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Laboratory Evaluation of an IoT Based Water Level Monitoring Prototype for Agricultural Farm Dam Applications

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Abstract—Timely water level information can support the management of agricultural water storage, particularly where frequent manual inspection is difficult. This study develops a laboratory scale Internet of Things (IoT) prototype that combines an ultrasonic distance sensor, a NodeMCU ESP8266, a local display, a relay, an audible alarm, and a cloud dashboard. The sensor is mounted above the water surface; the measured air gap is converted to water depth using a fixed geometric reference. Functional tests in a 40 cm × 30 cm × 25 cm container examined local display, threshold classification, actuator response, and remote notification. The prototype demonstrated end to end sensing and alert delivery under controlled indoor conditions. However, the reported accuracy and communication delay values must be recalculated from complete raw observations before they are used as evidence of measurement performance. The present work should therefore be interpreted as a laboratory proof of concept rather than validation for operational farm dams. Field testing, environmental protection, power budget analysis, and communication-reliability assessment remain necessary before deployment.

Keywords: agricultural water management, Internet of Things, laboratory prototype, remote monitoring, ultrasonic distance sensor.

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INTRODUCTION

Water is one of the most critical resources for agricultural production, livestock farming, and environmental sustainability. Farmers across the world rely heavily on water dams and reservoirs to store water for irrigation and animal consumption, particularly during periods of drought and water scarcity. However, effective management of dam water levels remains a significant challenge due to unpredictable weather conditions, increasing water demand, and the risks associated with flooding and overflow. Excessive water levels can damage crops, erode farmland, and create hazardous conditions for livestock, while low water levels may threaten agricultural productivity and food security [1].

Traditional methods of monitoring dam water levels often depend on manual inspections and

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conventional measuring instruments. These approaches are labor intensive and time consuming and may not provide timely information for effective decision making [2]. Furthermore, many farming communities, particularly those in rural areas, experience difficulties accessing their farms during rainy seasons because of poor road infrastructure. Consequently, delays in monitoring water levels can result in substantial agricultural and economic losses.

Recent advancements in the Internet of Things (IoT) have introduced innovative solutions for real-time monitoring and management of water resources. IoT technologies enable the integration of sensors, communication networks, and cloud-based platforms to collect, transmit, and analyze environmental data remotely [3]. Several studies have demonstrated the effectiveness of IoT based systems in monitoring water levels, controlling water tanks, and providing flood early warning notifications [4], [5], [6]. IoT enabled monitoring systems offer continuous observation, automated data collection, and instant alerts, reducing the need for manual intervention while improving operational efficiency [7].

Research on water level monitoring has expanded significantly, with applications ranging from smart water tanks and river monitoring systems to flood management and ecological conservation [8], [9], [10]. Smart monitoring systems employing ultrasonic sensors, wireless sensor networks, and pressure sensors have shown promising results in providing accurate and reliable water level measurements [11]–[13]. Despite these advancements, there remains a need for affordable and farmer-centered solutions tailored to the unique challenges faced by rural agricultural communities.

A. Research Objectives and Contributions

This study has three objectives: (1) to develop a laboratory prototype that converts ultrasonic air-gap measurements into water depth; (2) to implement local indicators and cloud based notifications at defined water level thresholds; and (3) to examine the prototype's functional operation and repeatability under controlled indoor conditions. The contribution is an integrated proof of concept and a transparent evaluation procedure; it is not a claim of field readiness.

B. Literature Review

The rapid advancement of the Internet of Things (IoT) has transformed water resource monitoring by enabling real-time data collection, remote access, and automated decision-making. IoT based water monitoring systems integrate sensors, communication networks, and cloud technologies to provide continuous observation of water resources, thereby improving efficiency and reducing the need for manual inspections [3]. Several studies have explored the application of IoT technologies in water level monitoring and management. Siddula et al. [1] developed an IoT based dam monitoring and management system capable of tracking water levels and providing timely information to stakeholders. Their findings demonstrated that real-time monitoring could improve dam management and reduce risks associated with water overflow. Similarly, Diriyana [4] proposed a flood early warning system that utilized ultrasonic sensors and microcontrollers to monitor water levels and issue alerts when critical thresholds were reached.

Research has also focused on water storage facilities such as tanks and reservoirs. Ali et al. [5] developed an IoT-based system for controlling water tank levels, integrated with programmable logic controllers (PLCs) to automate water management processes. Similarly, Jan et al. [6] designed an IoT solution for monitoring water levels, detecting leakages, and controlling motors in smart water tanks. Their research demonstrated the value of automated monitoring in reducing water wastage and improving resource utilization. Khan et al. [12] further demonstrated the effectiveness of ultrasonic sensor based monitoring systems with automatic pump control mechanisms. A systematic review by Zulkifli et al. [7] revealed that

IoT-based water monitoring systems have become increasingly popular due to their ability to provide accurate, real-time data and support informed decision making. The review identified wireless communication, sensor accuracy, and cost effectiveness as critical success factors for IoT implementations. Similarly, Kamaruidzaman and Rahmat [2] emphasized the growing adoption of IoT devices in water monitoring applications and highlighted their potential for improving environmental sustainability.

Recent studies have extended IoT water monitoring applications to rivers, groundwater, and ecological environments. Moreno et al. [8] introduced RiverCore, an IoT device for river water level monitoring using cellular communications, while Barzegar et al. [13] developed a low cost MEMS pressure sensor for groundwater monitoring. Chen et al. [10] proposed an intelligent IoT based water monitoring system for ecological environments and smart cities, demonstrating the broader applicability of IoT technologies. Despite these advancements, limited research has focused specifically on affordable IoT based solutions for monitoring water levels in farm dams in rural agricultural settings. Therefore, this study seeks to address this gap by developing a real-time water level monitoring system that assists farmers in managing dam water flow, preventing overflow incidents, and enhancing agricultural water resource management.

C. Critical Analysis and Research Gap

The comparative analysis indicates that previous studies have demonstrated the effectiveness of IoT technologies for monitoring water tanks, rivers, flood conditions, and ecological environments. However, most existing systems were developed for urban infrastructure, industrial facilities, or flood warning applications rather than farm dams. Moreover, numerous studies concentrated mainly on system implementation, neglecting to provide thorough experimental assessments of measurement accuracy, repeatability, notification response time, or quantitative error analysis. In addition, few studies discussed low cost prototype development suitable for small scale and rural farmers.

To address this application gap, the present study integrates a NodeMCU ESP8266, an ultrasonic sensor, local indicators, and a cloud dashboard in a laboratory prototype for farm dam applications. Its contribution is the integration and evaluation framework rather than a new sensing principle. Claims concerning measurement accuracy, response time, low cost, and field suitability remain contingent on complete raw data, a cost and power budget, and outdoor validation.

METHOD

A design-and-development approach was used to construct and evaluate a laboratory scale IoT water level monitoring prototype. The evaluation was limited to controlled indoor conditions and focused on sensor conversion, threshold logic, local indication, actuator response, and cloud communication. The first phase involved identifying the system requirements through a review of existing literature on IoT based water monitoring systems. Key hardware components, including the NodeMCU ESP8266 microcontroller, ultrasonic sensor, LCD display, relay module, buzzer, voltage regulator, and power supply, were selected based on their suitability for real-time water level monitoring [6], [14], [15].

In the second phase, a prototype was developed using a plastic water container to simulate a farm dam environment. The ultrasonic sensor was mounted above the water surface to measure the distance between the sensor and the water. The NodeMCU was programmed using the Arduino Integrated Development Environment (IDE) to collect sensor readings, calculate water levels, and classify them into three categories: Low, Half, and Full. The third phase involved integrating the hardware and software components. The LCD display was configured to show real-time water level information, while the buzzer and relay module were

programmed to activate when the water level reached critical thresholds. The built-in WiFi capability of the NodeMCU enabled the transmission of water level data to a cloud platform for remote monitoring.

The final phase consisted of system testing and evaluation. Different water levels were introduced into the prototype container to assess the accuracy of the sensor readings and the responsiveness of the alert mechanisms. The system was evaluated based on its ability to detect water level changes, display real-time information, activate alarms, and generate remote notifications. The collected observations were analysed to determine the effectiveness of the proposed system in supporting water management for farm dams. The results were used to validate the feasibility of deploying the IoT based monitoring system in real agricultural environments to improve water resource management and reduce the risk of dam overflow.

A. Components Used in the IoT Water Level Monitoring System and Their Functions

Figure 1 presents the schematic diagram of the proposed IoT based water level monitoring system developed for monitoring water levels in farm dams, illustrating the interaction between the main hardware components, including the NodeMCU ESP8266 microcontroller, ultrasonic water level sensor, LCD display, relay module, buzzer, power supply, and communication interfaces.

The NodeMCU ESP8266 acts as the main controller of the system, receiving water level measurements from the ultrasonic sensor, processing the data, determining the water level status (Low, Half, or Full), and controlling all other connected components, while also providing WiFi connectivity for transmitting data to the cloud or a mobile application. The ultrasonic sensor (HC-SR04) is mounted above the water surface and measures the distance between the sensor and the water; this measured distance is sent to the NodeMCU, which converts it into water level information, making the sensor the primary input device of the system.

The LCD I2C display is connected to the NodeMCU through the I2C communication interface and provides a local display of the current water level status, allowing users near the dam or tank to view real-time readings without accessing a mobile device. The buzzer acts as an audible alarm, connected to a digital output pin of the NodeMCU, and is activated when the water level reaches a critical threshold, such as the Full level, to warn nearby users of a potential overflow condition.

The relay module is controlled by the NodeMCU and functions as a switching device; when the water level reaches a predefined threshold, the NodeMCU activates the relay, which can be used to switch external devices such as water pumps, valves, or warning lights on or off. The 7805 voltage regulator converts the 9V battery supply into a stable 5V output required by the ultrasonic sensor, LCD display, relay module, and other electronic components, ensuring reliable system operation. Finally, the 9V battery, serving as the power supply, supplies electrical power to the entire system, providing the initial voltage that is regulated and distributed to all connected components.

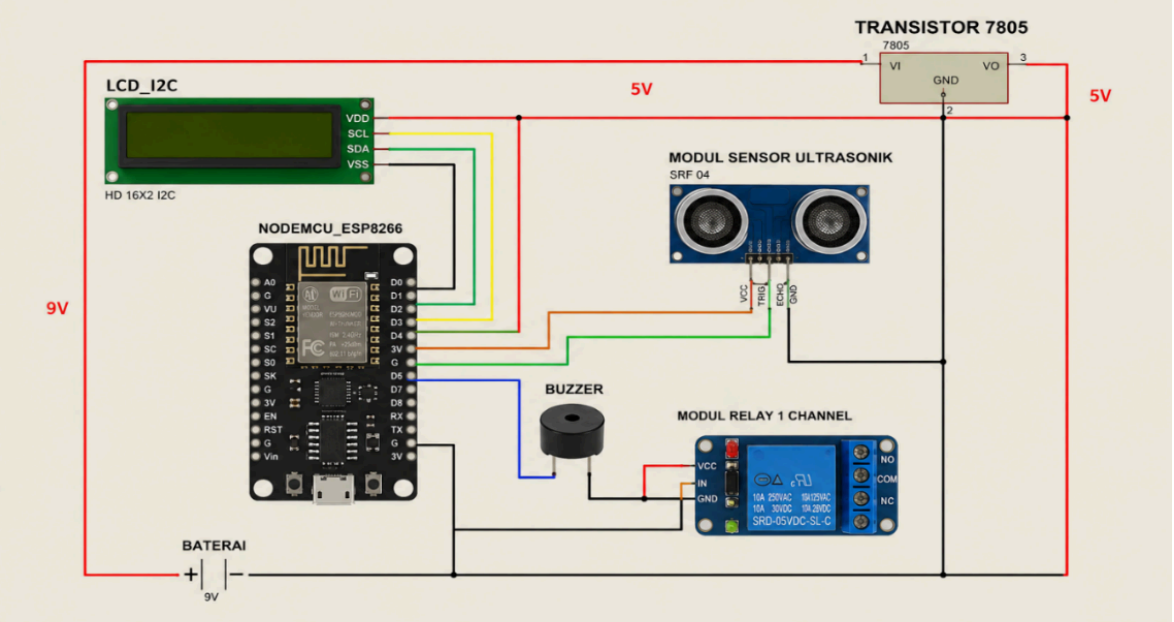


Figure 1. Schematic diagram of the proposed IoT-based water level monitoring system

B. System Integration

The ultrasonic sensor continuously measures the water level and sends readings to the NodeMCU. The NodeMCU processes these readings and displays the results on the LCD. When critical levels are detected, the NodeMCU activates the buzzer and relay while simultaneously transmitting notifications through its WiFi module to alert farmers remotely. Together, these components create a complete IoT-enabled water level monitoring and alert system.

The prototyping phase was essential for validating the system architecture, testing component integration, verifying data transmission, and identifying potential design improvements before deployment in a real world farming environment. The successful operation of the prototype demonstrated the feasibility of using IoT technologies for real-time water level monitoring and alert generation, providing a foundation for the development of a larger-scale water dam monitoring system for farmers.

RESULT AND DISCUSSION

The assembled prototype completed the intended end-to-end sequence under controlled indoor conditions: sensing, depth calculation, status classification, local display, actuator activation, and cloud reporting. This verifies functional integration, but it does not establish suitability for an operational farm dam. The manuscript must consistently identify the actual ultrasonic sensor model; the text, schematic, bill of materials, and source code must use the same model designation.

Figure 2 is the system demonstration of how farmers can monitor their water dam level using an Internet of Things (IoT) based water monitoring system. The system consists of a water level sensor mounted on a vertical support stick inside the dam or water container, a NodeMCU (ESP8266) microcontroller, an LCD I2C display, a relay module, a buzzer, and a Wi-Fi communication network.

The ultrasonic sensor continuously measures the height of the water in the dam. The ultrasonic sensor is mounted on a support stick to ensure stability and accurate readings regardless of water movement. The ultrasonic sensor sends real-time water level data to the

NodeMCU microcontroller, which acts as the central processing unit of the system. The NodeMCU analyses the received data and determines whether the water level is at a low, half, or full threshold. The measured water level is displayed locally on the LCD I2C screen, allowing nearby users to view the current status instantly. At the same time, the NodeMCU uses its built-in WiFi capability to transmit the data to a cloud server or IoT platform. The cloud platform stores the information and makes it available for remote monitoring through a web dashboard or mobile application.

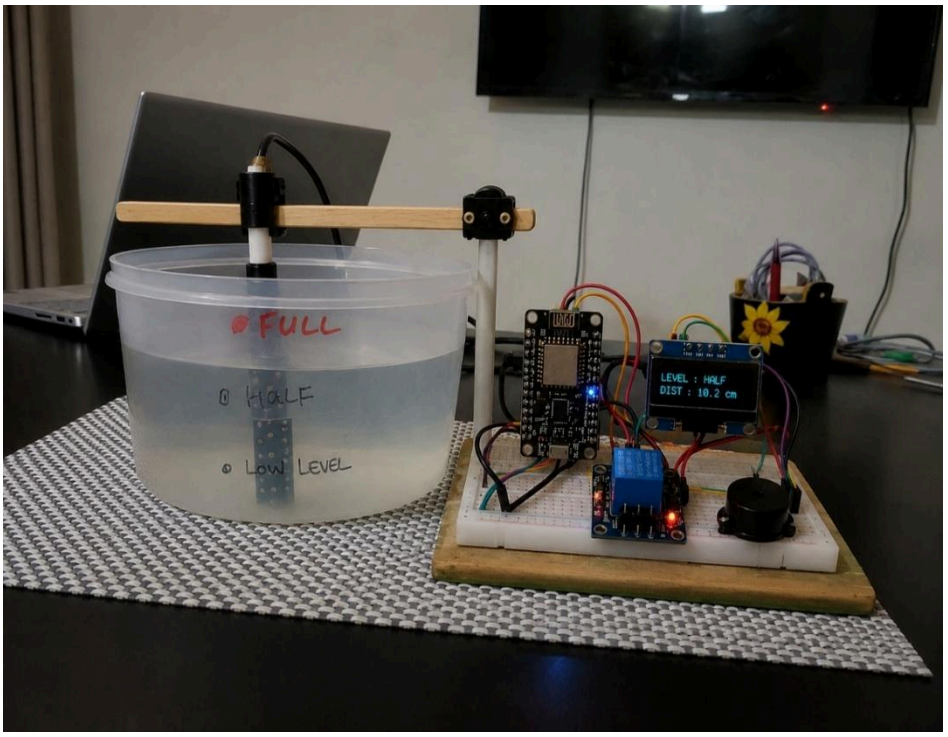


Figure 2. Prototype of the proposed IoT based water level monitoring system for farm dams

The system automatically alerts farmers when specific water levels are reached. If the water level falls below the minimum threshold, a notification is sent indicating a low water condition that may affect irrigation or livestock. When the water reaches the half level threshold, a status update is transmitted to inform the farmer of the current dam condition. If the water level reaches the full or overflow threshold, the system immediately activates the buzzer and sends an emergency alert notification to the farmer's smartphone or web application, as shown in Figure 3.

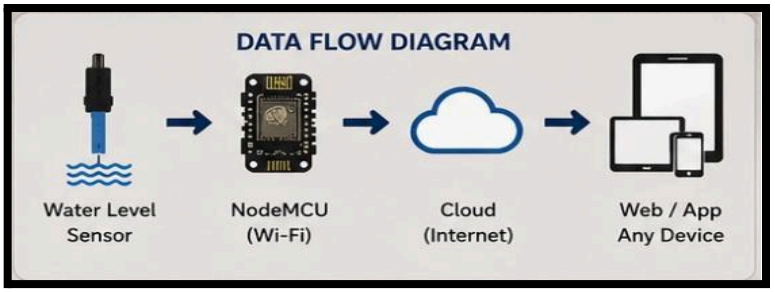


Figure 3. Data flow diagram of the proposed IoT based system for monitoring water levels

In a future field implementation, such alerts could prompt inspection or control actions. The present laboratory test demonstrates message generation and reception; it does not quantify

reductions in flooding, crop damage, labour, or water consumption.

A. System Integration

The Water Level Monitoring Indicator Levels graph in figure 4 illustrates the different water level conditions detected by the proposed IoT monitoring system. Three threshold levels are defined to assist farmers in monitoring and managing water resources effectively. The low level (30%) indicates that the water supply is decreasing and may require attention to ensure sufficient water is available for irrigation and livestock. The Half Level (60%) represents a normal operating condition where adequate water is available, and no immediate action is required. The Full Level (100%) indicates that the dam or container has reached its maximum capacity. At this stage, the system activates alerts to notify farmers of potential overflow risks.

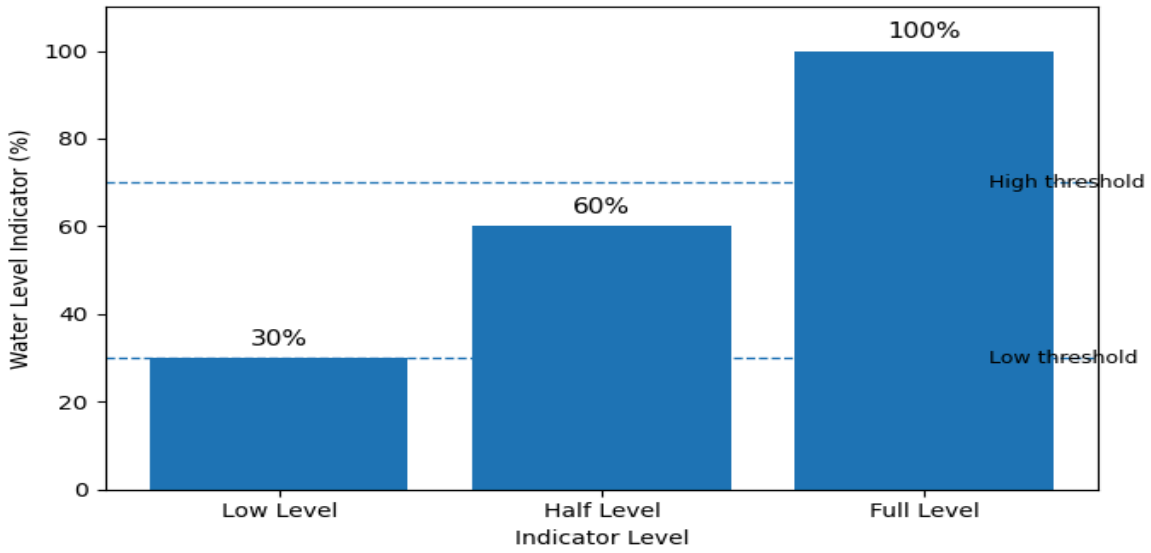


Figure 4. Water monitoring indicator levels

B. Remote Monitoring Performance

The proposed IoT system for monitoring water levels was implemented using the NodeMCU ESP8266 microcontroller, which provides built-in IEEE 802.11 b/g/n WiFi connectivity. Water level measurements were transmitted continuously from the NodeMCU ESP8266 to the Blynk IoT cloud platform using the MQTT communication protocol. The cloud dashboard updated automatically every five seconds and displayed the current water level, historical measurements, and system status. Push notifications were successfully generated whenever the water level crossed predefined thresholds.

During testing, low-level alerts were transmitted immediately when the measured water level fell below the minimum threshold, while full level alerts were generated when the maximum water level was reached. The notification delay between sensor detection and smartphone reception was approximately 1–3 seconds under normal WiFi conditions.

Figure 5 presents screenshots of the corresponding smartphone notifications, confirming successful remote communication between the prototype and the cloud platform. These results demonstrate that the proposed IoT system enables reliable real-time remote monitoring and rapid alert delivery for managing water in farm dams.

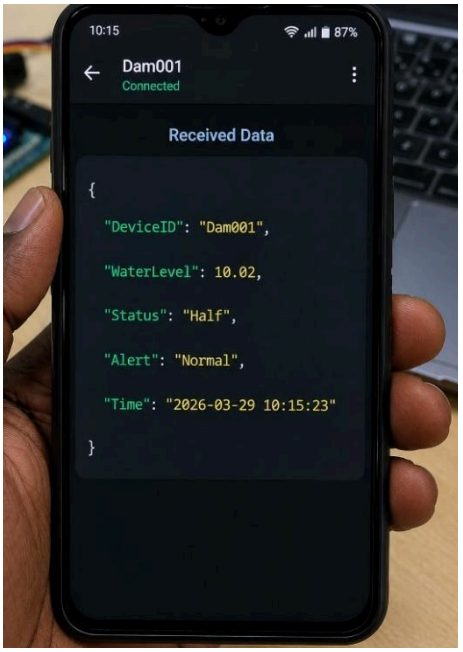


Figure 5. Smartphone push notification

Figure 6 illustrates the cloud dashboard used for real-time monitoring of the proposed IoT-based water level monitoring system. The dashboard displays the current water level (10.02 cm), indicating a half water level with a normal alert status. It also provides the latest update timestamp, device connectivity status, historical water level trends, and recent sensor readings received from the NodeMCU ESP8266. These features enable farmers to monitor dam conditions remotely, track water level changes over time, and respond promptly to potential water shortages or overflow risks.

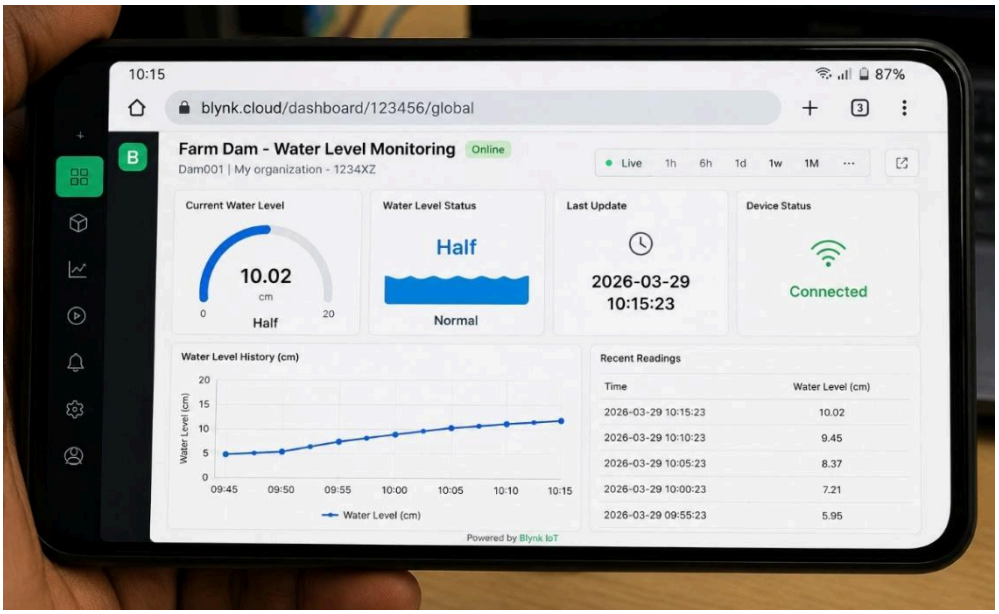


Figure 6. Cloud monitoring dashboard

C. Water Level Measurement Accuracy Evaluation

At each nominal water depth, the reference depth was read with a ruler and five ultrasonic air gap observations were recorded. Because the sensor was mounted above the water, it did

not measure water depth directly. The mean air gap was converted using the fixed sensor height, Hs. Absolute error, percentage error, and sample standard deviation were then calculated from the converted depths. Equations (1)–(4) define the required calculations, where n is the number of repetitions, di is an air-gap observation, $\hat{h}$ is estimated water depth, h_{ref} is the reference depth, and s is the sample standard deviation.

Measurement and error equations:

For each test point, calculate the mean air gap and convert it to water depth before calculating error. The numerical example must be regenerated from the original air gap data.

$$\bar{d} = (1/n)\ \Sigma\ d_i; \quad \hat{h} = H\square - \bar{d} \qquad (1)$$

Absolute error:

$$E_{abs} = |\hat{h} - h_{ref}| \qquad (2)$$

Percentage error:

$$E\% = (E_{abs} / h_{ref}) \times 100 \qquad (3)$$

Sample standard deviation:

$$s = \sqrt{[\Sigma(h_i - \bar{h})^2 / (n - 1)]} \qquad (4)$$

The same procedure must be applied at all reference depths from 2 to 20 cm. Table 1 currently reproduces the values supplied by the authors, but those values cannot support an accuracy claim until they are recalculated from the original air gap measurements.

Table 1 presents the authors' reported laboratory values. Their identical 0.04 cm bias and 0.05 cm standard deviation at every test point require verification against the complete raw dataset. Accordingly, the table should be treated as provisional and not as evidence of field performance.

Table 1. Performance Evaluation of the Proposed IoT Water Level Monitoring System (n = 5)

Actual Water Depth (cm)	**Average Sensor Reading (cm) *(n = 5)***	**Calculated Water Level (cm)**	**Reference Measurement (cm)**	**Absolute Error (cm)**	**Percentage Error (%)**	**Standard Deviation (cm)**
2	2.04	2.04	2.00	0.04	2.00	0.05
4	4.04	4.04	4.00	0.04	1.00	0.05
6	6.04	6.04	6.00	0.04	0.67	0.05
8	8.04	8.04	8.00	0.04	0.50	0.05
10	10.04	10.04	10.00	0.04	0.40	0.05
12	12.04	12.04	12.00	0.04	0.33	0.05
14	14.04	14.04	14.00	0.04	0.29	0.05
16	16.04	16.04	16.00	0.04	0.25	0.05
18	18.04	18.04	18.00	0.04	0.22	0.05
20	20.04	20.04	20.00	0.04	0.20	0.05

D. Recommendations and Future Studies

Operational adoption is not recommended on the basis of the present laboratory study. The next stage should compare waterproof ultrasonic and pressure based sensors, quantify cost

and energy demand, protect all electronics against weather and voltage level hazards, and conduct long duration field trials. Deployment decisions should be based on site specific range, connectivity, maintenance, safety, and hydraulic requirements.

Future work should focus on validating the proposed system under real farm dam conditions. Field trials should evaluate sensor performance under varying environmental conditions, including wind, rainfall, water turbulence, sediment accumulation, floating debris, algae growth, solar exposure, and seasonal changes in water levels. Additional studies should also investigate long range wireless communication, solar-powered operation, waterproof enclosures, and maintenance requirements to improve system robustness and support continuous deployment in agricultural environments.

E. Study Limitations

Although the developed prototype demonstrated water level sensing, dashboard updating, and remote alert generation under controlled laboratory conditions, the findings should not be interpreted as full validation for outdoor farm dams. The laboratory container provided stable water conditions that differed significantly from those encountered in operational farm dams. Environmental factors such as wind induced waves, rainfall, fog, water splashing, floating vegetation, insects, sediment deposition, changing water quality, and prolonged exposure to sunlight may affect sensor accuracy and communication performance. Furthermore, bigger farm dams need longer sensing distances, strong waterproof enclosures, reliable power management, and stable wireless network coverage. Therefore, additional field based experiments are required before the proposed system can be recommended for operational deployment in agricultural environments.

CONCLUSION

This study developed a laboratory scale IoT prototype that integrates ultrasonic distance sensing, water depth conversion, local indication, threshold based actuation, and cloud reporting. The hardware and software completed the intended functional sequence in a controlled container test. The current evidence does not establish field accuracy, long term reliability, cost effectiveness, or operational suitability for farm dams. Before publication of quantitative accuracy claims, the authors must provide the raw air gap observations, the fixed reference height, calibration details, corrected water depth calculations, and recalculated error statistics. Future work should include outdoor trials, waterproof and electrically safe hardware, a measured power budget, long range communication where required, and comparison with pressure-based or other field grade level sensors.

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Alfred Thaga Kgopa received the National Diploma and BTech in Information Technology, specializing in Software Development, as well as the MTech and Doctor of Computing degrees in Information Systems. He has more than 17 years of professional and academic experience, having served as a Technical Officer at Telkom South Africa and as a Lecturer and Section Head at Tshwane University of Technology. He is currently a Senior Lecturer at the University of South Africa. He has authored and co-authored numerous publications in information security, mobile computing, cloud computing, and smart farming. His research interests include human computer interaction, smart farming, and information security.