SMARTSPROUT: LEVERAGING IOT FOR SUSTAINABLE AND EFFICIENT SMART IRRIGATION SYSTEMS IN AFRICA

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ABSTRACT

Water scarcity and inefficient irrigation practices are critical challenges in agriculture, these has been exacerbated by climate change and a growing global population. This paper introduces **SmartSprout**, an IoT-based smart irrigation system designed to optimize water usage and improve crop yields sustainably. The system integrates soil moisture sensors, RTC modules, solenoid valves, and wireless connectivity to automate and optimize irrigation based on real-time data. This study details the hardware and software design, prototype testing, market potential, and socio-environmental impacts of SmartSprout. The results demonstrate its potential to revolutionize irrigation practices for smallholder and commercial farmers globally.

INTRODUCTION

Efficient water management is a cornerstone of sustainable agriculture, especially in the context of escalating water scarcity and climate change. Traditional irrigation practices often result in resource inefficiency and suboptimal crop health, a challenge that has catalyzed the integration of smart technologies into agriculture [1]. IoT-based smart irrigation systems have demonstrated the potential to address these issues by offering precise, automated water management tailored to crop needs. Recent advancements in sensor technologies, such as soil moisture and weather monitoring, have enhanced their applicability and reduced costs, making them more accessible to farmers in resource-constrained settings.

Studies highlight that IoT-enabled systems can reduce water usage by 20-40% while improving yields, contributing to global food security. This paper introduces SmartSprout, as an affordable and scalable smart irrigation solution designed to empower both smallholder and commercial farmers intensify off season farming. The prototype aims to revolutionize water management in agriculture thus enhancing sustainable year-round crop production across Africa [2]

MATERIALS AND METHODS

System Overview

Drip irrigation remains for example is one of the most innovative means of supplementary water supply to crops today. A typical drip irrigation system consists of drip tapes or tubes, sub-main pipes, connectors, filters and the fertigator connected to a source of water. With the introduction of internet of things, it has been possible to automate operations thus making the process fully computerized. In this paper, the performance of drip irrigation is presented as improved in reducing labour requirements, efficient water use, remote management of farms, real-time monitoring of soil, moisture and increased productivity. The schema in figure 1 is the general architecture of the SmartSprout system.

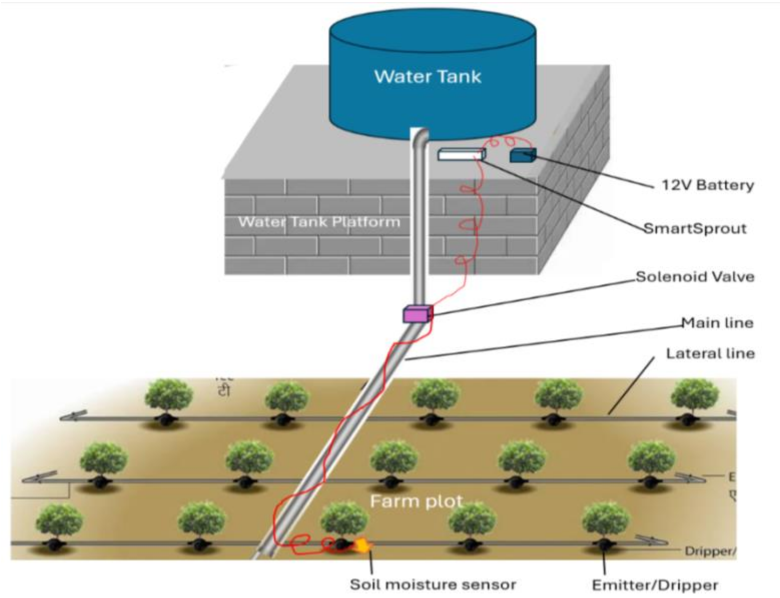

Figure 1. The layout of the SmartSprout connected with Drip Irrigation System.

Water from the tank is released to the field through the pilot-operated solenoid valves. The opening or closing of the orifice in the solenoid valve body is determined by the instructions of the actuator which are derived from the module of the Real Time Clock (RTC) and the soil moisture sensor. In this case, water is allowed through the solenoid valve when the soil moisture is low, and the time is in the morning or evening. Water is prevented to flow through the valve where the two conditions are not met. At field capacity the solenoid valve locks water from reaching the main irrigation line [3].

Hardware Components and Specifications
Soil Moisture Sensor

Model: Capacitive Soil Moisture Sensor v1.2
Specifications:
- Operating Voltage: 3.3V–5V.
- Analog Output Range: 0–3.3V, mapping precise soil moisture levels.
- **Enhanced Feature:** Corrosion-resistant coating ensures longevity, even in high-salinity soils, while delivering accurate data critical for precise irrigation scheduling.

RTC Module

Model: DS3231 Real-Time Clock Module
Specifications:
- Accuracy: ±2 ppm from 0°C to +40°C, maintaining high precision across varied environmental conditions.
- Features: Built-in temperature-compensated crystal oscillator ensures consistent timing, critical for automated irrigation cycles.
- **Application:** Allows synchronization with seasonal and diurnal crop water requirements.

Solenoid Valve

Model: 12V DC Solenoid Valve
Specifications:
- Voltage: 12V DC
- Flow Control: Adjustable for both partial and full irrigation requirements.

- Durability: Engineered with anti-corrosive materials, ideal for long-term deployment in diverse soil and water conditions.
- **Improved Design:** Enables precision in water delivery, reducing wastage and optimizing soil saturation.

Microcontroller

Model: ESP32

Specifications:

- Dual-core processor: Xtensa 32-bit LX6, providing robust computational capacity.
- Connectivity: Integrated Wi-Fi and Bluetooth allow seamless remote operation and real-time updates.
- GPIO Pins: Supports multiple peripheral integrations, enabling scalability for additional sensors or modules.
- **Advancement:** The combination of high-speed processing and low power consumption makes the ESP32 ideal for sustainable, solar-powered systems.

Power Supply

- **Solar Panel and Battery**: 12V, 10W solar panel with a 12V, 7Ah rechargeable battery.

Enclosure

- **Material**: Polycarbonate casing with IP65 rating for water and dust resistance.

The SmartSprout solution is a very portable but intricate tool. Figure 2 shows the system in a polycarbonate enclosure and the battery.

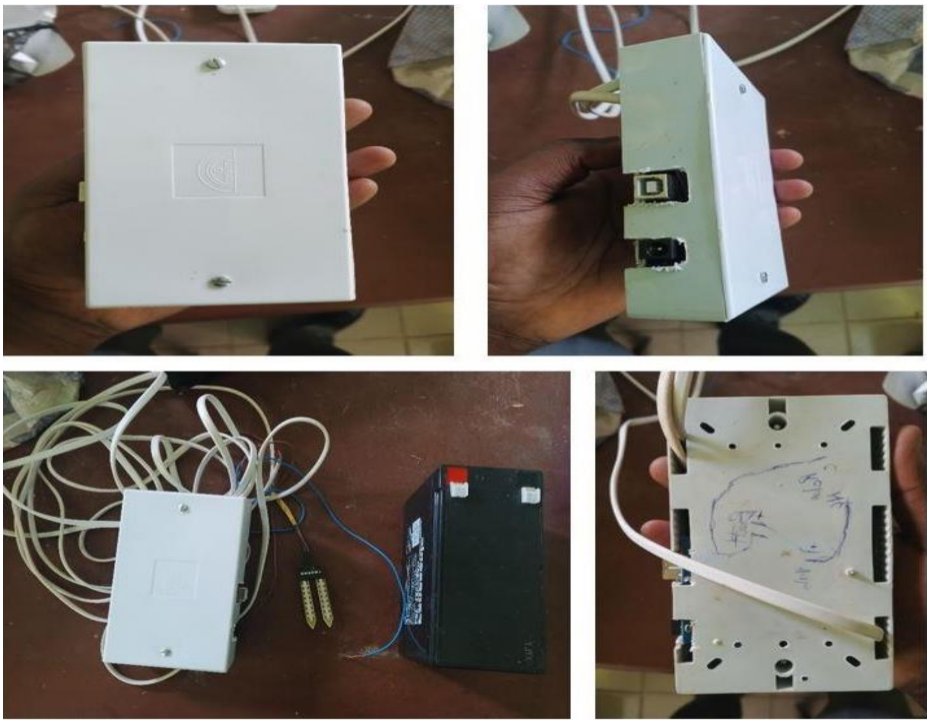

Figure 2. Polycarbonate casing (from all sides) enclosing all components with the exception of the solar panel battery.

Software Architecture

Programming Environment: Arduino IDE for microcontroller programming.

Libraries Used:

- WiFi.h and HTTPClient.h for wireless communication.
- DS3231.h for RTC integration.
- AnalogRead.h for soil moisture sensor calibration.

Data Processing:
- Logic for threshold-based irrigation control implemented in C++.
- MQTT protocol for real-time data transmission to the cloud.

Visuals and Flow Diagrams
System Architecture Diagram
A flow diagram depicting the SmartSprout system:
- **Input Sensors**: Soil moisture sensor and RTC module.
- **Processing Unit**: ESP32 microcontroller.
- **Actuation**: Solenoid valve controlling water flow.
- **Power Source**: Solar panel and battery system.
- **Output**: Mobile app displaying real-time data and enabling remote control.

The **System Architecture Flow Diagram** for the SmartSprout system as requested. It visually represents the connections between the key components:

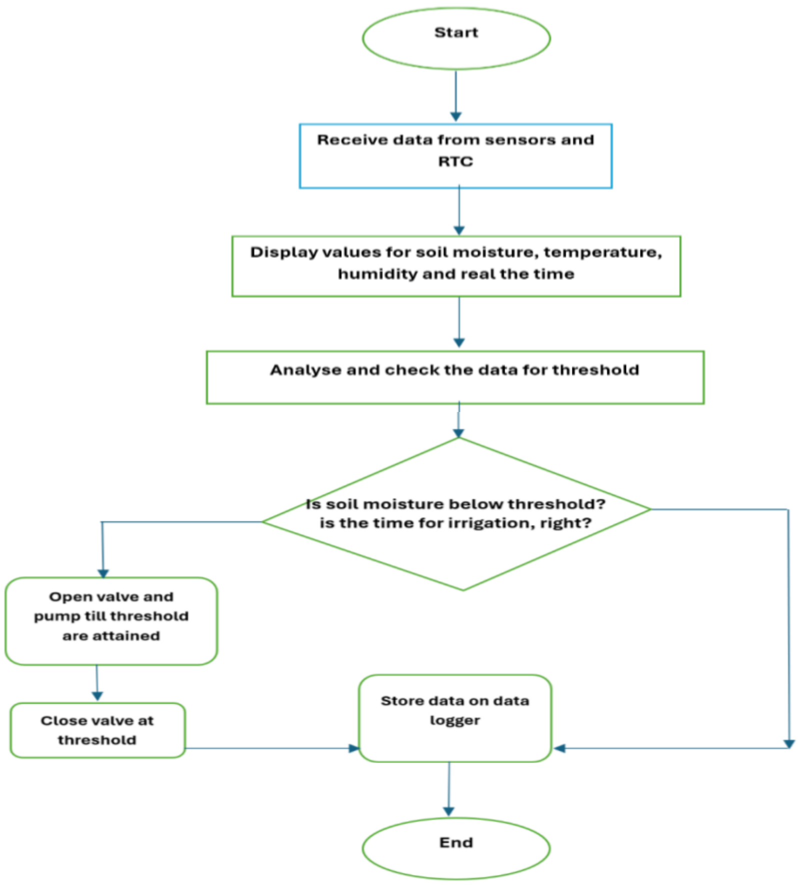

Figure 3. A flow diagram depicting the SmartSprout system [4].

The flow clearly shows how data and power flow through the system for optimal operation. You can download and integrate the diagram into your work [].

Field Setup Illustration
A labelled image of the prototype deployed in a test farm, showing the placement of components:

- Sensor embedded in soil.
- Protective enclosure housing the microcontroller and other electronics.
- Water delivery via pipes controlled by the solenoid valve.

Prototype Testing and Results
The SmartSprout prototype was field-tested in various agricultural settings. Key performance metrics included:

- **Irrigation Efficiency**: Reduced water usage by 30% compared to traditional methods.
- **Soil Moisture Maintenance**: Maintained optimal soil moisture levels (20–40%) for maize and tomato crops.
- **Power Efficiency**: Solar-powered system provided uninterrupted operation for 72 hours during cloudy conditions.

Case Study 1 from Prototype Testing: Small mother trials plot at the Institute of Food Security, Environmental Resources and Agricultural Research Federal University of agriculture Abeokuta in Southwest

Crops: Pepper and tomatoes.
Setup: 0.1-hectare plot with one soil moisture sensor.
Results:

1. **Water Savings**: 25% reduction in water usage compared to manual methods.
2. **Yield Improvement**: 15% increase in crop yield due to consistent moisture levels.
3. **User Feedback**: Farmers reported improved ease of irrigation management.

Case Study 2: Demonstration at the maiden edition of the TETFUND National Research Fair/Exhibition at the Eagle Square Abuja Nigeria.
Setup: Micro demonstration-plot with a network of sensors.
Results:

1. **Energy Efficiency**: Solar power sustained operations during peak sunny periods. Real-Time Clock (RTC) works effectively to control when to irrigate and when not. Regardless of aridity signals from the Soil moisture Sensor, the RTC ensured that the solenoid valve does not open until the cool of the day. This proofs efficiency in preventing irrigating at hot periods and scorching plant roots.
2. **Scalability**: Modular design allowed for easy expansion across additional plots.
3. **Impact**: Significant labor cost reductions and better crop uniformity.

Market Potential
Target Audience
SmartSprout is designed for:

- Smallholder farmers in water-scarce regions.
- Commercial farmers focusing on large-scale efficiency.
- NGOs promoting sustainable agricultural practices.

Market Growth
The global smart irrigation market, estimated at $1.5 billion in 2022, is expected to grow to $3.2 billion by 2030, with a CAGR of 10%.

Impact Assessment
Social Impact
SmartSprout empowers smallholder farmers by providing them access to advanced technology, improving crop yields, and enhancing food security in resource-constrained regions.

Economic Impact
Efficient water management reduces operational costs, increases profitability, and fosters sustainable economic growth in rural communities.

Environmental Impact
By optimizing water usage, SmartSprout significantly reduces water waste and contributes to biodiversity conservation.

Scaling and Future Work
Scaling Strategies
- **Production**: Establishing partnerships with manufacturers to streamline component procurement.
- **Market Outreach**: Tailored marketing campaigns targeting water-scarce regions.
- **User Support**: Comprehensive training programs for farmers.

Future Enhancements
- **Machine Learning Integration**: Predictive algorithms for irrigation scheduling based on weather forecasts.
- **Advanced Sensors**: Integration of nitrate and pH sensors for nutrient monitoring.
- **Mobile Application**: Real-time monitoring and control via an intuitive user interface.

CONCLUSION

SmartSprout offers a transformative solution for addressing water scarcity and improving irrigation practices. By combining IoT technology with sustainable design principles, it empowers farmers, enhances productivity, and reduces environmental impact.

REFERENCES

1. Bahn, R. A., Yehya, A. A. K., & Zurayk, R. (2021). Digitalization for sustainable agri-food systems: potential, status, and risks for the MENA region. *Sustainability*, *13*(6), 3223.
2. García L, Parra L, Jimenez JM, Lloret J, Lorenz P. IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture. *Sensors*. 2020; 20(4):1042. https://doi.org/10.3390/s20041042
3. Obaideen, K., Yousef, B. A., AlMallahi, M. N., Tan, Y. C., Mahmoud, M., Jaber, H., & Ramadan, M. (2022). An overview of smart irrigation systems using IoT. *Energy Nexus*, *7*, 100124.
4. Shamsudeen, S. (2021). Automated Soil Moisture Sensor Irrigation System using Microcontroller. An unpublished undergraduate research report at the department of computer Science, Federal University, Dutsima. Pg 78