ISOMAse
International Society of Ocean, Mechanical and Aerospace Scientists and Engineers

Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-
30th March 2025. Vol.69 No.1

March 30, 2025

# Design and Implementation of Arduino-Based PID Control System for Water Level Regulation Using Ultrasonic Sensors

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**Paper History**

Received: 28-February-2025
Received in revised form: 24-March-2025
Accepted: 30-March-2025

## ABSTRACT

Water resource management is a critical aspect of various sectors, including agriculture, industry, and household applications, where maintaining optimal water levels is essential for efficiency, sustainability, and safety. Traditional water level control methods often rely on manual operations, leading to inefficiencies, resource wastage, and potential system failures. To address these challenges, this study presents the design and implementation of an automated water level control system using a Proportional-Integral-Derivative (PID) controller, an HC-SR04 ultrasonic sensor, and an Arduino Uno microcontroller. The system is designed to enhance accuracy and reliability in liquid level regulation, particularly in industrial and domestic settings. By systematically tuning the Proportional Gain ($Kp$), Integral Gain ($Ki$), and Derivative Gain ($Kd$), the optimal parameter values were determined as $Kp$ = 20.0, $Ki$ = 11.0, and $Kd$ = 1.0. Experimental results demonstrated that the proposed system achieves stable water level regulation with rapid response times and minimal deviations. This research contributes to the advancement of automated liquid control technologies, offering a cost-effective and efficient solution for real-world water management applications.

**KEYWORDS:** *Water level control, PID controller, Arduino uno, Ultrasonic sensor, Automation.*

## NOMENCLATURE

| | |
|---|---|
| *PID* | Proportional Integral Derivative |
| *Kp* | Proportional Gain |
| *Ki* | Integral Gain |
| *Kd* | Derivative Gain |
| *e(t)* | Error Time |

## 1.0 INTRODUCTION

Water resource management is a crucial challenge across various sectors, including agriculture, industrial processes, and domestic applications. Maintaining optimal water levels is essential for ensuring efficiency, preventing resource wastage, and avoiding system failures [1], [2]. Traditional water level control methods still rely heavily on manual monitoring and mechanical float systems, which are prone to inaccuracies and inefficiencies [3]. These conventional approaches often lead to issues such as excessive water usage, overflow, and operational delays in critical industries such as water treatment plants and manufacturing [4], [5].

To address these limitations, various automation techniques have been introduced, including the use of electronic sensors and microcontroller-based control systems [6], [7]. Previous studies have explored water level regulation using ultrasonic sensors for flood monitoring systems, with notifications sent via SMS and websites [8], [9]. Other research has implemented fuzzy logic and artificial intelligence-based controllers to optimize water distribution and reduce measurement errors. However, many of these approaches lack real-time adaptability and often require complex infrastructure [10].

A well-established method for precise and adaptive water level control is the Proportional-Integral-Derivative (PID) controller. This control technique effectively reduces error rates, ensures fast response times, and stabilizes liquid levels in dynamic environments [11], [12]. PID controllers has been widely used in industrial automation, including chemical processing and irrigation systems, to maintain fluid stability and optimize energy efficiency[13], [14]. The integration of PID control with microcontrollers, such as the Arduino Uno, further enhances the automation process by providing an easily programmable and cost-effective solution [15], [16].

This research focuses on developing a water level control system utilizing a PID controller, an HC-SR04 ultrasonic sensor, and an Arduino Uno microcontroller [17]. The system is designed to automatically regulate water levels in a tank by continuously adjusting the pump operation based on real-time sensor data. The novelty of this study lies in its optimized PID tuning parameters and its application in small-scale industrial and household settings, ensuring improved accuracy and efficiency compared to conventional methods. The results of this study contribute to the advancement of automated water management systems, offering a reliable and cost-effective solution for diverse applications.

## 2.0 THEORITICAL BACKGROUND

### 2.1 Water Level PID Controller

Water level control systems are integral to various sectors, including agriculture, water treatment plants, industrial processes, and residential water management. These systems aim to maintain desired water levels within reservoirs, tanks, or other storage units to ensure optimal performance and prevent overflow or depletion. Efficient water level control is crucial for resource conservation, process optimization, and environmental protection. Proportional-Integral-Derivative (PID) controllers are widely used in these applications due to their simplicity, reliability, and effectiveness in maintaining desired set points [18], [19].

PID controllers are a type of feedback controller that combines proportional, integral, and derivative actions to control a process variable, such as water level. This combination allows PID controllers to address both transient and steady-state behaviors, ensuring that water levels remain within desired limits [20].

**Proportional Control (P)**

This term produces an output proportional to the current error, which is the difference between the desired setpoint and the measured water level. The proportional control helps reduce the magnitude of the error.

$$P(t) = K_p \cdot e(t) \tag{1}$$

where *Kp* is the propotional gain and e(t) is the error at time t.

**Integral Control (I)**

The integral term accounts for the cumulative sum of past errors, eliminating steady-state error by adjusting the control action based on the history of the error.

$$I(t) = K_i \cdot \int_0^t e(\tau)d\tau \tag{2}$$

Where *Ki* is the integral gain

**Derivative Control (D)**

The derivative term predicts future error based on the rate of change of the error, helping to dampen oscillations and improve system stability.

$$D(t) = K_d \cdot \frac{de(t)}{dt} \tag{3}$$

Where *Kd* is the derivative gain

The combined PID control action is given by:

$$PID(t) = K_p \cdot e(t) + K_i \cdot \int_0^t e(\tau)d\tau + K_d \cdot \frac{de(t)}{dt} \tag{4}$$

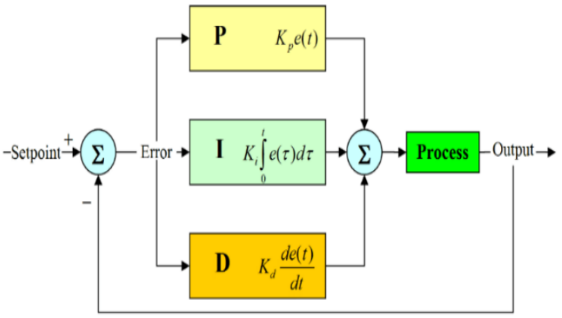

Figure 1: Stucture PID controller

Figure 1 shows a block diagram of a Proportional-Integral-Derivative (PID) controller. It starts with a setpoint, representing the desired value of the process variable, which is compared to the actual process variable to generate an error signal via a summation block. This error is processed by three components: the proportional term (P), producing an output proportional to the error; the integral term (I), producing an output proportional to the integral of the error over time; and the derivative term (D), producing an output proportional to the derivative of the error [21]. These components' outputs are combined in another summation block to form the control signal, which is then applied to the process being controlled. The output of the process is feedback and compared with the setpoint, maintaining a closed-loop system to continuously adjust and correct the process variable [4], [13], [14].

### 2.2 Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328, used for developing electronic prototypes. Arduino provides an easy-to-use platform for developing electronic systems, including control systems [15]. In the research on water level PID control, the Arduino Uno is used to read data from the water level sensor, calculate the control output based on the PID algorithm, and adjust the actuator to match the water level set point [10].

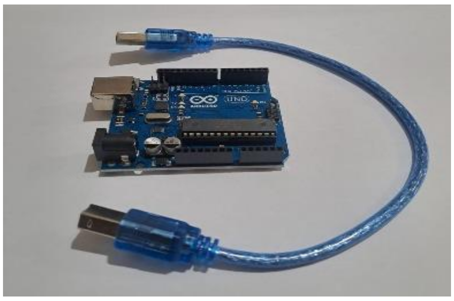

Figure 2: Hardware arduino uno

Arduino Uno Specification:
Microcontroller: ATmega328P; Operational Voltage: 5 Volts; Input Voltage (Recommended): 7-12 Volts; Input Voltage (Limit): 6-20 Volts; Digital I/O Pins: 14 (from 0 to 13); PWM Pins (Output Mode): 6 (Pins 0, 1, 3, 5, 6, 9, 10, & 11); Analog Input Pins: 6 (Pins A0 to A5); DC Current per I/O Pin: 20 mA; DC Current for 3.3V Pin: 50 mA; Flash Memory: 32 KB; SRAM: 2 KB; EEPROM: 1 KB; Clock Speed: 16 MHz

### 2.3 Ultrasonic Sensor HC-SR04

The HC-SR04 ultrasonic sensor is a popular device used in various electronic projects and applications, including robotics, par*K*ing systems, distance measurement, and water level control systems [8], [22]. The HC-SR04 provides non-contact distance measurements with high accuracy and a relatively wide operational range. In water level control systems, the HC-SR04 functions to measure the water level in the tank and send this data to the controller for processing.

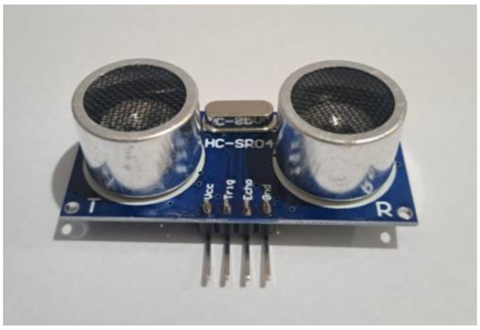

Figure 3: Ultrasonic sensor HC-SR04

HC-SR04 Specification:
Measuring Range: 2cm - 400 cm, precision 3mm; Operating Voltage: 5V DC; Measuring Angle: 15 degrees; Operating Frequency: 40 kHz.

### 2.4 Pump 12VDC

The 12VDC pump acts as an actuator that functions to transfer water from the reservoir into the tank according to the predetermined water level (set point).

Figure 4: Pump 12VDC

Pump 12VDC Specification:
Pump Size : 90mm x 40mm x 35 mm
Wor*K*ing voltage : DC 6V to 12V (5W to 10W)
Wor*K*ing current : 0.5-0.7A
Empty load current : 0.18A
Max suction : 2m
Inlet & Outlet dia. : dia. 6 mm, an outer dia. of 9 mm
Traffic : 1.5-2L / Min (approx)
Maximum suction : 2 meters
Lift : Vertical up to 3 meters
Life : up to 2500H, water temp.: up to 80 degree

### 2.5 MOSFET Module IRF520

The MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) is a type of transistor that uses voltage at the gate to control the flow of current between the source and drain. MOSFETs are used as current controllers and electronic signal amplifiers. They are utilized as switches, amplifiers, and motor controllers. MOSFETs exhibit exceptionally high input impedance, minimizing the current needed for gate voltage control. This characteristic enables them to function effectively at elevated frequencies. Furthermore, MOSFETs are known for their high efficiency in electronic circuits.

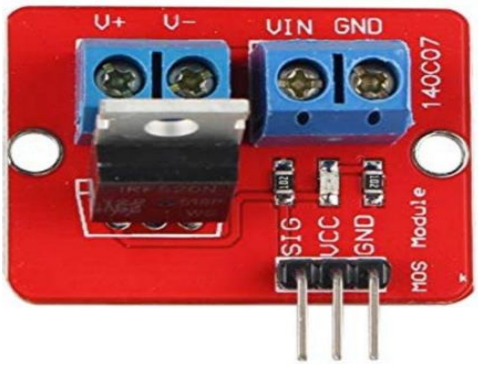

Figure 5: MOSFET module IRF520

MOSFET Module IRF520 Specification:
Ports : Digital Level
Voltage (VDC) : 3,3V, 5V
Output Load Voltage : 0 – 24V
Output Load Current : 5A

### 2.6 LCD2004 i2C

The LCD 2004 is a 20x4 character Liquid Crystal Display, meaning it can display 20 characters on each of its 4 lines. The addition of an I2C interface simplifies the connection and communication with microcontrollers, requiring only two pins for data (SDA) and clock (SCL), thus freeing up GPIO pins for other uses. To display the water level set point, current water level and provide feedback to the PID controller.

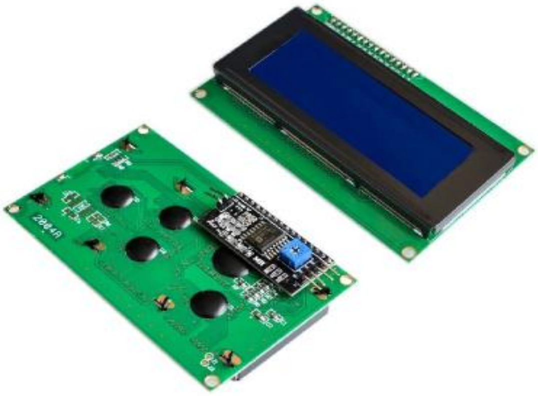

Figure 6: LCD2004 i2C

LCD2004 i2C Specification:
LCD display : Module with blue blacklight.
Fitur : IIC / I2C 4 kabel
Wide viewing angle and high contrast.
LCM type : Characters
Can display : 4-lines X 20-characters.
Voltage : 5V DC.

## 3.0 METHOD

The water level control system developed in this study is based on a Proportional-Integral-Derivative (PID) controller, integrated with an HC-SR04 ultrasonic sensor and an Arduino Uno microcontroller. The system is designed to regulate water levels in a tank by controlling a 12V DC water pump via a MOSFET IRF520 module. The system continuously monitors the water level using the ultrasonic sensor, compares it to a predefined setpoint, and adjusts the pump's operation accordingly.

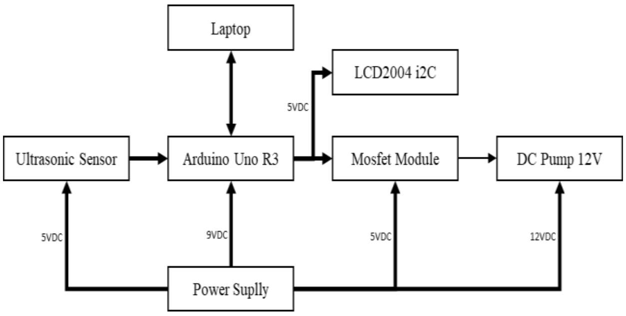

Figure 7: Block diagram water level PID control

Figure 7 illustrates the integration of these components, orchestrated by the Arduino UNO microcontroller. The Arduino UNO serves as the central hub for interpreting sensor data, executing the PID algorithm, and modulating the output of the Mosfet IRF520. Through practical experimentation and analysis, this research conceptualizes the system design and demonstrates its functionality and effectiveness in automated liquid management.

### 3.1 Experimental Setup

The experimental setup consists of the following key components:

**Water tank**: 4000 mL capacity, marked with a reference scale for measurement verification.

**HC-SR04 ultrasonic sensor**: Positioned at the top of the tank to measure the water level.

**Arduino Uno**: Serves as the control unit, executing the PID algorithm and sending signals to the pump.

**12V DC water pump**: Actuates water transfer from the reservoir to the tank.

**MOSFET IRF520 module**: Controls power delivery to the pump based on the PID output.

**LCD2004 I2C display**: Shows real-time water level and setpoint values.

The system was tested in a controlled laboratory environment, with stable temperature and minimal external disturbances to ensure accuracy in measurement and response analysis.

### 3.2 Testing Conditions and Performance Evaluation

The PID parameters (*Kp*, *Ki*, *Kd*) were determined using the Ziegler-Nichols tuning method, a widely used technique for optimizing PID controllers. The system's performance was evaluated through step response and disturbance tests, where response time, overshoot, steady-state error, and the system's ability to recover from disturbances were analyzed. Multiple test cycles were conducted, with real-time water level data logged using the Arduino serial monitor was used for graphical analysis to assess stability and further refine the PID parameters.

## 4.0 DESIGN AND IMPLEMENTATION

### 4.1 Design Water Level PID Control

The intended design water level PID control involves connecting the components so that all the components used are interconnected and can operate according to the system design.

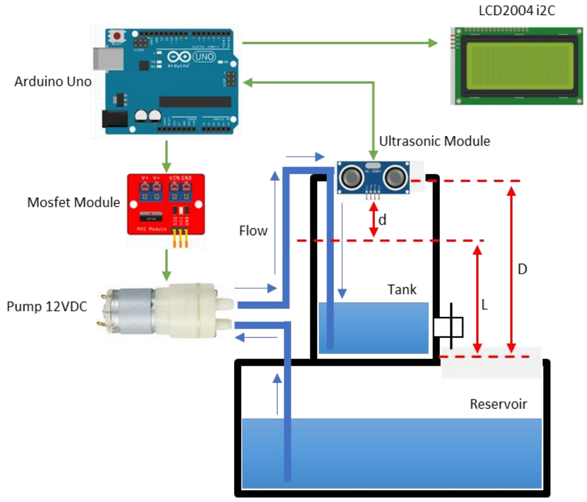

Figure 8: Design waterl level PID control

Figure 8, a schematic of the water level control system using PID control. An ultrasonic sensor is installed in the water tank. The water tank is located above a reservoir that stores the water source, which is equipped with a pump controlled by an IRF520 MOSFET to pump water from the reservoir to the water tank that has a marked line on the side of the tank as the setpoint. The device also includes an LCD2004 I2C to display the system's setpoint and the actual water level in centimeters. The entire system is controlled by a microcontroller, namely Arduino Uno.

### 4.2 Wiring Diagram Watel Level PID Control

The wiring diagram plays a crucial role in implementing the advanced Liquid Tank Filling Control System. This system coordinates the functionalities of various components, intricately connected to ensure smooth communication and interaction. At the heart of this setup is the Arduino Uno microcontroller, which serves as the central control unit. The system includes the HC-SR04 ultrasonic sensor, the MOSFET Module IRF520, and additional components such as a power supply, a LCD2004 i2C, and other ancillary parts. The PID control algorithm is seamlessly integrated into the Arduino's operating environment, enhancing its control capabilities.

The Arduino Uno acts as the central control hub, interfacing expertly with the HC-SR04 ultrasonic sensor to obtain real-time distance measurements. This data is crucial for determining the fluid level within the tank and forms the basis for effective control strategies. Simultaneously, the Arduino efficiently manages the MOSFET Module IRF520 by interpreting Pulse Width Modulation signals to regulate the water pump's RPM and, consequently, the fluid flow rate. Figure 9 illustrates the Wiring Diagram System.

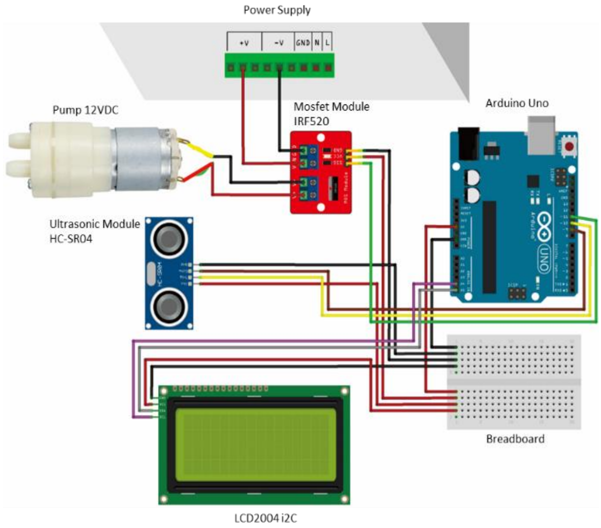

Figure 9: Wiring diagram water level PID control

Figure 9 demonstrates the connections between the HC-SR04 ultrasonic sensor, MOSFET Modul IRF520, LCD2004 i2C and Arduino Uno microcontroller, all supported by the advanced PID control algorithm. This innovative design represents a significant step forward in liquid tank filling control. The blueprint establishes a strong foundation for enhancing control precision and operational efficiency, enabling substantial advancements in areas where fluid management is crucial. For a clearer understanding of how to install each component of this system, it can refer to the following image, Figure 10.

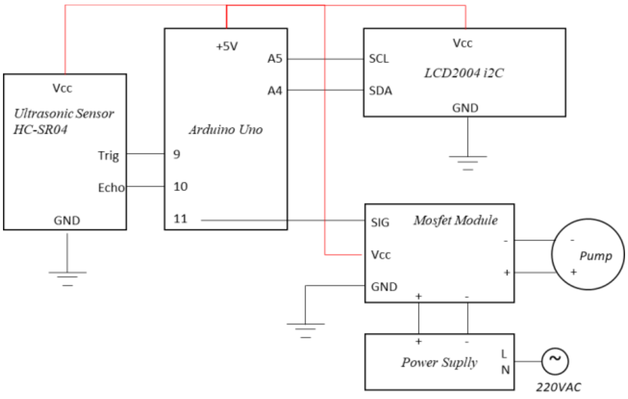

Figure 10: Circuit diagram water level PID control

In Figure 10, the connections between the components of this water level PID control system are shown.

### 4.3 Flowchart Water Level PID Control

In this study, Figure 11 illustrates a process flowchart that begins with initializing key parameters for the PID controller, such as the Set Point, Proportional Gain ($Kp$), Integral Gain ($Ki$), and Derivative Gain ($Kd$). Once these parameters are set, the system monitors the liquid level and computes the error relative to the target set point. The PID computation then generates an output used to control Pulse Width Modulation using MOSFET IRF520, which regulates the power supplied to the water pump. The system operates continuously under specified conditions and halts when conditions no longer apply (state becomes false).

This detailed flowchart visually outlines the sequential steps involved in the PID-based liquid filling control system, ensuring precise and efficient regulation of liquid levels. Such control is crucial in various industrial and research applications, enhancing temperature stability, maintaining desired set points, and improving overall operational efficiency and process control across different domains.

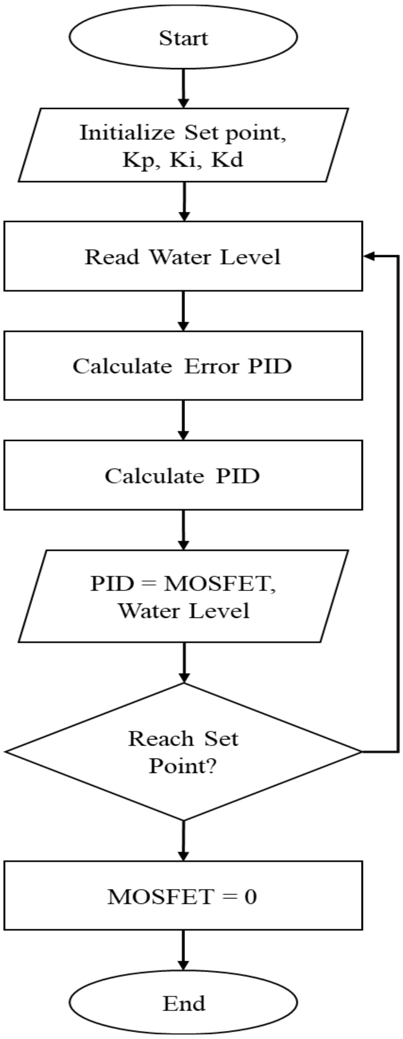

Figure 11: Flowchart water level PID control

## 5.0 DISCUSSION

The implementation of the PID-based water level control system demonstrated significant improvements in liquid level regulation. The experimental results revealed that with optimized PID parameters ($Kp$ = 20.0, $Ki$ = 11.0, $Kd$ = 1.0), the system achieved rapid response times, minimal overshoot, and stable water level maintenance. The ability of the system to adapt to disturbances, as observed when the outlet valve was opened, indicates its robustness in dynamic environments.

One of the key implications of this study is its potential contribution to the field of water management, particularly in automated liquid control systems. The findings highlight how PID controllers can enhance efficiency in industrial and household water storage applications. The system's quick response to changes in water level ensures reduced water wastage and energy consumption, maKing it an environmentally sustainable solution. Additionally, the integration of Arduino-based microcontrollers makes this approach cost-effective and accessible for small-scale industrial applications.

Despite these promising results, certain challenges remain. The observed overshoot during the initial filling process suggests the need for further refinement of the PID tuning process, possibly by implementing adaptive or self-tuning PID algorithms. Additionally, external factors such as sensor inaccuracies and water turbulence may affect the control system's precision. Future research should explore advanced control strategies, such as fuzzy logic or machine learning-based optimizations, to enhance adaptability and accuracy.

Moreover, the real-world application of this system in large-scale water management scenarios, such as irrigation networks or municipal water distribution, requires further investigation. The integration of IoT-based monitoring and remote-control functionalities could significantly enhance the practicality of this system, allowing for real-time data analytics and predictive maintenance.

The following features in Figure 12, this system include a 4000 milliliter tank capacity. It takes roughly 1602.99 milliliters per minute to fill the tank to the brim with a DC pump. Additionally, this tank has an outlet water valve with an average water flow rate of 1579 milliliters per minute when the valve is opened from full condition. A volume of 700 milliliters is the intended set point in this water level control system.

Figure 12, shows the PID control system response on the water level in the tank, with a PID value $Kp$ (20.0), $Ki$ (11.0), $Kd$ (1.0). The X-axis represented time and the Y-axis showing the water level. The blue line represents the set point at 7, while the red line shows the water level, which initially starts low and gradually rises with slight oscillations. When the pump fills the tank, an overshoot occurs around the 30-second mark, where the water level exceeds the set point before finally stabilizing at 7. This overshoot is caused by inaccurate or erroneous readings from the distance sensor. After a few small oscillations, the system reaches stability because the valve is closed. This graph shows that the PID control works well, after several trials for refinement to reduce overshoot and achieve faster stabilization time.

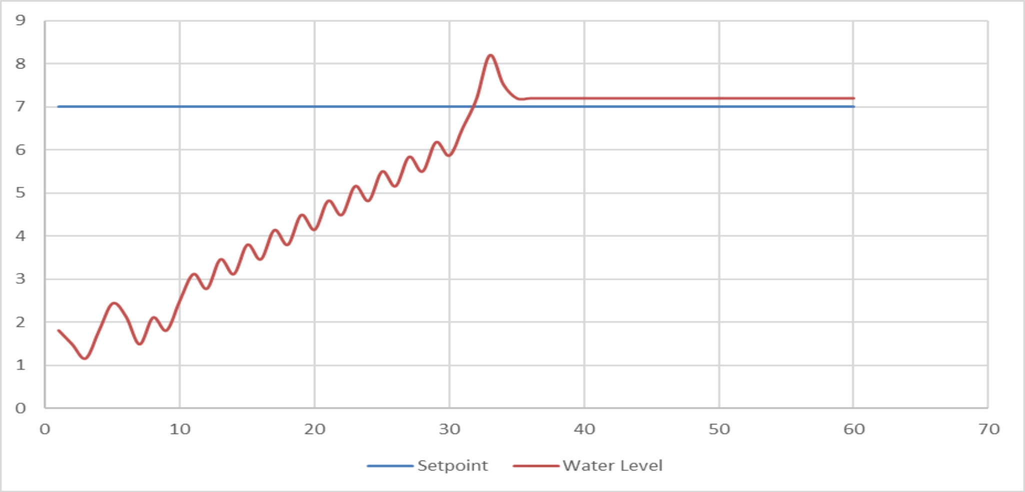

Figure 12: Rise time to reach the set point tank valve closed

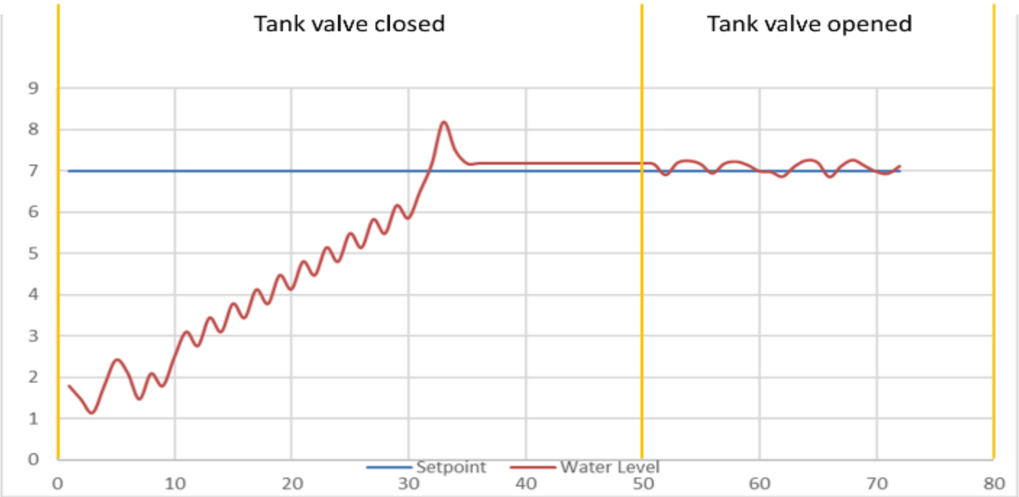

Figure 13: Rise time and step response water level PID control

In Figure 13 shows the results of water level control using a PID system, where the blue line represents the setpoint and the red line shows the actual water level. Initially, when the valve was closed (0-50 seconds), the water level gradually increased towards the setpoint with an overshoot around the 35th second, followed by minor oscillations before reaching stability. After the valve was opened (50-80 seconds), there was a slight disturbance, but the system quickly returned to the set point with smaller oscillations. This shows that the PID control is quite effective in maintaining the water level, although there is an overshoot that can be reduced with further tuning. Overall, the system has a fast rise time, small steady-state error, and good disturbance response.

## 5.0 CONCLUSION

This research successfully developed and implemented a PID-based water level control system utilizing an HC-SR04 ultrasonic sensor and an Arduino Uno microcontroller. Through systematic PID tuning, the study demonstrated an effective and reliable approach to maintaining stable water levels, reducing overshoot, and ensuring rapid response to disturbances. The main objective was to enhance the accuracy of liquid level control for both industrial and household applications. By systematically exploring the effects of Proportional Gain ($Kp$), Integral Gain ($Ki$), and Derivative Gain ($Kd$), the study gained valuable insights into their interactions and impact on system performance. Extensive testing identified optimal parameter settings: $Kp$ (20.0), $Ki$ (11.0), $Kd$ (1.0) for rapid responses with minimal overshoot and significant error reduction. The findings contribute to improving liquid level control techniques, providing effective solutions for automated liquid management and enhancing efficiency and reliability in various applications. The findings contribute to the advancement of automated water management technologies, particularly in small-scale industrial and household applications. However, further improvements, such as adaptive PID tuning and IoT integration, are recommended to enhance system performance and expand its applicability. Future research should focus on refining control algorithms, incorporating predictive analytics, and testing the system in larger, real-world environments to validate its effectiveness in broader water resource management contexts.

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