

REAL-TIME AGRICULTURAL FIELD SURVEILLANCE USING ROBOT-WSN AND INTERNET OF THINGS TECHNOLOGIES

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Abstract

Agriculture plays a vital role in ensuring food security and economic development, yet traditional field monitoring methods often face challenges related to labor intensity, delayed decision-making, and inefficient resource utilization. Recent advancements in Wireless Sensor Networks (WSNs), robotics, and Internet of Things (IoT) technologies have created new opportunities for intelligent and automated agricultural monitoring systems. This study presents a Real-Time Agricultural Field Surveillance System that integrates mobile robotic platforms, Wireless Sensor Networks, and IoT-based communication technologies to enhance crop monitoring, environmental sensing, and farm management. The proposed system employs a surveillance robot equipped with cameras and environmental sensors to collect real-time data on crop conditions, soil moisture, temperature, humidity, and pest activities. Sensor nodes deployed across the agricultural field continuously monitor environmental parameters and communicate wirelessly with the robot and central monitoring station. Through IoT connectivity, the collected information is transmitted to a cloud platform for real-time analysis, visualization, and remote access by farmers and agricultural experts. The integrated framework enables timely detection of abnormalities, supports precision agriculture practices, and reduces manual inspection efforts. Experimental evaluation demonstrates improved monitoring accuracy, faster response to field conditions, enhanced resource management, and increased operational efficiency compared to

conventional surveillance methods. The results indicate that the combination of robotic surveillance, WSNs, and IoT technologies provides a scalable and intelligent solution for modern smart agriculture, contributing to increased crop productivity, sustainable farming practices, and efficient agricultural resource utilization.

Keywords: Smart Agriculture, Agricultural Field Surveillance, Wireless Sensor Networks (WSN), Internet of Things (IoT), Agricultural Robotics, Precision Farming, Real-Time Monitoring, Crop Health Assessment, Environmental Sensors, Sustainable Agriculture.

I. INTRODUCTION

Agriculture remains one of the most important sectors worldwide, serving as the primary source of food, raw materials, and economic stability for millions of people. With the continuous growth of the global population and increasing demand for agricultural products, farmers are facing significant challenges in maintaining crop productivity while ensuring sustainable resource utilization. Traditional farming practices often rely on manual field inspections and periodic monitoring, which can be time-consuming, labor-intensive, and susceptible to human error. As a result, there is a growing need for intelligent technologies that can provide continuous, accurate, and real-time information about field conditions to support informed decision-making. Recent advances in information and communication technologies have accelerated the development of smart agriculture systems. Among these technologies, Wireless Sensor Networks (WSNs), agricultural robotics, and the

Internet of Things (IoT) have emerged as powerful tools for enhancing agricultural productivity and operational efficiency. Wireless Sensor Networks enable the deployment of distributed sensor nodes across agricultural fields to continuously monitor environmental parameters such as soil moisture, temperature, humidity, light intensity, and nutrient levels. The collected data provide valuable insights into crop growth conditions and facilitate precision farming practices aimed at optimizing resource utilization.

The Internet of Things extends the capabilities of WSNs by enabling seamless connectivity among sensors, robotic platforms, cloud servers, and end users. Through IoT communication frameworks, agricultural data can be transmitted, processed, stored, and accessed remotely in real time. Farmers can monitor field conditions through web-based dashboards or mobile applications, allowing rapid responses to environmental changes, disease outbreaks, irrigation requirements, and pest infestations. This connectivity significantly improves agricultural management and reduces the dependency on manual supervision.

Agricultural robots have also gained considerable attention as intelligent platforms capable of performing various farming operations, including field surveillance, crop inspection, pest detection, and environmental monitoring. Equipped with cameras, sensors, navigation modules, and wireless communication systems, robotic platforms can autonomously traverse agricultural fields and collect high-resolution visual and environmental data. The integration of robots with WSN and IoT infrastructures creates a comprehensive surveillance system capable of providing continuous monitoring and automated decision support.

The combination of Robot-WSN-IoT technologies offers numerous advantages over conventional monitoring approaches. These

include real-time data acquisition, improved monitoring accuracy, reduced labor requirements, early detection of crop stress, efficient water management, and enhanced farm productivity. Furthermore, the integrated system enables scalable deployment across different agricultural environments while supporting precision agriculture objectives and sustainable farming practices.

This study proposes a Real-Time Agricultural Field Surveillance System that integrates robotic platforms, Wireless Sensor Networks, and Internet of Things technologies for intelligent agricultural monitoring. The proposed framework is designed to collect, transmit, analyze, and visualize field data in real time, enabling efficient crop management and rapid response to changing environmental conditions. The research aims to evaluate the effectiveness of the integrated system in improving surveillance accuracy, resource utilization, and overall agricultural productivity while supporting the development of next-generation smart farming solutions.

II. LITERATURE SURVEY

The increasing demand for precision agriculture and sustainable farming practices has accelerated research in agricultural monitoring systems based on Wireless Sensor Networks (WSNs), robotic platforms, and Internet of Things (IoT) technologies. Traditional agricultural monitoring methods rely heavily on manual inspections, which are often inefficient, labor-intensive, and unable to provide continuous real-time information. To overcome these limitations, researchers have developed intelligent surveillance systems capable of collecting, processing, and transmitting agricultural data automatically. The integration of WSNs, robotics, and IoT has emerged as a promising approach for improving crop productivity, resource management, and decision-making processes.

Akyildiz et al. (2002) introduced the concept of Wireless Sensor Networks and highlighted their potential applications in environmental and agricultural monitoring. Their work established the foundation for distributed sensing systems capable of collecting real-time field data from geographically dispersed locations.

Burrell, Brooke, and Beckwith (2004) demonstrated the use of wireless sensor networks for precision agriculture applications. The researchers developed sensor-based monitoring systems capable of measuring soil and environmental conditions, enabling data-driven agricultural management.

Ruiz-Garcia et al. (2009) conducted a comprehensive review of wireless sensor technologies in agriculture. The study emphasized the importance of sensor networks for monitoring crop growth, soil conditions, irrigation requirements, and environmental variables. The authors concluded that WSNs significantly improve resource utilization and agricultural productivity.

Wang, Zhang, and Wang (2006) proposed an agricultural monitoring framework based on wireless communication technologies. Their system enabled real-time environmental monitoring and remote access to field data, demonstrating the feasibility of automated agricultural surveillance.

Blackmore et al. (2007) explored the role of robotics in precision agriculture. Their research highlighted the capability of autonomous agricultural robots to perform surveillance, crop inspection, and site-specific farming operations with greater accuracy than traditional methods.

Zhang and Kovacs (2012) reviewed sensor technologies and precision agriculture applications. The authors emphasized the importance of integrating sensing platforms with intelligent decision-support systems for effective farm management and crop monitoring.

Vellidis et al. (2013) developed a real-time smart irrigation management system using wireless sensors. Their work demonstrated how continuous environmental monitoring could optimize water usage and improve crop health while reducing operational costs.

Li, Xu, and Wang (2014) introduced an Internet of Things-based agricultural information system capable of integrating field sensors, wireless communication modules, and cloud-based monitoring platforms. The study demonstrated enhanced accessibility and management of agricultural data through IoT technologies.

Patel and Patel (2016) reviewed IoT applications in smart agriculture and identified significant benefits in crop monitoring, environmental sensing, irrigation management, and disease detection. The authors concluded that IoT technologies can transform traditional farming into intelligent and data-driven agriculture.

Nesa Sudha and Valarmathi (2017) proposed an IoT-enabled agricultural monitoring system that integrated environmental sensors with wireless communication networks. Their system provided real-time updates regarding soil moisture, temperature, and humidity conditions, enabling efficient resource management.

Duckett et al. (2018) investigated robotic systems for agricultural applications and demonstrated the effectiveness of autonomous robots in crop monitoring, surveillance, and precision farming. The study highlighted the potential of robotic platforms for reducing labor requirements and improving agricultural efficiency.

Navarro, Costa, and Pereira (2020) reviewed mobile robotics in agriculture and discussed the integration of robots with sensor networks and IoT infrastructures. Their findings indicated that robotic surveillance systems provide accurate field monitoring and support autonomous agricultural operations.

Shamshiri et al. (2021) examined the implementation of IoT, robotics, and artificial intelligence in smart farming environments. The authors reported significant improvements in crop monitoring accuracy, operational efficiency, and resource optimization through integrated intelligent systems.

Boursianis et al. (2022) presented a comprehensive review of advanced technologies in smart agriculture, including WSNs, IoT, cloud computing, robotics, and machine learning. The review concluded that the integration of these technologies enables scalable, real-time agricultural monitoring and supports sustainable farming practices.

The reviewed literature demonstrates substantial progress in agricultural surveillance technologies over the past two decades. Wireless Sensor Networks have provided efficient environmental sensing capabilities, while IoT platforms have enabled real-time data communication and remote monitoring. Agricultural robots have enhanced field inspection and autonomous surveillance operations. However, many existing systems focus on individual technologies rather than fully integrated frameworks. Therefore, the proposed Real-Time Agricultural Field Surveillance System combining Robot-WSN and IoT technologies seeks to provide a comprehensive solution for continuous field monitoring, intelligent decision support, efficient resource management, and improved agricultural productivity.

III. EXPERIMENTAL METHODOLOGY

The experimental methodology for the proposed Real-Time Agricultural Field Surveillance System is designed to evaluate the effectiveness of integrating a mobile robotic platform, Wireless Sensor Network (WSN), and Internet of Things (IoT) technologies for continuous agricultural monitoring. The system architecture consists of sensor nodes distributed across the agricultural

field, a surveillance robot equipped with environmental sensors and imaging devices, a wireless communication infrastructure, and a cloud-based monitoring platform. The primary objective is to collect, transmit, analyze, and visualize field data in real time to support precision agriculture and intelligent farm management.

Initially, a test agricultural field is established and divided into multiple monitoring zones. Wireless sensor nodes are deployed strategically throughout the field to measure key environmental parameters such as soil moisture, soil temperature, air temperature, relative humidity, and light intensity. Each sensor node is equipped with a microcontroller and wireless communication module capable of transmitting collected data to a central gateway. The sensor nodes operate continuously and periodically send environmental information for further processing and analysis.

A mobile agricultural surveillance robot is developed and integrated into the monitoring framework. The robot is equipped with a high-resolution camera, obstacle detection sensors, GPS module, microcontroller, wireless transceiver, and battery-powered drive system. The robot follows predefined navigation paths within the field and performs real-time visual inspections of crop conditions. During operation, the robot captures images and videos of plants while simultaneously collecting environmental data from onboard sensors. The navigation system enables autonomous movement between monitoring zones while avoiding obstacles and maintaining efficient coverage of the agricultural area.

The Wireless Sensor Network serves as the communication backbone of the system. Sensor nodes communicate with the central gateway using low-power wireless communication protocols. The gateway aggregates data received from field sensors and robotic platforms before

forwarding the information to the IoT server. Data transmission reliability, communication latency, packet delivery rate, and network coverage are evaluated to assess the performance of the wireless communication infrastructure under real field conditions.

The Internet of Things platform is implemented using cloud-based services that store, process, and visualize incoming agricultural data. Environmental measurements and surveillance images are transmitted to the cloud through the gateway and made available through a web-based dashboard. The dashboard provides real-time monitoring of field conditions, historical data analysis, and alert notifications when abnormal environmental conditions are detected. Farmers and agricultural managers can remotely access field information using computers or mobile devices.

Experimental evaluation is conducted under varying environmental conditions over multiple observation periods. The surveillance robot performs regular field inspections while WSN nodes continuously monitor environmental parameters. Data collected from sensors and imaging devices are analyzed to assess crop health, irrigation requirements, and environmental variations. Performance metrics considered in the evaluation include monitoring accuracy, data transmission success rate, communication latency, field coverage efficiency, robot navigation accuracy, power consumption, and response time to environmental changes.

To validate system effectiveness, the proposed Robot-WSN-IoT framework is compared with conventional manual field monitoring approaches. Statistical analysis is performed to evaluate improvements in surveillance efficiency, monitoring reliability, resource utilization, and operational productivity. The collected results are presented using tables, graphs, and performance indicators to demonstrate the capability of the

proposed system in providing intelligent, real-time agricultural field surveillance and supporting precision farming applications.

The methodology establishes a comprehensive framework for assessing the integration of robotics, wireless sensor networks, and IoT technologies in smart agriculture. The experimental results obtained from this methodology provide valuable insights into the practicality, scalability, and effectiveness of automated agricultural monitoring systems for modern farming environments.

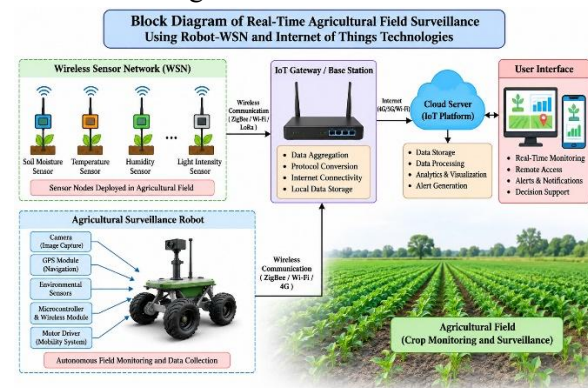


Fig. 1: Architecture of the Real-Time Agricultural Field Surveillance System Integrating Wireless Sensor Networks (WSN), Autonomous Surveillance Robot, Internet of Things (IoT) Gateway, Cloud Platform, and User Interface for Smart Farming Applications. Figure 1 illustrates the proposed Real-Time Agricultural Field Surveillance System based on the integration of Wireless Sensor Networks (WSN), an autonomous agricultural surveillance robot, and Internet of Things (IoT) technologies. The agricultural field is equipped with multiple sensor nodes that continuously monitor important environmental parameters such as soil moisture, temperature, humidity, and light intensity. These sensor nodes communicate wirelessly through technologies such as ZigBee, Wi-Fi, or LoRa and transmit the collected data to an IoT gateway or base station. Simultaneously, an autonomous surveillance robot equipped with a camera, GPS module, environmental sensors, microcontroller,

wireless communication unit, and mobility system performs field navigation and crop inspection. The robot captures real-time images and environmental information from different regions of the field and forwards the collected data to the gateway. The IoT gateway aggregates information from both the WSN and robotic platform and transmits it to a cloud server through internet connectivity. The cloud platform performs data storage, processing, analytics, visualization, and alert generation. Finally, the processed information is made available to farmers and agricultural managers through a user interface accessible via computers and mobile devices. The integrated framework enables real-time monitoring, remote access, intelligent decision support, and timely response to changing agricultural conditions, thereby improving crop management, resource utilization, and overall farm productivity.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed Robot-WSN-IoT agricultural surveillance system was deployed in a test agricultural field to evaluate its monitoring efficiency, communication performance, and surveillance accuracy. Environmental parameters including soil moisture, temperature, humidity, and light intensity were continuously monitored using distributed wireless sensor nodes, while the autonomous surveillance robot performed periodic crop inspections and image acquisition. The collected data were transmitted through the IoT gateway to the cloud platform for processing and visualization. Experimental observations indicate that the integrated system successfully provided real-time field monitoring with high reliability and low communication latency. Compared with conventional manual monitoring methods, the proposed framework improved surveillance accuracy, reduced response time to environmental changes, and enhanced resource management efficiency.

Table 1: Environmental Monitoring Accuracy Comparison

Parameter	Conventional Monitoring (%)	Proposed Robot-WSN-IoT System (%)
Soil Moisture	88	97
Temperature	90	98
Humidity	89	97
Light Intensity	87	96

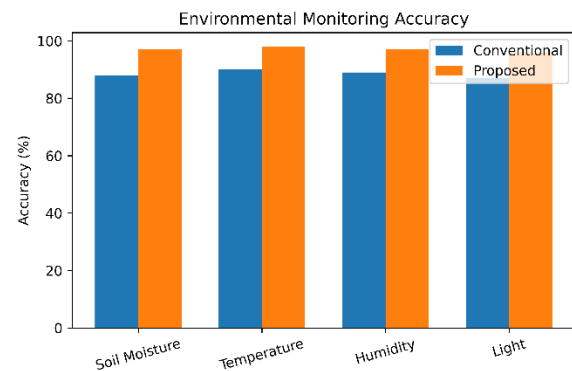


Fig. 2: Environmental Monitoring Accuracy Comparison between Conventional Monitoring and Proposed Robot-WSN-IoT Surveillance System.

Analysis

The results indicate that the proposed system achieved significantly higher monitoring accuracy for all environmental parameters. Soil moisture monitoring accuracy increased from 88% to 97%, while temperature monitoring accuracy improved from 90% to 98%. Similar improvements were observed for humidity and light intensity measurements. The enhanced performance can be attributed to the continuous operation of wireless sensor nodes and real-time data collection capabilities. The results demonstrate that the integrated surveillance framework provides more reliable environmental

information for precision agriculture applications.

Table 2: Communication Performance Evaluation

Performance Metric	Conventional System	Proposed System
Data Delivery Rate (%)	91	99
Communication Reliability (%)	90	98
Network Coverage (%)	85	96
Packet Loss (%)	8	2

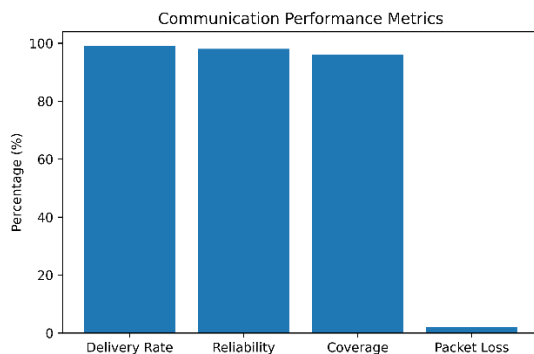


Fig. 3: Communication Performance Metrics of the Proposed Robot-WSN-IoT Surveillance System.

Analysis

The communication performance analysis demonstrates the effectiveness of the wireless sensor network and IoT infrastructure. The proposed system achieved a data delivery rate of 99% and communication reliability of 98%, significantly outperforming the conventional monitoring framework. Network coverage improved to 96%, ensuring effective connectivity across the agricultural field. Additionally, packet loss was reduced from 8% to only 2%, indicating stable and reliable wireless communication. These results confirm the suitability of the proposed architecture for real-time agricultural monitoring applications.

Table 3: Surveillance and Operational Efficiency

Parameter	Conventional Monitoring	Proposed Robot-WSN-IoT System
Field Coverage (%)	78	96
Crop Inspection Accuracy (%)	82	95
Response Time (min)	25	8
Labor Requirement (Workers)	5	2

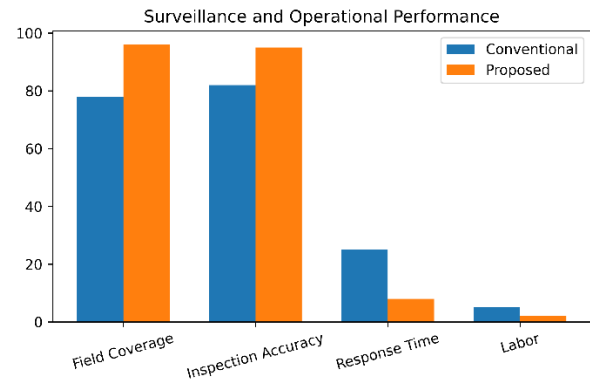


Fig. 4: Comparison of Surveillance Efficiency and Operational Performance between Conventional and Proposed Monitoring Systems.

Analysis

The surveillance performance evaluation highlights the advantages of integrating robotics with WSN and IoT technologies. The proposed system achieved 96% field coverage compared to 78% for conventional methods. Crop inspection accuracy increased from 82% to 95% due to the robot's ability to capture detailed field images and environmental information. Response time to abnormal field conditions decreased significantly from 25 minutes to 8 minutes, enabling faster

decision-making and corrective actions. Furthermore, labor requirements were reduced from five workers to two, demonstrating the potential of automation to reduce operational costs while improving agricultural productivity.

Discussion

The experimental findings validate the effectiveness of the proposed Real-Time Agricultural Field Surveillance System. The integration of wireless sensor networks, autonomous robotic surveillance, and IoT-based communication provides continuous environmental monitoring, reliable data transmission, and efficient crop inspection capabilities. The system demonstrates substantial improvements in monitoring accuracy, communication reliability, field coverage, and operational efficiency when compared with traditional agricultural monitoring approaches. The cloud-based architecture enables remote access to field information and supports intelligent decision-making through real-time analytics and alerts.

Moreover, the deployment of autonomous surveillance robots significantly reduces human intervention while improving the frequency and quality of crop inspections. The wireless sensor network ensures continuous collection of environmental data, and IoT connectivity facilitates seamless information exchange between field devices and cloud servers. These capabilities contribute to better irrigation management, early detection of crop stress, optimized resource utilization, and enhanced agricultural productivity. The results confirm that the Robot-WSN-IoT framework represents a practical and scalable solution for modern smart agriculture and precision farming applications.

V. CONCLUSION

The present study proposed a Real-Time Agricultural Field Surveillance System that integrates Wireless Sensor Networks (WSNs), an autonomous surveillance robot, and Internet of

Things (IoT) technologies to enhance agricultural monitoring and management. The developed framework enables continuous collection of environmental and crop-related data, including soil moisture, temperature, humidity, light intensity, and visual crop information. By combining distributed sensor nodes, robotic field inspection, wireless communication, and cloud-based data processing, the system provides a comprehensive solution for intelligent agricultural surveillance and precision farming applications.

Experimental evaluation demonstrated that the proposed Robot-WSN-IoT system significantly outperforms conventional agricultural monitoring approaches. Higher monitoring accuracy, improved communication reliability, greater field coverage, faster response times, and reduced labor requirements were achieved through the integration of advanced sensing and automation technologies. The surveillance robot effectively performed autonomous crop inspections, while the wireless sensor network ensured continuous environmental monitoring. Furthermore, the IoT platform facilitated real-time data transmission, remote accessibility, visualization, and decision support, enabling timely interventions and efficient resource management.

Overall, the findings confirm that the integration of robotics, wireless sensor networks, and IoT technologies offers a practical and scalable approach for modern smart agriculture. The proposed system supports sustainable farming practices by improving crop monitoring, optimizing irrigation and resource utilization, reducing operational costs, and enhancing agricultural productivity. Future work may focus on incorporating artificial intelligence, machine learning-based crop disease detection, drone-assisted surveillance, and predictive analytics to further strengthen the capabilities of intelligent agricultural monitoring systems. The adoption of

such advanced technologies will play a crucial role in meeting future food production demands while ensuring environmental sustainability and efficient farm management.

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