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Smart Irrigation System

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Abstract: The Smart Irrigation System is an advanced solution designed to optimize water usage by monitoring real-time soil moisture levels. It integrates sensors and a micro-controller to control water flow, ensuring that plants receive the ideal amount of hydration while conserving water resources. When soil moisture drops below a predetermined threshold, the system automatically activates a water pump or valve, delivering water to the plants until the moisture level is restored. This automation not only reduces water wastage but also promotes healthier plant growth. Key features of this system include Water Level Flow Measurement, where moisture sensors calculate the moisture content, guiding precise irrigation tailored to the crops' needs. Soil Analysis is another critical feature, allowing the system to evaluate different soil types and their moisture retention capabilities, providing valuable insights into their suitability for agriculture and their benefits. Additionally, the system incorporates Moisture Prediction According to the Weather, recognizing that soil moisture levels fluctuate with changing weather and seasonal patterns. By predicting these changes, the system can adjust its irrigation strategy accordingly. Data Storage in the Cloud is another significant feature, enabling the system to store sensor data online, where it can be accessed for various analyses and predictions. This data storage facilitates long-term tracking of soil conditions, contributing to more informed decision-making in agriculture. Finally, the development of a Mobile Application enhances the system's accessibility, allowing users to monitor and control irrigation remotely. The application can include an analytical dashboard with intuitive visualizations, making it easy for users, regardless of their technical expertise, to understand and manage the irrigation process effectively. Overall, the Smart Irrigation System represents a significant advancement in sustainable agriculture, combining technology and data to improve water management and crop health.

Index Terms: Water Management, Data Analysis, Crop Recommendation.

1 1. Introduction

• The Smart Irrigation with Soil Moisture Control represents a transformative approach to modern agriculture, leverag- ing advanced technology to optimize water usage and pro- mote sustainable farming practices. At its core, this system is designed to monitor real-time soil moisture levels and auto- matically adjust irrigation processes, ensuring plants receive optimal hydration while minimizing water wastage. By inte- grating sensors and a microcontroller, the system precisely controls water flow, activating pumps or valves only when soil moisture drops below a predefined threshold. This level of automation not only conserves water but also supports healthier plant growth and improved agricultural productiv- ity.

• One of the standout features of the Smart Irrigation with Soil Moisture Control is its ability to measure water flow and soil moisture content using advanced sensors. This functionality enables tailored irrigation strategies based on specific crop and soil requirements. Additionally, the system incorporates soil analysis capabilities, which evaluate the moisture reten- tion properties of different soil types. These insights provide valuable guidance for selecting suitable soils for cultivation and optimizing resource allocation.

• The system's predictive capabilities add another layer of ef- ficiency. By considering weather and seasonal variations, it anticipates fluctuations in soil moisture levels and adjusts ir- rigation schedules proactively. This weather-responsive fea- ture ensures optimal water use and prevents over-irrigation during rainy periods or under-irrigation during dry spells.

• To enhance usability, It integrates cloud-based data storage, allowing users to track historical soil and irrigation data over time. This feature supports in-depth analysis and decision-making, making the system particularly beneficial for large- scale agricultural operations. A dedicated mobile or web ap- plication complements the system, providing remote mon- itoring and control. The application includes an intuitive analytical dashboard, enabling users to visualize soil con- ditions, water usage, and irrigation schedules, regardless of their technical expertise.

• Overall, the system combines real-time monitoring, predic- tive analytics, and user-friendly interfaces to revolutionize water management in agriculture. By integrating sustain- ability and efficiency, it serves as a vital tool for address- ing global water challenges and supporting the growing de- mands of modern agriculture.

2 Background

Efficient water management is a critical challenge in modern agri- culture, particularly in the context of increasing water scarcity, unpredictable weather patterns, and the growing demand for food production. Traditional irrigation systems often rely on manual operation or fixed schedules, leading to over-irrigation or under- irrigation. These practices not only waste valuable water re- sources but also negatively impact crop health and yield. Further- more, farmers and agricultural stakeholders often lack access to real-time data on soil conditions and moisture levels, hindering their ability to make informed decisions. The inability to account for changing weather conditions and varying soil types further exacerbates inefficient irrigation practices, resulting in resource wastage, increased costs, and suboptimal crop performance. There is a pressing need for an intelligent, automated irrigation system that can:

1.Monitor real-time soil moisture levels.

2.Adapt to weather and seasonal variations.

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3.Provide actionable insights on soil types and moisture reten- tion capabilities.
4.Enable remote control and monitoring for enhanced accessi- bility and convenience.
This solution must be scalable, sustainable, and user-friendly, addressing the challenges of water conservation and precision agriculture while supporting farmers in improving productivity and promoting environmental sustainability.

2.1 Literature Review

Several research studies have demonstrated the effectiveness of smart irrigation technologies. Ramesh and Dhivya **ramesh2020** proposed an IoT-based smart irrigation system utilizing moisture sensors, a Raspberry Pi microcontroller, and a cloud-connected mobile app interface. Their system achieved a 40% reduction in water usage and proved accessible even for non-technical farm- ers.
In another study, Balaji and Kumar **balaji2021** integrated weather forecasting APIs to dynamically adjust irrigation sched- ules. This approach led to a 25% decrease in irrigation frequency during monsoon seasons, significantly benefiting crops sensitive to overwatering.
Zhao and Huang **zhao2019** investigated the deployment of wireless soil moisture sensor networks across agricultural fields. Their system improved water efficiency by 30%, particularly in arid regions, and demonstrated the scalability of low-cost sensor networks for large-scale farming.
These studies collectively highlight the potential of combining real-time monitoring, environmental data, and automation to en- hance irrigation efficiency and promote sustainable agricultural practices.

3 Methods

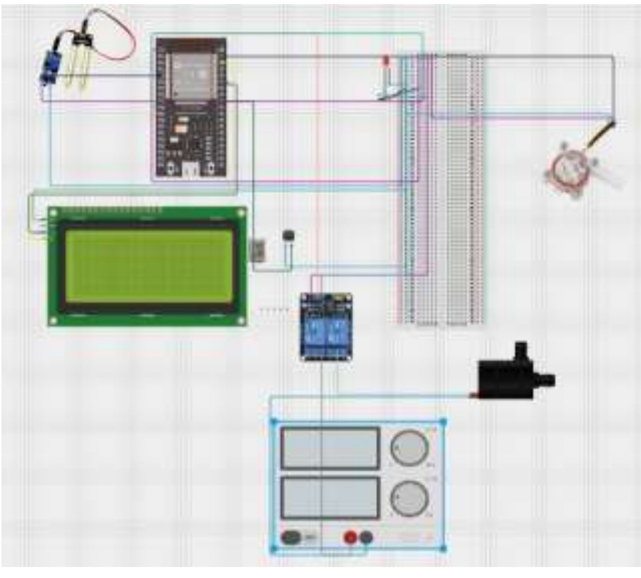

Figure 1. Circuit Diagram of the esp32 connected with the breadboard to the required devices like soil and flow sensor, lcd display, bldc pump, led and buzzer with the jumper wires.

3.1 Component List

1. Soil Moisture Sensor Description: Measures the moisture level in the soil. Pins: VCC, GND, A0
2. ESP32 Microcontroller (2 units) Description: A powerful mi- crocontroller with Wi-Fi and Bluetooth capabilities, used for pro- cessing and control. Pins: V5, CMD, SD3, SD2, G13, GND, G12, G14, G27, G26, G25, G33, G32, G35, G34, SN, SP, EN, 3V3, G23, G22, TXD, RXD, G21, G19, G18, G5, G17, G16, G4, G0, G2, G15, SD1, SD0, CLK
3. LCD 20X4 Display Description: Displays information such as soil moisture levels. Pins: GND, VCC, SDA, SCL
4. Buzzer Description: Provides audible alerts. Pins: VCC, GND
5. Relay Description: Controls the power to the water pump. Pins: NC, COM, NO, VCC, IN2, IN1, GND
6. Water Flow Sensor Description: Measures the flow rate of water. Pins: SIG, VCC, GND
7. Water Pump Description: Pumps water based on the control signal from the relay. Pins: VCC, GND
8. Power Supply 5V 5AMP Description: Provides 5V power to the circuit components. Pins: 220V Positive Pole (AC), 220V Neg- ative Pole (AC), GND, GND (DC), 12V-24V Output (DC)
9. Power Supply Description: Provides power to the water pump. Pins: +, -

3.1.1 WIRING DETAILS

1. Soil Moisture Sensor VCC: Connected to VCC of the ESP32. GND: Connected to the common ground with other components. A0: Connected to G34 of the second ESP32.
2. ESP32 Microcontroller (First Unit) 3V3: Powers the relay and water flow sensor. G21: Connected to SDA of the LCD. G22: Con- nected to SCL of the LCD. G18: Powers the buzzer. G27: Controls IN1 of the relay. G23: Receives signal from the SIG pin of the water flow sensor.
3. ESP32 Microcontroller (Second Unit) G34: Receives data from A0 of the soil moisture sensor.
4. LCD 20X4 Display GND: Connected to the common ground. VCC: Connected to the power supply. SDA: Connected to G21 of the first ESP32. SCL: Connected to G22 of the first ESP32.
5. Buzzer VCC: Connected to G18 of the first ESP32. GND: Connected to the common ground.
6. Relay VCC: Powered by 3V3 of the first ESP32. IN1: Con- trolled by G27 of the first ESP32. COM: Connected to VCC of the water pump. NO: Connected to the positive terminal of the power supply for the water pump. GND: Connected to the com- mon ground.
7. Water Flow Sensor SIG: Connected to G23 of the first ESP32. VCC: Powered by 3V3 of the first ESP32. GND: Connected to the common ground.
8. Water Pump VCC: Connected to COM of the relay. GND: Connected to the negative terminal of the power supply.
9. Power Supply 5V 5AMP GND (DC): Connected to the com- mon ground. Power Supply +: Connected to NO of the relay. -: Connected to GND of the water pump.

3.1.2 DATA TRANSMISSION – MQTT (Message Queuing Telemetry Transport)

It is a publish/subscribe protocol that allows devices (clients) to send (publish) and receive (subscribe) messages from a broker (e.g., Mosquitto). **Architecture**

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1.ESP32 acts as the client and central controller.
2.Flow Sensor: Measures water flow. Data is published to the MQTT broker.
3.Relay Module: Controls the water pump. The ESP32 sub- scribes to an MQTT topic to turn the relay on/off.
4.MQTT Broker: Handles all message routing (you can use Mosquitto locally or via cloud).

Data Flow (Sending Data from ESP32) ESP32 reads flow rate from the flow sensor. Publishes this data to an MQTT topic like: irrigation/flowrate. The dashboard, mobile app, or another sub- scriber receives this data for visualization/logging.

Data Control (Receiving Commands via MQTT) Your mobile app or dashboard publishes a command to a topic like: irriga- tion/pump/control ESP32 subscribes to this topic. When it receives "ON" or "OFF": It toggles the relay module to control the water pump accordingly.

4 Results

4.1 FUNCTIONAL TESTING

Each component of the smart irrigation system was individually tested to ensure correct operation before full system integration.

1. ESP32 Microcontroller: Successfully connected to Wi-Fi and communicated with sensors and the Flutter app. Verified GPIO functionality using simple LED and buzzer tests.
2. Soil Moisture Sensor: Calibrated with dry, moist, and wet soil. Sensor produced analog values as expected (e.g., 0–1023). Tested response using water to simulate irrigation.
3. Relay Module: Tested using a multimeter and connected BLDC pump. Confirmed activation when GPIO pin from ESP32 was HIGH.
4. LCD Display: Displayed real-time moisture values using I2C interface. Verified display refresh without lag.
5. Buzzer: Activated when soil moisture dropped below a threshold. Confirmed audible alerts.
6. LED: Turned ON/OFF based on soil moisture conditions, in- dicating dry or wet soil using a threshold value.
7. Flow Sensor: Accurately measured water flow in liters/minute. Validated against manual volume readings.
8. Flutter App: Successfully built and installed on Android. All UI elements responded correctly to real-time data and user inputs.

4.2 SYSTEM INTEGRATION TESTING

Once all components passed functional testing, they were inte- grated and tested as a complete working system. 1. Sensor → ESP32 → Relay Communication: Moisture data from the sensor was read by the ESP32. If values were below the threshold, the relay activated the pump automatically.

2. ESP32 → Flutter App Communication: Real-time soil mois- ture data was transmitted to the app using MQTT over Wi-Fi. Ver- ified with consistent updates every 2 seconds.
3. Manual Controls from App: The pump could be manually turned ON/OFF from the Flutter app. Commands were reliably sent to the ESP32 and acted upon instantly.
4. Alerts: The buzzer and LED activated correctly during low moisture conditions, and the alert message was displayed on the app.
5. Data Display: Moisture values, pump status, and water flow were displayed accurately on both the LCD and the mobile app.

4.3 Additional Observations

The system responded within 1-2 seconds of a condition change.The Flutter app remained stable during prolonged use and showed no crashes.The water usage was optimized, reducing un- necessary irrigation.Power consumption of components was min- imal, suitable for solar-powered deployment in remote areas.

5 Discussion

The implementation of the Smart Irrigation System highlights the potential of integrating automation and data-driven technologies into traditional agricultural practices. Through continuous moni- toring of soil moisture and automated water delivery, the system ensures that crops receive the precise amount of water needed, enhancing both plant health and resource efficiency. The use of weather-based moisture prediction further refines irrigation tim- ing, reducing unnecessary watering during rainy conditions and contributing to sustainable water management.

One of the standout advantages of the system is its adaptabil- ity. By analyzing soil characteristics and retention properties, the system can fine-tune its irrigation logic to suit different agricul- tural environments. This not only maximizes crop yield but also supports a wider range of soil types and climates. The cloud-based storage of sensor data enables long-term tracking, pattern analy- sis, and informed decision-making, which are essential for modern precision farming.

However, the system is not without its challenges. Sensor cal- ibration and maintenance can affect data accuracy, especially in variable field conditions. Additionally, reliance on internet con- nectivity for cloud features may limit the system’s effectiveness in remote or underdeveloped regions. Ensuring reliable connectiv- ity and incorporating offline data caching mechanisms could help mitigate this limitation.

The mobile application significantly improves user engagement by offering real-time monitoring and control, but its effectiveness depends on a user-friendly interface and robust security protocols to protect sensitive agricultural data.

Looking forward, the system could benefit from the integra- tion of machine learning algorithms to offer adaptive irrigation schedules based on historical data and crop-specific needs. Ex- panding compatibility with a broader range of sensors and intro- ducing modular components can also improve scalability and cus- tomization across diverse farming operations.

6 Conclusion

The Smart Irrigation System demonstrates a meaningful step to- ward more sustainable and intelligent agricultural practices. By integrating real-time soil moisture monitoring, predictive weather analysis, and automated water control, the system effectively min- imizes water wastage while supporting optimal plant health. Its ability to analyze soil types and adapt irrigation strategies ensures tailored water delivery suited to varying environmental condi- tions. Furthermore, cloud-based data storage and a user-friendly mobile application provide enhanced accessibility, long-term in- sights, and remote management capabilities. Collectively, these features empower farmers with data-driven tools to make in- formed decisions, ultimately promoting resource-efficient farming and supporting food security in a changing climate.

