Arduino-Powered Soil Nutrient and Moisture Management for Sustainable Farming

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***Abstract*—Climate change, limited natural resources, and increasing food demand pose major challenges to modern agriculture. Traditional irrigation and fertilization methods often result in inefficient resource use and contribute to soil degradation. This work presents an Internet of Things (IoT)-enabled system using Arduino technology for real-time monitoring of soil moisture, temperature, and humidity to enhance sustainable farming practices. The system automates the delivery of water and nutrients based on sensor readings and allows remote management through the Blynk mobile application. Components such as soil moisture and environmental sensors, solenoid valves, and a water pump are integrated to ensure precise and timely operation. Field testing demonstrated a significant reduction in water usage and fertilizer consumption compared to manual methods, leading to improved crop health and operational efficiency. While the system proved effective, further development is planned, including the integration of additional sensors for pH and salinity, solar-powered operation, and machine learning for predictive automation. These enhancements aim to increase system intelligence, scalability, and accessibility for diverse agricultural environments.**

***Keywords*— Arduino, Smart irrigation, Smart agriculture, Sustainable farming, Real-time monitoring, IoT.**

1. INTRODUCTION

1.1 Background

Agricultural productivity is under immense pressure due to rising global food demands, climate change, and declining water availability. Traditional farming methods, particularly those involving irrigation and fertilization, often lead to inefficient use of water and nutrients, thereby degrading soil health and reducing crop yields. In conventional systems, manual irrigation and fertilization are still widely practiced, which often results in over-application or under-application of vital inputs.

Recent advances in digital agriculture and the Internet of Things (IoT) have opened new avenues for addressing these inefficiencies. IoT-based systems enable continuous monitoring of soil and environmental conditions, allowing for data-driven and automated decision-making. Through the use of embedded sensors, wireless modules, and microcontrollers, these systems can collect and process real-time information to optimize the application of water and nutrients [1]. Precision agriculture, driven by such technologies, aims to deliver inputs only when and where they are needed, increasing efficiency and minimizing waste [2].

This research proposes a cost-effective, sensor-based irrigation and fertilization system powered by an Arduino UNO microcontroller, combined with an ESP8266 Wi-Fi module, soil moisture and DHT11 sensors, and solenoid valves. These components work in coordination with the Blynk mobile platform, providing farmers the ability to monitor soil and environmental parameters remotely and control field operations in real time. The system is designed to activate irrigation when soil moisture falls below a specific threshold and to deliver NPK fertilizers through solenoid valves, improving resource use and plant health.

1.2 Problem Statement

Despite technological advancements, many agricultural regions continue to suffer from inefficient irrigation and fertilization practices. Common issues include excessive water usage, nutrient leaching, and manual guesswork in decision-making. These challenges are especially prevalent in remote or under-resourced areas where access to smart farming technologies is limited [3].

In flood irrigation or surface application methods, significant quantities of water are lost due to evaporation, runoff, and deep percolation. Similarly, fertilizers are often applied manually and imprecisely, resulting in uneven distribution, over-fertilization, and increased costs. Furthermore, farmers lack real-time insight into field conditions, making timely interventions difficult [4].

The situation calls for the development of intelligent systems that can monitor critical parameters and respond automatically. By utilizing affordable, open-source technologies, it is possible to build IoT-based solutions that are accessible to small and medium-scale farmers. The goal is to ensure accurate, real-time control of irrigation and fertilization based on soil and environmental conditions.

1.3 Research Motivation

This project is motivated by the growing necessity for sustainable and efficient farming systems. The fusion of microcontroller-based systems, wireless communication, and environmental sensing offers a practical way to improve resource management in agriculture. When integrated effectively, such systems can help address major pain points in irrigation and nutrient application.

The Arduino UNO, a widely-used open-source microcontroller, provides an ideal platform for building lightweight, modular automation systems [1]. Paired with the ESP8266 module, it allows wireless communication and integration with mobile applications like Blynk. Sensors such as soil moisture probes and DHT11 units offer consistent and

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

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

real-time data about field conditions. When processed intelligently, this data can trigger automated actions, such as activating a water pump or opening fertilizer valves [5].
The system proposed in this research is designed with scalability and usability in mind. It is structured to be deployed in various agricultural settings and provides farmers with real-time control through a mobile app. The use of solenoid valves for NPK nutrient delivery ensures targeted application, thereby reducing chemical waste and cost. Such automation reduces manual labour and enhances accuracy in field operations.

1.4 Contribution of the Study
This study presents a fully functional IoT-based prototype that addresses the critical needs of smart irrigation and nutrient management. The system offers a blend of real-time monitoring, automation, and remote access components essential for modern agricultural systems. It is built on an open-source hardware and software ecosystem, ensuring adaptability and cost-effectiveness.

Key contributions of this work include:
- Integration of sensors (soil moisture and DHT11) with Arduino UNO and ESP8266 for real-time environmental data collection.
- Automated irrigation logic based on predefined soil moisture thresholds to reduce water wastage.
- Use of solenoid valves for precise NPK nutrient application, activated through mobile interface.
- Implementation of the Blynk app for remote monitoring and control of irrigation and fertilization processes.
- Storage of operational data for performance evaluation and optimization.
- Modular design, enabling future enhancements such as solar power, LoRaWAN communication, or AI-based prediction models.

Through extensive field simulation and testing, the system has shown its ability to reduce water consumption and improve fertilizer efficiency. This project demonstrates that practical, low-cost solutions can be implemented to address key challenges in agriculture. The system may be particularly useful for farmers in remote or resource-constrained areas, offering a path toward more sustainable and technologically supported farming.

2. RELATED WORK

In modern agricultural Internet of Things (IoT) ecosystems, sensors are integral components for continuously tracking environmental and soil-specific parameters. These devices collect real-time data, convert physical phenomena such as moisture or temperature into electrical signals, and relay this information to microcontrollers. This data is then processed to trigger automated responses, including irrigation and nutrient delivery, thereby ensuring efficient use of inputs and promoting sustainable farming practices [6].

2.1 Arduino UNO
Serving as the central processing unit in the system, the Arduino UNO microcontroller receives input from sensors such as the DHT11 and the soil moisture probe. It handles both analog and digital signals, compares sensor outputs against programmed thresholds, and triggers appropriate actuators when required. It also communicates with external devices like the ESP8266 Wi-Fi module for cloud-based data updates. Powered by a 16 MHz clock and 32 KB of flash memory, the UNO is well suited for lightweight data processing. Its open-source design allows for project-specific customization, while its extensive module compatibility ensures integration flexibility in smart farming setups [7].

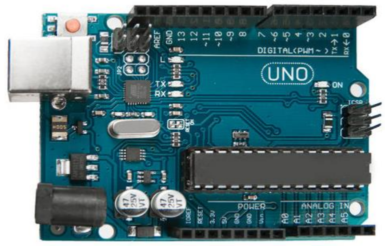

Fig 1. Arduino UNO

2.2 ESP8266 Wi-Fi Module
Wireless data transfer from the Arduino to the Blynk cloud interface is facilitated through the ESP8266 module, allowing remote system control. It establishes a stable connection with local wireless networks and facilitates remote command transmission. Through this setup, users can view sensor data, receive alerts, and activate devices like pumps or valves from a smartphone interface. Its low energy consumption, small form factor, and TCP/IP support make it a preferred choice for embedded IoT deployments in remote agricultural areas [8].


Fig 2. ESP8266

2.3 Soil Moisture Sensor
Soil moisture sensors are deployed to assess the volumetric water content in the soil. These sensors emit analog signals relative to moisture levels and send data to the Arduino UNO for analysis. If the measured value falls below a preset limit, the controller activates the irrigation system to prevent dehydration. Typically calibrated against both dry and saturated soil conditions, these sensors simplify interpretation and improve system response accuracy. Their low power requirements and durability make them suitable for long-term agricultural monitoring [9].

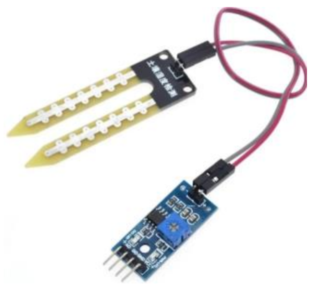
Fig 3. soil moisture sensor

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

2.4 DHT11 Temperature and Humidity Sensor

The DHT11 sensor provides periodic readings of air temperature and humidity levels. These parameters are critical in calculating evapotranspiration rates, which in turn inform irrigation schedules. Continuous updates from the sensor to the Arduino allow the system to adjust irrigation frequency and fertilizer delivery based on real-time environmental fluctuations. Its digital output simplifies integration, while the sensor's reliability ensures consistent environmental tracking [10].

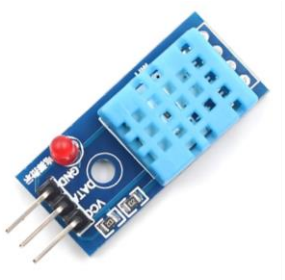

Fig 4. DHT11 sensor

2.5 Solenoid Valves

Solenoid valves are employed to manage the controlled distribution of macronutrients—namely nitrogen (N), phosphorus (P), and potassium (K)—through a drip irrigation system. Each valve corresponds to a specific nutrient and is operated via signals from the Arduino, often routed through a relay module. Using the Blynk application, farmers can manually regulate the dosage and timing. Solenoid valves offer fast switching times, compact form factors, and precise control, all of which contribute to minimized fertilizer waste and optimized soil enrichment [5].

Fig 5. solenoid valve

2.6 Relay Module

A relay module functions as the switching interface between the low-voltage logic of the Arduino and the higher power demands of devices like pumps and solenoid valves. It provides electrical isolation, protecting sensitive components from voltage spikes. The module can control multiple outputs concurrently, enabling synchronized irrigation and nutrient application. Its reliability and robust design ensure seamless operation under varying load conditions, which is crucial for consistent system performance [11].

Fig 6. relay module

3. METHODOLOGY

The deployment of the IoT-based irrigation and fertilization system is structured into four distinct phases, each focusing on a critical component to ensure efficient and automated agricultural practices. This phased methodology facilitates a systematic progression from data acquisition to automated action, integrating real-time monitoring and control mechanisms.

Fig 7. fertilization and irrigation system

Phase 1: Sensor Data Acquisition

Initially, the Arduino UNO microcontroller collects real-time data on soil moisture, ambient temperature, and humidity using integrated sensors. This information provides valuable insights into the field's current conditions, enabling precise decisions regarding irrigation and fertilization. The gathered data is processed and prepared for transmission to the Blynk mobile application, allowing farmers remote access to field conditions [12].

Phase 2: Real-Time Monitoring via Blynk App

The ESP8266 Wi-Fi module transmits the processed sensor data to the Blynk cloud platform. Through the Blynk mobile application, farmers can monitor real-time soil moisture levels, temperature, and humidity from their smartphones. The intuitive interface provides clear visualizations, aiding in the optimization of irrigation schedules and nutrient application strategies [12].

Phase 3: Data Analysis and Decision Making

Sensor data from the soil moisture probe is interpreted by the Arduino UNO, which triggers actions when readings fall below the configured 30% threshold value. This threshold aligns with agronomic recommendations, as maintaining soil moisture between 30% and 40% is considered ideal for most agricultural soils to support optimal plant growth and resource efficiency [13]. If the moisture content is insufficient, the system prepares to activate the irrigation mechanism. This

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

automated decision-making process ensures water is supplied efficiently through drip irrigation, conserving resources while maintaining optimal soil conditions [14].

Phase 4: Automated Irrigation and Fertilization

Upon detecting low soil moisture, the Arduino UNO activates the water pump via the relay module, initiating the drip irrigation process. Concurrently, farmers can control solenoid valves through the Blynk app to administer precise amounts of fertilizers as needed. Once the soil reaches optimal moisture levels, the system automatically deactivates the pump, preventing over-irrigation and nutrient leaching, thereby promoting sustainable farming practices.

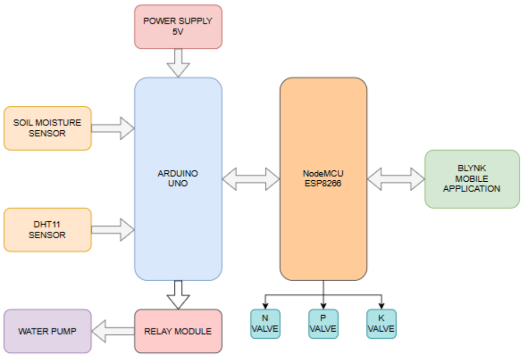

Fig 8. block diagram of proposed system

4. RESULTS AND DISCUSSION

The system demonstrates strong performance in real-time monitoring of soil moisture, temperature, and humidity by utilizing dependable sensors that deliver consistent and accurate readings. These timely data outputs enable immediate action, such as activating water pumps or solenoid valves when soil moisture falls below a predefined threshold. The internal processing logic is responsive, allowing the system to initiate irrigation operations without delay even when deployed in remote agricultural settings.

The Blynk mobile interface is designed for ease of use, offering intuitive controls and timely alerts regarding critical conditions such as moisture deficits or successful irrigation events. Cloud integration enhances the system's data management capabilities by enabling advanced analytics and historical trend observation. These features assist farmers in making better-informed decisions.

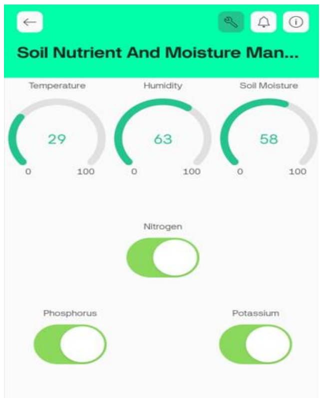

Fig 9. Blynk mobile application showing collected data and NPK control switches

The system is engineered for energy efficiency, making it well-suited for off-grid or rural environments with limited power infrastructure. It incorporates secure communication protocols and access controls to safeguard against unauthorized system manipulation. Moreover, it has been designed with maintenance simplicity in mind—sensor modules are easily accessible for recalibration or replacement, reducing downtime. Overall, the system has proven to be highly reliable and functionally robust, consistently meeting performance benchmarks. It offers real-time data delivery, stable long-term operation, and seamless integration with the Blynk platform, all of which contribute to enhanced farm management.

5. CONCLUSION

The system's deployment led to notable improvements in both resource utilization and agricultural productivity by enabling automated control based on real-time monitoring of soil moisture, temperature, and humidity. Irrigation was triggered only when soil moisture levels dropped below 30%, helping reduce water consumption. The use of a drip irrigation system ensured that water was delivered directly to the root zones of the plants, minimizing runoff and evaporation losses. Similarly, NPK fertilizers were administered through solenoid valves integrated into the drip system, allowing for targeted nutrient application directly at the plant base. These operational upgrades reduced nutrient wastage, improved nutrient absorption by crops, and led to healthier plant growth with lower input costs and increased yields for farmers. Looking ahead, enhancements such as the inclusion of pH, salinity, and light intensity sensors will offer a more detailed assessment of soil conditions. Additionally, integrating solar energy, LoRaWAN communication, machine learning algorithms, and a more refined user interface will boost the system's adaptability, automation, and user engagement.

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