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Smart Automated Shelter for Crop Protection Using IoT

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Abstract: Agriculture is very sensitive to unexpected changes in the environment, like heavy rain or animals entering the fields, which can cause a lot of damage to crops. Old ways of protecting crops depend mostly on people checking things manually and reacting after the fact, which isn't very effective when things happen quickly.
This paper introduces a Smart Automated Shelter for Crop Protection, a system based on the Internet of Things (IoT). It uses several sensors to track rain, soil moisture, and movement, helping to watch over the environment in real time and automatically take action. The system uses an ESP32 microcontroller to make decisions and an ESP8266 module to control the motor, allowing the protective shelter to open and close automatically.
The system also uses simple rules to make sure it doesn't trigger unnecessary actions, and it sends quick alerts to farmers using Blynk, an IoT platform. Tests show that this system responds faster, needs less human help, and better protects crops than old methods.
Keywords: IoT, Smart Agriculture, Crop Protection, ESP32, Sensor Networks, Automation

I. INTRODUCTION

The increasing impact of climate variability and envi-ronmental uncertainties highlights the need for intelligent agricultural support systems that can respond quickly and effectively in real-world farming conditions. Traditional crop protection methods rely heavily on manual monitoring and human intervention, requiring farmers to be physically present in the field to detect sudden rainfall or intrusion events. This approach is time-consuming, inefficient, and often results in delayed response, leading to significant crop damage and reduced productivity.

In agricultural scenarios, the available time to react to environmental changes is extremely limited, and farmers may not always be able to monitor their fields continuously. Sudden rainfall or animal intrusion can damage crops within minutes, especially in large or remote farmlands. At the same time, existing automated solutions are often limited in functionality, rely on single-sensor inputs, or depend heavily on internet connectivity, reducing their reliability and usability in ru-ral environments. Therefore, there is a strong need for a lightweight, automated, and reliable system that can monitor environmental conditions continuously and provide real-time protective actions with minimal human intervention.

This paper introduces a Smart Automated Shelter for Crop Protection, an IoT-based system that integrates multiple sen-sors with automated control mechanisms to enhance crop safety. The system supports real-time monitoring using rain sensors, soil moisture sensors, and motion detection, combined with rule-based decision logic to ensure accurate and timely response. A microcontroller-based architecture enables auto-matic deployment and retraction of a protective shelter, while IoT-based communication provides instant alerts to farmers, allowing remote monitoring and control.

The main contributions of this work are as follows:

1) An IoT-based automated crop protection framework that integrates multi-sensor monitoring with real-time shelter control.
2) A rule-based decision-making mechanism that reduces false activations and improves system reliability.
3) A lightweight and cost-effective system design using embedded systems and wireless communication suitable for rural deployment.
4) A comprehensive evaluation including unit, module, inte-gration, and system-level testing, along with performance comparison with traditional manual methods in terms of response time and efficiency.

The remainder of this paper is organized as follows. Section II reviews related work in IoT-based crop protection systems. Section III describes the proposed system methodology and ar-chitecture. Section IV presents implementation details. Section V discusses experimental results and performance analysis. Section VI outlines future work, and Section VII concludes the paper.

II. LITERATURE REVIEW

Smart agriculture technologies have been widely explored through IoT-based systems, automated crop protection mech-anisms, and sensor-driven monitoring solutions. Several approaches utilize microcontroller-based systems combined with environmental sensors such as rain and soil moisture to protect crops from unpredictable weather conditions. Subhani et al. proposed an automated rain shed system that triggers a motorized shelter during rainfall. While such systems reduce manual effort, they rely on single-parameter sensing, which can lead to inaccurate activation.

IoT-based crop protection systems have been introduced to improve automation and remote monitoring. Irpa et al. developed an automatically controlled shed system that deploys protection when rainfall is detected. Although these systems enhance response time, they depend on stable internet connectivity and lack integration of multiple environmental parameters, limiting their effectiveness in real-world scenarios. More advanced solutions integrate IoT communication with automated shelter mechanisms to provide alerts and remote monitoring. Pawan et al. [3] proposed an IoT-based system that notifies farmers about environmental changes and shelter activation. However, such systems often depend on Wi-Fi, lack structural robustness, and do not include multi-sensor decision-making or energy optimization, reducing their practical appli-cability.

Despite these developments, common limitations include single-sensor dependency, unreliable connectivity in rural areas, and lack of continuous monitoring and intelligent decision-making. Many systems fail to provide a complete and reliable solution for dynamic agricultural environments.

The proposed Smart Automated Shelter for Crop Protection addresses these limitations by integrating multiple sensors with rule-based decision logic for accurate operation. The system enables real-time automated response, reduces false triggers, and provides instant alerts to farmers. Additionally, it is designed to be energy-efficient and suitable for rural deployment, improving overall crop protection and reliability.

III. METHODOLOGY

The Smart Automated Shelter framework is designed as a multi-sensor, always-active crop protection system that inte-grates environmental monitoring with automated actuation and IoT-based communication. The methodology includes system architecture design, functional module integration, decision-making logic, and a structured development workflow used to implement and evaluate the system.

A. System Architecture

The system follows a modular architecture that connects environmental sensors, microcontroller units, motor control mechanisms, and IoT communication modules. The ESP32 microcontroller acts as the central processing unit, collecting data from sensors such as rain, soil moisture, and PIR motion sensors. Based on the analyzed data, control signals are sent to the ESP8266 module, which manages the motorized shelter mechanism.

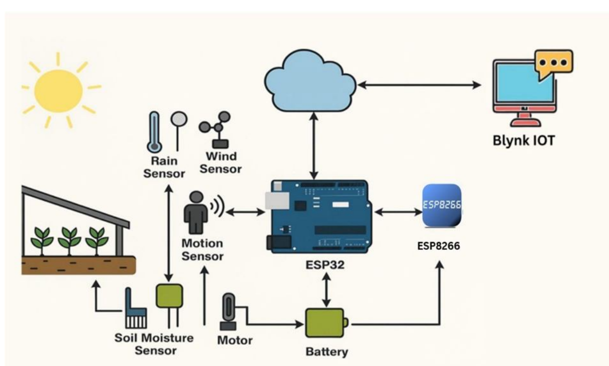

Fig. 1. System architecture of the Smart Automated Shelter showing interaction between sensors, microcontrollers, motor control, and IoT com-munication.

The system continuously monitors environmental conditions and makes real-time decisions to protect crops. When specific conditions such as rainfall or intrusion are detected, the system automatically activates the shelter mechanism. Additionally, IoT communication enables the system to send alerts and status updates to the farmer, ensuring remote monitoring capability.

B. System Workflow

The end-to-end system workflow is described as follows:

1) The system initializes all sensors, microcontroller units, and communication modules.
2) Environmental sensors begin continuous monitoring of rainfall, soil moisture, and motion.
3) The microcontroller processes real-time sensor data and compares it with predefined threshold values.
4) During normal conditions, the system remains in moni-toring mode without triggering any action.
5) When an abnormal condition is detected, such as rainfall or intrusion:
    - Rain detection triggers evaluation of soil moisture conditions.
    - Motion detection activates intrusion alert mecha-nisms.
6) Based on decision logic, the system activates the motor to deploy or retract the shelter.
7) IoT module sends real-time alerts to the farmer regarding system actions and environmental conditions.
8) After execution, the system returns to continuous mon-itoring mode.

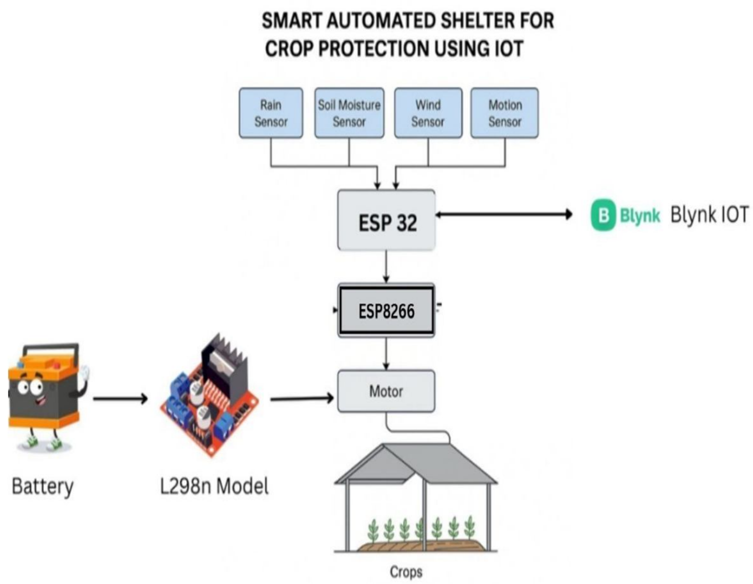

Fig. 2. System workflow illustrating sensor monitoring, decision-making, shelter control, and alert generation.

This workflow ensures real-time response with minimal human intervention while maintaining continuous monitoring of the agricultural environment.

C. Decision Techniques and Control Logic

The proposed system integrates multiple sensing and control mechanisms to ensure accurate and reliable operation.

1) Sensor-Based Monitoring: Rain, soil moisture, and PIR sensors continuously collect environmental data. These inputs are used to determine field conditions and detect potential threats.
2) Rule-Based Decision Logic: The system applies predefined rules to analyze combined sensor inputs. For example, rainfall combined with high soil moisture triggers full shelter closure, while rainfall with low moisture may result in partial action. This approach reduces false activations and improves decision accuracy.
3) Motor Control Mechanism: The shelter is controlled using a motor driver (L298N), which ensures smooth and controlled deployment and retraction based on system decisions.
4) IoT Communication: The system uses IoT platforms such as Blynk to send real-time notifications to farmers, enabling remote monitoring and quick awareness of field conditions.
5) Continuous Monitoring Logic: The system operates in a loop, ensuring uninterrupted sensing, decision-making, and actuation throughout operation.

D. Development Approach

The project follows a structured Waterfall development methodology consisting of requirement analysis, system de-sign, implementation, testing, and evaluation phases. The requirement phase focused on identifying key functionalities such as real-time monitoring, automated shelter control, and alert communication.

The system design phase involved creating architecture diagrams, workflow models, and control logic structures. The implementation phase included programming the ESP32 and ESP8266 microcontrollers using Embedded C and integrating sensors and motor drivers.

The testing phase consisted of unit testing, module test-ing, integration testing, and system testing under simulated environmental conditions such as rainfall and intrusion events. These tests ensured system reliability, responsiveness, and accuracy. The evaluation phase analyzed system performance in terms of response time, automation efficiency, and reduction of manual intervention.

IV. IMPLEMENTATION

A. Software Implementation

The system software is developed using embedded pro-gramming and IoT integration techniques to enable real-time monitoring and automated control of the shelter mechanism. The ESP32 microcontroller serves as the primary processing unit, executing the control logic and managing communication between sensors and actuators. The firmware is developed using Embedded C in the Arduino IDE, ensuring efficient execution of sensor data acquisition and decision-making processes.

The software continuously reads inputs from environmental sensors such as rain, soil moisture, and PIR motion sensors. These inputs are processed using predefined threshold-based logic to determine the appropriate system response. Based on the evaluated conditions, control signals are generated and transmitted to the ESP8266 module, which handles motor control operations.

The system is organized into multiple functional modules:

1) Sensor Monitoring Module: Collects real-time data from rain, soil moisture, and PIR sensors for environ-mental analysis.
2) Decision-Making Module: Implements rule-based logic to evaluate sensor inputs and determine appropriate ac-tions.
3) Motor Control Module: Generates control signals to operate the motor driver for shelter deployment and retraction.
4) IoT Communication Module: Sends real-time alerts and system status updates to farmers using IoT platforms.
5) Continuous Monitoring Module: Ensures uninterrupted system operation through loop-based execution.

B. Hardware Implementation

The hardware system is designed using low-cost and widely available components to ensure affordability and ease of de-ployment in agricultural environments. The ESP32 microcon-troller acts as the central controller, interfaced with multiple sensors and communication modules. The ESP8266 module is used for wireless communication and motor control.

The system integrates environmental sensors including a rain sensor for detecting rainfall, a soil moisture sensor for measuring soil water content, and a PIR motion sensor for de-tecting intrusion. These sensors continuously provide realtime data to the microcontroller for processing.

The motorized shelter mechanism is controlled using an L298N motor driver, which enables smooth and controlled movement of the shelter. The system is powered using a battery or solar-based power supply, ensuring uninterrupted operation even in remote areas with limited electricity access. The hardware design focuses on durability, energy ef-ficiency, and ease of maintenance, making it suitable for continuous operation in outdoor agricultural conditions.

C. Tools and Technologies

The development and implementation of the system utilized the following tools and technologies:

1) Arduino IDE: Used for writing, compiling, and upload-ing firmware to ESP32 and ESP8266 microcontrollers.
2) Embedded C: Programming language used for imple-menting system logic and sensor integration.
3) ESP32 Microcontroller: Serves as the main processing unit for sensor data analysis and decision-making.
4) ESP8266 Module: Handles wireless communication and motor control operations.
5) IoT Platform (Blynk): Provides real-time monitoring and alert notification to farmers.
6) Sensors: Rain sensor, soil moisture sensor, and PIR motion sensor for environmental monitoring.
7) Motor Driver (L298N): Controls the movement of the shelter mechanism.
8) Hardware Tools: Breadboards, jumper wires, and power supply units used for circuit design and testing.

V. RESULTS AND DISCUSSION

A. *Testing Strategy*

The system was evaluated through unit testing, module testing, integration testing, and system-level testing to ensure reliable performance across all components.

Unit testing focused on verifying individual components such as rain sensor detection, soil moisture threshold valida-tion, PIR motion detection, and motor driver control.

Module testing validated key system modules including sensor monitoring, decision-making logic, motor control, and IoT communication.

Integration testing ensured proper interaction between ESP32 processing, ESP8266 communication, and motor actu-ation. The system was tested under simulated conditions such as rainfall, varying soil moisture levels, and intrusion events, confirming accurate response and reliable automation.

System testing evaluated real-time performance under dif-ferent environmental conditions. The system consistently re-sponded as expected, ensuring automated crop protection with minimal delay. The working prototype is shown in

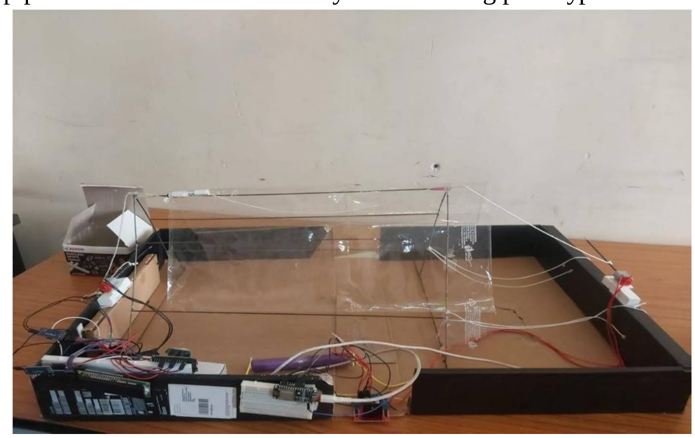

Fig. 3. Working prototype of the Smart Automated Shelter showing sensor-based monitoring and automated shelter control.

B. *Performance Analysis*

To evaluate system effectiveness, key metrics such as re-sponse time, detection accuracy, reliability, and automation efficiency were analyzed.

Manual crop protection methods typically require 15–20 seconds for human response. In contrast, the proposed system automatically activates the shelter within 2–5 seconds after detecting environmental changes.

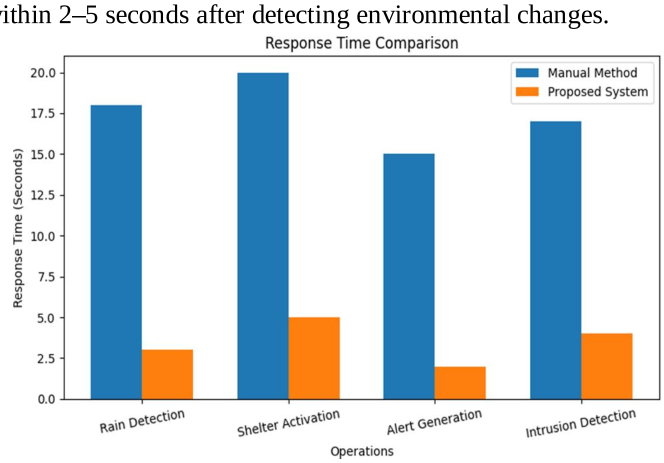

Fig. 4. Comparison of response time between manual methods and the proposed system.

Sensor performance showed high accuracy, with rain detec-tion accuracy of approximately 95%, soil moisture accuracy of around 90%, and motion detection reliability close to 93%. The system also demonstrated stable operation with consistent IoT alert delivery and reliable motor actuation.

TABLE I
PERFORMANCE COMPARISON BETWEEN MANUAL METHOD AND PROPOSED SYSTEM

Operation	Manual Method	Proposed System
Rain Detection Response	18 sec	3 sec
Shelter Activation	20 sec	5 sec
Alert Generation	15 sec	2 sec
Intrusion Detection	17 sec	4 sec
Automation	Not Available	Fully Automated

C. Discussion

The experimental results demonstrate that the Smart Auto-mated Shelter system effectively improves crop protection by enabling real-time monitoring and automated response. The integration of multiple sensors enhances decision accuracy and reduces false activations compared to single-sensor systems.

The system significantly reduces response time and elim-inates the need for continuous manual monitoring, making it highly suitable for modern agricultural environments. IoT-based alert features further improve usability by allowing farmers to monitor field conditions remotely.

However, certain limitations exist, such as dependency on sensor calibration and environmental factors affecting sensor accuracy. Future improvements can include AI-based deci-sion systems, additional environmental sensors, and enhanced power management for long-term deployment.

Overall, the proposed system provides a reliable, cost-effective, and scalable solution for automated crop protection in smart agriculture.

VI. FUTURE SCOPE

Future enhancements to the Smart Automated Shelter sys-tem will focus on extending system functionality, improving decision intelligence, and strengthening real-time crop protec-tion capabilities. One important direction is the integration of additional environmental sensors such as temperature, humid-ity, and light intensity sensors. These parameters can provide a more comprehensive understanding of field conditions and enable more accurate decision-making for shelter activation.

Another enhancement involves incorporating advanced IoT communication frameworks that support cloud-based data stor-age, mobile applications, and real-time dashboards. This would allow farmers to monitor environmental conditions, shelter status, and historical data remotely. Integration with mobile push notifications and analytics platforms can further improve user interaction and enable data-driven agricultural decisions. The system can also be extended by integrating AI-driven prediction models. Machine learning algorithms can analyze historical environmental data and identify patterns related to rainfall, soil conditions, and intrusion events. This would allow the system to predict potential risks and activate the shelter proactively rather than reactively, significantly improving crop protection efficiency.

Further improvements include enhancing the power man-agement system by integrating solar energy solutions and energy-efficient components. This would ensure continuous operation in remote agricultural areas with limited power availability while reducing maintenance requirements. Addi-tionally, implementing adaptive sensor sampling techniques can optimize energy consumption and extend system lifespan. Another important research direction is the integration of smart irrigation systems with the shelter mechanism. By com-bining crop protection with automated irrigation, the system can evolve into a complete precision agriculture solution. This integration would enable optimal water usage, improved crop yield, and better resource management. The system can also be scaled for large agricultural fields by implementing wireless sensor networks (WSN) and distributed control architectures. This would allow multiple sensor nodes and shelter units to operate collaboratively, ensuring efficient coverage of large farmlands.

Future developments may also focus on improving system durability and robustness by designing weather-resistant hard-ware enclosures and advanced mechanical structures for the shelter. These enhancements would ensure reliable operation under harsh environmental conditions. Overall, these future enhancements aim to transform the Smart Automated Shelter from a basic automated protec-tion system into a comprehensive intelligent farming solution capable of predictive analysis, large-scale deployment, and sustainable agricultural management.

VII. CONCLUSION

This paper presented a Smart Automated Shelter for Crop Protection, an IoT-based system designed to provide real-time monitoring and automated response to environmental conditions affecting agricultural productivity. The proposed framework integrates rain, soil moisture, and motion sensors with ESP32 and ESP8266 microcontrollers to create a reliable and efficient crop protection solution. By incorporating rule-based decision logic, the system ensures accurate shelter acti-vation while reducing false triggers and improving operational reliability.

The automated shelter mechanism enables timely deploy-ment and retraction of protective covers without requiring manual intervention. This feature is particularly useful in large or remote agricultural fields where continuous monitoring is difficult. In addition, IoT-based communication allows farmers to receive real-time alerts and monitor field conditions re-motely, improving awareness and decision-making efficiency. The system was developed using a structured engineering approach involving system design, implementation, and com-prehensive testing. Experimental results demonstrated that the proposed system significantly reduces response time when compared to traditional manual methods while maintaining high detection accuracy and stable operation. The lightweight and energy-efficient design further improves its suitability for real-world agricultural deployment.

Overall, the proposed Smart Automated Shelter demon-strates the effectiveness of integrating IoT technologies with automation for modern agriculture. The system improves crop safety, reduces manual effort, and enhances operational effi-ciency through continuous monitoring and intelligent response mechanisms.

Future enhancements may include integration of additional environmental sensors, AI-based predictive models, solar-powered energy systems, and large-scale deployment using wireless sensor networks. These improvements can further transform the system into a comprehensive intelligent farming solution capable of predictive analysis, real-time monitoring, and sustainable agricultural management.

VIII. ACKNOWLEDGMENT

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