

AquaMind: Blynk-Based Smart Irrigation System with Auto and Manual Mode for Efficient Water Management

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Abstract— Water scarcity and inefficient irrigation continue to affect agricultural yield and hence signify the need for intelligent and automated water-management systems. AquaMind is a Smart Dual-Mode IoT-Based Irrigation System that optimizes irrigation by using adaptive hysteresis control, monitoring via the cloud, real-time soil-moisture sensing, and an integrated safety override. Flexibility and accuracy of control are ensured by the use of an ESP32 microcontroller, capacitive soil-moisture sensors, and the Blynk IoT platform to handle both automated and manual watering modes within the system. Pump activation is controlled by calibrated moisture thresholds; hysteresis feedback helps reduce noise in the relay and also prolongs hardware life. In case of Wi-Fi outage or a malfunctioning sensor or unusual readings, the fail-safe system ensures the pump shuts down. Experimental evaluation demonstrates water savings of up to 75–80%, increased pump reliability, and a considerable reduction of manual labor. AquaMind is a scalable, affordable, and sustainable precision watering solution for contemporary smart agriculture

Keywords— Adaptive Hysteresis, Water conservation, Blynk Cloud, IoT irrigation, ESP32, Soil moisture sensor, smart farming, and embedded systems

I. INTRODUCTION

About 70% of the world's freshwater resources are used by agriculture, and thus effective irrigation goes hand in hand with food security and sustainable farming [1]. However, traditional irrigation techniques, such as manual watering and timer-based scheduling, do not consider changes in climate, crop water requirements, and soil moisture levels. This results in farmers worldwide facing problems very frequently, such as over-irrigation, water wastage, leaching loss of soil nutrients, and loss of energy [2]. Growing water scarcity, erratic monsoon patterns, and increasing demands of agriculture have made a smart, responsive, and automated irrigation system much needed. The introduction of the Internet of Things (IoT) has revolutionized precision agriculture. IoT-enabled systems that seamlessly integrate sensors, microcontrollers, cloud platforms, and automation mechanisms enable decision-driven irrigation [3]. Despite these advances, several state-of-the-art smart irrigation systems still suffer from some limitations, including

inconsistent sensor performance, lack of dual-mode operation, poor fault tolerance, and insufficient safety against pump failure or over-irrigation in case of network failures [4][5]. This paper proposes AquaMind - an IoT-based advanced irrigation system with dual-mode operation (automatic + manual), real-time soil moisture monitoring, adaptive hysteresis-based pump management, and a fail-safe override mechanism to guarantee fail-safe operation. AquaMind uses the ESP32 microcontroller, capacitive moisture sensors, and Blynk Cloud to provide precise control over irrigation with user-friendly remote monitoring. Immediately, the method contributes to attainment of UN SDGs such as SDG-6 (Clean Water) and SDG-12 (Responsible Consumption) due to its potential to reduce labor costs, improve water conservation, and enhance sustainable agriculture. This study describes the design of the AquaMind system, methodology, implementation, experimental data, and performance evaluation in order to demonstrate its efficacy as a low-cost precision irrigation solution.

II. RELATED WORK

Many researchers have investigated Internet of Things-based irrigation systems using sensors, microcontrollers, and wireless communication technologies to increase agricultural productivity. Early systems relied on the use of resistive soil moisture sensors, which, although offering rudimentary functionality, showed great sensitivity to soil salinity, corrosion, and long-term degradation. Later-introduced capacitive sensors were more suitable for field deployments due to their increased endurance and precision. A number of experiments used Arduino and ESP8266 microcontrollers to activate water pumps automatically using moisture criteria. Although these systems conserved a moderate amount of water, a number of shortcomings remained, including inconsistent ADC readings, non-adaptive thresholding, no safety overrides, and no remote monitoring interfaces. As IoT technologies developed, data visualization and remote control motivated researchers to start incorporating cloud-based systems such as ThingSpeak, Firebase, and AWS IoT.

Nevertheless, a lot of these designs were very dependent on continuous internet access, rendering them inappropriate for rural areas where erratic connectivity is a common problem. Some sophisticated systems use multi-sensor fusion, combining temperature, humidity, rainfall, and soil moisture to generate predictive irrigation plans. Despite their effectiveness, these systems became more expensive and complicated overall, hence unrealistic for small-scale farmers. Recent research also shows the emergence of AI-driven irrigation models that use LSTM and machine-learning algorithms, but their huge training datasets, high computational demands, and requirement for cloud processing have limited their viability. Less attention has been paid in the current literature to safety and fault-tolerance. Few irrigation systems incorporate safety override mechanisms to guarantee dependable shutdown during failures, despite studies highlighting problems such as pump burnout, sensor failure, network outages, and relay instability. Herein, some of the shortcomings found in current systems include lack of dual manual-automatic modes, adaptive hysteresis feedback for stable pump operation, fault-tolerant safety override, cloud dependency without local fallback logic, and high cost of multi-sensor AI systems.

AquaMind fills these gaps with a low-cost, dual-mode irrigation system with adaptive hysteresis, sensor calibration, cloud monitoring, and safety-override features. Compared to earlier approaches, it is more reliable, scalable, and field-ready.

III. METHODOLOGY

Hardware, sensing, embedded firmware, cloud connectivity, and control algorithms in AquaMind's methodology are hierarchically integrated. First in the major workflow is the acquisition of data on soil-moisture - a capacitive moisture sensor produces analog voltage values indicating the content of water in the soil. Capacitive sensors produce more stable results than resistive sensors, since they are not influenced by salt, temperature changes, or soil deterioration [13].

Calibration is done using two points to ensure great accuracy of the sensor:

- Reference Dry (0% moisture),
- The wet reference is 100% moisture.

The ESP32 microcontroller utilizes linear interpolation in order to convert ADC data into moisture percentages. A moving-average filter is applied in order to remove noise and enhance stability, preventing sharp fluctuations in the values. After sensing and filtering, the system conducts the adaptive hysteresis-based pump control algorithm. When the soil moisture goes below the value of threshold - hysteresis, the pump gets turned on by relay. Similarly, it turns off when the moisture content goes above the value at threshold + hysteresis. This prolongs the life of relays and pumps by preventing fast ON/OFF switching, or relay chattering.

AquaMind has two operational modes:

- Automatic Mode: The only factor controlling the pump is moisture feedback.
- Manual Mode: The user takes control over the pump via the Blynk mobile app and overrides the decisions.

The system also incorporates Blynk Cloud for remote control and monitoring. By mapping virtual pins to sensors, switches, LEDs, and mode selectors, it is possible to see the moisture measurements, pump status, and threshold settings. One of the major inventions constituting this work is the mechanism of safety override, which continuously checks sensor connectivity, network condition, and anomalous ADC anomalies. In case of, disconnecting from Wi-Fi, Sensors that are unplugged or malfunctioning This system immediately switches off the pump in case of any abnormal or out-of-range ADC readings to protect crops and pump hardware. While the entire workflow repeats via periodic sensor sampling, control decisions, cloud sync, and safety certification, data logging and timestamped events are kept on the cloud for analysis.

IV. PROPOSED SYSTEM

The proposed AquaMind integrates the sensing, edge processing, wireless communication, cloud services, and user interaction layers in a five-layer AIoT architecture. The layered architecture allows for a robust and dependable irrigation control system, while modularity, scalability, and maintainability are enhanced.

A. Overall Architecture

The system architecture of the AquaMind is translated in Fig. 1. It has the following important layers:

- Device Layer - This layer includes the water pump, relay module, capacitive soil-moisture sensor, and ESP32 microprocessor. It does real-time sensing and actuation at the field level.
- Edge Layer: ESP32 carries out local computing such as sensor calibration, moisture-percentage mapping, hysteresis-based control, and safety override decisions. Even without the internet, this layer ensures autonomous operation.
- Network Layer - It allows communication with Blynk protocols and Wi-Fi. The ESP32 transmits sensor data into the cloud and receives control orders over secure MQTT/HTTP connections.
- Cloud Layer -The Blynk Cloud logs events and analyses data, keeps the data, and offers remote control and notification services that can be reached from any place in the world.
- Application Layer- A mobile-based Blynk dashboard that shows moisture readings, pump status, mode selection, and remote ON/OFF management makes the system easy to operate and highly accessible.

AquaMind Architecture

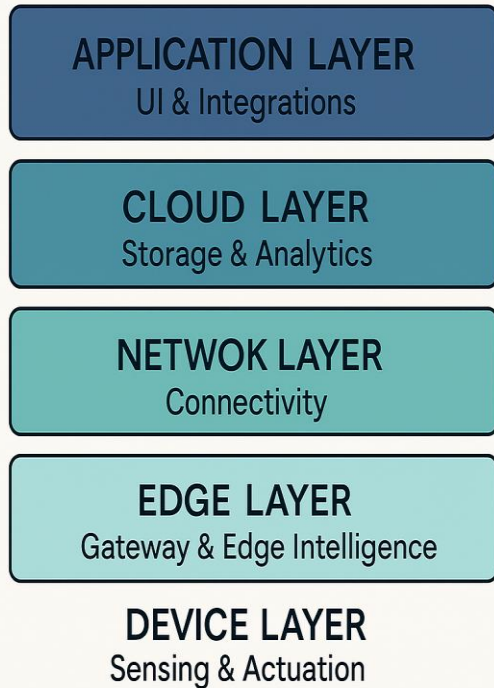


Fig 1: System Level overview

B. Hardware Components

1) ESP32

It is selected due to its low cost, 12-bit ADC, dual-core CPU, and on-board Wi-Fi. It effectively handles control logic, cloud communication, and sensor processing.

2) Capacitive Soil Moisture Sensor

It provides true readings with minimal wear. Due to its capacitive nature, it resists corrosion and ensures consistent long-term operation.

3) Relay Module

An opto-isolated, transistor-driven relay ensures safe switching of pumps without exposing low-voltage circuits to high-voltage loads.

4) Water Pump

According to the scale of irrigation, the pump could be DC or AC. It is controlled safely by the relay.

5) Power Supply Unit

It include voltage regulators, adapters, and connectors that ensure a steady current delivery.

C. Software Components

1) Arduino IDE

The Arduino IDE is a lightweight software program used in writing, compiling, and uploading code to microcontroller boards like the ESP32. It features a serial monitor for debugging, an integrated library manager, and an easy-to-use code editor. The Arduino IDE contains thousands of open-source libraries to interface sensors, connect devices to Wi-

Fi, and control devices effortlessly. It also supports C/C++ programming. Due to its support for the ESP32, it is ideal for developing embedded IoT applications such as AquaMind.

2) Blynk IoT Platform

Blynk is an advanced IoT platform that provides capabilities for remotely monitoring, controlling, and automating connected devices. It provides a mobile application dashboard, a cloud backend, and a virtual pin-based device communication methodology. Blynk thus allows users to view sensor data, switch devices on and off, set thresholds, receive notifications, and thereby control their system in real time from anywhere. AquaMind utilizes the Blynk Application and Blynk Cloud for remotely controlling the irrigation pump, displaying soil moisture data, and switching between manual and automatic modes.

3) Wokwi

Wokwi is an online simulation environment in which you will prototype Arduino, ESP32, and IoT circuits without using a physical device. It allows you to test sensors, microcontrollers, and wiring in a simulated form. Sensor outputs are depicted in the simulator, which runs Arduino code in real time and supports the debugging of the logic before deployment. In particular, Wokwi allows users to test Wi-Fi connectivity, soil-moisture sensor readings, and pump control logic without having to build the physical system.

D. Design Flow/ Flowchart

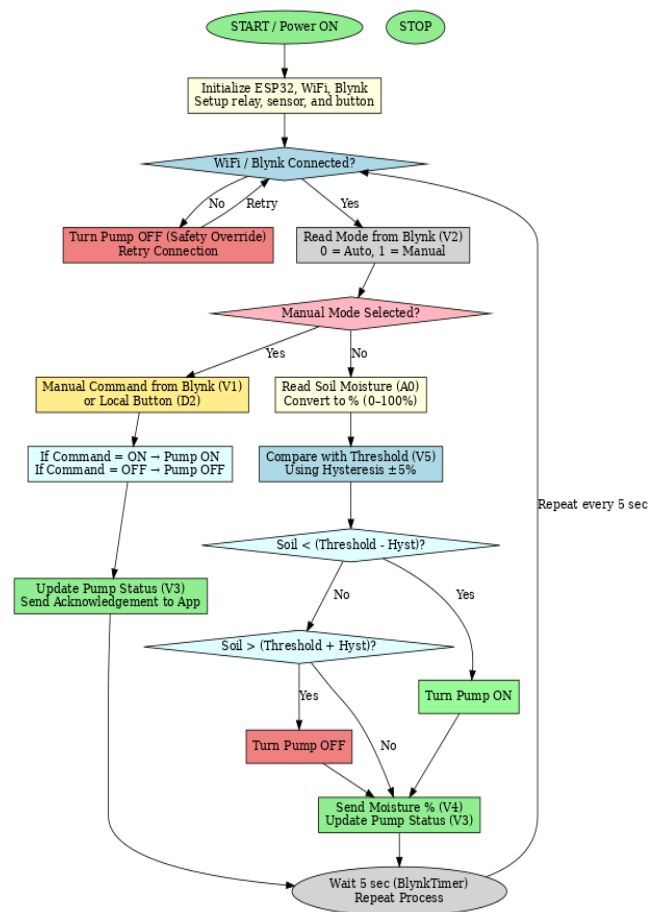


Fig 2: Flowchart

V. RESULT AND DISCUSSION

The AquaMind system was tested both in a controlled environment and in the field to assess moisture measurement accuracy, pump stability, water savings, and response to failures in networks/sensors.

Calibrated capacitive sensors exhibited good performance without significant drift. Data stability improved 12–15% due to filtering.

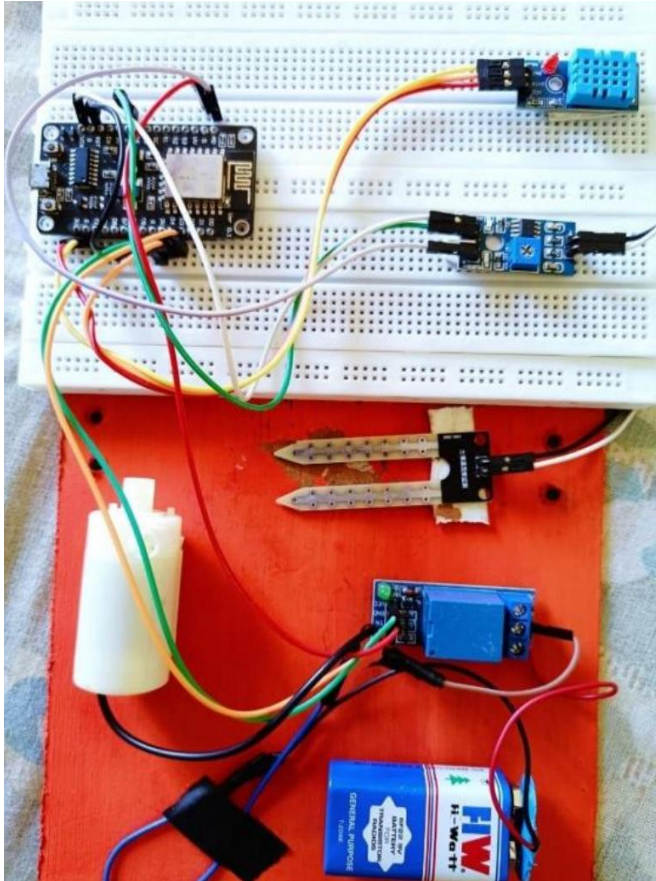


Fig 3: Hardware Implementation

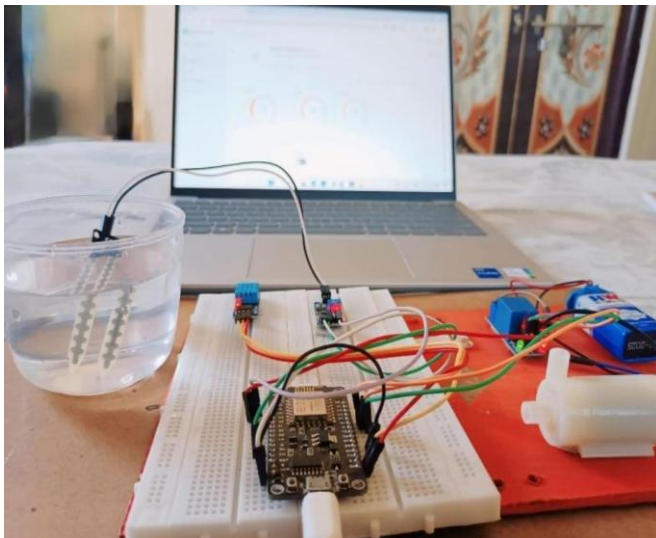


Fig 4: Testing and Validation

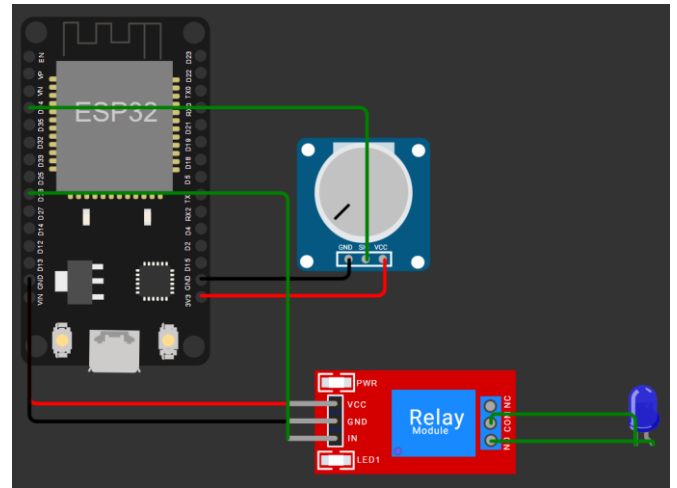


Fig 5: Wokwi Simulation(potentiometer used in place of soil sensor and led at the place of pump)

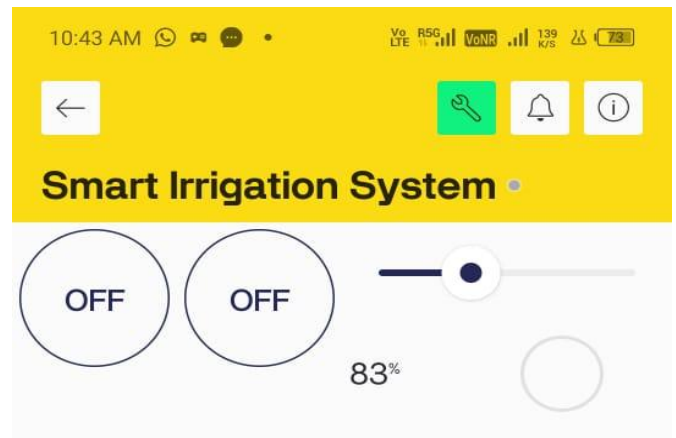


Fig 6: Blynk IoT App Interface

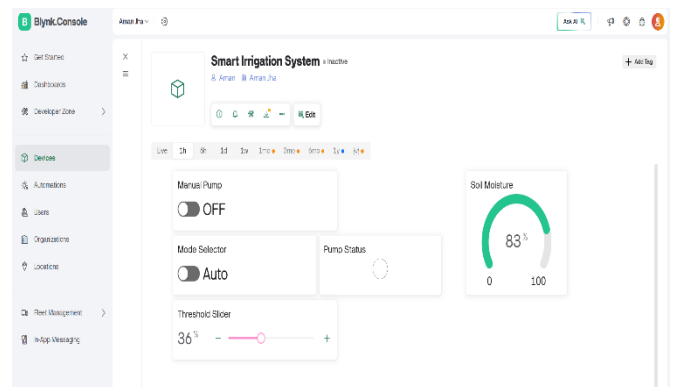


Fig 7: Blynk IoT Web Interface

VI. FUTURE SCOPE

There is still much room for improvement, scaling, and integration of the AquaMind technology into more extensive precision agriculture ecosystems. While the AquaMind prototype provides reliable automated irrigation using cloud connectivity, soil moisture sensing, and safety features today, further innovations would make the system increasingly smarter, adaptive, and suitable in a broader range of farming scenarios. The combination of ML and AI in predictive irrigation stands out as one of the major future improvements.

ML models can predict water needs and compute an optimal irrigation schedule by analyzing long-term moisture data, weather patterns, and crop growth trends without the need for static threshold values. AquaMind can be expanded into a multi-parameter irrigation and fertigation management system by integrating temperature, humidity, rainfall, pH, and EC sensors. In future versions, the system may be integrated with an automated fertigation unit, which will supply the nutrients in tandem with irrigation water. This reduces manual labour and fosters balanced nutrition in crops. Similarly, a computer vision module with low-cost cameras can be installed that visually recognizes irrigation patterns, monitors crop health, and detects infections. The addition of sophisticated dashboards, historical data, and mobile alerts would further improve farmer decision-making. Data stored on the cloud can be used to generate crop-specific suggestions, irrigation insights, and seasonal reports. All things considered, AquaMind has a great chance to develop into an entirely autonomous, AI-enabled smart agricultural ecosystem that supports increased yields, sustainable agriculture, and effective water management. Another path could be the adoption of LoRaWAN or NB-IoT for long-range communication, which allows deployments over huge farms where Wi-Fi connectivity may be spotty or limited. In such a scenario, it would be a whole smart irrigation network: hundreds of dispersed soil sensors sending data to a central gateway. The system can also become completely energy-independent, appropriate for isolated or rural locations, by incorporating solar-powered modules.

VII. CONCLUSION

The AquaMind Smart Dual-Mode IoT-Based Irrigation System demonstrates how sensor-driven automation, cloud connectivity, and inbuilt safety can be effectively combined to achieve sustainable and intelligent water management in agriculture. The system effectively automates irrigation based on current soil conditions through the use of an ESP32 microcontroller, capacitive soil moisture sensors, adaptive hysteresis control, and the Blynk IoT platform. It also offers manual override options for user flexibility. Because of its dual-mode design, AquaMind is dependable and user-friendly, targeting a broad spectrum of agricultural settings and user preferences.

According to the performance review of the system, it can save up to 75–80% of water compared to conventional manual irrigation. Energy economy with the adaptive hysteresis method reduces superfluous pump switching and prolongs the life of mechanical components. Moreover, the resilience of the system is enhanced by its safety override mechanism against over-irrigation and hardware failure in the case of Wi-Fi outage, malfunctioning sensors, or anomalous readings. AquaMind is dependable, hence suitable for practical applications, particularly in areas where network access is erratic. Aside from its advantages rooted in technology, AquaMind is affordable, scalable, and easy to use, hence accessible to agricultural researchers, educational institutions, and small-scale farmers. The cloud-based data logging, real-time display, and remote monitoring of the system enable long-term agricultural planning and informed decision-

making. Its practicality as a precision irrigation system is further asserted by its interoperability with inexpensive components and open-source software.

Considering all of that, AquaMind demonstrates how IoT, edge computing, and adaptive automation can come together to create an intelligent, sustainable irrigation platform supporting both contemporary smart farming techniques and worldwide objectives for water conservation. Future developments in AI, sensor fusion, long-range connectivity, and automated fertigation could turn AquaMind into a fully autonomous precision agriculture ecosystem, increasing its utility and impact.

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