Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 05, May-2025

Wireless Remote Control and Monitoring of Irrigation Pump

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***Abstract*— Watering to the field is a crucial task in agriculture and often becomes a time consuming responsibility for farmers, especially in remote areas where power availability and monitoring tools are limited. Many farmers struggle with determining the right time, amount of water to be supplied, and duration for watering their crops, which affects crop growth and yields. To make farmers' work easier, a wireless remote-control irrigation system is developed using ESP32 microcontrollers and LoRa communication technology. This system monitors temperature, humidity, soil moisture, and voltage levels in real-time and enables the pump to be controlled remotely without any dependency on the internet. With a communication range of up to 2 km, it is ideal for remote agricultural fields. This work integrates sensors such as DHT11, soil moisture, and voltage sensors, and uses two ESP32 modules for field and farmer sides. The pump can be operated using push buttons or voice commands, and the data is displayed on an OLED (Organic LED) screen. It also supports Blynk IoT platform for optional Wi-Fi-based monitoring. By automating water delivery based on real-time data, the system reduces water wastage, saves energy, and minimizes labor, offering a sustainable and farmer-friendly solution for efficient irrigation management.**

***Keywords*— Wireless control, Remote Monitoring, Long-Range Communication, Smart Irrigation, Voice Control**

I. INTRODUCTION

Water is a resource that all living species need. It is therefore very precious and has to be used with moderation, to be preserved for the generations to come. Agriculture is an industry that uses a lot of water. Most of the time, this resource is not used efficiently and substantial amounts of water is wasted. In the near future, these wastes will represent a large sum of money. The ones who manage this resource efficiently will be noteworthy. The old method used for irrigation was the use of watering cans, water channels that have to be opened and closed manually or backpack sprinklers. In this case, a lot of water is wasted in the process. There is need for improvement on the existing or old forms of irrigation.

Efficient water management is crucial for sustainable agricultural practices, and irrigation pumps play an integral role in ensuring crops receive the necessary water for optimal growth. However, conventional irrigation systems often face significant limitations. Manual control methods require farmers to physically visit the site to operate pumps, which is both time-consuming and labor-intensive. This often results in water wastage or inadequate irrigation, impacting crop health and yield. Sustainable agriculture depends on effective water management, and the Internet of Things (IoT) to offer a novel approach to irrigation process optimization. In order to improve water utilization in agriculture.

In an attempt to modernize irrigation practices, SIM-based control systems were introduced, allowing farmers to remotely operate pumps through GSM modules [1]. Despite their benefits, these systems heavily depend on reliable network coverage and incur recurring costs for SIM usage and maintenance. Such limitations make them unsuitable for remote areas with poor connectivity or for farmers seeking cost-effective solutions.

Recognizing these challenges, this project proposes a novel solution that integrates wireless technology and artificial intelligence for irrigation pump control. By leveraging radio transceiver modules, the system offers a robust, internet-independent communication range of 2 km, enabling seamless operation without relying on GSM networks. Furthermore, the integration of AI models enhances irrigation efficiency by analyzing real-time [2] and historical environmental data, ensuring precise water delivery tailored to crop needs. This approach enables precise water delivery based on actual crop needs, minimizing water waste and promoting efficient irrigation practices. [3]

II. METHODOLOGY OVERVIEW

The Wireless Remote Control and Monitoring of Irrigation Pump project uses ESP32 microcontrollers, LoRa communication, and various sensors to let farmers control and monitor irrigation pumps remotely, even in areas without internet.

A. Methodology:

a) System Architecture

The system is composed of two main units: the field unit and the farmer unit. The field unit, installed at the irrigation pump site, uses an ESP32 microcontroller to collect data from a DHT11 sensor for temperature and humidity, a soil moisture sensor, and a voltage sensor. It controls the pump through a relay and communicates with the farmer's unit via a 433 MHz LoRa module, offering a wireless range of 2 kilometers. The unit also receives remote commands, such as turning the pump on or off, and provides real-time status updates. The farmer unit, also powered by an ESP32 microcontroller, allows the farmer to control the pump using physical push buttons or voice commands through a VC02 voice recognition module. A 128x64 OLED display shows current readings for temperature, humidity, soil moisture, voltage levels, and pump status. If internet access is available, the unit can also connect to the Blynk IoT platform for Wi-Fi-based monitoring. Secure data transmission is ensured through encryption between the two modules.

b) Wireless Communication
Communication between the two units is established using LoRa modules, enabling long-distance control without relying on internet infrastructure—ideal for remote agricultural settings. The system supports voice control through the VC02 module, allowing the farmer to operate the pump with simple voice commands like "Turn on pump" or "Turn off pump." In addition, push buttons provide a manual method for controlling the pump locally, offering an alternative in case voice recognition fails or is not preferred.

c) Sensor Integration
The system integrates several sensors to support informed irrigation decisions. Soil moisture levels are monitored and displayed, allowing the farmer to determine when to irrigate, although the system does not automate pump activation. A voltage sensor is included to monitor power supply stability and prevent pump operation under unsafe electrical conditions. Environmental data, such as temperature and humidity, are collected using the DHT11 sensor to give further context to the farmer's irrigation planning. All collected data is displayed in real-time on the OLED screen, offering easy access to vital information without requiring a mobile device.

d) Control Flow
The ESP32 microcontroller at the field unit receives commands via LoRa from the farmer unit and activates the pump through a relay as instructed. It also sends continuous status updates back to the farmer's module. At the farmer's end, inputs from either the push buttons or the voice recognition module are processed to generate commands, which are then transmitted wirelessly. Sensor data from the field unit is also received and displayed on the OLED screen, giving the farmer real-time feedback.

e) Testing & Validation
The system undergoes thorough field testing to verify sensor accuracy, LoRa communication reliability, and power monitoring effectiveness over a 2-kilometer range. Both manual and voice control functions are tested for response speed and accuracy in real conditions. Real-time data transmission and display updates are evaluated across different environmental scenarios. Feedback from actual farmers is collected to identify potential improvements in usability and performance. After successful testing, the system is deployed in selected agricultural fields. Parameters are fine-tuned based on specific crop types, soil conditions, and local power availability. The final phase of implementation includes evaluating the system's impact on irrigation management, farmer time savings, and ease of use.

B. Block Diagram

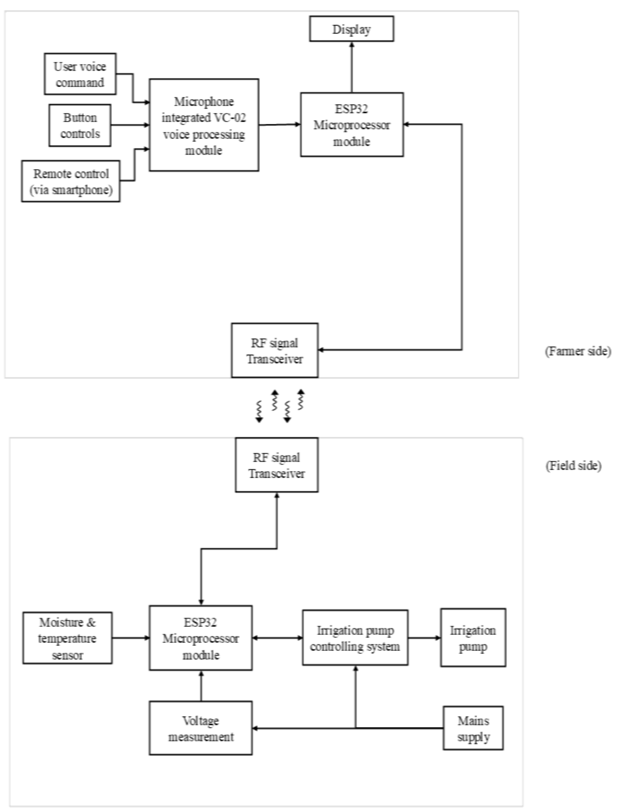

Fig 1. Block diagram

The block diagram (Fig 1) shows how the wireless irrigation control system works. Each component helps enable remote, reliable control and monitoring of a water pump.
The wireless irrigation system allows farmers to control and monitor their pump remotely using voice commands, push buttons, or the Blynk app when internet is available. Voice input is processed by the VC-02 module, while push buttons offer manual control. The ESP32 microcontroller on the farmer's side handles these inputs and communicates wirelessly with the field unit through a LoRa transceiver. An OLED display shows real-time data like soil moisture, temperature, humidity, voltage, and pump status, enabling farmers to make informed irrigation decisions without needing a smartphone.
At the field site, another ESP32 receives commands via LoRa and reads data from soil moisture, voltage, and DHT11 (temperature and humidity) sensors. It controls the irrigation pump through a relay and sends status updates back to the farmer's unit. LoRa ensures encrypted, long-range communication (up to 2 km) without relying on the internet. The system provides essential environmental and electrical information but leaves control decisions to the farmer, combining automation with practical flexibility for rural conditions.

C. Flowchart

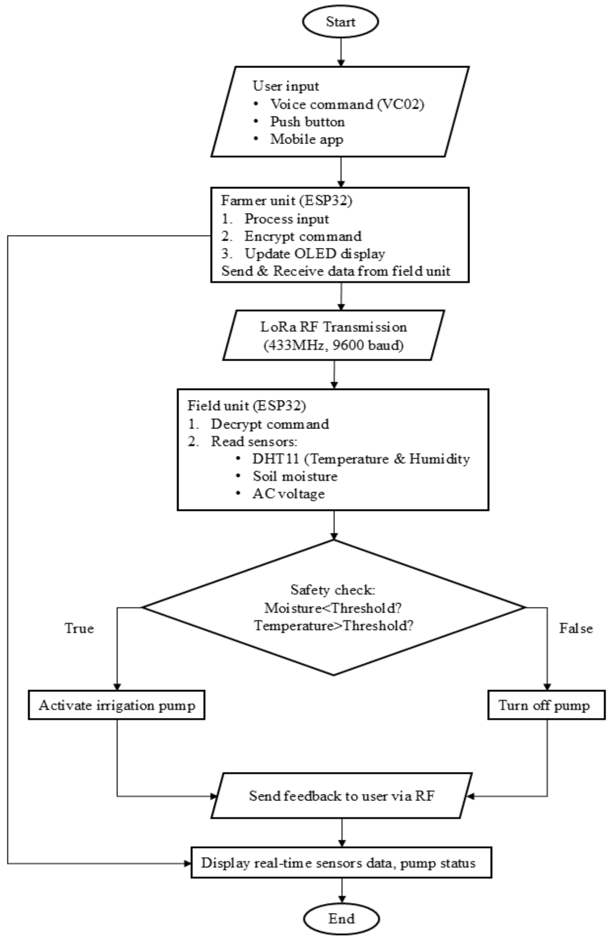

Fig 2. Flowchart

The flowchart (Fig 2) outlines the operation of the wireless remote-control and monitoring system for an irrigation pump. The system starts when power is supplied, which initializes all components and prepares the system for use. Farmers have three input methods to control the system: voice commands processed by the VC02 module, manual push buttons for hands-on control, or the Blynk mobile app for remote access when Wi-Fi is available. The ESP32 microcontroller on the farmer's side processes these inputs, encrypts the data for secure transmission using XOR encryption, and displays real-time status updates on an OLED screen.
Once the farmer's unit sends the encrypted data via LoRa, the field-side ESP32 receives and decrypts the commands. It then gathers sensor data from various components, such as temperature and humidity (DHT11 sensor), soil moisture levels, and AC voltage stability. A safety check is performed to ensure that the voltage is above 180V, the soil moisture is below the predefined threshold, and the temperature is within safe operating limits. If all conditions are met, the system proceeds to activate the irrigation pump via a relay. If any condition fails, the pump remains off, and an alert is triggered to inform the farmer of the issue.
Once the pump is activated, the field unit sends back real-time sensor data and the pump status (ON/OFF) to the farmer's unit. The farmer unit displays this information on the OLED screen and synchronizes with the Blynk app for remote monitoring. The entire process is repeated in a continuous loop, ensuring ongoing monitoring of field conditions and system status. This real-time feedback helps farmers maintain optimal irrigation and prevent issues like power instability or insufficient soil moisture.

III. HARDWARE AND SOFTWARE DESCRIPTION

A. Hardware Description

The system integrates several key hardware components to enable wireless remote control and monitoring of irrigation pumps. At its core are two ESP32 microcontrollers, which serve as the central processing units for the farmer-side and field-side units. The farmer-side unit includes a VC-02 voice recognition module for hands-free operation via voice commands, push buttons for manual control, and a 128×64 OLED display to show real-time sensor data. Wireless communication is facilitated by a LoRa RF transceiver module (433MHz), which ensures long-range, internet-independent connectivity. The field-side unit features a soil moisture sensor (FC-28) for measuring water content, a DHT11 sensor for monitoring temperature and humidity, and a ZMPT101B voltage sensor to ensure safe pump operation by detecting unstable power conditions

TABLE I. HARDWARE COMPONENTS

VC-02 Voice Recognition Module	OLED Display
LoRa RF Module (SX1278)	Soil Moisture Sensor
Antenna (3dBi)	DHT11 Sensor
ESP32	Voltage Sensor

B. Software Description

The system's software is developed using the Arduino IDE, which provides a flexible and user-friendly environment for programming the ESP32 microcontrollers. The Arduino IDE supports essential libraries such as LoRa for wireless communication, DHT sensor library for environmental monitoring, and U8g2 for OLED display management. The farmer-side code processes inputs from voice commands, push buttons, and the optional Blynk IoT app, encrypts data using XOR encryption, and transmits commands to the field unit via LoRa. The field-side code handles sensor data acquisition (soil moisture, temperature, humidity, voltage), executes pump control commands, and sends real-time updates back to the farmer unit. Key functionalities include a handshake protocol for secure communication, sensor data transmission at 2-second intervals, and error handling for unstable conditions.
The VC-02 voice recognition module enables hands-free operation, allowing farmers to control the pump using simple voice commands like "Pump ON" or "Pump OFF." The module connects to the ESP32 via UART and supports up to 255 customizable voice commands. This feature is particularly useful for farmers who may have limited mobility or prefer a more intuitive control method.
For enhanced remote monitoring, the system integrates the Blynk IoT platform, allowing farmers to control and monitor the irrigation system via a smartphone app when internet connectivity is available. Blynk provides a user-friendly dashboard where real-time data—such as temperature, humidity, soil moisture, and pump status—can be visualized. Farmers can also send ON/OFF commands to the pump through the app, adding an extra layer of convenience.

IV. CIRCUIT DIAGRAM

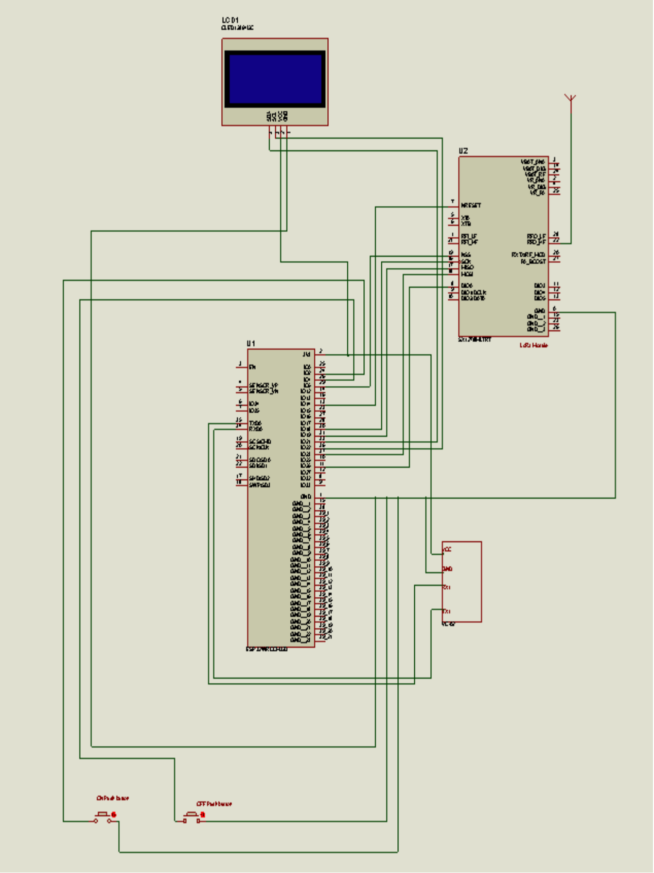

Fig 3. Circuit diagram of farmer side unit

The farmer-side circuit (Fig 3) is built around an ESP32 microcontroller, serving as the control hub for the irrigation system. It integrates a 128×64 OLED display (SH1106) connected via I2C (SDA-D21, SCL-D22) to show real-time sensor data and system status. A LoRa module (433MHz) interfaces with the ESP32 through SPI (NSS-D5, MOSI-D23, MISO-D19, SCK-D18) for long-range wireless communication with the field unit. The VC-02 voice recognition module is linked via UART (TX2/RX2) to process voice commands like "Pump ON/OFF." User inputs are facilitated through push buttons (ON-D2, OFF-D4) for manual control, while the DIO0-D26 pin handles LoRa transmission interrupts. All components operate on 3.3V power, ensuring efficient and stable performance.

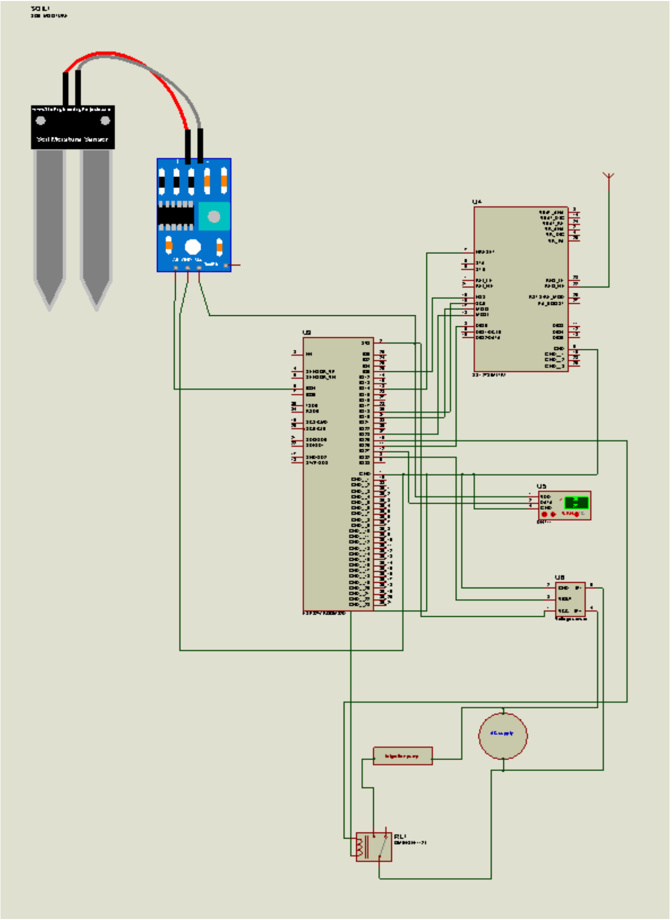

Fig 4. Circuit diagram of field side unit

The field-side circuit (Fig 4) acts as the remote actuator and sensor hub, centered on another ESP32 microcontroller. It connects to critical components, including a soil moisture sensor (A0-D34), DHT11 sensor (D27) for temperature/humidity, and a ZMPT101B voltage sensor (D32) to monitor power stability. A 5V relay module (IN1-D25, IN2-D33) controls the irrigation pump based on commands received from the farmer unit via the LoRa RF module (SPI: NSS-D5, MOSI-D23, MISO-D19, SCK-D18, RST-D14, DIO0-D26). The circuit is powered through the ESP32's 3.3V and GND pins, with the relay module isolated using a transistor driver to handle high-current pump operation. This setup ensures reliable, encrypted communication while providing real-time sensor feedback for safe and efficient irrigation management.

V. RESULTS AND DISCUSSION

The wireless irrigation control system successfully demonstrates reliable remote monitoring and pump control functionality. The integration of LoRa-based communication enabled stable long-range connectivity between the farmer and field units, fulfilling the requirement for internet-independent operation. The system effectively processed multiple input methods, including voice commands and manual push-button controls, providing farmers with flexible operation modes.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 05, May-2025

A. Practical Setup and Working

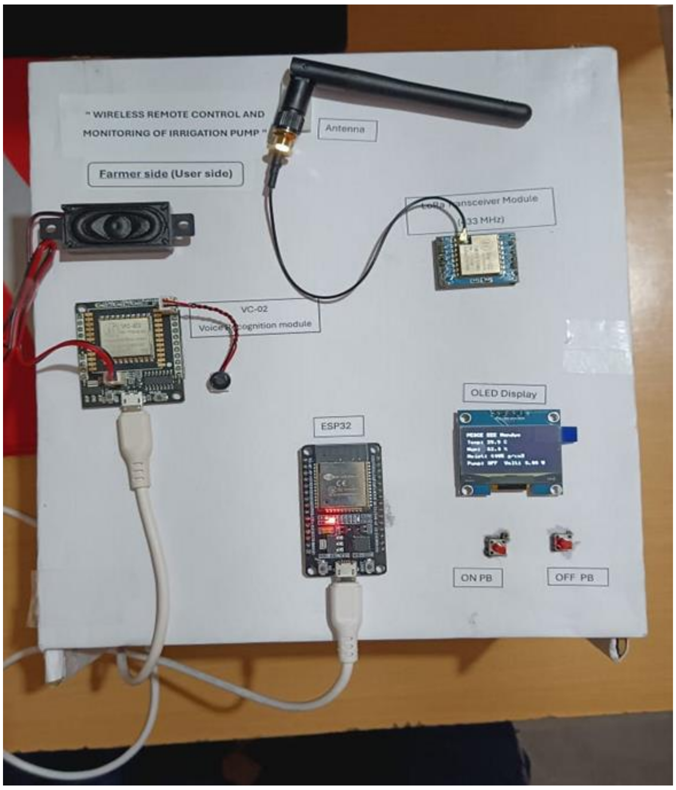

Figure 5. Farmer side unit

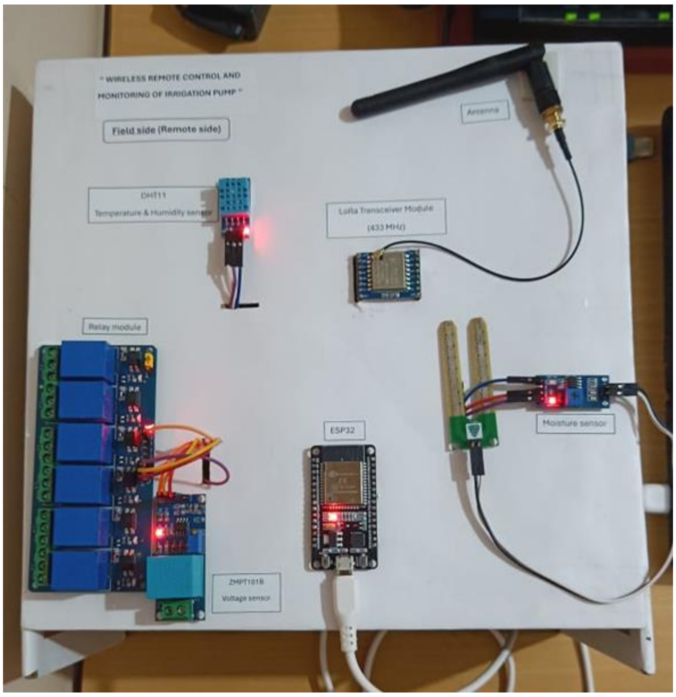

Figure 6. Field side unit

1. Communication & Encryption (For LoRa):
The communication between the field and the farmer units is carried out using LoRa (Long Range) SX1278 transceiver modules, operating at 433 MHz A secure 3-step handshake mechanism ensures reliable and authenticated communication between the devices. The process begins when the field-side device waits to receive a message labelled HS_REQ (handshake request). Upon receiving this request, it sends back a HS_ACK (handshake acknowledgment). The handshake completes successfully when the final HS_CONFIRM is received by the field unit. Once the handshake is successful, a status LED blinks three times, indicating a secured connection.
For communication security, all messages exchanged between devices are XOR-encrypted using a predefined encryption key 0x42. This lightweight encryption ensures that the transmitted sensor data and control commands cannot be easily intercepted or manipulated.

2. Sensor Data Collection (Field Side)
The field-side ESP32 is responsible for collecting environmental and electrical parameters necessary for decision-making. The data acquisition takes place at regular intervals of every 2 seconds. The system collects:

- Temperature and humidity data using a DHT11 digital sensor.
- Soil moisture level via an analog resistive soil moisture sensor.
- AC voltage level using a ZMPT101B voltage sensor, which performs RMS calculation using 500 analog samples for accurate results [10].

3. Remote Pump Control (Field Side)
The field-side ESP32 also handles pump control based on the commands received over LoRa. The commands follow a predefined format such as:

- CMD:PUMP_ON to activate the pump.
- CMD:PUMP_OFF to deactivate it.

Upon receiving a command, the ESP32:

- Decrypts the message using the XOR method.
- Activates or deactivates the pump using a relay module.
- Sends an acknowledgment message such as ACK:PUMP_ON or ACK:PUMP_OFF back to the farmer's device.
- Updates sensor data accordingly and resumes continuous monitoring.
-

4. Voltage, Moisture, and Temperature Monitoring
To ensure both equipment safety and optimal irrigation, the system continuously monitors two critical environmental parameters: soil moisture and temperature.

- Soil Moisture Monitoring: A resistive soil moisture sensor is deployed in the field to assess the water content in the soil. The sensor provides analog readings, and the system uses thresholds of 1.3 g/cm^3 (dry, pump ON when $\leq$ 1.3 g/cm^3) and 1.8 g/cm^3 (wet, pump OFF when > 1.8 g/cm^3) to manage irrigation for paddy cultivation.
- Temperature Monitoring: The DHT11 temperature and humidity sensor monitors ambient environmental temperature. If the temperature rises above 38°C, typical for paddy stress conditions, the system logs this and turns ON the pump to mitigate heat stress.

5. OLED Display (Farmer Side)
The farmer-side ESP32 is equipped with an OLED display, which provides a real-time local view of all the field data. The following parameters are displayed on the screen in a clean and readable format:

- Temperature (°C)
- Humidity (%)
- Soil Moisture Level (g/cm^3)
- Voltage (V)
- Pump Status (ON/OFF)

6. Blynk IoT Dashboard

To enable remote control and visualization over the internet, the system integrates with the Blynk IoT platform. The farmer-side ESP32 is connected to Wi-Fi, and the Blynk app is configured with widgets such as:

- A virtual button to toggle the pump ON or OFF.
- Live gauges to display temperature, humidity, moisture level, and voltage in real-time.

Pump Control Decision Table:
For paddy crop reference in loam-clay soil,

TABLE II. PUMP ON/OFF STATUS

Soil moisture (g/cm³)	*Temperature (°C)*	*Pump action*
<=1.3	Any	ON
>1.3 to <=1.8	<=38	OFF
>1.3 to <=1.8	>38	ON
>1.8	<=38	OFF
>1.8	>38	ON

The irrigation pump turns ON when soil moisture is ≤1.3 g/cm³, or when moisture is >1.3–1.8 g/cm³ and temperature exceeds 38°C, or when moisture is >1.8 g/cm³ but temperature is >38°C (to prevent heat stress). In all other cases, the pump remains OFF to avoid overwatering [14]. This logic ensures optimal irrigation while protecting crops from both drought and extreme heat.

The wireless irrigation system enables remote monitoring and automated pump control using long-range communication technology, operating independently of internet connectivity while supporting multiple user input methods. It incorporates secure data transmission with encryption between control units and field devices. The system continuously tracks environmental conditions including soil moisture, temperature and electrical parameters to make irrigation decisions. An intelligent control algorithm activates the pump based on soil conditions and temperature thresholds to prevent both water stress and overheating. Real-time data visualization is provided through a local display interface, complemented by cloud-based remote monitoring capabilities for flexible oversight. The design effectively combines autonomous operation with user accessibility for agricultural water management.

VI. ADVANTAGES

a) Water conservation: By optimizing irrigation schedules based on real-time data, the system minimizes overwatering, leading to significant water savings. Ensures that crops receive the precise amount of water they need, preventing under-watering and maximizing water utilization.

b) Increased productivity: Consistent and optimized water supply promotes healthy plant growth, leading to higher yields and improved crop quality.

c) Cost savings: Optimizing pump operation minimizes energy usage, resulting in lower electricity bills.

d) Improved sustainability: By minimizing water usage and optimizing irrigation practices, the system contributes to sustainable agriculture by reducing the strain on water resources.

e) Enhanced convenience: Farmers can control and monitor the irrigation system remotely, providing flexibility and convenience. Hands-free operation through voice commands further enhances user convenience and ease of use.

d) Data-driven decision making: The system provides real-time data and insights into various parameters, enabling farmers to make informed decisions regarding irrigation management.

VII. CONCLUSION

This paper successfully develops a wireless irrigation control system using ESP32 and LoRa technology for remote farm management. It supports voice commands, push-button control, and a mobile app (Blynk), making it accessible to farmers with different technical skills. The system integrates soil moisture, temperature, humidity, and voltage sensors to ensure smart and safe pump operation. With a 2 km communication range and encrypted LoRa messaging, it functions reliably without internet, ideal for rural areas. The prototype model shows how low-cost components can reduce water usage, save energy, and minimize manual labor. Its modular design allows future upgrades like predictive watering, or multi-pump control. This scalable, cost-effective solution brings smart farming tools within reach for small-scale farmers. Overall, it bridges the gap between modern IoT technology and practical, real-world agriculture.

ACKNOWLEDGMENT

The authors would like to express the deepest thanks to the Principal, PESCE, Mandya, and the Management, PET®, Mandya, for their timely support and constant encouragement in successful completion of this work.

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