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Implementation of Agricultural Crop Protection using Solar Rooftop PV panel

Gaana. H, Kushishree KT, Abhisek BK, Ambuja HM, Somasundara KP

Assistant Professor, Department of Electrical & Electronics Engineering, P.E.S. College of Engineering, Mandya,
Karnataka, India

U.G. Student, Department of Electrical & Electronics Engineering, P.E.S. College of Engineering, Mandya,
Karnataka, India

U.G. Student, Department of Electrical & Electronics Engineering, P.E.S. College of Engineering, Mandya,
Karnataka, India

U.G. Student, Department of Electrical & Electronics Engineering, P.E.S. College of Engineering, Mandya,
Karnataka, India

U.G. Student, Department of Electrical & Electronics Engineering, P.E.S. College of Engineering, Mandya,
Karnataka, India

ABSTRACT: This project presents the design and implementation of an intelligent crop protection system powered by a solar rooftop photovoltaic (PV) panel, aimed at enhancing agricultural resilience to unpredictable weather conditions such as excessive rainfall. The system leverages embedded technology and environmental sensors to automate both crop protection and irrigation, ensuring optimal field conditions with minimal human intervention. A rain sensor detects the onset of rainfall and triggers a motorized protective cover, made from polythene or foaming sheet, to shield crops from potential damage. Simultaneously, soil moisture sensors monitor ground hydration levels, activating or deactivating the irrigation system via a relay-controlled water pump. The entire setup is powered sustainably using a solar PV panel connected to a rechargeable battery, ensuring uninterrupted operation even in off-grid or rural settings. Real-time data, including soil moisture, temperature, humidity, and rainfall, is displayed locally on an LCD and remotely transmitted to a cloud platform such as ThingSpeak for remote monitoring. The system also supports manual override via SMS or mobile control. Additionally, the rainwater collected on the protective sheet is redirected and stored for future irrigation, promoting water conservation through rainwater harvesting. This solution offers a low-cost, energy-efficient, and scalable approach to precision farming, improving crop yield, reducing manual labor, and supporting sustainable agriculture practices in regions affected by climate variability.

KEYWORDS: Smart Agriculture, IoT-Based Irrigation, Rainfall-Responsive System, WIFI Crop Protection, Soil Moisture Monitoring.

I. INTRODUCTION

Agriculture remains a vital contributor to economic development and food security, especially in countries like India, where a large portion of the population relies on farming for their livelihood. However, conventional farming practices often fall short in addressing challenges such as erratic weather conditions, inefficient irrigation, and lack of real-time monitoring. To address these limitations, smart agriculture solutions leveraging the Internet of Things (IoT), wireless sensor networks, and renewable energy sources are rapidly gaining traction [1][2]. The integration of IoT with embedded systems allows for real-time monitoring of key environmental parameters such as temperature, humidity, soil moisture, and rainfall, thereby enabling automated decision-making processes to enhance crop yield and protection [3][4]. intensive and prone to human error [1], [4], [7].

Numerous studies have demonstrated the potential of IoT-based systems to transform agriculture. For instance, Suma et al. [1] and Kodali et al. [2] developed smart monitoring platforms using sensors and cloud platforms to optimize

greenhouse environments, while Bhattacharya et al. [3] showed how wireless sensor networks can be used for continuous environmental data collection. Liu et al. [4] introduced a cloud-based intelligent plant wall system for indoor plant care, which shares design similarities with field-level crop protection. These systems have shown significant benefits in terms of resource optimization, early threat detection, and automation of irrigation or protective actions.

The proposed system in this project builds upon these foundational works by combining IoT-based environmental sensing with solar energy harvesting to implement an intelligent crop protection and irrigation system. The system utilizes a solar rooftop PV panel as the primary energy source, ensuring sustainable and uninterrupted operation, particularly in off-grid or rural settings. Rain sensors detect rainfall and automatically activate a motorized protective roof that shields the crops. Simultaneously, soil moisture sensors monitor hydration levels and control irrigation via a relay-driven water pump only when required. This ensures optimal water usage and protects crops from both under- and over-watering.

The collected environmental data is processed by a microcontroller and transmitted to an IoT platform like ThingSpeak, enabling remote visualization and real-time monitoring [6][10]. The system also supports manual control using mobile communication or web-based interfaces, offering farmers full flexibility. Advanced studies have emphasized the need for systems capable of automating not just irrigation but also providing actionable insights into climate and soil variations [7][8][12], traceability [13][18], and crop quality management.

Furthermore, rainwater collected from the protective sheet is stored through a rainwater harvesting mechanism, and reused for irrigation, promoting sustainability. The use of solar power, along with efficient energy converters and batteries, adds another layer of eco-friendliness to the design. This makes the system not only smart but also green and scalable for larger field applications [14][15].

In summary, the proposed project aims to address key agricultural challenges through an integrated approach involving sensor-based automation, IoT-enabled monitoring, and renewable energy. The system's ability to self-operate, monitor, and respond to environmental changes makes it a viable solution for modern precision agriculture and resource-efficient farming practices.

II. LITERATURE SURVEY

Recent advancements in the Internet of Things (IoT), wireless sensor networks (WSNs), and embedded systems have enabled smart agriculture solutions that focus on automation, precision monitoring, and remote accessibility. Numerous researchers have explored these technologies to enhance crop productivity, reduce water wastage, and improve resilience against climate uncertainties.

Dr. N. Suma et al. [1] proposed an IoT-based smart agriculture monitoring system that uses various sensors to detect soil moisture, temperature, and humidity. The data is relayed to farmers through wireless networks, allowing them to make informed decisions. Their system emphasizes ease of implementation and affordability, making it suitable for small-scale farmers.

Kodali et al. [2] developed an IoT-based smart greenhouse system that automates irrigation and climate control using soil moisture sensors and DHT11 sensors. The system integrates WIFI communication to send real-time alerts, demonstrating how embedded systems and IoT can create intelligent environments for controlled agriculture.

Bhattacharya et al. [3] investigated a wireless sensor network (WSN) for monitoring indoor air quality. While their study focused on health-based applications, the use of low-power wireless communication and real-time environmental data acquisition presents opportunities for adaptation in agricultural settings.

Liu et al. [4] introduced an active plant wall system for indoor climate regulation using cloud connectivity and IoT. This system demonstrated how sensor-based networks can manage environmental conditions effectively in real time, laying a foundation for smart farming applications.

Kim et al. [5] addressed security in multi-domain RFID systems, a critical aspect when deploying smart agriculture systems that rely on sensor and data communication. Ensuring secure data transmission is essential for reliable agricultural automation.

Jiang et al. [6] presented an environmental monitoring system using LinkIt One and the Yeelink platform. Their work highlights the benefits of integrating low-power embedded devices with cloud-based platforms to monitor environmental variables such as temperature and air quality.

Brocca et al. [7] and Laiolo et al. [8] conducted studies on soil moisture estimation using remote sensing technologies like ASCAT and AMSR-E. Their research shows the importance of accurate soil moisture data for irrigation planning and crop health assessment. These remote sensing techniques complement in-situ sensors by providing large-scale validation.

Sorathia et al. [9] explored a web services orchestration approach for agricultural marketing reforms. Though not sensor-based, this work underscores the importance of integrating information systems into agriculture to optimize supply chains and resource management.

Yang et al. [10] proposed an intelligent cloud-based system for indoor environmental management. Similar architecture can be adapted for agricultural greenhouses and field monitoring, utilizing cloud computing for efficient data handling. Madrid et al. [11] demonstrated remote monitoring of winery and creamery environments using a WSN. Their study validates the feasibility of deploying wireless sensor systems in harsh and sensitive environments, similar to agricultural fields.

Labidi et al. [12] implemented a humidity control system inside greenhouses using feedback control loops. Their findings confirm that sensor-based automatic regulation enhances crop yield and environmental balance within protected agriculture.

Banerjee and Menon [13] emphasized traceability in food and agricultural products. Their work supports the need for integrated systems that monitor not only crop conditions but also post-harvest storage and logistics.

Anire et al. [14] developed an environmental wireless sensor network using Raspberry Pi for greenhouse monitoring. Their system showcases the potential of combining low-cost hardware with IoT for real-time field data acquisition. Li et al. [15] proposed a design framework for workshop environment monitoring based on IoT, demonstrating scalability and modularity—features beneficial for large agricultural lands.

Gouadria et al. [16] compared self-tuning fuzzy PID and classic PID controllers for greenhouse environments, concluding that adaptive control techniques offer better performance. In a related study [17], they used a PSO-tuned PI controller to improve greenhouse system control.

Gunawan et al. [18] explored traceability systems in the bulk food industry. Their analysis reveals that data integration from field to fork is crucial in reducing losses and improving food safety—objectives supported by smart agriculture systems.

III. METHODOLOGY

The methodology starts with system initialization, where all sensors and modules—including the soil moisture sensor, rain sensor, DHT11 (temperature and humidity), WIFI module, and actuator modules—are powered up and configured by the Arduino microcontroller. Once initialized, the system enters its main loop, beginning with data acquisition. It continuously reads the current soil moisture level, rain detection status, and atmospheric temperature and humidity. The first decision block evaluates whether it is raining. The system checks if the soil moisture is low if it is not raining. If the soil is dry, the Arduino activates the water pump via a relay to irrigate the land. Once the pump is triggered, the system updates the LCD display with the current action (e.g., "Irrigating..."). If the soil is not dry, the system simply does nothing and loops back after a predefined delay. If it is raining, the system proceeds to check whether the soil moisture is already adequate. If it is, this indicates that irrigation is unnecessary, and rain could lead to overwatering or

crop damage. To prevent this, the Arduino activates a rain protection mechanism (such as rolling out a roof or sheet using a DC motor through the H-Bridge), then sends an alert to the farmer via WIFI and initiates rainwater collection. The system then checks if any portion of the land is dry. If dry land is detected, it pumps stored rainwater from the collection unit to the dry areas, efficiently reusing natural resources. After completing the action, the LCD is updated with the relevant status. After each cycle of action—whether it's irrigation, rain protection, or idle state—the system enters a loop or wait interval before repeating the process. This ensures that it continuously monitors the field while optimizing energy and water usage.

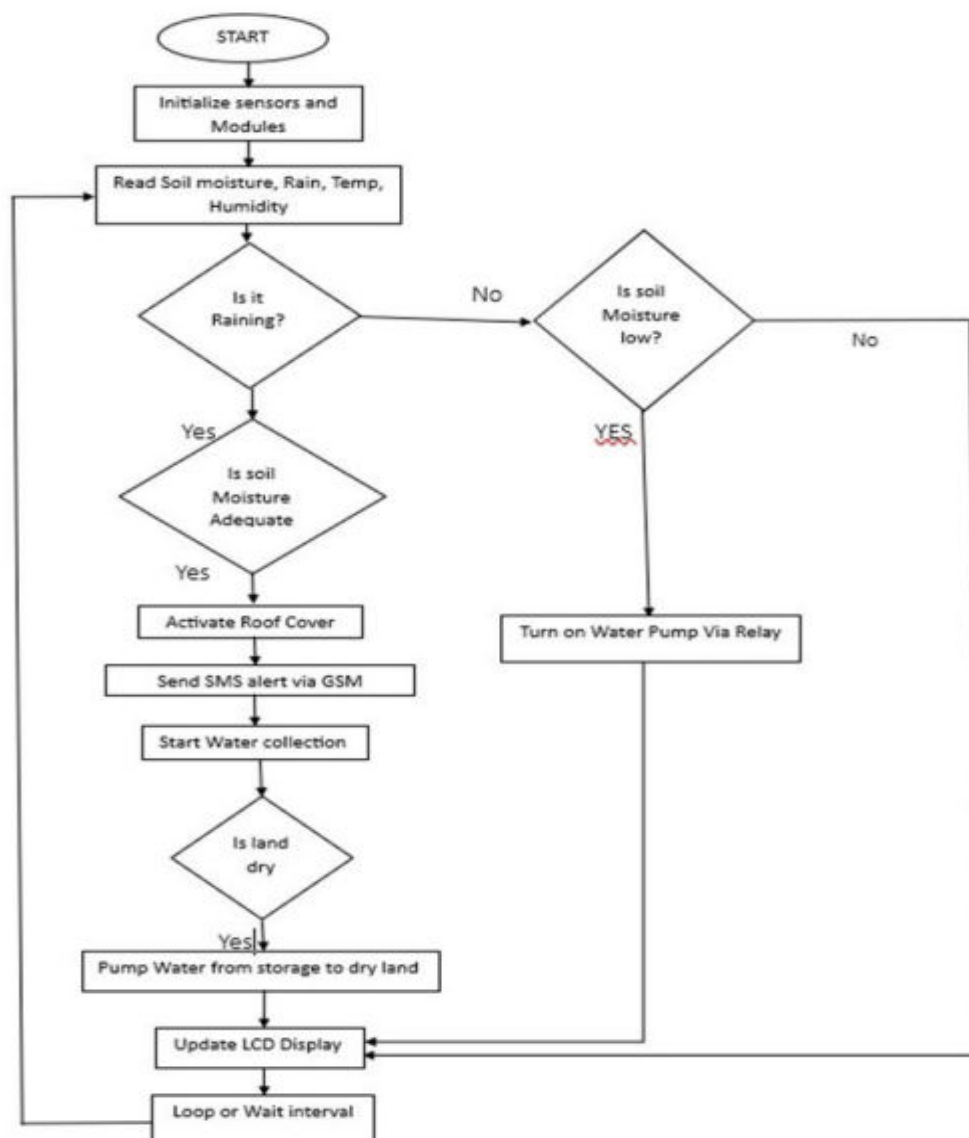


Fig 1 Methodology Flowchart of the Arduino-Based Automated Rain Protection and Irrigation System

IV. EXPERIMENTAL RESULTS.

The developed system was successfully implemented and tested for real-time agricultural automation using Arduino, sensors, and IoT technologies. The system effectively automated both irrigation and crop protection based on environmental conditions. During testing, the soil moisture sensor accurately measured the moisture content in the soil and, upon detecting values below the predefined threshold, the processor automatically activated the relay, which in

turn powered the water pump. This ensured timely irrigation without human intervention, thereby optimizing water usage and avoiding overwatering. Once the soil reached the ideal moisture level, the pump was turned off automatically, demonstrating the effectiveness of the threshold-based logic.



Fig. 2 Model Representation

The rain sensor responded precisely during rainfall events. When rain was detected and the soil moisture was already adequate, the system initiated the rain protection mechanism by activating the motor through the H-bridge driver. This motor deployed a polythene or foam sheet to cover the crops, protecting them from excessive rainfall. After the rain stopped, the system automatically retracted the cover, ensuring minimal manual effort. The water falling on the protective sheet was redirected and collected using a harvesting mechanism, and the stored water was later used for irrigation, promoting sustainable water reuse.

The LCD display provided real-time status updates, such as temperature, moisture levels, and rain detection, making the system user-friendly. Additionally, sensor data was transmitted to the ThingSpeak IoT platform, where it was visualized in graphical format. This remote monitoring capability allowed farmers to view environmental conditions and system actions through the cloud, enhancing decision-making and accessibility. Furthermore, the system featured manual control via mobile SMS, allowing farmers to override automation when required, adding a layer of flexibility and reliability.

Power for the entire setup was provided by a solar panel connected to a battery through a buck-boost converter. This renewable energy approach ensured uninterrupted operation, especially in rural or off-grid areas. The integration of IoT, sensors, cloud communication, and automation created a smart, self-sustained solution capable of improving crop yield, conserving water, and reducing the burden on farmers. Overall, the system proved to be responsive, efficient, and suitable for real-world agricultural applications, particularly in regions affected by unpredictable weather and water scarcity.

V. CONCLUSION

In conclusion, the proposed IoT-based smart agriculture system effectively addresses key challenges faced by farmers, including unpredictable rainfall, inefficient irrigation, and limited real-time monitoring. By integrating sensors for soil moisture, rainfall, temperature, and humidity with a microcontroller-based control unit, the system ensures timely irrigation and protects crops from damage due to excessive rainfall. The automated roof mechanism, triggered during rain, not only safeguards crops but also supports rainwater harvesting for future irrigation needs. The inclusion of Wi-Fi or GSM modules enables remote monitoring and control, providing farmers with real-time updates and alerts through platforms like ThingSpeak or mobile communication. Additionally, the system operates on renewable energy via solar power, making it suitable for rural and off-grid agricultural areas. The successful implementation and testing of the prototype demonstrate its potential to reduce manual labor, conserve water, improve crop yield, and promote sustainable farming practices. Overall, the system presents a scalable, cost-effective, and intelligent solution that can

significantly enhance agricultural productivity through automation and IoT integration.

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