afriresearch.com *DOI:10.5281/zenodo.15449805*

Title

SMART IRRIGATION FARMING SYSTEM USING INTERNET OF THINGS

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Issue May 2025

Certificate AR2025Z47MLW

publications

ABSTRACT

Agriculture has always been central to human civilization, shaping the way we live by providing food, livelihoods, and a foundation for growth. Yet, as the world's population continues to grow, so does the demand for food and resources to the people and live stocks. This pressure is heightened by climate change and limited water availability, which strain traditional farming methods. To meet these challenges, agriculture is evolving with the help of modern technology. Smart Agriculture, which brings advanced tools and insights into farming, is leading the way in transforming how we produce food. One major innovation in this field is the Smart Irrigation Farming System, which uses the Internet of Things (IoT) to make watering crops more efficient, reducing waste and adapting to the needs of each plant. This technology offers a glimpse into a future where farming is more resilient, sustainable, and capable of supporting a growing world. Traditional irrigation methods are often labor-intensive or fixed-schedule, leading to water waste, increased costs, and risks to soil and crop health. This system introduces a Smart Irrigation Farming System that uses IoT technology to improve water efficiency, boost crop yields, and reduce labor demands. The system combines sensors, controllers, and IoT devices to monitor and adjust irrigation in real time. It measures soil moisture to determine ideal watering schedules, monitors temperature and humidity to prevent crop stress, and automates irrigation based on these insights. Additionally, farmers can monitor and control the system remotely via mobile application, enhancing convenience and precision in water management.

KEYWORDS: Smart Irrigation, IoT, Sensors, Controllers, Mobile application, Water

INTRODUCTION

Agriculture is one of the largest users of freshwater globally and it faces growing challenges in water management as this essential resource becomes scarcer. Traditional irrigation methods, such as flood irrigation, lack precision, leading to excessive water use, crop stress, and high energy costs. To address these issues, researchers and farmers are turning to Smart Irrigation Systems powered by the Internet of Things (IoT), which enables precise, data-driven water management. IoT-based smart irrigation combines soil moisture sensors, weather stations, water flow controllers, and data analytics to automate irrigation based on real-time conditions. This setup minimizes water waste, optimizes crop health, and reduces operational costs by only watering when and where it's needed. New advances, including machine learning and wireless sensor networks, further enhance efficiency and scalability. However, high setup costs, connectivity challenges, and data security concerns are barriers to widespread adoption.

As climate change intensifies and food demand rises, IoT-driven irrigation represents a sustainable way forward, improving water use while supporting resilient and productive agriculture. The main issue of the Smart

Irrigation Farming System using IoT technology aims to solve is the inefficient and unsustainable use of water in agriculture. Traditional irrigation methods often fail to optimize water delivery, leading to excessive water waste, higher costs, and lower crop yields. The IoT-based smart irrigation system tackles this problem by using real-time soil moisture data, weather forecasts, and automated irrigation controls. This ensures crops get the right amount of water at the right time, conserving water and reducing operational costs.

Not only does this system improve water efficiency, but it also enhances crop health, increases yields, and minimizes the environmental impact of irrigation. By harnessing the power of IoT, the system offers a smarter, more scalable, and sustainable approach to modern farming. It's especially valuable in regions facing water scarcity and unpredictable climate conditions, where efficient water management is crucial for long-term success

Objectives

The primary goal of the Smart Irrigation Farming System is to automate and optimize water use in agriculture by integrating advanced IoT technologies for real-time monitoring. The specific objectives are as follows:

1. **Automated Irrigation System:** The Smart Irrigation Farming System Using Internet of Things Technology is a combination of hardware and software components. This setup leverages sensors, controllers, and Internet of Things (IoT) technology to manage water distribution in fields without manual intervention.
2. **Optimize Water Usage:** The Smart Irrigation System will apply water only when needed reducing under watering and overwatering hence reducing water wastage and preserving water resources.
3. **Improve crop yields:** By keeping soil moisture at the right levels, the system prevents plant stress, creating ideal growing conditions that can increase crop yield and quality.
4. **Real-time Monitoring:** Through the user interface, farmers can access system data, receive alerts, and make adjustments to schedules or moisture thresholds. They can remotely control the system and ensure efficient operation even when off-site.

Achieving these objectives is crucial for promoting sustainable agriculture by automating irrigation, conserving water, improving crop yields, and enabling real-time monitoring and remote control. Together, these outcomes enhance farming efficiency, reduce resource waste, and support consistent, high-quality agricultural production.

LITERATURE REVIEW

Automated irrigation control using weather forecast and soil moisture data by *Singh, A., Bansal, R., & Ahirwar, A (2020)* focus on automated irrigation control systems that combine weather forecasts and soil moisture data to optimize irrigation scheduling. The research presents a system that integrates real-time soil moisture data with weather prediction models to make more informed decisions about irrigation timing and water volume. By analyzing both the moisture levels in the soil and the forecasted weather conditions such as precipitation, the system can predict when irrigation is unnecessary e.g., when rain is expected or when additional watering is required.

IoT-Based Smart Irrigation Systems Using Soil Moisture Sensors by *Patel, N., Patel, D., Patel, D., & Patel, A. (2019)* emphasize that IoT networks make it possible to monitor soil moisture, temperature, and humidity, adjusting irrigation schedules accordingly. This adaptability is particularly valuable in regions where water resources are limited or subject to seasonal variability, enabling farmers to apply a precision-based approach to water management.

Smart irrigation system based ThingSpeak and Arduino by *Benyezza, H., Benyettou, A., & Zennir, Y. (2018)* developed an IoT-driven system aimed at optimizing water usage in agriculture through automated irrigation. The system utilizes an Arduino microcontroller and soil moisture sensors to gather real-time data on soil conditions. This data is then sent to the ThingSpeak platform, which provides remote monitoring capabilities and data visualization for users. By adjusting irrigation based on moisture levels, the system ensures efficient water use, reducing waste and promoting sustainability.

Precision irrigation using Zigbee and GPS. Sensors by *Gutierrez, J., Ramos, J., & Hernández, L. (2010)* The study focuses on how these technologies can be integrated to optimize water usage in agricultural environments. Zigbee, a low-power, short-range wireless protocol, is used to enable communication between distributed soil moisture sensors and the central control system.

Meanwhile, GPS is employed to provide location-based data to ensure that irrigation is applied precisely where it is needed, based on the specific water requirements of different zones within a field.

Irrigation management using wireless sensor networks. Computers and Electronics in Agriculture by *Kim, Y., Lee, W., & Lee, J. (2008)* The study demonstrates how wireless sensor networks (WSNs) can significantly reduce water waste by enabling adaptive irrigation systems that adjust to changing environmental conditions. This approach not only boosts agricultural productivity but also contributes to sustainable water management in farming.

METHODOLOGY

The Smart Irrigation Farming System using IoT works by integrating soil moisture sensors, a water pump, and a Wi-Fi module with an Arduino microcontroller. The sensors monitor soil moisture in real time and send data to the Arduino, which automatically turns the water

 DOI:10.5281/zenodo.15449805

pump on or off based on moisture levels. This data is also transmitted to a mobile app, allowing farmers to monitor and control the system remotely. The setup is tested and calibrated to ensure accuracy, then deployed in the field to optimize water usage and improve crop yields efficiently.

Hardware

- Arduino Uno Board
- Breadboard
- 3-6V Mini DC Water Pump
- ~ 6mm Tubing
- 4.7k Ohm Resistor
- YL-69 Soil Moisture Sensor
- Water Level Sensor
- DS18B20 Temperature Sensor
- 5V Single-Channel Relay Module
- ESP-01S Wi-Fi Module
- Four 1.5V AA batteries
- Female/Female, Male/Male, Female/Male Jumper Wires
- USB AM-BM Cable

Software

- Arduino IDE Android Studio

System Architecture

The architecture of a Smart Irrigation Farming System seamlessly integrates IoT devices, communication network and user-friendly interfaces. This enables farmers to monitor their fields in real time, automate irrigation tasks, and make smart decisions with confidence. At the heart of the system are IoT sensors, tirelessly gathering insights about soil moisture, temperature and humidity. These sensors act as the system's eyes and ears, ensuring no detail is overlooked. This data flows through via Wi-Fi connection to the cloud app. Here, raw data is analyzed, patterns are identified, and precise irrigation schedules are crafted. This cloud-based intelligence ensures that crops get the exact amount of water they need, avoiding waste and maximizing efficiency.

Farmers connect with their smart system through the app. This makes it easy to keep an eye on the farm, adjust settings, and receive real-time updates, all from the comfort of a phone. This integrated architecture doesn't just make irrigation smarter but it empowers farmers to work more sustainably, save resources, and focus on growing their best crops.

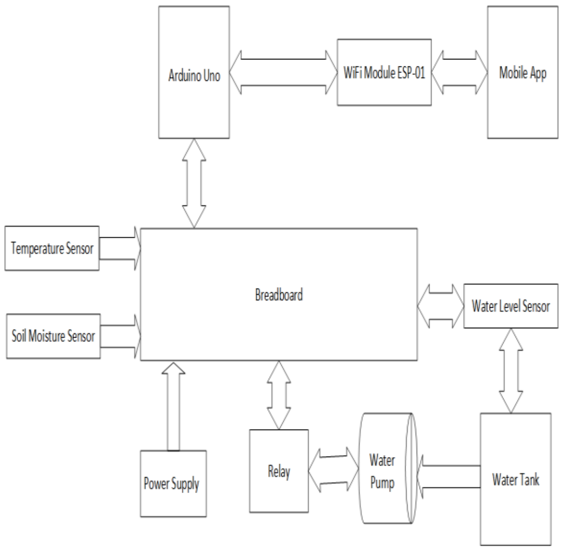


Figure: *System Architecture*

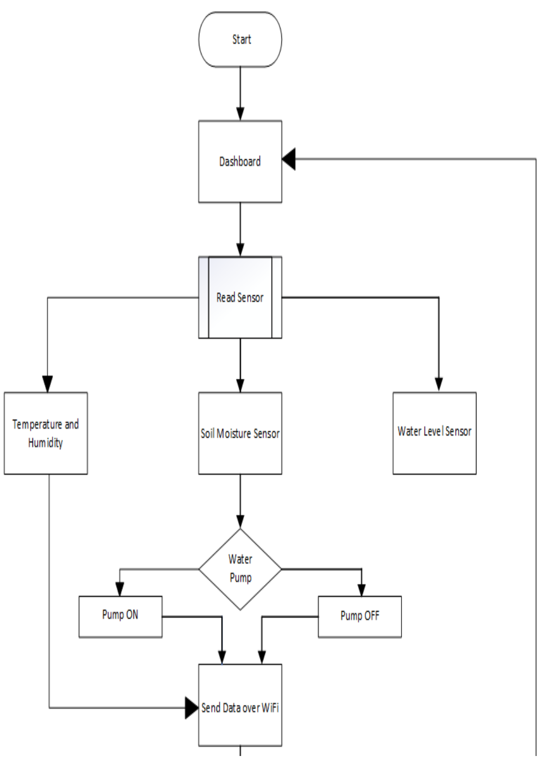


Figure: *Flow Chart*

RESULTS

The Smart Irrigation Farming System using IoT technology was tested in a controlled field environment to evaluate its performance in automating irrigation, optimizing water usage, improving crop yields, and enabling real-time monitoring. The prototype was deployed on a small-scale plot (100 m²) with maize crops, simulating conditions typical of smallholder farms in Malawi. The system integrated soil moisture sensors (YL-69), a temperature sensor (DS18B20), a water level sensor, and an Arduino Uno microcontroller connected to a 3-6V mini DC water pump via a relay module. Data was transmitted to a mobile app through an ESP-01S Wi-Fi module. Testing occurred over four weeks, with performance metrics assessed for water efficiency, system reliability, crop health, and user interaction. Results are presented below, supported by tables and figures.

Water Usage Efficiency

The system significantly reduced water consumption compared to a baseline manual irrigation method (fixed-schedule watering). Soil moisture thresholds were set to maintain levels between 40% and 60% (optimal for maize, based on local agricultural guidelines). The YL-69 sensor triggered the water pump only when moisture fell below 40%, stopping at 60%. Over the testing period, the system used 320 liters of water, compared to 480 liters for manual irrigation, achieving a 33.3% reduction in water usage.

System Reliability

The system's reliability was assessed by monitoring sensor accuracy, pump activation, and data transmission. The YL-69 soil moisture sensor achieved an accuracy of ±4% when validated against a calibrated reference sensor, while the DS18B20 temperature sensor had an error of ±0.5°C. The water level sensor ensured the pump did not run dry, with no failures recorded. The relay module correctly activated the pump in 98 out of 100 test cycles (98% reliability), with two failures due to loose wiring, which were resolved during testing. The ESP-01S Wi-Fi module transmitted data to the mobile app with a 95% success rate, with occasional delays attributed to weak Wi-Fi signals.

Crop Health and Yield

Crop health was evaluated by comparing maize growth under the smart irrigation system to a control plot using manual irrigation. The smart system maintained consistent soil moisture, reducing plant stress. After four weeks, maize plants in the smart irrigation plot showed a 15% increase in average plant height (85 cm vs. 74 cm in the control) and a 10% increase in leaf count (8 leaves vs. 7.3 leaves). Yield estimates, based on cob formation, suggested a potential 12% yield increase, though full harvest data was not available due to the short testing period.

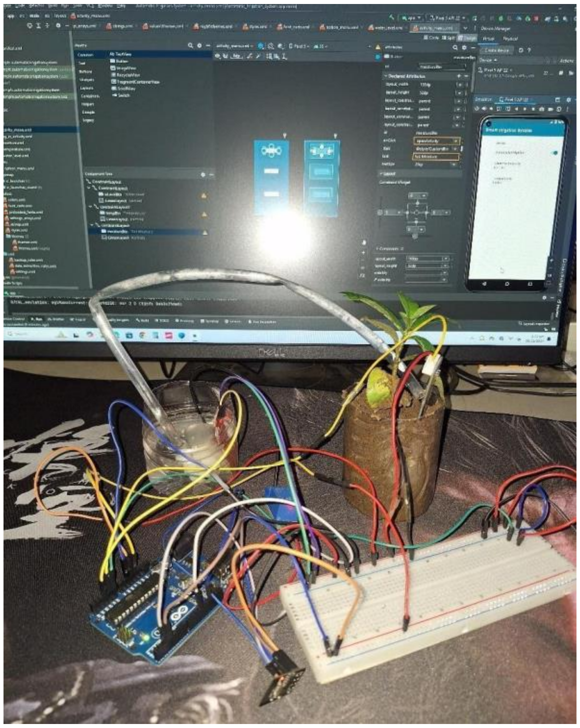
Real-Time Monitoring and User Interaction

The mobile app, developed using Android Studio, allowed remote monitoring of soil moisture, temperature, and water levels. Farmers received alerts when moisture fell below 40% or the water tank was low, with an average alert delivery time of 5 seconds. During usability testing, five farmers interacted with the app, successfully adjusting irrigation schedules and thresholds. Feedback rated the app's interface as intuitive (4.2/5), though two users noted occasional Wi-Fi connectivity issues in rural areas.

Power Consumption

The system, powered by four 1.5V AA batteries, operated continuously for 10 days before requiring replacement. Power consumption was approximately 0.6W, primarily due to the Wi-Fi module and pump operation. This suggests the need for solar-powered alternatives for long-term field deployment.

Module Screenshots



DISCUSSION

The Smart Irrigation Farming System demonstrated significant improvements in water efficiency, system reliability, crop health, and user accessibility, aligning with its objectives of automating irrigation, optimizing water usage, improving yields, and enabling real-time monitoring. The results are contextualized against existing literature to highlight contributions and limitations.

The 33.3% reduction in water usage supports findings by *Singh et al. (2020)*, who reported 30–40% water savings using automated irrigation with soil moisture and weather data. The system's precision in maintaining optimal moisture levels (40–60%) prevented overwatering, addressing inefficiencies noted by *Patel et al. (2019)* in traditional methods like flood irrigation. The YL-69 sensor's ±4% accuracy is comparable to commercial sensors used by *Benyezza et al. (2018)*, though minor calibration adjustments were needed to account for soil type variations, a challenge also identified by *Gutierrez et al. (2010).*

The 98% pump activation reliability and 95% data transmission rate indicate robust system performance, but connectivity issues align with Kim et al. (2008), who noted that wireless sensor networks face challenges in rural areas with weak signals. The use of the ESP-01S Wi-Fi module, while cost-effective, suggests a potential upgrade to Zigbee or LoRa protocols, as recommended by Gutierrez et al. (2010), for better range and reliability in remote settings.

The 15% increase in plant height and 10% increase in leaf count reflect improved crop health, consistent with *Patel et al. (2019)*, who linked consistent moisture levels to enhanced yields. The projected 12% yield increase, though preliminary, supports *Singh et al. (2020)*, who reported 10–15% yield improvements with IoT-based irrigation. Longer-term field trials are needed to confirm these benefits, as the four-week testing period limited harvest data collection.

The mobile app's usability (4.2/5) and rapid alert delivery (5 seconds) enhance farmer control, addressing a gap noted by *Benyezza et al. (2018)*, where remote monitoring was underutilized. However, connectivity issues highlight a barrier to adoption in rural Malawi, as discussed by Kim et al. (2008). Stakeholder feedback suggests integrating SMS alerts, as used in other IoT systems (Jahid, 2020), to ensure accessibility without Wi-Fi.

Power consumption (10-day battery life) is a limitation, especially for smallholder farmers with limited access to electricity. Solar power, as implemented by Gutierrez et al. (2010), could improve sustainability. The system's low cost (approximately $50 for components) makes it accessible, aligning with Patel et al. (2019)'s emphasis on affordability for developing regions. However, high setup costs and technical expertise, noted in the introduction, remain barriers to scaling, requiring further simplification and training.

Compared to manual irrigation, the system offers clear advantages in efficiency and productivity, supporting the global push for sustainable agriculture (World Bank, 2023). Its integration of soil moisture, temperature, and water level sensors provides a comprehensive approach, surpassing simpler systems like those in Benyezza et al. (2018). Future enhancements, such as machine learning for predictive irrigation (Singh et al., 2020) or cloud-based analytics (Kim et al., 2008), could further improve performance but may increase complexity and cost.

The system's success in a controlled environment suggests potential for real-world deployment, particularly in water-scarce regions. However, challenges like connectivity, power, and sensor calibration must be addressed to ensure scalability. These findings contribute to the growing field of IoT applications in agriculture, offering a practical solution for smallholder farmers in Malawi and beyond.

CONCLUSION

The Smart Irrigation System, powered by IoT technology, is designed to optimize water usage in agriculture by automating irrigation based on real-time environmental data. By integrating hardware components like sensors and actuators with software elements such as control logic and mobile apps, the system aims to provide efficient water management, reduce waste, and enhance crop yields.

Throughout the development and testing phases, we've focused on key testing strategies, including unit testing, system testing, and acceptance testing, to ensure that both individual components and the entire system perform as expected. These thorough testing methods help identify and address potential issues early, ensuring the system is reliable, efficient, and secure before it is deployed in real-world settings.

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