IoT-Integrated Remote Monitoring and Automated Management Architecture for Overhead Tank Pumping Systems

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ABSTRACT

Modern water infrastructure requires a transition from manual oversight to automated, data-driven management to address inefficiencies like resource wastage and equipment failure. This paper presents the development of a cost-efficient monitoring and control framework for heavy-duty motors in water pumping stations using the Internet of Things (IoT). Centered on the ESP32 microcontroller and the Blynk IoT platform, the system integrates real-time ultrasonic level tracking, turbidity-based quality assessment, and comprehensive motor protection protocols, including dry run and overload detection. Experimental results confirm that the system successfully automates pump cycles based on predefined thresholds while providing users with remote manual overrides and maintenance alerts. This integrated approach bridges the gap between simple level controllers and expensive industrial SCADA systems, offering a scalable solution for both residential and small-scale industrial water management.

INTRODUCTION

The management of water resources in residential and industrial sectors remains a significant challenge, particularly in regions where supply must be strictly optimized. Traditional water pumping relies heavily on manual operation, which is prone to human error, resulting in tank overflows, excessive energy consumption, and catastrophic motor damage due to dry running. While basic automation like float switches exists, these systems typically lack the sophisticated fault detection and remote accessibility required for modern smart infrastructure. This research proposes an IoT-based Remote Control and Monitoring System designed to provide a comprehensive suite of features: water conservation, energy efficiency, and predictive maintenance. By leveraging wireless communication, the system allows for real-time diagnostics of motor health and water quality, significantly extending the lifespan of the pumping infrastructure. A review of existing literature reveals a progressive shift toward smart monitoring. Patil et al. (2020) demonstrated the efficacy of ultrasonic sensors and Wi-Fi modules for cloud-based level tracking, though their model lacked essential motor protection. Similarly, work by Parimala et al. (2021) utilized Arduino-based systems for automated refilling but did not address water quality or advanced electrical fault detection. Current research gaps indicate a need for a unified platform that combines level monitoring with predictive maintenance through current and flow analysis. This project addresses these shortcomings by integrating multi-sensor data into a single IoT ecosystem.

Research Gap

1. Most existing solutions focus on either remote control or motor protection, lacking an integrated system that combines
2. Real-time water level monitoring.
3. Predictive maintenance using fault detection algorithm.

MATERIALS AND METHODS

The proposed system integrates cleaning alerts, dry run detection, remote operation, and water level monitoring to enhance the efficiency, reliability, and automation of water pumping systems. The system architecture is designed around the **ESP32 microcontroller**, selected for its dual-core 32-bit LX6 microprocessor, integrated Wi-Fi, and low power consumption. The ESP32 serves as the central processing unit (CPU), managing data from five primary sensors and executing control logic via a relay module.

Hardware Components:

1. **Ultrasonic Sensor (HC-SR04):** Positioned inside the overhead tank (OHT), it uses sound waves to calculate the distance to the water surface, providing non-contact level measurement.
2. **Turbidity Sensor:** This sensor measures suspended particles by analyzing light scattering, allowing the system to monitor water clarity and trigger cleaning alerts.
3. **Water Flow Sensor (YF-S201):** Utilizing a Hall-effect sensor, it generates pulse signals proportional to water movement to track consumption and identify dry run conditions.
4. **Current Sensor (ACS712):** It monitors the electrical draw of the centrifugal pump to detect overloads or phase imbalances, ensuring the motor operates within safe limits.
5. **Relay Module (5V):** Acts as an electronic switch between the low-power ESP32 and the high-power 12V centrifugal pump, providing essential electrical isolation.

Software and Logic:

The system utilizes the **Blynk IoT platform** for its user interface and cloud connectivity. The software logic is programmed to automate pump operations: when the ultrasonic sensor detects water levels below a set threshold, the ESP32 activates the relay to start the pump.

Conversely, the pump is deactivated once the "full" capacity is reached to prevent overflow. Safety protocols are embedded directly into the code. The system monitors the flow and current sensors; if the pump is active but no water flow is detected (a dry run), or if the current draw exceeds safe parameters (an overload), the microcontroller immediately terminates the power to the pump and sends an alert to the user's mobile device. Water quality is monitored via the turbidity sensor, with a specific threshold set at **50 NTU**; exceeding this value triggers a "Tank Cleaning Needed" notification via the Blynk app.

Cleaning Alerts for Overhead Tanks (OHTs)

To maintain water quality and prevent sediment buildup, the system features an automated cleaning alert mechanism. A timer-based notification system tracks pump runtime and sends alerts when cleaning is due, typically on a monthly or customizable schedule. Additionally, a turbidity sensor detects impurity levels in the water and triggers cleaning alerts when contamination is high. This ensures timely cleaning and prevents clogging, bacterial growth, and inefficiencies in the system.

Dry Run Detection and Motor Protection

Dry running occurs when the pump operates without water, leading to overheating, wear, and motor failure. The proposed system includes current and flow sensors that detect if the motor is running without sufficient water supply. If a dry run condition is detected, the system automatically shuts down the pump to prevent damage. Additionally, ultrasonic or float sensors continuously monitor water levels in both the overhead tank (OHT) and the underground sump, ensuring the pump only runs when there is adequate water available.

Remote Operation and Control

Remote operation and control of water pumps enhance efficiency by eliminating manual intervention and enabling automated monitoring. Traditional wired control systems, such as relay-based panels and PLCs, are reliable for industrial applications but are costly and limited by physical wiring constraints. IoT-based solutions provide real-time monitoring, automation, and cloud-based control through smart phones, ideal for urban and smart water management applications. Advanced safety features, including dry run detection, overload protection, and real-time alerts, prevent pump damage and operational failures. The choice of technology depends on factors like cost, range, and network availability, ensuring optimal water usage, energy efficiency, and reduced maintenance efforts.

Automatic Water Level Monitoring and Pump Control

Efficient water usage requires automated water level monitoring to prevent overflow, water wastage, and pump dry runs. The system integrates ultrasonic sensors to measure the water level in the OHT. When the water level drops below a predefined threshold, the pump automatically starts to refill the tank. Once the tank reaches its full capacity, the system stops the pump, preventing overflow.

BLOCK DIAGRAM

The system consists of several key components, including an ultrasonic sensor to measure the water level in the overhead tank, a turbidity sensor to assess water quality, a current sensor to monitor power consumption and detect faults such as overload and dry run, and a flow sensor to measure the water flow rate. These sensors are interfaced with a microcontroller, which processes real-time data and determines whether the centrifugal pump should be activated or deactivated. The pump operation is controlled via a relay module, which acts as a switch to turn the pump ON or OFF based on the microcontroller's decision. A Wi-Fi module enables wireless communication, allowing the system to transmit data to a remote server, where users can monitor and control the pump through a mobile or web interface.

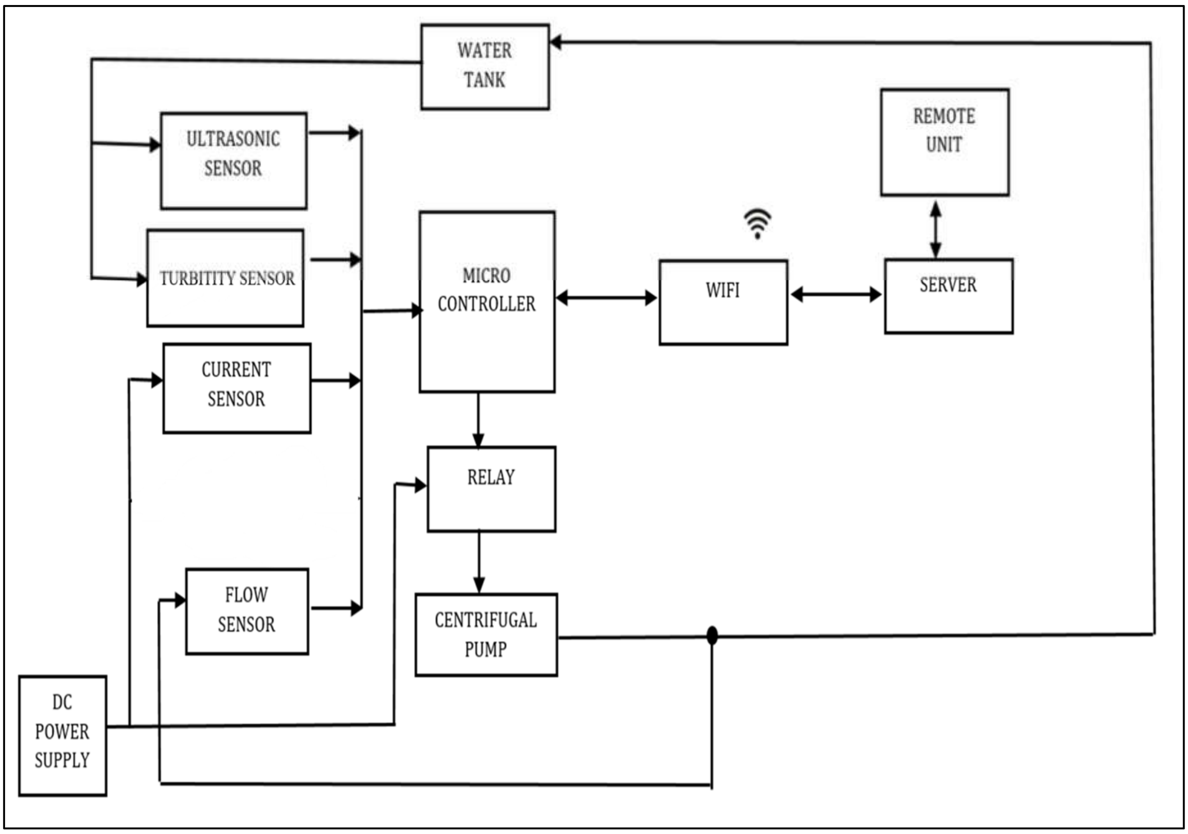

Figure 1: Block Diagram

CIRCUIT DIAGRAM

The ESP32 microcontroller is interfaced with various sensors and components. The ultrasonic sensor is placed inside the overhead tank to measure water levels and sends signals to the ESP32, which processes this data to control the pump. The turbidity sensor continuously monitors water quality, while the flow sensor ensures efficient water movement by detecting flow rates. A relay module is connected to the pump, acting as an electronic switch controlled by the microcontroller. The entire system is powered by a DC power supply, ensuring continuous and stable operation. The Wi-Fi connectivity allows real-time monitoring and remote operation, reducing manual intervention and enhancing the reliability of the water management process.

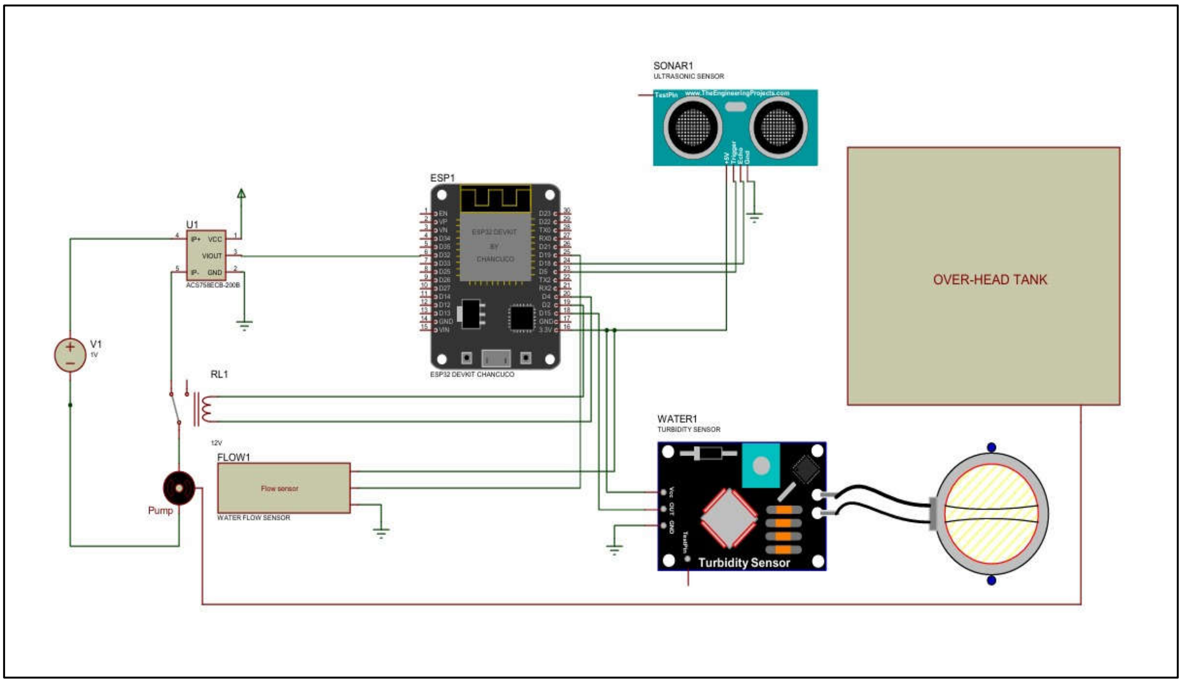

Figure 2: Circuit Diagram

Water Conservation

One of the most critical advantages of implementing a remote-controlled system is the ability to monitor and manage water usage efficiently. Traditional pumping systems often lead to water wastage due to overflow or undetected leaks. With remote monitoring, water levels in the overhead tank can be tracked in real time. When the tank reaches a specified threshold, the system can automatically turn off the pump, preventing overflows and saving water. Additionally, if there is any abnormal drop in water levels (indicating leakage), the system can send alerts to users, enabling quick action.

Energy Efficiency

Remote water pumping systems ensure that pumps operate only when necessary. This prevents dry runs (where the pump runs without water, risking damage), reduces overall run time, and ensures optimal energy use. By preventing overuse and optimizing run cycles, they contribute significantly to energy savings over time.

Operational Convenience

A remote system allows for automated pump control and real-time access through smart phones or computers. This is particularly beneficial for properties with multiple tanks or pumps located in hard-to-access areas. Automation ensures the tank is refilled consistently, without the need for constant human intervention.

Cost Savings

By optimizing pump usage, reducing water wastage, and preventing equipment damage, a remote control system can significantly lower operational and maintenance costs. Over time, the savings in electricity, reduced manual labor, and fewer repairs often justify the initial investment in the system.

RESULTS AND DISCUSSION

The implementation of the system yielded highly accurate real-time data and responsive automated control. During testing, the **ultrasonic sensor** provided precise distance measurements, which were converted into water level percentages and displayed on the Blynk dashboard. The automated logic proved reliable, effectively managing the pump cycles without manual intervention, while the **Virtual Pin V1** on the Blynk app allowed for seamless manual overrides when necessary. The safety mechanisms functioned as intended. The **current sensor** accurately detected abnormal load conditions, and the **flow sensor** provided the necessary feedback to halt the pump during simulated dry run scenarios. A key highlight of the discussion is the turbidity monitoring; by providing alerts when water impurity reached 50 NTU, the system ensures that maintenance is performed based on actual need rather than arbitrary schedules. Compared to existing solutions like **PLCs or SCADA systems**, which are often prohibitively expensive and complex for residential use, this ESP32-based model offers a high degree of reliability at a fraction of the cost. It overcomes the limitations of simple float switches by providing a holistic view of the system’s health and the quality of the resource being managed.

Figure 3: Hardware Setup

OUTPUT

The implemented Remote Control and Monitoring System for Overhead Tank Water Pump using the ESP32 microcontroller and Blynk IoT platform has successfully achieved its intended objectives. The system continuously monitored the water level using an ultrasonic sensor, and accurately calculated and displayed the percentage of water in the tank on the Blynk mobile application. The relay module allowed seamless remote switching of the pump based on user input through the app or automatically based on predefined thresholds. The turbidity sensor effectively assessed water quality, and cleaning alerts were generated when turbidity levels exceeded acceptable limits. The water flow sensor provided real-time feedback on water movement, helping to detect dry run conditions, while the current sensor monitored the motor's load to prevent overload and operational failures. All sensor data was periodically updated and sent to the mobile application, ensuring real-time feedback and control. The system demonstrated high reliability, responsiveness, and accuracy, confirming its suitability for real-world smart water management applications.

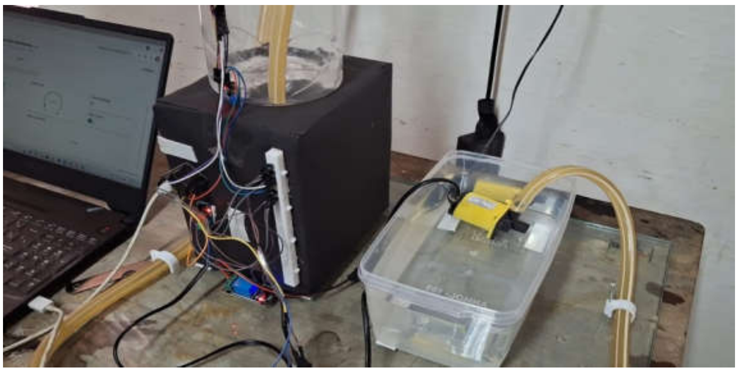

Figure 4: Hardware Output

CONCLUSION

The IoT-based remote monitoring system developed in this study provides a robust, scalable solution for modern water management. By integrating automated control with multi-sensor safety protocols, the system successfully minimizes water and energy waste while protecting expensive pumping hardware. Future iterations could incorporate **Artificial Intelligence (AI)** for predictive maintenance or integrate with renewable energy sources to further enhance sustainability. Ultimately, this architecture represents a significant step toward smarter, more resilient water infrastructure for both urban and rural environments. The future of remote control and monitoring systems for overhead tank water pumping is increasingly relevant for smart infrastructure, water conservation, and automation. As urbanization expands and demand for sustainable water management grows, such systems are set to become standard in residential and industrial settings. IoT technology enables real-time monitoring of water levels, pump status, and system health, ensuring efficient operation. AI and machine learning will enhance predictive maintenance, optimize pump operations, and reduce human intervention. Cloud connectivity will enable centralized control through mobile apps and web dashboards, providing historical data analytics to optimize water usage. Energy efficiency improvements will reduce costs and environmental impact, integrating pumps with low-tariff electricity periods or renewable energy sources. Future systems will link with smart home ecosystems, allowing pump control via voice commands through digital assistants like Alexa or Google Assistant. Alerts via SMS, email, or app notifications will become more advanced, helping users address emergencies like leaks, dry running pumps, or overflow instantly. Scalability will support multi-tank and multi-pump installations in commercial complexes, schools, and apartment buildings.

Automation, connectivity, and intelligence in water pump monitoring systems will revolutionize water management, improving efficiency while addressing global challenges related to water scarcity, energy usage, and infrastructure sustainability. These advancements will pave the way for smarter, more resilient water management systems tailored to modern infrastructure demands, ultimately contributing to the sustainability of urban and rural communities worldwide.

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