Agricultural Crop Protection Against Natural Weather Changes and Animal Detection Using STM32 And AI

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Abstract

The growing demand for sustainable agricultural production has accelerated the adoption of intelligent technologies such as the Internet of Things (IoT), Edge Artificial Intelligence (Edge-AI), and wireless sensor networks. These technologies enable real-time monitoring, data-driven decision-making, and automation in precision farming. This paper presents a comprehensive review of IoT- and Edge-AI-based agricultural systems published between 2020 and 2025, highlighting key methodologies, hardware components, and intelligent frameworks applied in modern agriculture. The study consolidates advances in irrigation control, animal detection, crop protection, and environmental monitoring. By integrating low-cost sensors, embedded microcontrollers, and renewable energy systems, these solutions demonstrate high efficiency and reliability. Furthermore, this work identifies the challenges of scalability, interoperability, and data standardization while outlining potential future improvements to achieve fully autonomous smart farming systems.

Keywords

IoT ,Edge-AI , Smart Agriculture ,Precision Farming, Embedded Systems Sensors, Machine Learning.

I. INTRODUCTION

Agriculture remains one of the most vital sectors supporting global food security, yet it faces mounting challenges such as unpredictable climate conditions, pest infestation, water scarcity, and labor shortages. The fourth industrial revolution has introduced emerging technologies—particularly IoT, artificial intelligence (AI), and cloud computing—that have redefined conventional farming practices. These technologies collectively enable smart agriculture, where interconnected devices monitor field conditions and assist in precision decision- making to enhance productivity and sustainability.

The IoT ecosystem in agriculture integrates various sensors, controllers, and wireless communication modules to collect and analyze environmental parameters such as soil moisture, humidity, temperature, and crop health. The inclusion of Edge-AI enables real- time decision-making directly at the device level, reducing latency and dependence on cloud processing. Studies have shown that

combining IoT with Edge-AI significantly improves automation efficiency, reduces water wastage, and enhances resource optimization.

Recent research (Adami et al., 2024; Reddy et al., 2024) demonstrates how embedded intelligence using devices such as ESP8266 and Arduino supports localized inference for irrigation control, animal repelling, and climate regulation. These developments illustrate a shift from reactive farming to predictive and autonomous systems. However, despite notable progress, several limitations persist in energy management, communication range, and interoperability across platforms. Addressing these gaps can lead to robust, scalable, and eco-friendly agricultural solutions.

II. LITERATURE REVIEW / RELATED WORKS

Between 2020 and 2025, several studies have advanced the integration of Internet of Things (IoT), Edge Artificial Intelligence (Edge-AI), and embedded sensor systems for precision farming. Adami et al. (2024) developed an Edge-AI animal-repelling system using YOLOv3 and LoRa communication, achieving nearly 97% accuracy in real-time field trials. Similarly, Mane et al. (2024) introduced a GSM-based intrusion detection setup combining PIR and ultrasonic sensors, reducing manual field surveillance for farmers.

Rajeshwari et al. (2024) designed an ESP32-based IoT irrigation system that improved water efficiency by 18%, while Mahajan et al. (2025) demonstrated a low- cost solar-powered protection network suitable for small farms. Borhade et al. (2025) presented an automated rainwater protection system capable of safeguarding crops during storms and reusing collected water for irrigation.

Soussi et al. (2024) surveyed smart-sensor data frameworks and emphasized interoperability challenges in precision agriculture. Selvam and Al-Humairi (2023) built an IoT weather-monitoring node with ML-based forecasting, and Hajder et al. (2025) developed an Edge-AI multi-sensor model combining camera and PIR data for real-time pest detection.

Zhang et al. (2025) implemented LoRa- enabled irrigation with 4 km communication range and local edge analytics, while Mutunga et al. (2024) applied IoT electrochemical sensors to detect pesticide pollution in real time. Mowla et al. (2024) compared WSN technologies such as LoRaWAN and ZigBee, recommending hybrid connectivity for wide rural areas. Reddy et al. (2024) proposed a TinyML-based framework for animal detection using only
1.6 MB model size with 96.7% accuracy.

Further innovations include agro- photovoltaic tunnels merging IoT monitoring and renewable energy (Wielgat et al., 2024), and fuzzy-neural network climate controllers for greenhouse environments (Wu et al., 2021). Hong et al. (2020) and Shashank et al. (2020) demonstrated embedded STM32 and Raspberry Pi systems for environmental control and animal detection. Collectively, these works highlight a strong movement toward connected, energy-efficient, and intelligent agricultural systems, though large-scale deployment and data standardization remain key challenges for future research.

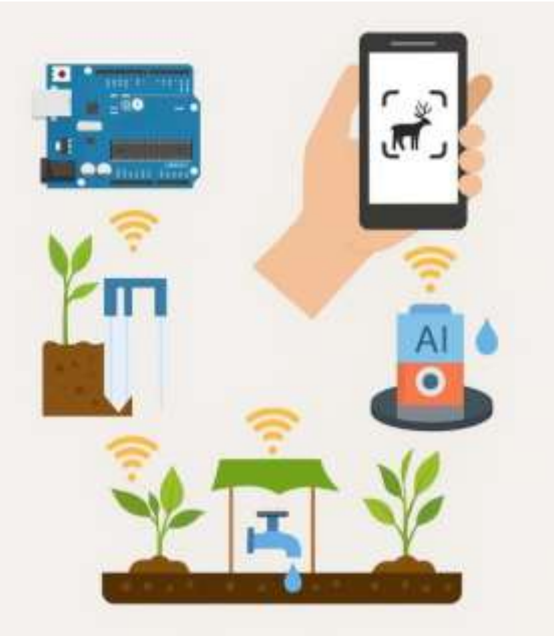
III. METHODOLOGIES AND TECHNOLOGIES USED

3.1 Methodology

Recent advancements in smart agriculture integrate IoT, embedded systems, and automation technologies to enable efficient farm management and precision monitoring. The proposed system employs a combination of sensors, microcontrollers, and communication modules for real-time data collection and automated control.

The soil moisture sensor monitors the soil's water content and activates the water pump when the moisture level falls below a preset threshold. The rain sensor detects rainfall and triggers a motorized polythene sheet mechanism to protect crops from excessive water. An animal detection sensor identifies intrusions in the field, upon which a buzzer alerts the farmer and a camera module captures the image of the detected animal. This image, along with an alert message, is sent to the farmer's mobile device through an IoT or GSM module.

For processing and automation, a microcontroller (such as Arduino or NodeMCU) is used, programmed using Arduino IDE. The data collected from sensors are processed locally and transmitted wirelessly for remote monitoring.



3.2 Technologies used

Microcontroller (Arduino UNO / NodeMCU Core processing unit for automation and control.

Soil Moisture Sensor: Detects soil water content for irrigation control.

Rain Sensor: Activates protective cover during rainfall.

PIR / Ultrasonic Sensor: Detects animal or human intrusion.

Camera Module: Captures images of detected intrusions.

Relay and Motor Driver: Operates water pump and motorized cover.

Buzzer: Provides local alert during intrusion.

GSM / IoT Module: Sends notification and captured image to the farmer's phone.

Power Supply (12V / 5V): Provides operating voltage to all components.

This integrated approach ensures efficient irrigation, crop protection, and real-time monitoring, minimizing human effort and promoting sustainable farming practices.

IV. CHALLENGES AND FUTURE SCOPE

4.1 Challenges

1. Connectivity Limitations:

Rural areas often lack stable network infrastructure, making continuous real- time monitoring and data transmission difficult. Technologies such as GSM experience signal loss over long ranges or in uneven terrain.

2. Energy Efficiency and Power Management:

Continuous operation of multiple sensors and microcontrollers increases power demand. Although solar-based systems are common, energy storage and night-time reliability remain major issues.

3. Hardware Durability:

IoT devices deployed in outdoor environments face challenges from dust, humidity, rainfall, and temperature variations that reduce lifespan and sensor accuracy.

4. Data Standardization and Interoperability:

Devices from different vendors often use incompatible communication protocols and data formats, creating obstacles for unified smart-farming systems.

5. Cybersecurity Risks:

Weak encryption and unsecured wireless communication make IoT nodes vulnerable to hacking or unauthorized access, compromising data integrity and system reliability.

4.2 Future Scope

1. AI-Driven Predictive Analytics:

Future systems will utilize machine learning and deep learning models to predict crop diseases, optimize irrigation schedules, and forecast yields in real time.

2. Edge-Cloud Collaboration:

Combining on-device Edge-AI processing with cloud analytics will enable adaptive learning, reduced latency, and better decision accuracy.

3. Next-Generation Networks (6G and Satellite IoT):

Upcoming communication technologies will expand data coverage in rural regions, ensuring reliable long-range IoT connectivity.

4. Blockchain Integration:

Secure blockchain-based platforms can enable transparent data exchange, traceability, and trusted transactions in agricultural supply chains.

5. Energy Harvesting and Sustainable Sensors:

Future devices will adopt self-powered, biodegradable sensors and hybrid renewable systems for longer operational life and reduced environmental impact.

V. CONCLUSION

The integration of IoT and Edge-AI technologies in agriculture has revolutionized traditional farming methods by enabling real-time monitoring, predictive decision-making, and automation. Studies reviewed from 2020 to 2025 demonstrate that combining embedded sensors, low-cost controllers, and renewable energy systems significantly improves crop protection, irrigation efficiency, and resource utilization. The shift toward edge-based intelligence reduces latency and dependence on cloud infrastructure, enhancing scalability and sustainability for rural applications.

Despite these advances, challenges persist in ensuring connectivity, energy efficiency, and interoperability among heterogeneous devices. Future developments in communication technologies, AI-driven analytics, and blockchain-based data management will play a crucial role in overcoming these barriers. The continuous evolution of IoT and AI will eventually lead to fully autonomous, self-learning, and environmentally adaptive farming ecosystems, driving the global transition toward sustainable smart agriculture.

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