International Journal of Computer Sciences and Engineering
Vol.**12**, Issue.**7**, pp.**41-47**, July **2024**
ISSN: 2347-2693 (Online)
Available online at: www.ijcseonline.org

Review Article

Advanced Strategies for Enhancing Smart Farming Through Innovative IoT Techniques

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Received: 24/May/2024; **Accepted**: 26/Jun/2024; **Published**: 31/Jul/2024. **DOI**: https://doi.org/10.26438/ijcse/v12i7.4147

Abstract: Smart farming is a significant application of the Internet of Things (IoT). It minimizes water, fertilizer, and crop yield waste. Sustainable development is confronted with two of the world's most pressing problems: the food shortage and the rapid increase in population. Utilizing the infrastructure to use modern technologies like the Internet of Things, big data, and the cloud, smart farming has evolved into a systematic method of managing and monitoring sustainable agriculture. Data optimization is necessary for IoT-cloud systems due to the large amounts of data involved, both organized and unstructured. IoT-based smart farming improves the farming system by monitoring fields of crops. The IoTs in agriculture enable farmers to save time and reduce the consumption of resources such as water. The main aim of this review article is to offer a comprehensive analysis from a social and technological perspective. Important application domains, IoT architecture, and various problems are covered in this paper. In addition, the paper explores the available literature and shows their impact on many parts of the Internet of Things.

Keywords: Smart farming, Internet of Things, modern technologies, big data, IoT-cloud systems, IoT architecture.

1. Introduction

The term 'Agriculture' comes from the Latin words 'Ager' (Land) and 'Culture' (Cultivation). The agricultural industry's working conditions have changed drastically because of technological advancements in the last several years [1]. Now more than ever, the success or failure of an agricultural enterprise hinges on the ability to make quick and complicated decisions [2]. When it comes to making decisions during their specific stages of production and yielding, farmers now have access to more tools and knowledge thanks to technological advancements like big data, the Internet of Things, artificial intelligence, neural networks, and cloud computing [3]. Intelligent agricultural systems have been developed to address current issues such as population growth, climate change, and labor shortage. These systems assist farmers with everything from planting and watering crops to monitoring their health and harvesting them [4, 5]. The use of the Internet of Things (IoT) for environmental and remote monitoring and automation is rapidly growing in the agricultural sector, leading to better tools and services for farmers [6]. Using wireless Internet of Things (IoT) sensors in the fields, smart farming can provide farmers with vital, personal environmental data that can boost their competitiveness and profitability [7].

The term "Internet of Things" (IoT) refers to a system of networked devices, often called "smart objects," that work together to gather information and offer services to people [8]. This decade is experiencing a transition from traditional methods to more advanced ones due to technological advancements. The Internet of Things (IoT) has had a significant impact on the agriculture sector in terms of quality and quantity. Approximately 58% of the Indian population relies on agriculture for their livelihood. Most of India's population relies directly on agriculture. The projected global population by the year 2050 is 9.1 billion [9, 10].

In terms of global fruit production, India ranks second, according to market size. There is proof to suggest that income from agriculture in India will more than double by the year 2025. Predicting the quality of crops has been an area where ML/DL technologies have recently come into their own [11]. A typical Internet of Things (IoT) device will have sensors to gather data about its surroundings, actuators that can be connected wirelessly or through wires, and an embedded system with a CPU, memory, communication modules, I/O interfaces, and battery power [12].

Figure 1. IoT applications for smart farming [7]

As the Internet of Things (IoT) continues to gain popularity in the agricultural sector, thanks to advancements in digital technology, sensing capabilities, and the Internet of Things (Internet), new types of sensors that make use of these technologies are appearing and progressing in the direction of miniaturization, intelligence, integration, and embeddedness [13].

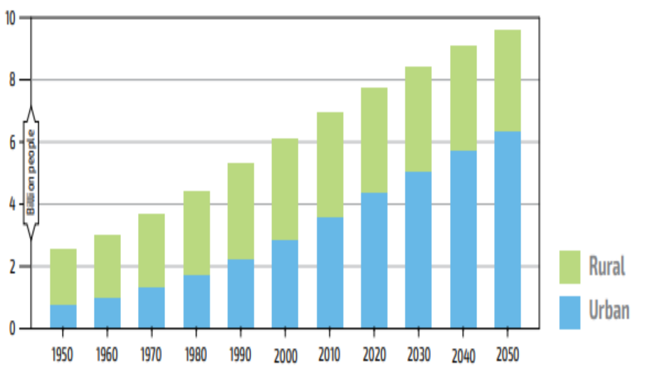

Figure 2. Global urban and rural populations: historical and projected [10]

Presently, the farming and agricultural sectors are undergoing a substantial technological revolution referred to as Agriculture 4.0 and Smart Agriculture (SA). Future scenarios centered on situational awareness will involve the utilization of advanced technology such as Unmanned Aerial Vehicles (UAVs), autonomous tractors, and satellite systems [14]. The combined implementation of Precision Agriculture (PA) and Internet of Things(IoT) technology will be essential for contemporary farmers. To effectively address upcoming challenges including global population expansion, climate change, and depletion of natural resources, a highly efficient and sustainable agricultural production system must be achieved, as emphasized by several governmental organizations [15]. Thus, research and technological innovation are considered essential to address these difficulties. Many Internet of Things (IoT) architectures are designed to track factors, even though they are widely used on farms and in precision agriculture. Integrating Internet of Things (IoT) architectures with machine learning(ML) [16]and deep learning(DL) models to extract accurate information for decision-making is one of the largest issues today [17]. This is a great strategy to boost agricultural output. The only purpose of the existing solutions is to track crops to gather data for superior plantations in the future[6, 18].

Smart farming is one of the many areas where the Internet of Things (IoT) is having a profound impact on the agricultural industry. The Internet of Things is having a significant impact on the following important areas: Internet of Things (IoT) sensors placed across fields measure soil moisture, temperature, pH, and nutrient levels; this information is used for precision agriculture. To maximize resource utilization and increase crop yields, farmers may use this real-time data to make educated decisions on irrigation, fertilization, and pest management[19, 20].

1.1 Cattle Monitoring:
Smart collars and ear tags, which are Internet of Things (IoT) enabled, monitor the whereabouts, activity, and health of cattle. With this information, farmers can better regulate grazing patterns, track reproductive cycles, and identify symptoms of disease [21].

1.2 Management and Monitoring of Crops
Drones fitted with cameras and Internet of Things sensors take detailed pictures of crops and record information about their condition, development, and pest infestations. With this data, farmers can spot problem areas early and fix them quickly [1].

1.3 Supply Chain Optimisation
By utilizing IoT technology, the whole supply chain can be monitored and traced, allowing for full visibility into agricultural products from farm to fork. To keep products safe and secure throughout storage and transit, sensors track factors like humidity and temperature[5, 22].

1.4 Mechanised Gear and Devices
Tractors, harvesters, and irrigation systems that are Internet of Things (IoT) enabled may operate independently and remotely. These smart machines achieve optimizing operations, reducing fuel consumption, and minimizing environmental effects by utilizing real-time data[22].

1.5 Conservation of Natural Resources
Internet of Things (IoT) sensors track a variety of environmental variables, including farm-related air and water quality, weather, and more. With this information, farms may better safeguard natural resources, reduce pollution, and adopt sustainable practices. Data collected from the Internet of Things (IoT) when combined with sophisticated analytics and machine learning algorithms allow for decision support systems and predictive modeling, which are useful tools for farmers. These programs analyze past data and present circumstances to make weather predictions, crop production projections, and recommendations for best agricultural practices.

1.6 Controlled Environment Agriculture (CEA) and Smart Greenhouses:

Internet of Things (IoT) sensors and actuators manage the indoor agricultural environment's temperature, humidity, light, and CO2 concentration. The perfect growth conditions for crops are created by this exact management, leading to bigger yields and better-quality food. Irrigation systems, reservoirs, and water sources are all subject to quality and consumption monitoring by Internet of Things (IoT) sensors. To save water and cut down on resource waste, smart irrigation systems change when plants are watered depending on soil moisture levels and real-time weather predictions.

1.7 Online Marketplaces and Farm Management

Using IoT platforms and mobile applications, farmers are given access to resources such as financial services, agricultural best practices, and market information. Inventory monitoring, labor management, and budgeting are just a few of the many farm management responsibilities that may be made easier with the help of these digital technologies.

2. Literature Review

Various agricultural applications exist for the Internet of Things, and there is a current push to improve farming technology by integrating various technologies. An analysis of the protocols utilized by IoT applications, and a survey of the most common challenges middleware face are part of this article's thorough review of the most popular IoT middleware [2].

Combining ML and IoT technology can significantly improve agricultural decision-making in Somalia, according to this study's findings. The study analyses DT, KNN, and Random Forest algorithms using a crop recommendation system as an example. Notable among the algorithms is the Decision Tree one, which attained a 99.2% accuracy rate while maintaining a balanced recall, F1 score, and precision [3]. Due to its ease of understanding and complete transparency, it is perfect for guiding decisions in agriculture. With accuracies of 99.0% and 97.2% respectively, Random Forest and KNN algorithms are still viable choices in some contexts, despite their slight performance disadvantage.

An increasing number of farms and agricultural fields are opting to automate certain tasks to boost output. By combining the data collected by sensors with the actual actions taken by actuators, we can automate the process of repairing system problems. Using data from many sources, this work introduces a novel three-layer architecture dubbed FARMIT, which combines deep learning with the Internet of Things (IoT) to continually assess crop quality. Analysis of aggregated data, information extraction, and the recommendation of action to fix quality problems are all made easier by the design. When an operator specifies a range for a parameter, they can set up corrective policies to take action when the parameter goes outside that range. Here, sensors that capture both visual and non-visual data were used to implement the concept in a tomato plantation. Data on pests, defects, and crop treatments were examined to determine the tomatoes' quality. When used to assess crop quality, a Random Forest model produced findings that were highly congruent with those of a human expert taster. Here they experimented to compare the efficiency of our multi-source data integration approach to that of more conventional approaches that rely solely on sensor data. Here they demonstrated a lower percentage error of 6.59% compared to the old solution's 6.71% [4].

Smart agriculture AI models hosted in the cloud are utilized in this study. The paradigm change in computing has been accelerated by the usage of sophisticated microcontrollers in hardware. New LoRa technology enables network connectivity, which endows Internet of Things devices with intelligence. With the help of AI, the microcontroller unit keeps a constant eye on the data from the sensors and, if it rises above a certain point, notifies the remote owner by SMS. Reduce your farming's environmental impact using smart agriculture's sustainable methods, which include using fewer pesticides and fertilizer and making better use of the resources nature provides. There will soon be a 5.0 version of agriculture in the field [19].

While the Internet of Things (IoT) and wireless sensors offer great promise for the future of farming, this essay explores both those possibilities and the challenges that may develop from integrating them with more traditional farming practices. The agricultural uses of Internet of Things (IoT) devices and communication mechanisms linked to wireless sensors are extensively investigated. The following is a list of the various agricultural sensors currently on the market: those for use in soil preparation, crop monitoring, irrigation, and pest and insect identification [21]. It explains how this technology aids farmers through the crop life cycle, from planting seeds to harvesting, packaging, and transport. In addition, this article discusses the application of UAVs for crop monitoring and other beneficial purposes, such as maximizing crop production [12].

This research presents an IoT-based method for monitoring soil and atmosphere to optimize crop growth. The system can monitor temperature, humidity, and soil moisture levels via NodeMCU and associated sensors. A Wi-Fi-enabled SMS notification will alert farmers of field environmental conditions [23].

This article examines the power usage of five standard microcontroller (MCU) boards that perform a collection of shared operations and functionalities. This involves investigating the impact on the power consumption of varying the clock speed, serial bit rate, sampling rate of the analog-to-digital converter, and optimizations made by the compiler. Furthermore, the impact of power consumption on the use of on-chip floating point units (FPU) is examined. On all boards, the results demonstrate that subtraction uses somewhat more energy than addition. The energy consumption of the division is much higher than that of any other activity. Designers and developers can use the precise data given in this paper as a good guideline to build embedded systems that use less energy [24].

This survey explores the security structure of IoT, outlining the main challenges and key technologies such as Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSN) that play a crucial role in advancing IoT. The study also explores protocols appropriate for IoT infrastructure and open-source tools and platforms for its advancement. An overview of significant unresolved matters, prospective resolutions, and future research paths is provided. Globalization has enabled the international trading of agricultural products. Farmers and stockbreeders should differentiate themselves by offering consumers top-notch products along with detailed information about the product's origin and the many stages it has been through in the value chain before reaching the retail outlet. The agri-food business has to adopt technologies like the Internet of Things and Distributed Ledger Technologies, such as Blockchain, to enable monitoring [25].

In this work, the author suggested developing and testing an AI-powered smart farming system that utilizes a smart platform to let farmers make predictions. There are three primary steps to implementing this system, which is based on wireless sensor network technology: (i) gathering data from sensors placed in an agricultural field; (ii) cleaning and storing the data; and (iii) applying AI algorithms for predictive processing. The use of CC3200 single-chip sensors for temperature and humidity monitoring in agricultural fields is covered in this work. With the help of the CC3200 interface, the camera can take pictures, which are then sent to the farmers' mobile devices over Wi-Fi and MMS [26].

The article presents a thorough and detailed examination of the current status of research in the agricultural Internet of Things (IoT). Here begin by reviewing the current state of the Internet of Things (IoT) in agriculture and providing a description of its underlying architecture. The next part explores the five fundamental technologies of agricultural IoT: sensor perception, information transmission, wireless communication, information processing, and radio-frequency identification. Afterward, five representative fields are shown as prospective applications of agricultural IoT. Ultimately, an analysis is conducted on the present challenges associated with agricultural IoT, and a forecast is provided regarding the future progress in this domain.

Table 1: Survey table of different methodologies and applications for Smart farming

Authors	Year	Methodology	Application
Abdullahi, M.O et al.[3]	2024	Agricultural Assessment and Sensor Deployment Data Acquisition and Transmission Data Analysis and Machine Learning Automation and Control	Crop Monitoring Precision Agriculture Pest and Disease Management Decision Support System Resource Optimization
Dhal S. et al. [6]	2023	Sensor technology, Cloud computing, Machine Learning	Precision agriculture, Livestock monitoring, Crop prediction
V. A. Diya et al. [13]	2023	IoT framework, Wireless Sensor Networks (WSNs)	Crop monitoring, Soil monitoring, Water management
Indira, P. et al.[5]	2023	Sensor Selection and Installation Data Acquisition and Transmission Data Analysis and AI Implementation	Crop Health Monitoring, Environmental Monitoring, Precision Agriculture, Crop Yield Prediction, Pest Management, Decision Support System
Jinyuan Xu et al. [21]	2022	AI algorithms and machine learning techniques analyze agricultural data. Natural Language Processing (NLP)	Disease and pest detection, Weather reports
Shabir Ahmad S. et al.[18]	2022	IoT sensors, Wireless communication, Data analytics	Precision irrigation, Crop monitoring, Pest control
Liu J. [22]	2021	IoT devices, Edge computing, Artificial Intelligence	Crop health monitoring, Climate adaptation, Supply chain management
A. Dahane et al. [1]	2020	IoT, Machine Learning	Crop monitoring, irrigation scheduling, livestock tracking
Farooq S. et al. [9]	2020	IoT architecture, Data Analytics, Decision support systems	Crop yield optimization, Resource management, Environmental monitoring
MSD A et al. [23]	2020	Sensor Deployment and Configuration Data Acquisition and Transmission Data Analysis and Decision Support Automation and Control	Environmental Monitoring, Precision Agriculture, Crop Yield Optimization, Resource Optimization, Pest Management

3. Research Gap

3.1. Barriers to the implementation of smart agriculture

1. Technically:

High Initial Costs

The cost of acquiring and installing smart agriculture technology, such as sensors, drones, and automated systems, can be prohibitive for small and medium-sized farms.

Complexity and Usability

Advanced technologies often require specialized knowledge to operate and maintain. Many farmers may find these technologies difficult to understand and use effectively.

Interoperability Issues

Different systems and devices may not be compatible with one another, leading to integration challenges.

Data Management

Handling the vast amounts of data generated by smart agriculture technologies requires robust data management systems and expertise in data analysis.

2. Economic Barriers

Cost of Adoption

Apart from the initial investment, there are ongoing costs related to maintenance, upgrades, and training.

Return on Investment (ROI)

Farmers may be uncertain about the ROI, especially in the short term, which can deter investment in new technologies.

Funding and Financing

Limited access to financing options and subsidies can hinder the adoption of smart agriculture technologies, particularly for small-scale farmers.

3. Social Barriers

Resistance to Change

Farmers may be resistant to adopting new technologies due to a lack of familiarity or comfort with traditional farming practices.

Skills Gap

There is often a shortage of skilled labor capable of managing and operating advanced technological systems in agriculture.

Digital Literacy

Low levels of digital literacy among farmers can impede the effective use of smart agriculture technologies.

4. Infrastructural Barriers

Connectivity

Many rural areas lack reliable internet connectivity, which is essential for real-time data transmission and the functioning of IoT devices in agriculture.

Power Supply

Inconsistent or unreliable power supply can affect the operation of smart agriculture equipment and sensors.

5. Regulatory and Policy Barriers

Regulatory Uncertainty

Ambiguities in regulations surrounding the use of drones, data privacy, and other aspects of smart agriculture can create hurdles.

Lack of Standards

The absence of standardized protocols for data sharing and technology integration can lead to inefficiencies and increased costs.

Policy Support

Insufficient government support in terms of policies, subsidies, and incentives for adopting smart agriculture technologies can slow down their implementation.

6. Environmental Barriers

Climate Variability

Unpredictable weather patterns and extreme weather events can disrupt the functioning of smart agriculture systems.

Sustainability Concerns

There may be concerns about the environmental impact of certain technologies, such as the energy consumption of IoT devices.

3.2. Strategies to Overcome These Barriers

To mitigate these barriers, various strategies can be employed:

Training and Education

Providing training programs and resources to improve digital literacy and technical skills among farmers.

Subsidies and Incentives

Offering financial incentives and subsidies to reduce the initial cost burden and encourage adoption.

Public-Private Partnerships

Collaborating with private sector companies to improve infrastructure, such as internet connectivity and power supply in rural areas.

Developing Standards

Establishing standardized protocols for interoperability and data sharing.

Policy and Regulatory Support

Enacting supportive policies and regulations that address the specific needs and challenges of smart agriculture.

Addressing these barriers requires a holistic approach involving stakeholders from government, industry, academia, and the farming community. Through concerted efforts, the potential of smart agriculture technology can be fully realized, leading to more efficient, sustainable, and productive agricultural practices.

4. Conclusion

As the global population continues to rise, there is a growing demand for high-quality, sustainably produced food. Smart farming, empowered by digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), and information communication technology (ICT), offers a promising solution to meet this demand. By integrating these technologies, smart farming enables precise and efficient agricultural practices, reducing waste and optimizing resource use. This approach benefits both large and small farms, providing tools for remote monitoring and management through internet connectivity. AI algorithms can process sensor data to offer valuable insights from planting to harvesting, including packaging and transportation.

The adoption of smart farming techniques holds the potential to revolutionize agriculture by enhancing productivity, sustainability, and profitability. However, to fully realize these benefits, it is essential to address existing barriers such as high initial costs, technical complexity, and the need for robust data management systems. Strategies like providing training and education, offering financial incentives, developing standardized protocols, and enacting supportive policies can help overcome these challenges.

In conclusion, the advancement of smart farming through innovative IoT techniques represents a significant step toward achieving sustainable agricultural practices. By leveraging digital technologies, farmers can improve crop yields, conserve natural resources, and contribute to global food security. Continued research and collaboration among stakeholders will be crucial in driving the successful implementation and evolution of smart farming systems.

Declarations:

Competing interests

No known competing/financial interests are reported in this paper.

Funding Sources:

No Funding was received by the authors.

Author's Contribution:

Dr. Garima Mathur significantly contributed to this research as a guiding mentor. Her expertise and invaluable feedback were crucial throughout the process, from the initial conceptualization to the final stages of manuscript preparation. Dr. Mathur provided critical insights, supervised the methodology, and ensured the research met academic standards.

Vaibhav Tripathi was responsible for the primary research and data collection. He conducted the experiments, analyzed the data, and drafted the initial versions of the manuscript. His work transformed raw materials into a comprehensive and structured research paper.
Both authors have read and approved the final manuscript.

Acknowledgement:

I would like to express my deepest gratitude to Dr. Garima Mathur for her exceptional guidance and mentorship throughout this research. Her insightful feedback and unwavering support were instrumental in transforming this project from initial ideas into a completed paper.
I would also like to thank my family and friends for their continuous encouragement and understanding during this period. Their support has been invaluable in helping me stay motivated and focused.

Finally, I am grateful to my colleagues and peers who provided their input and assistance along the way. Their contributions, although not directly reflected in the paper, were crucial in shaping the direction and quality of the research.
Vaibhav Tripathi

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AUTHORS PROFILE

Dr. Garima Mathur has recently completed her PhD in the Department of Computer Science and Engineering. She has an impressive publication record with nearly 20 papers spanning various fields. Her areas of expertise include machine learning, image processing, blockchain technology, and bioinformatics. In addition to her research accomplishments, Dr. Mathur brings over seven years of teaching experience from prestigious institutions, where she has made significant contributions to both undergraduate and postgraduate education.

Vaibhav Tripathi is from Datia, Madhya Pradesh. I completed my schooling at Rani Laxmi Bai Public School in Datia. I pursued my undergraduate studies in B.Tech with a major in Computer Science, achieving a CGPA of 8.03 out of 10. I come from a traditional Indian Hindu family; my father works as a Panchayat Coordination Officer (PCO) in the Janpad Panchayat Department, and my mother is a homemaker. My future goal is to pursue higher education in my respective field from an overseas institution, further enhancing my knowledge and expertise.