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IoT-Based Integrated Monitoring System for Household Water Level and Usage Tracking

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ABSTRACT
Conventional household water management often results in inefficiencies, including tank overflow, unexpected shortages, and a lack of awareness about daily consumption. Most existing solutions address these issues only partially—either by monitoring water levels, automating pump control, or recording usage data—without integrating the three into a unified system. To address this gap, this research developed and validated a low-cost Internet of Things (IoT) prototype that combines real-time water-level monitoring, daily consumption measurement, and automatic pump control within a smartphone-connected platform. The system is built on a NodeMCU ESP8266 microcontroller equipped with an HC-SR04 ultrasonic sensor, a YF-S201 flow sensor, and a relay-controlled pump, with data transmitted via Wi-Fi to the Blynk application. Using a Research and Development (R&D) methodology with a prototyping model, the study conducted functional, accuracy, and usability testing. Results show that the prototype achieved reliable performance, with an average error below 2% for both sensors and stable operation during 24-hour trials. Beyond technical validation, the system demonstrated its potential as an eco-feedback tool by providing clear consumption data that can encourage more sustainable water use at the household level.

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1. Introduction

Household water management is often carried out conventionally, relying on manual observation and control. Such practices are prone to inefficiency, including wasted resources due to overflowing tanks or sudden shortages when supplies run dry. The absence of real-time consumption data further prevents users from recognizing patterns of excessive use and hinders awareness of the importance of conservation in the context of increasing water scarcity. Previous research has offered a range of solutions, yet most have addressed isolated aspects of the problem rather than providing an integrated approach. For example, ultrasonic sensors such as the HC-SR04 have been calibrated and applied successfully to measure water levels in flood early-warning prototypes (Andayani *et al*., 2016). In addition, automation of household pumps has been developed to prevent tanks from running empty (Harimasari *et al*., 2024), while IoT-based monitoring systems have been implemented for specific applications such as hydroponic water control (Murdiyantoro *et al*., 2021) and water-level alerts delivered via Telegram bots (Safii *et al*., 2022).

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Similar efforts are evident in studies focusing on potable water processing during fluctuating river discharge (Rizki, 2025), PDAM household water monitoring prototypes (Wahyu *et al*., 2024), and IoT-based turbidity monitoring at water sources (Udin *et al*., 2021). Other researchers have introduced automatic water tanks using Arduino Uno (Dewanto *et al*., 2018), or IoT-based prototypes that calculate both consumption and cost (Riadi *et al*., 2024). Further developments include monitoring of multi-storey building water usage (Sri Hartanto, 2024), IoT-based level monitoring with Blynk applications (Sarif & Hasanah, 2025), ultrasonic sensor alternatives such as JSN-SR04T (Az-zikri *et al*., 2025), PDAM consumption tracking with ESP32 (Adzra' Labiibah & Fadhli, 2024), and remote-controlled pump management via NodeMCU (Munazzar & Nasir, 2024). Despite these advances, the majority of prior studies remain partial. They either focus solely on water-level monitoring, on automating pump control, or on tracking consumption without combining these three essential aspects into a single platform. A truly integrated system is critical because water conservation at the household level requires continuous monitoring, reliable control, and transparent feedback on daily use.

Research in smart water management supports the need for systems that combine these functions in practical, affordable ways (Tjendani *et al*., 2022). Studies on boiler-level monitoring and industrial water control further illustrate the importance of robust IoT-based solutions that can sustain accuracy and reliability over time (Prasetyo *et al*., 2023). Additional work has explored automatic monitoring with Blynk platforms (Tri *et al*., 2023), IoT-based hydroponic irrigation (Soliata & Suryono, 2024), low-cost automation of household pumps (Bakhrul Ulum *et al*., 2022), flood monitoring via Thingspeak (Hendrian *et al*., 2024), IoT-based weather and flood alert systems (M. bahrul Ulum, 2023), and even water flow–based pump protection tools (Faishol *et al*., 2022). Collectively, these studies show the breadth of IoT's application in water management, but also underscore the gap in fully unifying measurement, monitoring, and control. Addressing this gap, the present research aims to design and build a functional IoT-based prototype that integrates three core features simultaneously: real-time water-level monitoring, daily consumption measurement, and automatic pump control.

The system is built around a NodeMCU ESP8266 microcontroller linked to ultrasonic and flow sensors, with data transmitted via Wi-Fi to the Blynk application for smartphone-based monitoring and control. To ensure iterative validation, the study employs a Research and Development (R&D) methodology with a prototyping model, as outlined in prior work on engineering-oriented product development (Fayrus & Slamet, 2022). This approach enables repeated hardware and software testing to achieve both functionality and accuracy. Technical foundations in electronics and IoT (Mulyana & Ismanto, 2022; Budiyanti, 2021) also serve as references for the architecture. Ultimately, this research not only delivers proof of concept but also demonstrates the potential for household-level smart water management that is low-cost, practical, and scalable. The following sections describe the design process, functional validation, experimental findings, and broader implications for resource conservation.

2. Methodology

The research adopts a Research and Development (R&D) methodology combined with a prototyping model, which is considered appropriate for engineering-based product development involving hardware and software integration. This approach enables iterative validation, ensuring that each component performs as intended before the system is finalized. The R&D method has been widely recommended for applied technology research that requires experimental validation and incremental refinement (Fayrus & Slamet, 2022). In this study, the development process consists of system architecture design, hardware and software implementation, and structured testing to verify functionality, accuracy, and usability. Technical aspects of electronics provide a foundation for circuit design and sensor calibration (Mulyana & Ismanto, 2022), while concepts from Internet of Things learning modules offer theoretical grounding for system architecture and connectivity (Budiyanti, 2021).

The system architecture employs a three-layer design, as shown in Figure 1, to achieve modularity and simplify system management. The physical layer consists of the HC-SR04 ultrasonic sensor for water-level detection, the YF-S201 flow sensor for consumption measurement, and a water pump controlled by a relay module as an actuator. The network/edge layer is managed by the NodeMCU ESP8266 microcontroller, which processes sensor data locally, executes pump control logic, and maintains Wi-Fi connectivity. The application layer is supported by the Blynk platform, functioning both as a cloud-based backend for data storage and as a mobile interface for visualization and user interaction. Similar three-tier approaches have been highlighted in studies on smart water management and monitoring systems, showing their flexibility for both domestic and industrial applications (Tjendani *et al*., 2022; Prasetyo *et al*., 2023).

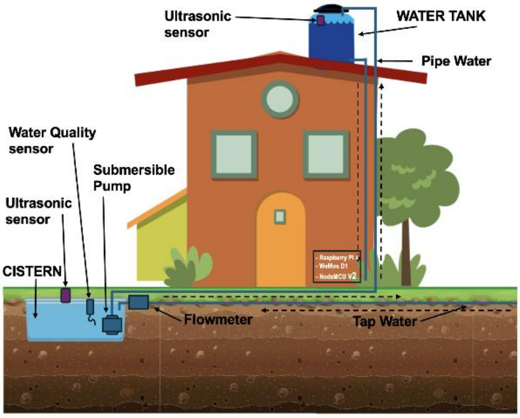


Figure 1. Three-Layer IoT System Architecture

The hardware implementation integrates all components into a functional prototype, illustrated in Figure 2. NodeMCU ESP8266 was selected as the central processing unit because of its built-in Wi-Fi module and sufficient GPIO pins to support multiple sensors. The firmware was developed using Arduino IDE with C++ programming, allowing straightforward integration of libraries for sensor reading and Wi-Fi communication. Program logic, illustrated in Figure 3, continuously cycles through sensor data acquisition, data processing, transmission to Blynk via virtual pins, and pump control based on predefined water-level thresholds. These steps are consistent with earlier works on IoT-based automation where microcontroller reliability and modular coding play a crucial role in ensuring consistent system responses (Tri *et al*., 2023; Soliata & Suryono, 2024; Bakhrul Ulum *et al*., 2022).

Figure 2. Hardware Circuit Diagram

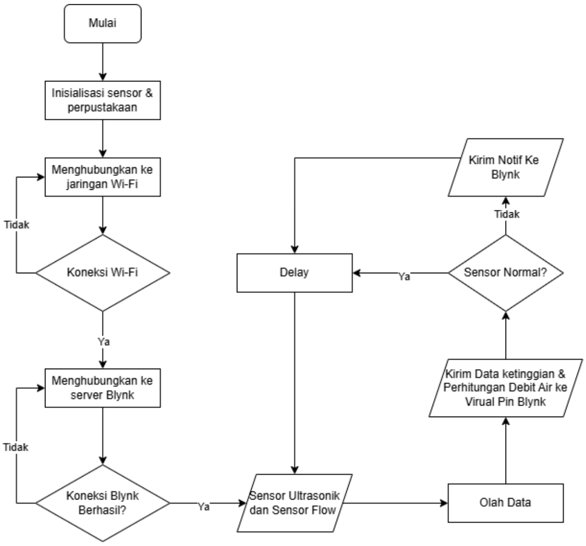


Figure 3. Program Logic Flowchart

The testing procedure was divided into three stages. First, functional testing was performed using black-box methods to confirm whether the core functions—Wi-Fi connection, sensor reading, data transmission, and relay switching—operated correctly. Second, accuracy validation was conducted by comparing system sensor readings with manual measurements using precision rulers and calibrated measuring cups. Third, usability evaluation was carried out through the System Usability Scale (SUS) questionnaire administered to respondents who tested the prototype. This approach provides not only technical validation but also end-user perspectives on system practicality. Similar validation processes have been reported in research on automated pump systems and IoT-based flood and weather monitoring tools (Hendrian *et al*., 2024; M. bahrul Ulum, 2023; Faishol *et al*., 2022). By combining layered system architecture, iterative prototyping, and comprehensive testing, the methodology ensures that the prototype achieves both reliability and user-centered functionality. The integration of references across electronics, IoT frameworks, and applied system testing underscores the rigor of this approach and positions the research within a broader body of studies on water management automation.

3. Results

The findings of this study demonstrate the successful design and implementation of an IoT-based prototype capable of monitoring water levels, measuring daily consumption, and automatically controlling the pump. All hardware components were integrated into a compact unit that can be easily placed near household water tanks, as illustrated in Figure 4.

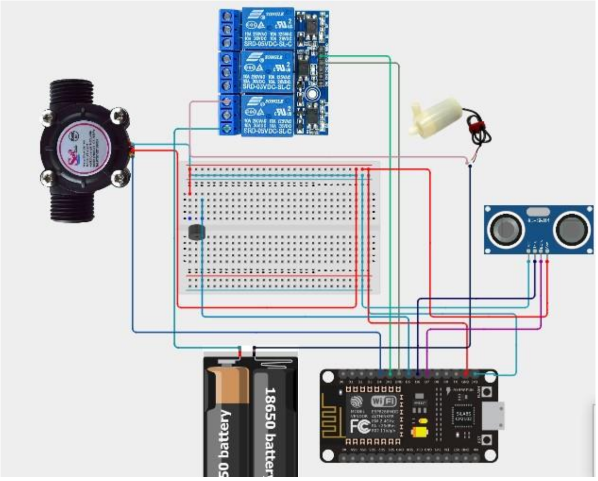


Figure 4. Prototype System Appearance

The user interface was developed through the Blynk platform with an intuitive and user-friendly display. Users can monitor water levels in real time using a gauge widget, observe historical daily consumption through the SuperChart, and control the pump both automatically and manually. This visualization is shown in Figure 5.

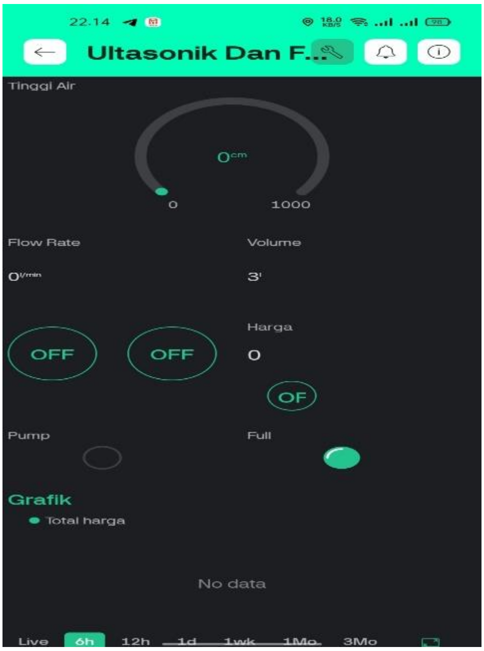
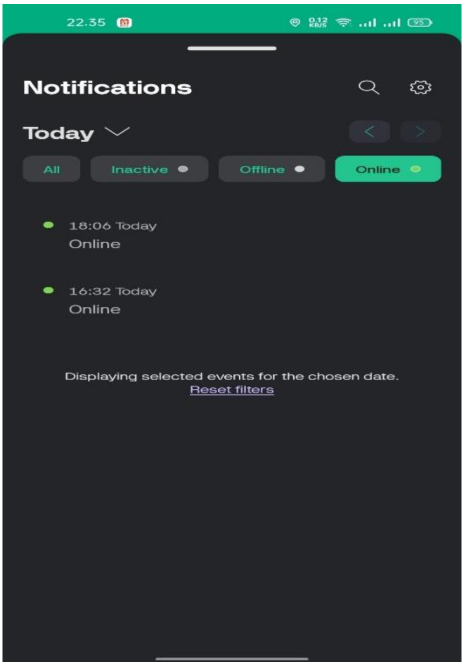


Figure 5. Blynk Application Interface

Functional testing was conducted to ensure that all system features worked as designed. The results confirmed that all core functions—from sensor initialization, Wi-Fi connectivity, server communication, data transmission, and visualization, to automatic pump control and alert notifications—operated successfully. The outcomes are summarized in Table 1, while an example of an alert notification is shown in Figure 6.

Table 1. Functional Testing Results

No	Function Tested	Result
1	Initialization of HC-SR04 & YF-S201 sensors	Successful
2	ESP8266 connectivity to Wi-Fi network	Successful
3	ESP8266 connectivity to Blynk server	Successful
4	Data transmission & visualization in the application	Successful
5	Automatic pump control based on level	Successful
6	Alert notification delivery	Successful



18:06 Today
Online

16:32 Today
Online

Displaying selected events for the chosen date.
Reset filters

Figure 6. Water-Level Alert Notification

Sensor validation was conducted to assess accuracy. The HC-SR04 ultrasonic sensor was compared with manual measurements using a precision ruler, resulting in an average error of 1.34%, as shown in Table 2.

Table 2. HC-SR04 Sensor Validation Results

Test	Actual Distance (cm)	Sensor Reading (cm)	Error (%)
1	35	35.5	1.43
2	30	30.2	0.67
3	25	25.4	1.60
4	20	20.2	1.00
5	15	15.3	2.00
Average	-	-	1.34

Similarly, validation of the YF-S201 flow sensor was performed by comparing recorded volumes with actual water usage. Across three test scenarios, the sensor achieved an average error of 1.72% (Table 3), confirming its ability to record daily water consumption with high accuracy.

Table 3. YF-S201 Flow Sensor Validation Results

Test	Actual Volume (L)	Sensor Volume (L)	Error (%)
1	1	0.98	2.00
2	2	2.03	1.50
3	3	2.95	1.67
Average	-	-	1.72

In addition to accuracy, response-time analysis was conducted to measure delays in sending data and executing pump control commands through the Blynk application. Results in Table 4 show variations between 2 and 10 seconds, depending on Wi-Fi or LTE/4G network stability.

Table 4. Response Time of Pump Control via Blynk

Test	Pump On (s)	Pump Off (s)
1	2.10	2.15
2	2.39	2.86
3	3.50	3.90
4	3.25	3.74
5	6.90	6.97
6	7.59	8.28
7	8.59	10.28
8	9.59	9.28

A 24-hour operational test was conducted to assess system stability. The results showed a gradual decline in water levels during normal household consumption, followed by sharp increases during refilling events. In addition, the system consistently recorded daily consumption accumulation, as visualized in Figure 7.

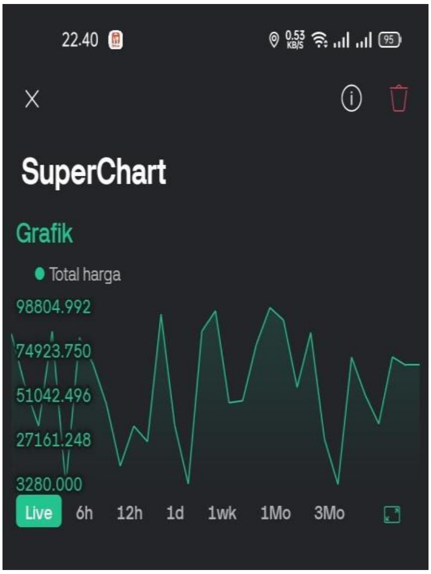


Figure 7. Daily Water Consumption Accumulation

4. Discussion

The results provide strong evidence that the IoT-based prototype achieved all of its intended objectives. The functional testing outcomes in Table 1, along with the high sensor accuracy demonstrated in Table 2 and Table 3, confirm the technical feasibility of the proposed system architecture. The HC-SR04 ultrasonic sensor produced an average error of 1.34%, which is consistent with previous calibration studies that demonstrated its reliability in water-level applications (Andayani *et al*., 2016; Sarif & Hasanah, 2025). Similarly, the YF-S201 flow sensor achieved an error rate of only 1.72%, aligning with prior evaluations of IoT-based flow measurement systems (Faishol *et al*., 2022). These findings demonstrate that the hardware choices and integration strategy were appropriate for low-cost yet precise monitoring. Beyond accuracy, the 24-hour operational test (Figure 7) confirmed the system’s ability to deliver actionable data. By visualizing consumption patterns, the system enabled detection of peak usage periods and verification of automatic refill cycles. Such eco-feedback mechanisms are recognized as effective tools for influencing user behavior toward conservation, as noted in earlier works on smart water management and IoT-enabled household monitoring (Tjendani *et al*., 2022; Riadi *et al*., 2024). Unlike previous prototypes that focused only on water-level monitoring and alerts (Safii *et al*., 2022; Hendrian *et al*., 2024) or automated pumping without consumption logging (Harimasari *et al*., 2024; Bakhrul Ulum *et al*., 2022), this study successfully integrates monitoring, control, and consumption tracking into a single platform.

This integration distinguishes the present system as a more holistic solution compared to prior partial approaches (Murdiyantoro *et al*., 2021; Dewanto *et al*., 2018). Nevertheless, some limitations must be acknowledged. The accuracy of the HC-SR04 ultrasonic sensor can be influenced by environmental factors such as temperature variation or surface turbulence (Andayani *et al*., 2016; Az-zikri *et al*., 2025). The YF-S201 flow sensor, being mechanical, is susceptible to sediment accumulation in long-term use, which may degrade accuracy (Udin *et al*., 2021). Moreover, the use of hobby-grade components in a controlled laboratory setting means that the system’s long-term durability under real household conditions remains uncertain. Similar concerns have been raised in studies testing IoT-based prototypes for turbidity monitoring and boiler water-level control (Prasetyo *et al*., 2023; Munazzar & Nasir, 2024). Another critical issue is response time. While the system responded within 2–10 seconds depending on network conditions (Table 4), this delay highlights dependence on Wi-Fi or LTE connectivity. Such latency is a known challenge in IoT architectures, as also observed in research using Blynk and other cloud platforms (Tri *et al*., 2023; Labiibah & Fadhli, 2024).

Potential solutions include local server integration, hybrid architectures, or optimizing communication protocols to reduce delays. The broader implication of this study is its role as an eco-feedback system for households. By transforming the abstract concept of “saving water” into daily measurable data accessible on a smartphone, the system empowers users to track and evaluate their consumption. Prior research has shown that providing clear, real-time consumption feedback can effectively promote sustainable behavior (Wahyu *et al*., 2024; Soliata & Suryono, 2024). Therefore, the prototype does not merely automate household water management but also contributes to conservation practices by raising user awareness. In conclusion, this research addresses a critical gap by combining water-level monitoring, consumption logging, and automatic pump control into one integrated and low-cost system. While future work is needed to improve robustness and scalability, the prototype demonstrates both technical viability and social relevance in supporting more efficient and responsible water use at the household level.

5. Conclusion

This study successfully designed, developed, and validated a functional Internet of Things (IoT) prototype for household water management. The system integrates three essential features—real-time water-level monitoring, daily consumption measurement, and automated pump control—into a single platform accessible through a mobile application. Experimental results confirmed that the system operates as intended and achieves high accuracy, with both sensors maintaining an average error rate below 2%. These outcomes establish the prototype as a strong proof-of-concept for a low-cost, practical, and efficient smart water management solution. While the findings are promising, the research also highlights several directions for improvement and future investigation. First, integrating temperature sensors such as the DS18B20 could enable dynamic compensation for ultrasonic measurements, thereby enhancing accuracy under varying environmental conditions. Second, implementing data filtering techniques, such as a Simple Moving Average, at the microcontroller level could stabilize sensor readings and mitigate noise. Third, long-term testing with industrial-grade sensors, including radar-based level sensors and electromagnetic flow meters, would provide valuable insights into durability and reliability under real-world operating conditions. Overall, this work demonstrates both the technical feasibility and potential societal value of IoT-enabled household water management systems. By combining affordability, accuracy, and user accessibility, the prototype lays a foundation for future advancements that could support more sustainable and responsible use of water resources.

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