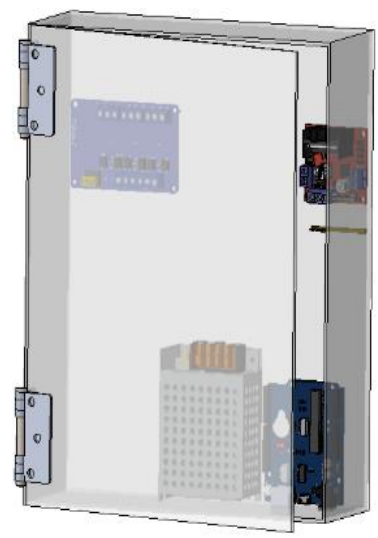
Figure 2. Diagram of the tool's working system

2.2. Mechanical design

This mechanical design discusses how to design a device with multiple components, including a water tank, tower frame, control system panel, and several electronic components, such as a water pump, solenoid valve, YF-S201 water flow sensor, HC-SRF04 ultrasonic sensor, and HX710. Figure 3 shows the overall mechanics used in this study. As shown in Figure 3(a), the tank has a height of 47 cm and a diameter of 26 cm, while the tower frame measures 1 meter in length, 26 cm in width, and 0.5 cm in height. In Figure 3(b), this unique mechanical design is intended for the placement of components on the control system panel, such as the Arduino R3, L298N controller module, power supply, relay, and cable terminals, to protect these components from damage.



(a)



(b)

Figure 3. Overall mechanics used in this stud: (a) storage tank and tower and (b) control box

2.3. HMI block diagram design in LabVIEW software

This HMI block diagram design in LabVIEW software discusses how to design an HMI display in the form of a screen panel that can display monitoring data, control the system, such as entering PID parameter values, and activate and turn off the pump or solenoid valve simply by pressing the button on the panel screen, as can be seen in Figure 4. It contains block diagrams for reading ultrasonic sensors and actuators in the form of water pumps and solenoid valves, contains block diagrams used to send input and output data so that they can be stored, and contains block diagrams used to control the system, such as activating or deactivating water pumps and solenoid valves, and entering PID parameter values if there is interference with the ultrasonic sensor in detecting the water level in the water storage tank.

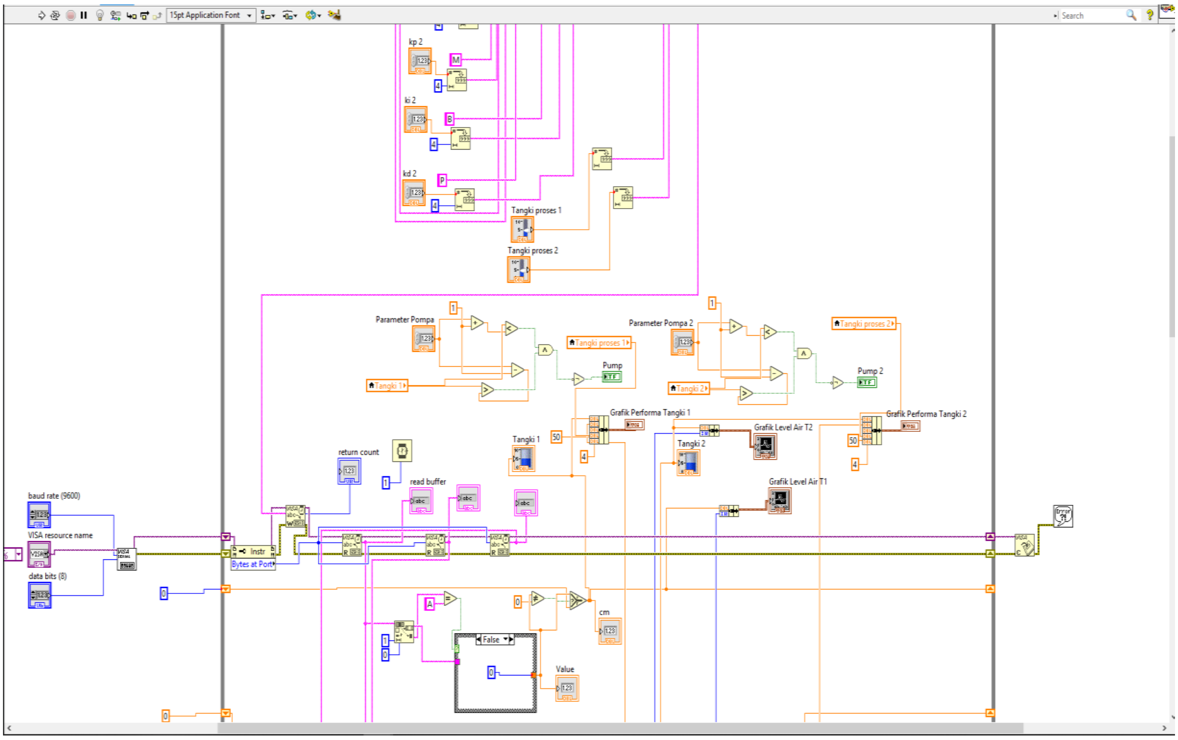


Figure 4. HMI screen design in LabVIEW

2.4. Design of water flow rate control system with PID

The flowchart illustrates the steps to control water flow using PID control through LabVIEW. Here is the explanation of the flow, as shown in Figure 5. The PID control process for water flow begins by setting the setpoint (SP) and the parameters Kp, Ki, and Kd in LabVIEW. The process variable (PV) is obtained from the water flow sensor, which measures the current flow rate. The pump is then activated to start circulating water. The sensor detects the flow rate, calculates the error (E) as the difference between the SP and PV, and uses it to determine the PID output (MV). This process repeats until the flow rate reaches 4 liters per minute in Figure 5, at which point the process ends.

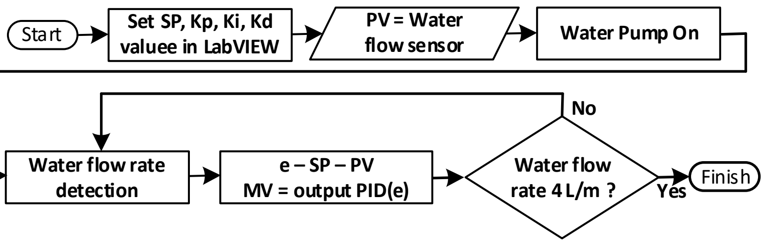
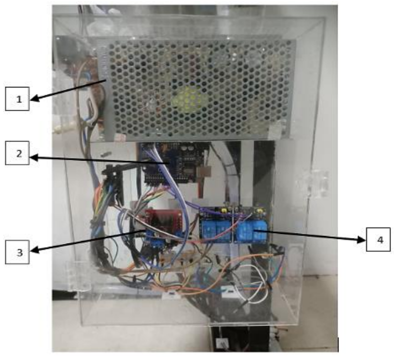


Figure 5. Water flow rate control working system with PID

3. RESULTS AND DISCUSSION

3.1. Overall electronic design results

The results of the electronic design of the water control system in the water storage tank are used to monitor and control parameters in the water tank, such as water flow rate, water level, and water pressure. Then, these parameters can be controlled and monitored in LabVIEW. Arduino UNO R3, L298N driver module, power supply, relay, and cable terminals are in the control system panel box, as shown in Figure 6.



Description: 1. Power supply
2. Arduino UNO R3
3. Module driver L298N
4. Relay 2 channel

Figure 6. Control box design results

3.2. Realization of SCADA system on water storage tank using LabVIEW

The implementation of the SCADA system for water storage tanks using LabVIEW facilitates real-time monitoring and control of water levels. The system, designed and tested based on the tool's specifications, involves installing a water level sensor on the tank, which is connected to a controller integrated with LabVIEW. To ensure safety, the primary power source is initially turned off. An ultrasonic sensor, mounted at the tank's top, measures the water level, with the data sent to the controller for monitoring. The system is then connected to a LabVIEW interface, providing real-time water levels and pump status updates. After installation, the continuity and security of the connections are verified to ensure no circuit issues. The SCADA system autonomously begins monitoring water levels after restoring the primary power source. LabVIEW continuously updates water parameters, allowing real-time tracking of fluctuations and controlling the pump according to a predefined water level setpoint. The pump adjusts the flow rate to 4 L/m using PID control, activating when the water level drops below the minimum threshold and stops automatically when the maximum level is reached, as shown in Figure 7. The result of the HMI display design in LabVIEW is to monitor and control the parameters in the water tank, such as water flow rate, water level, and water pressure. These parameters can be controlled and monitored on the LabVIEW screen display, as shown in Figure 8.

Description: 1. Sensor pressure HX710
2. Ultrasonic HC-SRF04
3. Water storage tank
4. Storage tank tower
5. Solenoid valve
6. Water pump
7. Box control
8. HMI in LabVIEW

Figure 7. Tool configuration testing with HMI

3.3. Water level and water pressure monitoring system in tank

After the SCADA system is successfully installed on the water storage tank with NI-VISA LabVIEW, the next step is to set the port for Arduino, the water height setpoint at 40 cm, and the water discharge setpoint at four p.m. Then, run the monitoring and control system on the run icon, which can be directly seen on the LabVIEW monitor screen display, as shown in Figure 9.

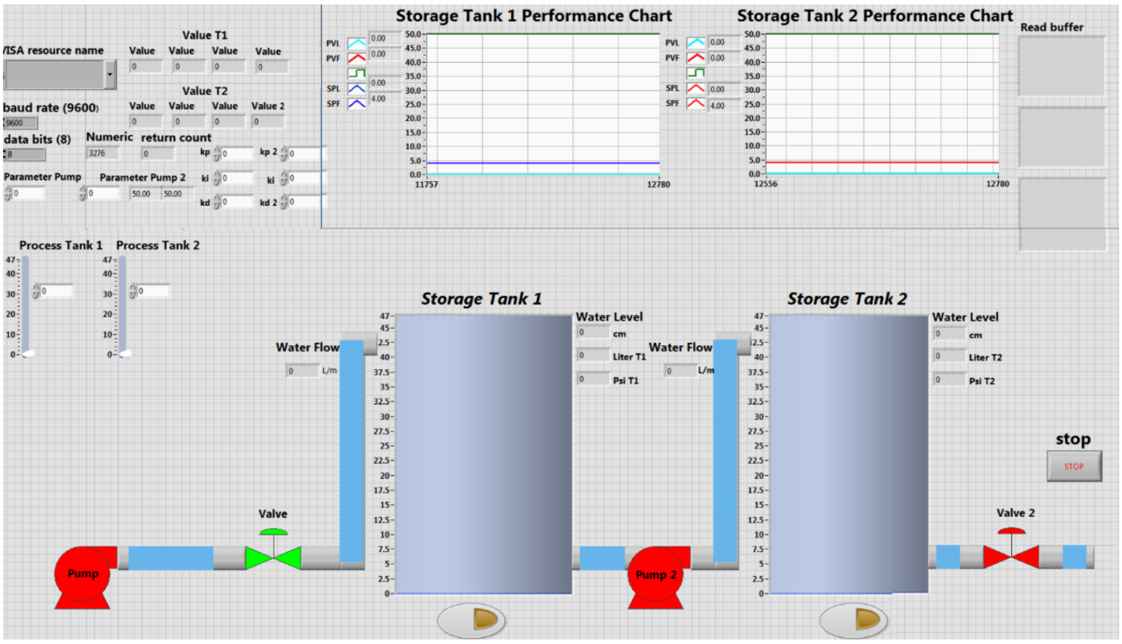


Figure 8. HMI design results in LabVIEW

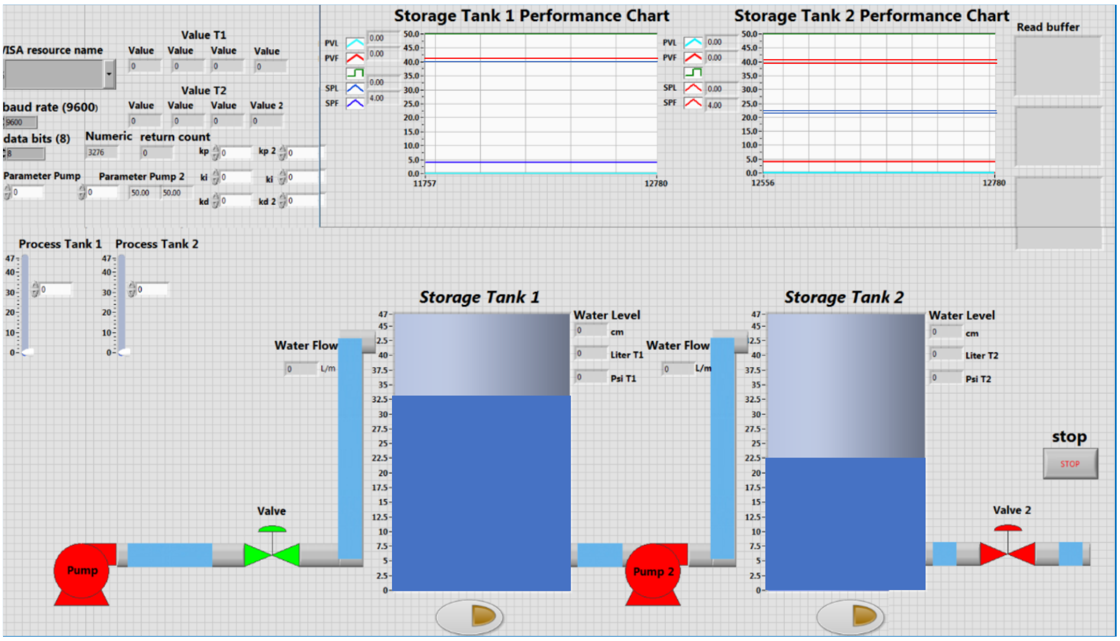


Figure 9. Test results for monitoring water level and water pressure in the tank

The figure illustrates the successful integration of LabVIEW with Arduino to monitor the water levels in two tanks in real-time. The display includes several key components, such as performance graphs for tracking the present value (PV) and set point (SP) values. In this configuration, the water level setpoint is established at 40 cm, indicating that the system is designed to maintain the water level around this value. During testing, the pump activates to fill the water until it reaches a height of 40 cm, while the valve control automatically adjusts the water flow. The system relies on data from a water level sensor connected to the

Arduino, which is transmitted to LabVIEW for processing. As the water level approaches the 40 cm setpoint, the control system stabilizes the water level around this target. This test demonstrates the system's ability to maintain the water level at the specified setpoint, ensuring that each component, including the pump, valve, and sensor, functions properly to preserve the system's stability around the setpoint. The results of the system test shown in Table 1 confirm that the water level remains at the 40 cm setpoint.

Table 1. Monitoring results of water level and water pressure

No	Time (seconds)	Pump Status (On/Off)		Valve Status (Open/Close)		Water Level In Tank		Water Pressure In Tank	
		Pump 1	Pump 2	Valve 1	Valve 2	Tank 1 (cm)	Tank 2 (cm)	Tank 1 (Psi)	Tank 2 (Psi)
1	0	On	On	Open	Open	0.0	0.0	0.0	0.0
2	1	On	On	Open	Open	0.12	0.13	0.01	0.01
3	2	On	On	Open	Open	0.24	0.26	0.01	0.01
4	3	On	On	Open	Open	0.36	0.39	0.02	0.02
5	4	On	On	Open	Open	0.48	0.52	0.02	0.02
6	5	On	On	Open	Open	0.6	0.65	0.03	0.03
7	6	On	On	Open	Open	0.72	0.78	0.03	0.03
8	7	On	On	Open	Open	0.84	0.91	0.04	0.04
9	8	On	On	Open	Open	0.96	1.04	0.05	0.05
10	9	On	On	Open	Open	1.08	1.17	0.05	0.05
11	10	On	On	Open	Open	1.2	1.3	0.06	0.06
12	11	On	On	Open	Open	1.32	1.43	0.06	0.06
13	12	On	On	Open	Open	1.44	1.56	0.07	0.07
14	13	On	On	Open	Open	1.56	1.69	0.07	0.07
15	14	On	On	Open	Open	1.68	1.82	0.08	0.08
16	15	On	On	Open	Open	1.8	1.95	0.08	0.09
17	16	On	On	Open	Open	1.92	2.08	0.09	0.09
18	17	On	On	Open	Open	2.04	2.21	0.1	0.1
19	18	On	On	Open	Open	2.16	2.34	0.1	0.1
20	19	On	On	Open	Open	2.28	2.47	0.11	0.11
21	20	On	On	Open	Open	2.4	2.6	0.11	0.12
22	21	On	On	Open	Open	2.52	2.73	0.12	0.12
23	22	On	On	Open	Open	2.64	2.86	0.12	0.13
24	23	On	On	Open	Open	2.76	2.99	0.13	0.13
25	24	On	On	Open	Open	2.88	3.12	0.14	0.14
26	25	On	On	Open	Open	3.0	3.25	0.14	0.14
27	26	On	On	Open	Open	3.12	3.38	0.15	0.15
28	27	On	On	Open	Open	3.24	3.51	0.15	0.16
29	28	On	On	Open	Open	3.36	3.64	0.16	0.16
30	29	On	On	Open	Open	3.48	3.77	0.16	0.17
31	30	On	On	Open	Open	3.6	3.9	0.17	0.17

The system test data for maintaining a 40 cm water level set point is summarized in Table 1, showing pump and valve statuses and the water levels in both tanks at specific time intervals. From 0 to 31 seconds, the water level in both tanks increases steadily. During this period, pumps one and two remain "On," and valves one and two stay "Open," ensuring a continuous water flow. At 31 seconds, the water level reaches approximately 3.6 cm in tank 1 (with a pressure of 0.17 Psi) and 3.9 cm in tank 2 (with a pressure of 0.17 Psi). This consistent rise in water levels confirms the system's ability to maintain a smooth flow, moving steadily towards the 40 cm set point.

3.4. Water flow rate testing using PID

PID testing evaluates the input water level and output flow rate, represented by the water filling time in the storage tank, with the water pump speed controlled via the L298N driver module to regulate the output. The initial tests assess the impact of the water flow rate on the PWM value of the pump and its effect on the water filling time. The testing procedure involves activating the pump to introduce water into the storage tank, recording the initial water flow rate, and monitoring time changes. The data from these tests provides PWM values, which are then used for PID calculations. The next step is identifying the controlled system and determining key parameters such as control time, overshoot, and steady-state error. The Zigler-Nichols method is applied to compute the initial PID parameters, utilizing the relationship between the water flow rate and PWM values. This testing process involves observing the system's response to step changes until stable oscillation occurs, allowing PID parameters to be calculated without requiring a mathematical model of the system. The open circuit system's response to a unit step function produces an S-shaped curve, from which a dead time (L) of 0.551 and a delay time (T) of 7.59 are derived.

In tuning the PID parameters, this method consists of Kp, Ti, and Td, where:

a. Kp (proportional gain) is 60% of the proportional value calculated by comparing T and L.
b. Ti (integral time) 50% of Tu, where Tu equals the time constant T.
c. Td (derivative time) 12.5% of Tu. This helps with smooth changes in system response.

So, the PID tuning obtained by the Ziegler-Nichols method is as follows.

a. Proportional (P) control

$$K_p = \frac{T}{L} = \frac{7,59}{0,551} = 13,77$$

b. Proportional-integral (PI) control

$$\mathrm{K_p} = 0.9\mathrm{x}\frac{\mathrm{T}}{\mathrm{L}} = 0.9\mathrm{x}\frac{7,59}{0,551} = 12,39$$

$$T_i = \frac{L}{0,3} = \frac{0,551}{0,3} = 1,83$$

c. PID control

$$K_p = 1,2\frac{T}{L} = 1,2\frac{9,50}{0,551} = 16,52$$

$$T_i = 2\mathrm{xL} = 2\mathrm{x}0,551 = 1,102$$

$$T_d = 0.5\mathrm{xL} = 0.5\mathrm{x}0,551 = 0,2755$$

After PID tuning with the Ziegler-Nichols method, the parameters obtained are Kp = 16.52, Ti = 1.102 seconds, and Td = 0.2755 seconds. Furthermore, the PID value obtained from the tuning results using the Ziegler-Nichols method shows the system response by looking at the step response of the S curve produced.

A step change in response to PID control of the water flow rate. The image also gives data on the rise time of 0.296 seconds, an overshoot of 10.5%, and settling time of 1.49 seconds. The value shows a gradual decrease from the overshoot value point. This is a result of the Td value of 12.5% of Tu, which acts to help smooth the change in the system response.

3.5. Monitoring of overall system parameters

After testing the use of PID on the water flow rate control system with a water flow setpoint of 4 l/m, system performance testing is carried out by setting the water level setpoint and water flow rate in the tank water level control; a setpoint of 40 cm is used on the LabVIEW HMI screen. At the same time, the water flow rate in the water storage tank uses a setpoint of 4.00 l/m. The parameters reviewed from the experiments carried out on water flow rate control using PID are delay time, rise time, peak time, maximum overshoot, steady state error, and settling time with PID parameter values of Kp 16.52, Ti 1.102, and Td 0.2779. Furthermore, the system is run on the LabVIEW HMI screen, as shown in Figure 10.

Figure 10 shows that the system can maintain the water level setpoint and flow rate. The water flow rate is set using the PID parameter value. By adjusting this PID parameter, the system can maintain the water flow rate close to the setpoint even though conditions are disturbed or changed, such as pressure fluctuations in the tank or changes in water level-the system's test results are shown in Figures 11 and 12.

The water flow rate test shows the system's response to PID control aimed at achieving and maintaining a water flow setpoint of around 4.0 l/m. At the beginning of the test, the flow rate increased from zero and reached a slight overshoot of 4.1 l/m, which is about 2.5% above the setpoint. This overshoot occurred due to the system's rapid response to the PID signal, mainly due to the considerable Kp value (16.52) to accelerate the system's initial reaction to the setpoint. After the overshoot, the system immediately adjusted the flow rate to the setpoint of 4.0 l/m. The system's delay in starting to increase the flow rate was observed to be around 1 second. This means that the system takes about 1 second from zero time to the start of a significant increase in flow rate. Then, after the overshoot, the water flow rate enters a transient phase with a slight fluctuation around the setpoint value. The system settling time, which is the time required for the flow rate to stabilize at around 4.0 l/m with a tolerance of ±2%, was recorded at around 10 seconds. After this period, the system reached a steady state, where the flow rate was successfully maintained at 4.0 l/m with a slight variation of around ±0.1 l/m, which is considered reasonable for this application. The table also shows that the water level increases linearly and stably, indicating that the sensor readings are functioning accurately, as well as the water pressure readings, indicating that when the water level in tank 1, 2.04 cm, the sensor reads a water pressure of 0.1 Psi, as well as the water level in tank 2, 2.21 cm, the sensor reads a water pressure of 0.1 Psi. The table shows that the sensor reads the parameters in the tank accurately until the water level in Tank 1 is 40 cm, as well as in the tank, the water pressure sensor reads a water pressure of 1.88 Psi in tank 1 and 1.77 Psi in tank 2. Overall, the system consistently maintains a flow rate close to the setpoint without significant fluctuations until the end of the test at 325 seconds. At that point, the flow rate on both sensors, flow 1 and flow 2, was consistently at 4.0 l/m without any additional overshoot or significant fluctuations, indicating the system’s stability in a steady state. These results suggest that the PID parameters that are set are compelling enough to achieve and maintain flow stability at the desired setpoint

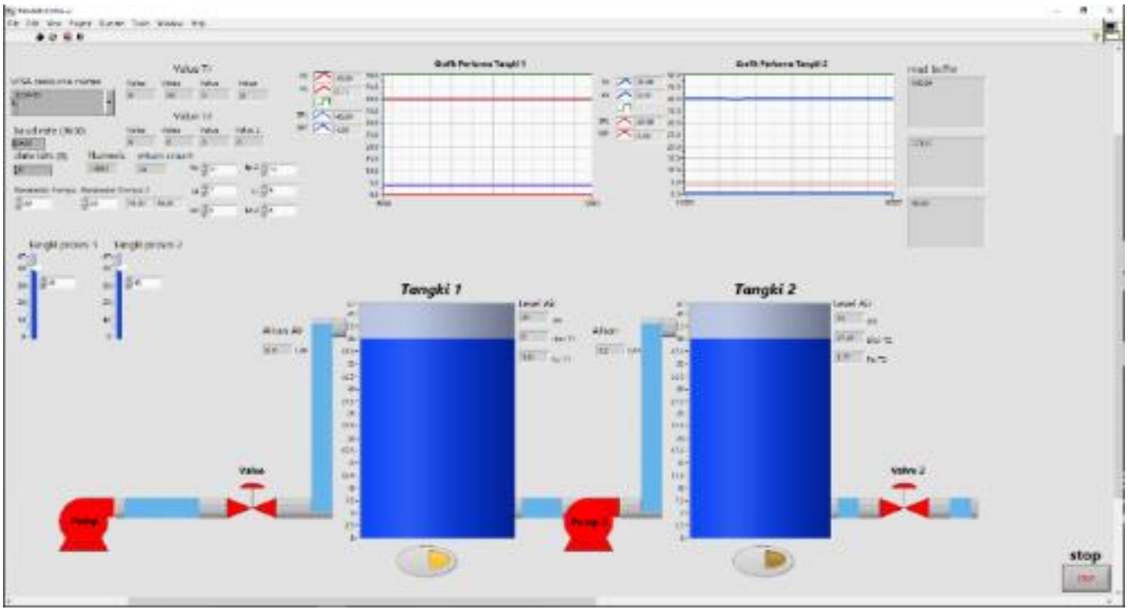


Figure 10. LabVIEW view when entering PID values

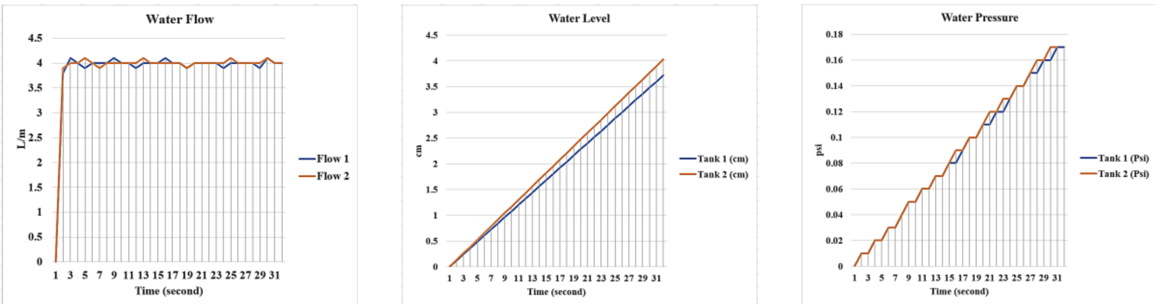


Figure 11. Parameter monitoring graph on the tank

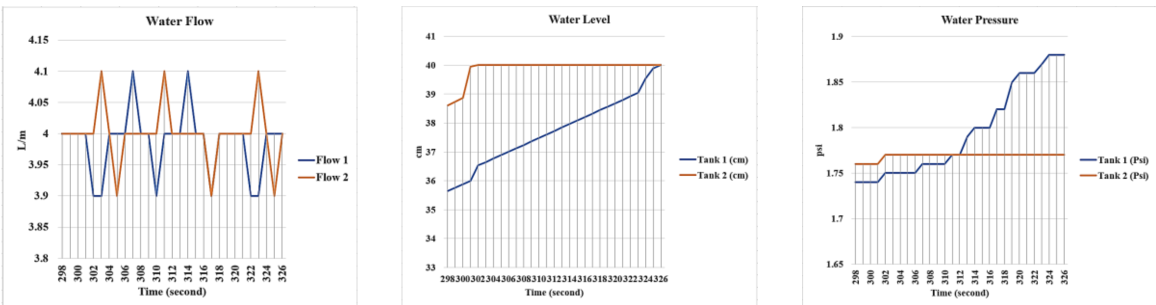


Figure 12. Parameter monitoring graph on the tank

4. CONCLUSION

This research introduces a water management system based on SCADA, which integrates LabVIEW and Arduino for monitoring and controlling water levels and flow rates in a storage tank. The system employs ultrasonic sensors for measuring water levels and pressure sensors for pressure measurements. Pulse width modulation (PWM) regulates the water flow rate, ensuring stability. The SCADA system minimizes water and energy waste, promoting sustainable water management in industrial and environmental contexts. The HC-SRF04 ultrasonic sensor achieves a water level measurement accuracy of 99.77%, with the LabVIEW human-machine interface (HMI) displaying these readings. Water pressure in both tanks is measured by the HX710 sensor, with an accuracy of 98.54%, and the corresponding data is also shown on the LabVIEW HMI. The Ziegler-Nichols method tunes the PID controller, which adjusts the PWM to regulate the water flow rate. The optimized PID parameters are $K\ p$ = 16.59, $T\ i$ = 1.102, and Td = 0.2755 seconds, resulting in optimal flow control. The YF-S201 sensor measures the water flow rate on both pumps, accurately detecting the flow. The PID control successfully maintains a flow rate setpoint of 4 l/m, with minimal fluctuations around the target, initially exceeding by 2.5% before stabilizing within approximately 10 seconds. The SCADA system efficiently transmits sensor data to LabVIEW, facilitating a reliable real-time monitoring and control interface, ensuring effective water level management, and reducing water and electricity waste.

FUNDING INFORMATION

We will jointly bear the costs incurred in conducting this research, without involving any other parties, whether individuals, groups, or institutions.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Kartika	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	
Misriana		✓		✓	✓	✓	✓	✓		✓	✓		✓	
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Asran		✓		✓	✓		✓			✓	✓	✓		✓
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Suryati	✓		✓	✓	✓		✓	✓		✓			✓	

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author Kartika (kartika@unimal.ac.id) on request.

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