DESIGN AND IMPLEMENTATION OF AN IOT-BASED AUTOMATIC WATER PUMP CONTROL SYSTEM FOR RESIDENTIAL APPLICATIONS

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Abstract

Inadequate water pressure and inefficient energy utilization remain critical challenges in residential plumbing, especially in densely populated housing complexes during peak demand intervals. Conventional water pumps react directly to pressure fluctuations, leading to frequent cycling, energy inefficiency, and diminished equipment lifetimes. This paper presents an IoT-based control system for household water pumps, incorporating an ESP3 2 microcontroller, a pressure transducer transmitter (PTT) sensor, and an ultrasonic water level sensor to tackle these difficulties. The system functions in automated and manual modes using the Blynk mobile application, controlling electric ball valve and water pump operations according to real-time data and user-specified thresholds. A case study involving a single residence validated the system's efficacy in sustaining consistent water pressure, surpassing 12.0 psi, with an average of 19.4 psi and a maximum of 23.4 psi. The PTT sensor exhibited a relative error of less than 1.7%, remaining within the ±2% accuracy threshold. Furthermore, the system diminished electrical consumption by 31.4% relative to traditional functioning. The results underscore the system's potential to enhance energy economy, operational dependability, and remote control capabilities as well as facilitate its incorporation into intelligent and sustainable home water management.

Keywords: Energy efficiency, IoT, Pressure sensor, Residential applications, Water pump

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Introduction

Water is an essential resource, crucial for the lives of humans and other living species. The availability of clean and adequate water for residential use and consumption is regarded as a fundamental human right that should be widely and fairly available. Access to clean water significantly influences public health and overall well-being. In Thailand, various governmental entities, such as the Metropolitan Waterworks Authority, the Provincial Waterworks Authority, and local administrative groups, are responsible for ovesrseeing water delivery systems in urban and rural regions. The Department of Health and the Department of Water Resources are tasked with the creation and transfer of village-level water delivery systems to local authorities to ensure sustainable management (Babel et al., 2021). Nonetheless, the escalating impacts of global warming have resulted in more frequent and severe droughts, especially during the summer months when water demand markedly rises. Simultaneously, Thailand is undergoing population growth, swift economic development, and significant infrastructure enhancement, all of which escalate the demand for water resources (Ancheta et al., 2025; Tangworachai et al., 2023). The establishment of clean water supply infrastructure to adequately service all sections of the nation has emerged as a paramount national objective. Many residential areas, particularly those within housing estate developments, experience poor water pressure at the home level. This condition frequently leads to the incapacity to utilize water efficiently at various locations inside the residence concurrently. As a result, numerous homeowners opt to install supplementary water pump systems to enhance water pressure. Conventional pump systems, however, often respond instantly to water demand, even for short periods, resulting in frequent motor responses. Such behavior leads to increased electricity consumption and diminishes the operating lifespan of the pump motor and related devices (Abdelsalam & Gabbar, 2021).

A review of pertinent literature demonstrates that using automatic control systems with microcontrollers, like Arduino boards, along with pressure sensors, has worked well for checking water pressure and managing water pump operations based on real usage. These systems have shown the capability to diminish system effort and enhance energy efficiency (Isminarti, 2023; Akhund et al., 2022). Furthermore, the advancement of information technology has facilitated the remote control of electrical devices via the Internet, often known as the Internet of Things

(IoT). This technology enables real-time monitoring and remote operation of equipment, such as water pumps, via smartphones or other mobile devices, thereby enhancing convenience and increasing the ability to manage the system from a distance (Bouali et al., 2021; Hahm et al., 2020). Recent studies have highlighted the role of IoT in water resource optimization, system automation, and energy savings, especially in the context of smart homes and sustainable infrastructure (Tran et al., 2023; Ismail et al., 2022). In addition, IoT frameworks integrated with fog computing have been proposed to meet the low-latency requirements of control systems in smart utilities (Kumari et al., 2019). This research aims to design and implement a water pump control system for residential applications by integrating IoT technology with real-time pressure sensor data processing. The suggested system is designed to autonomously control water pump operation based on real-time water pressure, thereby optimizing water usage, minimizing unnecessary energy consumption, and enhancing operational efficiency and system maintenance. This study employed a residential property in a housing development as a case analysis.

Objectives

The objectives of this study are to investigate present water pressure situations and water consumption behaviors in a residential area and to develop, install, and evaluate the performance of an IoT-based control system for water pump operation.

Materials and methods

1. Examination of Water Pressure and Consumption Habits

This study chose a residential unit inside a designated housing development project for recording empirical data regarding low water pressure issues in the domestic water supply system and to examine the water consumption habits of residents. Data collection transpired from March 3-9, 2025. A custom system for monitoring water pressure was fitted into household plumbing. A pressure transducer transmitter (PTT) sensor measured 0–100 pounds per square inch (psi) with a specified accuracy of within 2.0% of the reading (full scale) and converted pipe water pressure into an analog electrical output. An ESP32 microcontroller board processed the analog signal in real time. The Blynk app displayed processed data for real-time water pressure monitoring during actual consumption.

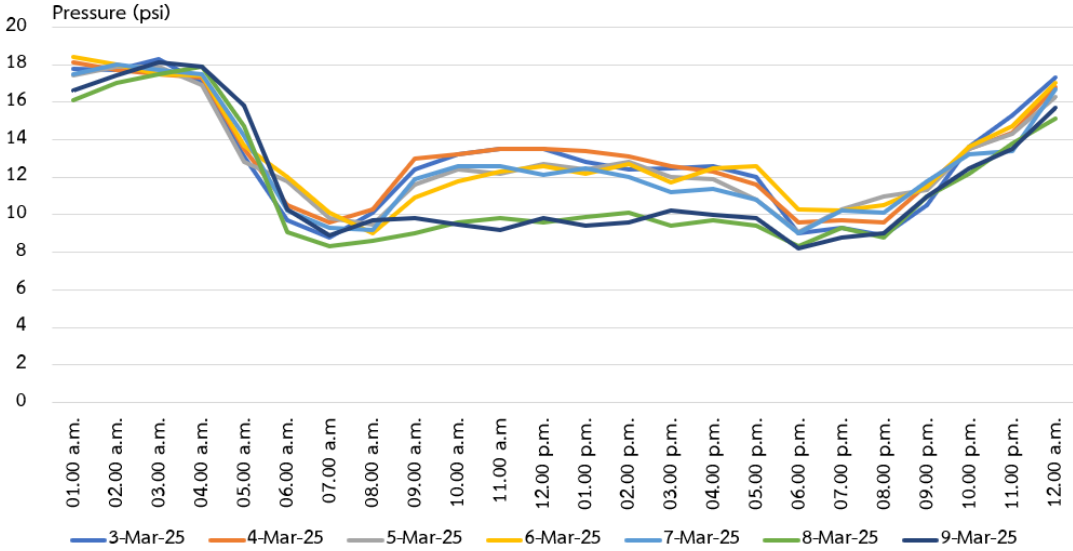


Figure 1 Pipe water pressure recordings from March 3–9, 2025.

The data monitoring system was set to record water pressure values constantly at hourly intervals for a duration of seven days. This design allowed the researchers to analyze variations in water pressure at different times of the day and during the week. The reported results are illustrated in Figure 1. The results demonstrate that water pressure varied according to the time of day and the day of the week. During weekends (Saturday and Sunday), the water pressure demonstrated a significant decline. The minimum pressure measured was 8.2 psi on Sunday, March 9, 2025. On weekdays, from Monday to Friday, the water pressure generally increased, reaching a minimum of 8.8 psi on Monday, March 3, 2025. This tendency corresponds with the customary water consumption routines of residents in the housing estate, who often utilize water simultaneously during morning hours (Prior to departing for work) and evening hours (Subsequent to returning home). The concurrent utilization habits lead to a significant decrease in water pressure during peak times, causing an insufficient water supply for residential needs. The interviews with participating residents indicated that a minimum water pressure of roughly 12.0 psi is deemed sufficient for daily routine home activities. Consequently, the proposed system established 12.0 psi as the reference value for the design and control of the autonomous water pump system.

2. Design and Implementation of a Water Pump Control System.

The design and development of the control system for the water pump in residential applications in this research were performed in accordance with the system architecture depicted in Figure 2. The system's major purpose is to improve the efficiency of domestic water management through the application of IoT technology, solving the problem of low water pressure experienced at specific periods in residential housing estates utilized as the case study. Figure 3 illustrates that the control system utilizes an ESP32 microcontroller as its central processing unit. The ESP32 features an embedded ESP-WROOM-32 chip, a 32-bit microcontroller that facilitates wireless communication using Wi-Fi, rendering it ideal for IoT applications. The system utilizes two PTT sensors (0–100 psi) to continuously monitor water pressure at two points inside the household plumbing system. One sensor is strategically placed to gauge water pressure from the supply pipe, while the other is installed post-pump to measure pressure prior to distribution to residential ends. The pressure measurement value from both sensors is transmitted to the ESP32 microcontroller for comparison with a reference value established based on actual water pressure and usage behaviors detailed in Section 1. The system operates under two separate control cases based on this comparison:

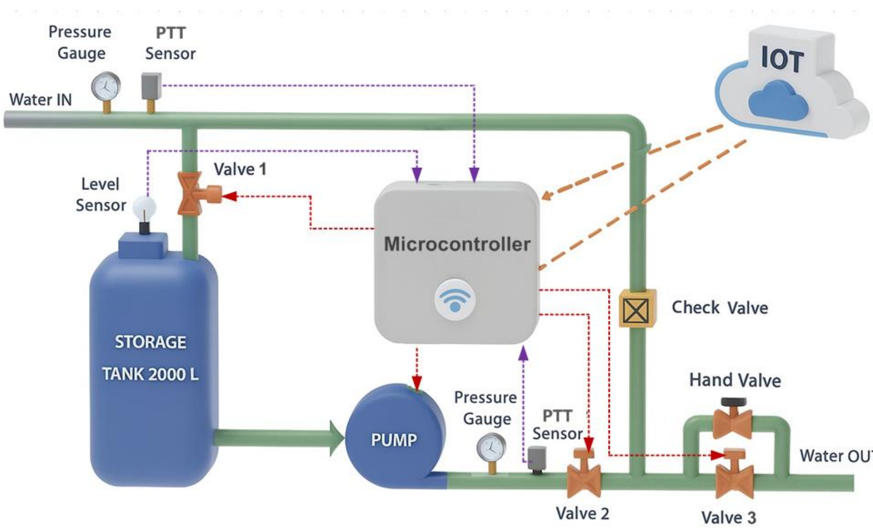


Figure 2 Diagram of the proposed water pump control system for residential applications.

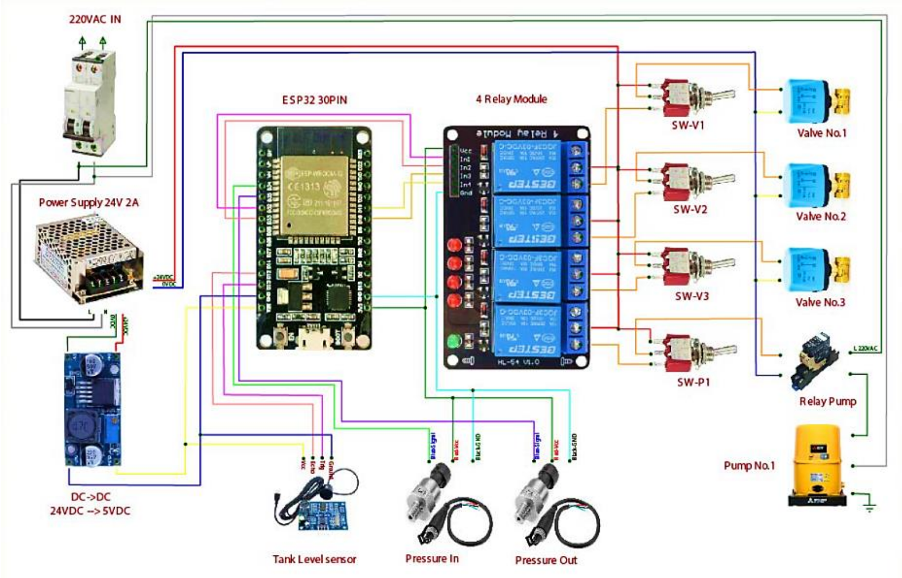
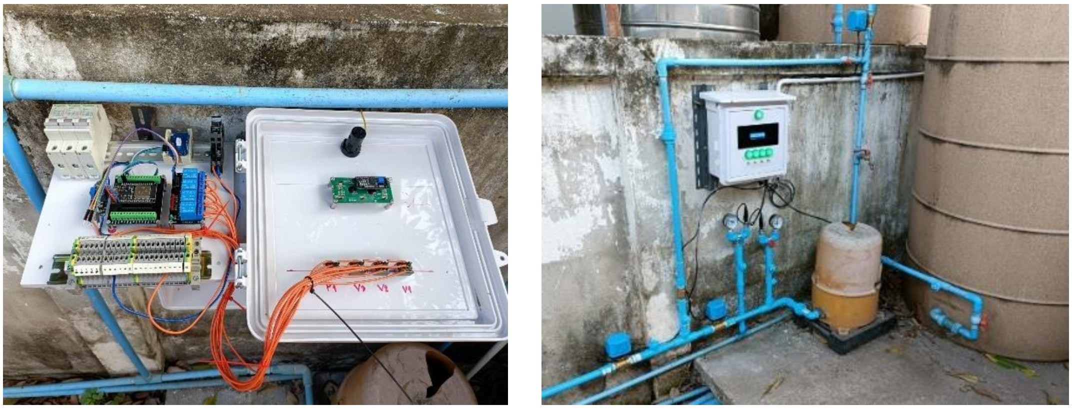


Figure 3 Hardware configuration of the proposed control system for water pumps in residential applications.

Case 1: The water pressure from the supply meets or exceeds the reference value. In this situation, the control system turns on Relay 3 on the JQC3F-03VDC-C relay module to connect the circuit and provide 24 VDC to Electric Ball Valve 3 (Valve 3). This approach enables water to flow directly from the municipal system to the residential ends without operating the pump. This method minimizes unnecessary pump running and facilitates energy conservation.

Case 2: The water pressure from the municipal supply falls below the limit. The system activates both Relay 2 and Relay 3 to turn on Electric Ball Valves 2 (Valve 2) and 3 while concurrently transmitting a control signal to Relay 4 to turn on the contact and deliver 220 V AC single-phase power to a 150 W Mitsubishi water pump. The pump draws water from a storage tank and supplies it for home use. A check valve was installed to prevent the reverse flow of water into the supply line.

The system is fitted with a JSN-SR04T ultrasonic water level sensor to guarantee uninterrupted water availability from the storage tank. Should the water level in the tank descend beyond a designated threshold, the ESP32 transmits a control signal triggering Relay 1, which supplies power to Electric Ball Valve 1 (Valve 1) to facilitate the intake of water from the municipal supply into the storage tank. Upon reaching the designated upper water level, the valve is automatically stopped.



(a) (b)

Figure 4 Overview of the proposed system (a) Control devices and circuitry, (b) Practical installation in a residential

3. Control Program Development

The control programming for the IoT-based water pump system for households, designed and developed in actual settings as illustrated in Figure 4, was established according to the steps outlined in the flowchart in Figure 5. The control process begins with an inspection of the Auto Mode variable, which defines the system's operational mode. When the Auto Mode value is entered as 1, the system operates in Automatic Mode and performs device control according to a predetermined set of logical circumstances. In this mode, the system first measures the water level in the storage tank with an ultrasonic sensor and compares it to the reference level. If the water level is lower than 95% of the tank's capacity, the system sends a logic HIGH to turn on Relay 1, thereby opening Valve 1 to begin water filling. When the water level surpasses 95%, the system automatically sends a command to close the valve. The system concurrently measures the water pressure using a PTT sensor located in the primary water supply line and compares the obtained result with a reference pressure of 12.0 psi. However, users can set a reference value through the Blynk app, which is adjustable between 8.0 and 16.0 psi according to their preferences. When the detected pressure falls below the reference value, the system delivers a logic HIGH to Relays 2 and 3, thereby opening Valves 2 and 3, while concurrently sending a logic HIGH to Relay 4 to start the water pump. When the outlet pipe pressure surpasses twice the established reference value, the control system sends a logic LOW signal to deactivate Relays 2 and 4, thus closing Valve 2 and shutting off the water pump.

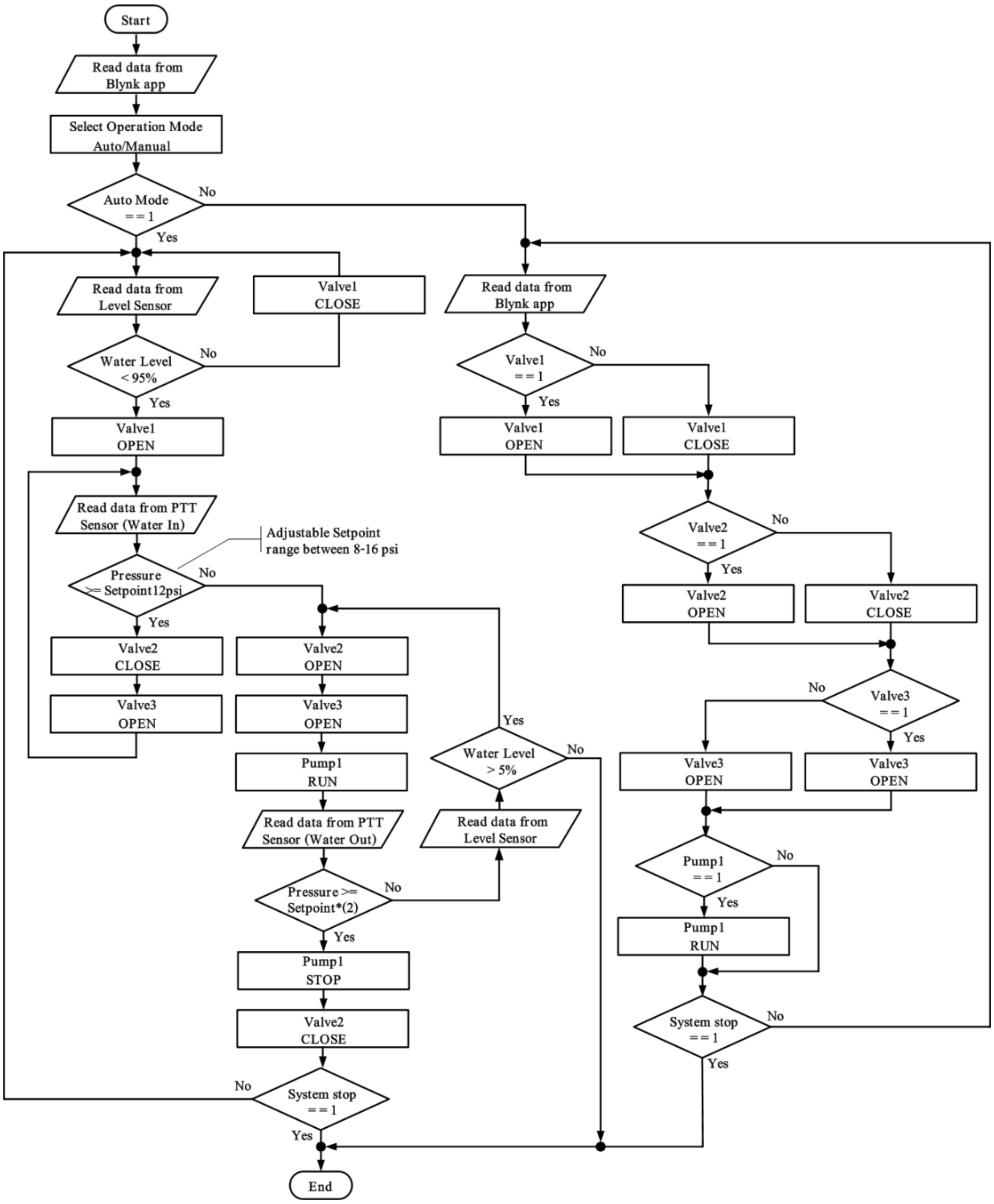
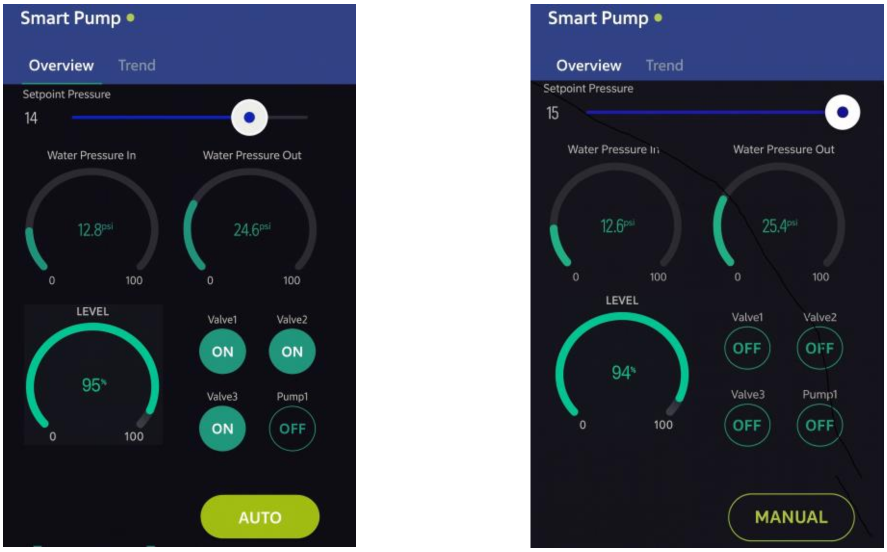


Figure 5 Flowchart of the control program design for the proposed system

Furthermore, if the water pressure falls below the reference value while the pump is running, the system continuously monitors the water level in the storage tank. When the level falls below 5%, the system immediately stops the pump and closes Valve 2. However, the pump resumes only when the water level is above 5% and the supply pressure stays below the set limit. While the Auto Mode value is 0, the system operates in Manual Mode. In this mode, the Blynk app enables users to turn on or off each electric valve using direct commands. The system provides complete user autonomy for real-time control without automated interference.



(a) (b)

Figure 6 Screenshots of the Blynk app interface for IoT control. (a) Automated control mode, (b) Manual control mode

4. Designing and Applying an IoT-Based Control System

The IoT-based control solution for the residence's water pump enables real-time monitoring and control remotely through smartphones or mobile devices utilizing the Blynk app. This technology allows users to remotely manage electric valves and the water pump, providing real-time feedback on the application interface. The system was designed to facilitate two operational modes: Automatic Control Mode and Manual Control Mode. Figure 6(a) depicts the system performing in automatic mode. In the testing, the reference pressure was set at 14.0 psi, although the actual pressure from the municipal water supply was measured at 12.8 psi. The water level in the storage tank was concurrently measured at 95%. Under these conditions, the system autonomously started the pump, as evidenced by the statuses of Valve 2 and Valve 3, both of which were bright green. The proposed control system produced a maximum water pressure output of 24.6 psi, which did not exceed twice the reference pressure (28.0 psi). Figure 6(b) illustrates the system performing in Manual Control Mode, allowing the user to directly control the opening and closing of each valve via the Blynk interface. All commands and real-time system status are presented on the smartphone screen, facilitating intuitive and transparent user interaction. The proposed IoT-based control system augments user convenience and enhances the overall efficacy of the system. Crucially, the capacity to remotely monitor and control the system enhances safety, particularly during emergencies.

Results and discussion

To evaluate the feasibility and performance of the proposed IoT-based control system for residential water pumps, the system was installed and implemented in a household designated as the case study. We recorded system performance evaluations under real operating situations after installation. We illustrate the testing approach and results as follows:

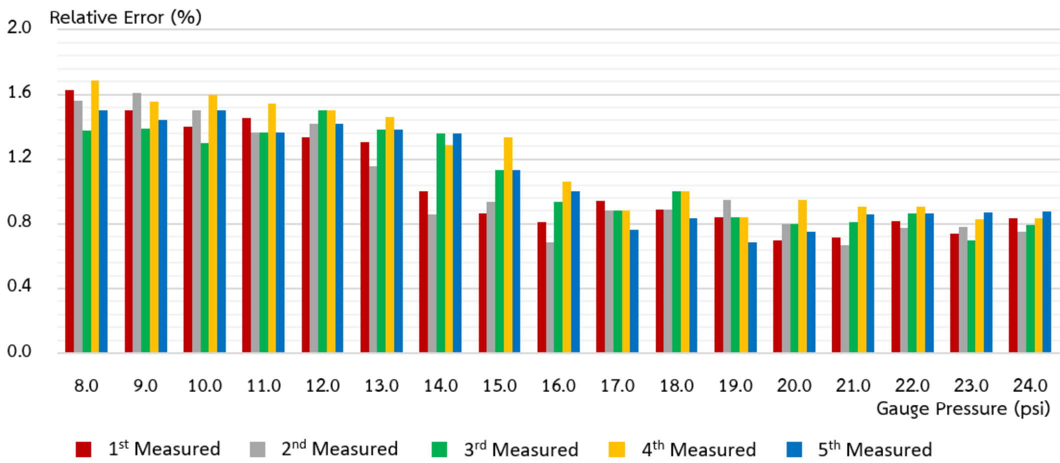


Figure 7 Relative error of PTT sensor measurements at various gauge pressures

1. Evaluation of the Precision of the PTT Sensor

The PTT sensor utilized in this study has a measuring range of 0–100 psi and is capable of monitoring pressure in oil, air, and water systems. The manufacturer specifies an accuracy of 2% of the reading (full scale). The performance was evaluated by carefully comparing the values from the PTT sensor with those from a calibrated water pressure gauge that measures 0–100 psi, connected in parallel, as seen in Fig. 4(b). The municipal supply line's water pressure was changed using a manually operated valve at the pipe inlet, allowing for a variation between 8.0 psi, the minimum recorded before the proposed system, and 24.0 psi, the maximum observed during the proposed control system's operation. Five independent measurement trials were executed, each separated by a three-minute interval, with the results depicted in Figure 7.

Figure 7 demonstrates that throughout all trials, the relative error continuously remained below 1.7%, which is comfortably within the manufacturer's specified accuracy range of 2%. Furthermore, the trend seen indicates a progressive decline in relative error as the applied pressure escalates, with the minimal errors nearing 0.6% at pressures exceeding 18.0 psi. The experimental results confirm that a selected PTT sensor delivers adequately precise measurements for the specified application. The error levels adhere to the designated tolerance and guarantee the trustworthiness of the measured pressure values for incorporation into the proposed control system.

2. Evaluation of Water Pump Performance Relative to Water Pressure

This section executed the performance evaluation of the proposed control system to regulate water pressure in the distribution pipeline via practical applications. The system communicated with the IoT to record water pressure in the pipeline before distribution to different areas of the house. Measurements were carried out hourly throughout a continuous week from May 12-18, 2025. The data recorded are illustrated in Figure 8.

Figure 8 illustrates that the maximum water pressure recorded during the monitoring period was 23.4 psi, recorded on May 13, 2025, at 11:00 a.m. On the contrary, the minimum recorded pressure was 12.5 psi, noted on May 16, 2025, at 10:00 p.m. This result indicated that all recorded measurements consistently exceeded the setting reference value of 12.0 psi. The average water pressure recorded for the week was 19.4 psi. The results indicate that the proposed control system successfully maintained water pressure within the designated range specified in the control program, reflecting steady and dependable performance under real-world operating situations.

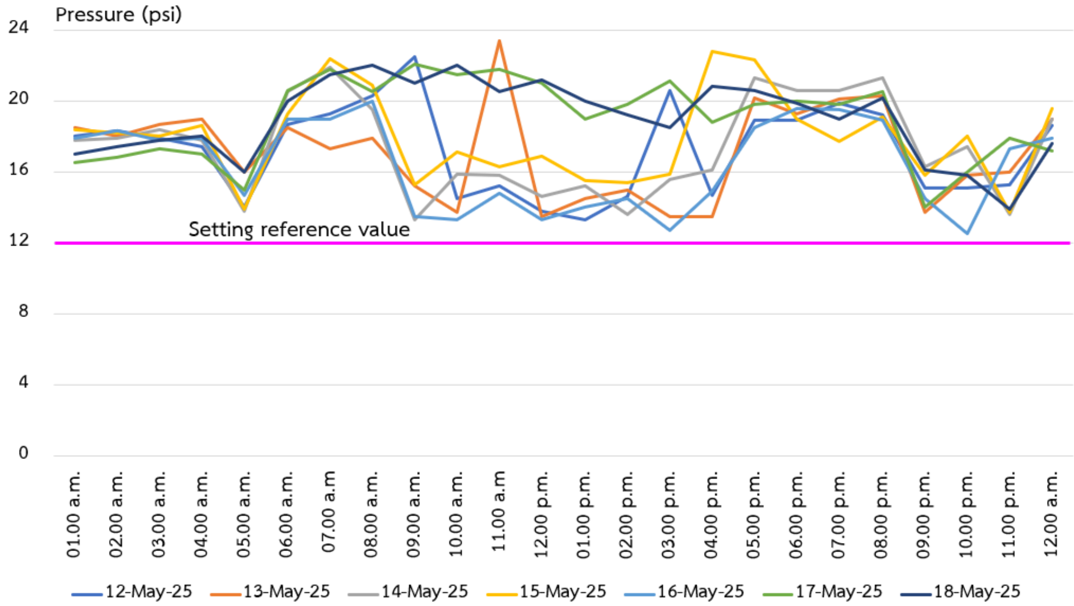


Figure 8 Graph depicting recorded water pressure from May 12-18, 2025

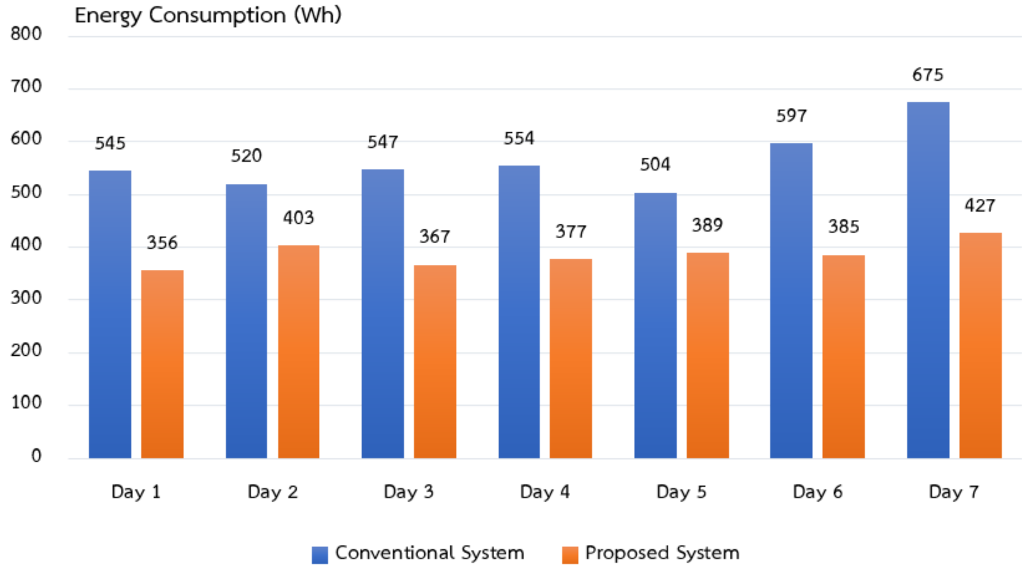


Figure 9 Comparison of energy consumption between the traditional and proposed systems.

3. Comparative Evaluation of Electric Energy Consumption

Figure 9 shows the daily electrical energy use measured over a week, from May 5 to May 11, 2025 (Monday to Sunday), when water was supplied directly by the water pump without using the proposed control system. The conventional system for controlling a 150 W Mitsubishi water pump, which reacts instantaneously to water demand without optimization, recorded a weekly energy use of 3.9 kWh. The maximum daily usage was recorded on May 11, 2025, at 675.0 Wh, and the minimum was 504.0 Wh. When the proposed control system was adopted during a second seven-day period, from May 12 to May 18, 2025. The residents preserved their water consumption behaviors from the preceding week to guarantee consistency in comparison. The results indicated that the weekly total energy consumption decreased to 2.70 kWh. This amount denotes an energy savings of 1.2 kWh, corresponding to a 31.4% decline in overall energy use. The decrease in energy consumption is due to the effective performance of the water pump under the control scheme, which minimized unnecessary pump runtime and thus lowered the total power demand.

Conclusions

The research detailed the design, implementation, and evaluation of an IoT-based system to control a water pump specifically for residential use. The system successfully controlled water distribution in low-pressure conditions by integrating real-time pressure and water level monitoring with a dual-mode control system (Automatic and manual). The ESP32 microcontroller, along with PTT sensors and ultrasonic sensors, allowed for quick control using the Blynk mobile app, enabling users to check and manage the system from afar. The experimental results confirmed the system's reliability and performance in real-world situations. The selected PTT sensor exhibited a relative error of less than 1.7%, which is well within the manufacturer’s stated accuracy margin of 2.0%. The proposed system consistently produced water pressure exceeding the user-defined threshold of 12.0 psi, attaining an average weekly pressure of 19.4 psi and a maximum of 23.4 psi. The control technique markedly enhanced energy efficiency, decreasing electrical consumption by 31.4% relative to traditional pump operation. The proposed system improves user convenience, operational stability, and energy efficiency, showcasing its promise as a scalable and economical solution for intelligent household water management. Future research ought to focus on enhancing the system's scalability for use in multi-story residential buildings or small towns, where pressure distribution dynamics are more intricate. The incorporation of machine learning or adaptive control techniques may improve system response to fluctuating demand patterns. Integrating cloud-based data logging and analytics systems could enhance long-term performance monitoring, predictive maintenance, and system optimization. These developments would enhance the application and resilience of IoT-based water management solutions in various household settings.

Recommendation

The research case study focused on a single-story residential dwelling situated within a housing estate. Consequently, the application of the results and control system design to alternative residential buildings or office facilities necessitates additional research. It is crucial to reassess the current water pressure conditions and residents' water consumption behavior in the new context to guarantee the system is optimized to sustain sufficient water pressure levels that correspond with usage demands at various times of the day. This contextual adaptation is essential for maintaining system performance, reliability, and user pleasure across many situations.

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