**Role of Internet of Things in the Agriculture Sector: A Comprehensive Review**

**ABSTRACT**

This study aims to evaluate the role and influence of the Internet of Things (IoT) in the agricultural sector. Drawing from an initial analysis that outlines a narrative and conceptual framework for understanding IoT, the research specifically focuses on the use of artificial intelligence (AI) and IoT technologies in agriculture. In India, agriculture has historically lagged behind other sectors in adopting automation and advanced technologies. This delay is largely attributed to limited financial resources and a shortage of technical expertise required for implementing new innovations. A qualitative approach was adopted, utilizing a literature review as the primary research method. The study explores the integration of IoT-driven solutions—such as drones, smart sensors, and agricultural robots (agribots)—that are gradually being introduced into farming practices. The findings indicate that IoT adoption in Indian agriculture is gaining momentum, particularly with the rise of Agritech startups that are encouraging the implementation of smart farming solutions. IoT represents a significant advancement in the evolution of internet technology, enabling physical devices to be interconnected through sensing, computing, and actuating capabilities. These smart devices communicate via the internet, facilitating collaborative tasks and decision-making processes. Components such as sensors, microcontrollers, and actuators gather environmental data, analyze it, and execute appropriate responses, thereby enhancing efficiency and precision in various applications.

The emergence of IoT marks a transformative shift toward intelligent and connected systems, making it a focal point in current scientific research. Although the use of IoT in agriculture is still in its early stages, it is attracting increasing attention. The Government of India has recognized its potential and incorporated smart farming into its Digital India initiative. According to a NASSCOM report, there are approximately 40 startups in India focused on smart agriculture solutions. This review paper explores the concept of IoT, traces its development alongside the evolution of the internet, and examines its current and potential applications in agriculture. Additionally, it highlights the key benefits and challenges associated with IoT integration in farming and presents a review of relevant academic and industry literature.

**KEYWORDS:** Internet of Things (IoT), Smart agriculture, Artificial intelligence, Sensor, Drones.

1. **INTRODUCTION**

 India's economy is primarily agrarian, though services and manufacturing also play significant roles, with agriculture contributing approximately 16.92% to the national GDP in the fiscal year 2020–21. As the global population is projected to reach 9.7 billion by 2050 [1], the demand for food is expected to rise substantially. It is estimated that by 2050, India alone will require around 350 million tons of food grains [2]. To meet the global food demands of a growing population, agricultural production will need to increase by approximately 60% [3].

To achieve this growth sustainably and efficiently, the agricultural sector must adopt smarter, technology-driven approaches. Integrating the Internet of Things (IoT) into various facets of farming can significantly improve efficiency, resource management, and productivity. The declining availability of water resources and the accelerating impacts of climate change further highlight the urgent need for modernization and automation in agriculture.

IoT, through its network of connected devices equipped with sensors and software, enables the collection and exchange of real-time data. This data-driven approach helps in better decision-making and automation of traditional agricultural tasks such as weather prediction, livestock management, soil monitoring, and irrigation control—areas that have traditionally relied on manual labor and experience.

The term "Internet of Things" was introduced by British innovator Kevin Ashton in 1999. It refers to a system of interconnected physical objects embedded with technologies that allow them to collect, transmit, and act on data via the internet or other communication networks [4].

Advancements in cloud computing and widespread internet access have accelerated the adoption of IoT technologies in agriculture. Current research suggests that the agricultural IoT market is growing rapidly, with an expected compound annual growth rate (CAGR) of 20%. By 2025, the number of IoT-connected agricultural devices is projected to reach 225 million.

Studies also show that the use of IoT in farming can lead to significant improvements: average yields can increase by approximately 1.75%, energy costs may drop between $17 and $32 per hectare, and water usage for irrigation can decrease by about 8% [5]. These technologies contribute to reduced operational costs, minimized waste, and improved crop quality.

With the potential to boost global agricultural productivity by as much as 70% by 2050 [3], IoT stands out as a transformative force in the agricultural sector. While adoption is accelerating—with nearly 43% of enterprises globally integrating IoT solutions—the current use of IoT in agriculture represents only the early stages of a much broader technological evolution.

1. **INTERNET OF THINGS IN CURRENT AGRICULTURE**

The term *Internet of Things (IoT)* evokes the concept of a vast network in which "things"—such as sensors, machines, robots, and devices—are connected to the internet, equipped with capabilities for data collection, processing, and autonomous action. Conceptually, IoT merges two ideas: "Internet" and "Things." It can be defined as a global infrastructure of interconnected devices, uniquely identifiable and addressable, operating through standardized communication protocols [6].

According to industry reports, the number of connected agricultural devices has seen exponential growth—from approximately 13 million in 2014 to a projected 225 million by 2024—driven by a global compound annual growth rate (CAGR) of 20% in IoT device installations [7]. The global smart agriculture market is also expanding rapidly and is expected to triple in size, reaching $15.3 billion by 2025, compared to just over $5 billion in 2016 [8].

IoT holds vast potential for transforming the agricultural sector. It significantly reduces human labor, minimizes errors, curtails resource wastage, and enables remote, real-time monitoring of various parameters. As a result, the automation of many farming activities is becoming increasingly practical. A wide variety of IoT-based sensors are now being utilized to collect environmental and crop-related data, which allows for real-time analysis and even prediction of future conditions [9,10].

In recent years, several systems have been developed to monitor and control crop environments using IoT-based frameworks. These systems aim to replace manual methods with automated, accurate, and scalable solutions, as documented in various studies [11,12]. Climate change has adversely impacted agriculture, making data-driven, smart agriculture a necessity. Leveraging IoT technologies can help mitigate these effects by improving both the quantity and quality of agricultural output [13,14].

For instance, Akkas et al. proposed an IoT-based system for greenhouse condition monitoring. The system includes multiple Wireless Sensor Network (WSN) nodes and a central monitoring unit that visualizes data on a graphical interface [15]. Ramu et al. developed a cost-effective agricultural monitoring system utilizing an 8051 microcontroller paired with GSM technology [16]. Sonawane et al. introduced an environment control and monitoring system specifically designed for polyhouse farming, which ensures consistent environmental conditions through real-time data acquisition, online storage, and automated processing [17]. Their system also includes emergency notifications via SMS or email and uses LabVIEW software for monitoring, with data transmitted via TCP/IP protocols. Similarly, Tan et al. demonstrated an IoT-based healthcare monitoring system, where physicians can monitor patient data remotely using advanced sensor analytics [18].

The adoption and study of IoT applications in agriculture have seen significant growth over the years. Figure 1 illustrates the number of related publications indexed in three major scientific databases over the period from 2010 to 2017. Figure 2 further shows a sharp upward trend in research submissions concerning IoT in agriculture during the same timeframe. For this paper, Google Scholar was used to compare publication counts using keywords such as "IoT and agriculture," "IoT and precision agriculture," "IoT and farming," and "IoT and smart agriculture." This notable increase in scholarly interest underlines the importance and relevance of continued investigation into IoT’s role in modern agriculture.



**Figure 1**: Number of publications indexed in the major three scientific databases over an eight years period between 2010 and 2017



**FIGURE 2.** Sharp rise in the trend of submitted research articles related to applications of the internet of things in agriculture in the scientific databases

**B. PURPOSE OF THE STUDY**

With the ongoing integration of information technology across various sectors, agriculture has inevitably experienced significant transformations—particularly through the application of the Internet of Things (IoT). This study aims to explore the impact of IoT on different aspects of agriculture, with a specific focus on how these technologies influence efficiency, productivity, and crop quality on farms. The central objective is to evaluate the extent to which IoT has contributed to improving agricultural outcomes.

The findings of this study are expected to be valuable to a wide range of stakeholders in the agricultural sector. By contributing to the growing body of research on digital agriculture, this study will offer insights that benefit scholars, professionals, and policymakers alike. It will also serve as a reference point for future research examining the implications of IoT in farming practices.

Furthermore, the insights generated from this research can support government agencies in formulating evidence-based policies and strategic initiatives. With a deeper understanding of IoT’s role in enhancing agricultural productivity, improving food quality, and reducing operational costs, policymakers will be better equipped to promote the adoption of technologies such as sensors, automation tools, and smart controllers. Ultimately, this research aims to guide practical actions and policy decisions that maximize the positive impact of IoT in agriculture.

**C. REVIEW STRATEGY**

**1) MATERIALS AND METHODS**

This study aims to evaluate the impact of the Internet of Things (IoT) on agriculture, with a particular focus on understanding how IoT technologies have influenced various agricultural processes and outcomes. To achieve this, the study adopts a retrospective approach, relying on the analysis of secondary sources, including existing research, scholarly articles, and reports. As noted by Snyder, a systematic or semi-systematic literature review allows for a deeper and more comprehensive understanding of a research phenomenon by synthesizing findings from previous studies [19].

This methodology ensures that the study is grounded in empirical evidence, drawing on research—such as meta-analyses and case studies—that directly relates to the adoption and application of IoT in agriculture. By reviewing documented findings, the study seeks to identify and analyze the key ways in which IoT has contributed to changes in agricultural productivity, efficiency, and management practices.

A qualitative research design has been employed, incorporating thematic and content analysis as the primary methods for data interpretation. These analytical techniques involve critically examining the literature to identify recurring patterns, themes, and insights that emerge across multiple sources. Such an approach is particularly suited to descriptive research and provides a foundation for developing informed conclusions about the influence of IoT in the agricultural sector [20].

Given the study’s objective—to explore the multifaceted impacts of IoT on agriculture—this research design is appropriate and effective in achieving meaningful and evidence-based results.

**2) SEARCH STRATEGY**

To identify relevant literature for this study, a series of keywords and search strings were used to conduct searches across multiple academic databases, including IEEE Xplore, ScienceDirect, and SpringerLink. Additionally, Google Scholar and ResearchGate were utilized to locate further peer-reviewed articles and research studies that focus on the impact of the Internet of Things (IoT) in agriculture.

Once relevant articles were identified, the journals in which they were published were evaluated using the SCImago Journal Rank (SJR). Only journals with an H-Index of 20 or higher were included in the final selection. The H-Index is a metric that reflects both the productivity and citation impact of a journal or author, serving as an indicator of the publication's scholarly influence. Journals with a higher H-Index are generally considered more reputable and influential within their academic fields.

Following this selection and screening process, more than forty sources—including peer-reviewed journal articles, professional publications, and reports from government and institutional bodies—were chosen for in-depth review. This eliminative and quality-focused approach ensures that the study is built upon credible and high-impact academic work.

**3) SAMPLING: EXCLUSION AND INCLUSION CRITERIA**

An initial pool of 150 articles, published after 2005, was selected based on the predefined criteria—namely, alignment with the identified keywords and search strings, and publication in journals with an H-Index of 20 or higher. A subsequent in-depth review of these articles was conducted to further refine the selection. This process involved identifying studies that specifically examined the nature of IoT and its impact on agriculture, as well as re-evaluating their relevance and quality using the H-Index as an additional filtering tool. As a result of this evaluative process, the number of articles was narrowed down to a final sample of 30. This sample size was deemed sufficient to support a meaningful analysis and to draw informed conclusions regarding the impact of IoT on agriculture, consistent with the retrospective and evidence-based approach adopted in the study. Furthermore, studies employing a quantitative methodology to assess the influence of IoT in agricultural contexts were given preferential consideration—provided they also met the inclusion criteria. This emphasis on quantitative research ensured that the findings were supported by empirical data and measurable outcomes, thereby strengthening the reliability and validity of the study's conclusions.

1. **INTERNET OF THINGS IN AGRICULTURE**

Building upon the insights from Stočes et al. regarding the convergence of the Internet of Things (IoT) with agriculture, this study focuses on several key dimensions: the architecture of IoT systems, the role of IoT in modern agriculture, its primary areas of application within the sector, as well as the associated benefits and challenges. This section of the report presents an overview and concise discussion of the findings derived from a comprehensive review of various scholarly articles and studies that have explored the nature and impact of IoT in agriculture.

1. **NATURE OF IOT**

The Internet of Things (IoT) has traditionally been closely associated with wireless sensor networks (WSNs). However, a review of recent literature, particularly in the context of agriculture, indicates a shift beyond WSNs alone. While WSNs have historically served as the foundation for IoT development, the scope of IoT has expanded significantly. IoT now refers more broadly to a network of physical objects embedded with sensors, software, processing capabilities, and other technologies that enable them to connect to and exchange data with other devices and systems over the Internet.

IoT represents an ecosystem where physical objects—whether devices, animals, or humans—are equipped with unique identifiers and can transmit data over the Internet without requiring human-to-human or human-to-computer interaction [21]. The technology integrates both legacy communication systems such as GSM, LTE, Bluetooth, and Wi-Fi, as well as newer, purpose-built IoT communication protocols and networks. Examples of these include SigFox, LoRaWAN, IEEE P802.11ah (low-power Wi-Fi), Dash7 Alliance Protocol, RPMA, and nWave [22]. A key feature of these newer IoT networks is their low energy consumption, which allows devices to operate for extended periods—potentially years or even decades—using simple battery systems [23].

The concept of the “Internet of Things” or “Internet of Objects” broadly refers to a collection of networked devices, each embedded with sensors and connected to the Internet [24]. The term was first introduced in 1998 [25] and was popularized by Kevin Ashton in 1999 in the context of supply chain management [26]. IoT is a compound term comprising “Internet,” referring to the global communication infrastructure, and “Things,” which denotes the multitude of connected devices that possess unique identities and are capable of remote sensing, actuation, data collection, and real-time monitoring [27,28].

These devices not only gather and transmit data but can also interact with other devices and systems, either directly or indirectly. In more advanced implementations, they can process data locally or in the cloud, make decisions, and autonomously trigger specific actions. The International Telecommunication Union defines IoT as a “dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols, where physical and virtual ‘things’ have identities, physical attributes, and virtual personalities, and use intelligent interfaces, and are seamlessly integrated into the information network” [29].

IoT devices come in many forms, including wearable sensors, smartwatches, home automation systems, intelligent transportation networks, and health-monitoring tools. These devices often incorporate advanced software capabilities, including machine learning algorithms and artificial intelligence, enabling them to sense their environment, process data, and autonomously execute actions. Collectively, these characteristics reflect the core essence of IoT: the creation of intelligent, connected devices capable of sensing, communicating, analyzing, and acting in real time.

1. **ROLE OF IOT IN AGRICULTURE**

One of the most active and rapidly evolving areas of IoT-based research and product development is agriculture. Recognized globally as a critical sector for ensuring food security, agriculture is increasingly being transformed by smart technologies aimed at improving productivity, efficiency, and sustainability. In the context of India, farmers continue to face numerous challenges, including limited land holdings, inadequate access to modern technology, inconsistent trade policies, fluctuating government support, and the growing impact of climate change. Although Information and Communication Technology (ICT) solutions have addressed some of these issues, they remain insufficient for ensuring reliable and efficient agricultural production. In recent years, ICT has advanced into the realm of IoT—often referred to as “ubiquitous computing”—bringing with it a more dynamic and integrated approach to problem-solving in agriculture [30].

Agricultural production involves a wide range of tasks such as soil and crop monitoring, environmental control (e.g., temperature and moisture), transportation, infrastructure and supply chain management, livestock tracking, pest control, and systems automation. IoT-based convergence technologies offer significant value in this context by enhancing crop quality, increasing yields, and substantially reducing the physical and operational burdens on farmers [31]. In particular, the rise of *precision agriculture*—an approach that relies on real-time data, smart equipment, and predictive analytics—is shaping the future of farming. According to market projections, precision agriculture was expected to reach a value of $3.7 billion by 2018, and it continues to grow.

Precision agriculture integrates GPS data, smart sensors, and automated farming machinery with big data analytics to help farmers make informed decisions. These technologies enable more efficient use of water, fertilizers, and pesticides while minimizing waste and maximizing yield. Given the multifaceted challenges currently facing the agricultural sector, the implementation of IoT-driven smart farming is not only beneficial but increasingly essential.

To realize the full potential of smart agriculture, it is critical to accelerate the development and deployment of IoT-based solutions. These technologies must be introduced at regular intervals and scaled rapidly to meet the demands of modern farming.

IoT in agriculture involves the interconnection of multiple devices—including sensors, actuators, drones, and smart objects—with mobile platforms and cloud infrastructure via the Internet. By leveraging advanced technologies such as robotics, remote sensing, aerial drones, and computer vision—coupled with continuous advances in machine learning and data analytics—IoT enables comprehensive monitoring and management of crop growth, irrigation systems, field mapping, and resource use. This real-time, data-driven approach empowers farmers to make better decisions, thereby saving both time and resources while improving overall productivity and sustainability [32].

1. **INTERNET OF THINGS ARCHITECTURE LAYER**

The Internet of Things (IoT) architecture is commonly divided into three distinct layers: (i) the perception layer, which is primarily supported by wireless sensor networks (WSNs); (ii) the network layer, responsible for transmitting sensor data over long distances through various communication protocols and gateways; and (iii) the application layer, which typically comprises web servers and databases to manage and utilize the data [33], as illustrated in Figure 3.

In the perception layer, sensor nodes are deployed across different agricultural environments such as farms, crop fields, livestock areas, greenhouses, and agricultural machinery to monitor diverse parameters in real time. These sensor nodes collect data which is then transmitted to a local gateway. Within the network layer, this gateway aggregates the sensor data and uploads it to cloud platforms using wireless communication technologies. The layered architecture enables a wide range of agricultural applications including real-time monitoring, management, process control, and the operation of autonomous machinery [34, 35].



**Figure 3**. Architecture of IoT including the application layer, network layer, and perception layer

1. **APPLICATION OF INTERNET OF THINGS IN AGRICULTURE**:

Recent advances in wireless sensor networks have made it easier to measure a variety of data types [45]. These advances have made it possible for IoT to address various agricultural problems and enable sustainable and efficient farming [46]. In agriculture, IoT is used for a wide range of activities, and applications can be broadly divided into four categories as follows: (a) management systems, (b) monitoring systems, (c) control systems, and (d) unmanned machinery, as shown in Fig. 4 [47, 48].

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**Figure 4.** Application of IoT in agriculture, including management systems, monitoring systems, control systems, and unmanned machinery

1. **Management System:** Historically, farmers lacked adequate tools to effectively manage their farms through detailed analyses of costs, benefits, and profitability. However, with advancements in sensor and communication technologies, collecting and storing agricultural data has become significantly easier. This progress highlights the growing need to efficiently manage and utilize the diverse data gathered. Agricultural management systems now encompass various aspects such as farm operations, energy use, water management, and machinery monitoring. Table 1 provides examples of sensors and network technologies integrated into smart management systems, as reported in previous studies.
2. **Agricultural Machinery**

AGCO, a prominent global manufacturer of agricultural machinery, introduced the “Connected Farm Service,” a comprehensive management system designed for farms and agricultural equipment [50]. This system incorporates remote monitoring terminals installed on large-scale smart agricultural machinery, complemented by dedicated mobile and server applications to facilitate seamless operation management [10]. By integrating IoT technology into traditional farming practices, the system delivers valuable insights on machinery usage, real-time equipment status, and operational control requirements [51]. Such innovations enable remote monitoring of field and equipment conditions, ultimately enhancing agricultural productivity through more efficient management.

1. **Farm**

IoT-based Farm Management Information Systems (FMISs) have been developed to support farmers in making informed decisions by organizing and analyzing data collected from various on-farm sensors [52, 53]. These systems provide comprehensive insights into the usage of farm inputs such as machinery, seeds, fertilizers, and pesticides, along with financial evaluations derived through big data analytics. One such system, the Precision Agricultural Management System (PAMS), integrates IoT technology with WebGIS to cater specifically to the management needs of large-scale farming operations [54]. PAMS enables a range of functionalities including data collection, retrieval, analysis, real-time monitoring, remote control of farming processes, and support for strategic production decisions. More broadly, Agricultural Management Information Systems (AMIS) can be applied throughout the entire agricultural cycle to improve productivity and assist farmers in making data-driven decisions [55].

1. **Water**

In response to the growing challenge of water scarcity, the Multi-Intelligent Control System (MICS) was developed to enhance water resource management within the agricultural sector [56]. This IoT-based system is designed to monitor and regulate water usage and reservoir levels in real time, enabling more efficient control of water distribution. By integrating smart sensors and automated control mechanisms, MICS offers a comprehensive solution for optimizing water consumption in farming practices. Reports indicate that the system has proven effective, with the potential to reduce water usage by as much as 60%, making it a promising tool for sustainable agricultural water management.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Sensors** | **Network** | **Reference** |
| **Agricultural machinery** | GPS | GPRS, Wi-Fi, 4G | [10] |
| GPS | GPRS, Bluetooth | [50] |
| **Farm** | Soil temperature sensor, soil pH sensor, soilmoisture sensor | Wi-Fi | [57] |
| **Water** | Moisture sensor, passive infrared sensor,temperature sensor | GSM | [56] |
| Pressure sensor, flowmeter, ultrasonic sensor | Wi-Fi | [44] |

**Table 1**: IoT-based smart management systems applied in agriculture

1. **Monitoring System**

In agriculture, previous studies related to monitoring have been classified into monitoring diseases, fields, greenhouses, livestock, pests, and soil. Table 2 shows the sensors and networks used in the previous studies.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Sensors** | **Network** | **Reference** |
| **Disease** | Air temperature and humidity sensor, soil temperature and moisture sensor, wind speed/direction sensor, rain meter, solar radiation sensor, leaf wetness sensor  | GRPS, GSM, 3G, 4G | [58] |
| Humidity sensor, temperature sensor | ZigBee | [43] |
| **Field** | Soil moisture sensor, temperature sensor | Wi-Fi | [59] |
| Humidity sensor, soil moisture sensor, temperature sensor | Wi-Fi | [60], [61] |
| CO2 sensor, humidity sensor, light intensity sensor,relative humidity and ambient temperature sensor, soilmoisture sensor | LoRa, 4G | [62] |
| Ball float liquid level sensor, digital light intensity sensor,magnetic float sensor, soil moisture sensor, temperatureand humidity sensor | Wi-Fi, 3G | [63] |
| Camera module, light sensor, temperature and humiditysensor | Wi-Fi | [64] |
| **Greenhouse** | Humidity sensor, illumination sensor, pressure sensor,temperature sensor | MICAz | [65] |
| Air humidity sensor, air temperature sensor, soiltemperature sensor | ZigBee | [35] |
| Air quality (CO2) sensor, light sensor, soil moisture sensor | GSM | [66] |
| Illumination sensor, temperature and humidity sensor | GSM, Wi-Fi, ZigBee | [40] |
| **Livestock** | Biometric sensor, temperature and humidity sensor,weathermeter (wind direction, wind speed, and rainfall) | LoRaWAN | [67] |
| Biogas sensor, fire sensor, humidity sensor, temperaturesensor, ultrasonic sensor, water level sensor | Wi-Fi | [68] |
| Accelerometer, air contaminant sensor, CO2 sensor,humidity sensor, NO2 sensor, O2 sensor, temperaturesensor | ZigBee, 3G | [69] |
| **Pest** | Humidity sensor, illumination sensor, temperature sensor | GSM, ZigBee | [70] |
| Hyperspectral sensor | LoRa | [40] |
| **Soil** | pH sensor, soil humidity sensor, soil temperature sensor | Bluetooth | [71] |
| Wi-Fi | [72] |
| Soil moisture sensor | Bluetooth, GPRS, Wi-Fi (2.4 GHz),Wi-Fi (5 GHz), ZigBee, 3G | [73] |
| pH sensor, soil moisture sensor, soil temperature sensor | ZigBee | [13] |
| Soil moisture and temperature sensor, temperature and humidity sensor, ultraviolet light radiation sensor | Wi-Fi, ZigBee | [74] |
| Soil moisture sensor, temperature and humidity sensor, ultrasonic sensor | Wi-Fi | [75] |

**Table 2**: IoT-based smart monitoring systems applied in agriculture

**IoT in Agriculture in India: Applications and Examples**

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Application Area** | **IoT Technology/Tool** | **Example** |
| Crop Monitoring | Real-time soil and crop health monitoring | Soil moisture sensors, temperature sensors | Kheti Smart – Offers real-time crop monitoring via sensor data |
| Smart Irrigation | Automated irrigation based on soil data | Drip irrigation with soil moisture IoT sensors | Fasal – Predictive irrigation schedules based on weather and soil |
| Weather Forecasting | Localized weather prediction | Weather stations with IoT-enabled data logging | Skymet Weather – Provides IoT-based weather data for precision farming |
| Livestock Monitoring | Animal health and activity tracking | GPS collars, RFID, biometric sensors | Stellapps – IoT-based dairy monitoring for cattle health and milk yield |
| Greenhouse Automation | Climate control in greenhouses | Sensors for humidity, temperature, CO₂, light | AgriNext – Smart greenhouse solutions with cloud-based controls |
| Supply Chain & Logistics | Real-time tracking of produce post-harvest | Real-time tracking of produce post-harvest | Ninjacart – Uses IoT and AI to manage fresh produce logistics |
| Pest & Disease Control | Early pest detection and prevention | Camera sensors + AI, pesticide control systems | TartanSense – IoT-powered robots for targeted pesticide application |
| Farm Management Systems | Comprehensive data-driven farm decisions | Mobile apps + IoT sensors + cloud analytics | CropIn – Provides actionable insights through IoT and satellite data |

**Table 3: IoT in Agriculture in India: Applications and Examples**

**Potential IoT Value in Agriculture**

Feeding the growing global population has become an increasingly critical challenge, with the Food and Agriculture Organization (FAO) projecting that by 2050, food production must increase by approximately 70% compared to 2006 levels to meet global demand. The Internet of Things (IoT) has emerged as a transformative solution to address this issue, offering innovative tools to enhance agricultural efficiency and sustainability [105]. Numerous studies have explored the application of IoT technologies to improve food safety and optimize resource use. For example, Libelium employed 3G connectivity to support environmental monitoring and management in vineyards in northwest Spain. This implementation led to a reduction of over 20% in phytosanitary treatments such as fungicides and fertilizers, while also achieving a 15% increase in crop yield [106]. In another study, an Integrated Control Strategy (ICS) for greenhouse irrigation of romaine lettuce significantly reduced water and electricity consumption—by up to 90% [107]. Similarly, the development of an Automated Irrigation System (AIS), utilizing Wireless Sensor Networks (WSNs) and GPRS modules, demonstrated a 90% reduction in water usage compared to traditional irrigation systems [92].

The global market for IoT devices in agriculture has also shown substantial growth. Business Insider’s premium research service reported that while global shipments of agricultural IoT devices were valued at just $30 million USD in 2015, this figure was projected to reach $75 million USD by 2020, representing an annual growth rate of nearly 20%. Furthermore, the broader economic potential of IoT is expected to rise dramatically, with estimates suggesting a total value of up to $15 trillion USD by 2022, compared to $1 trillion in 2013, even without accounting for increased revenues [108]. As sensor technologies and network infrastructures continue to advance, the role of IoT in agriculture is poised to expand rapidly, offering new opportunities to meet global food security goals.

**Discussion**

In recent years, a significant number of studies have explored the application of Internet of Things (IoT) technologies in agriculture. The majority of this research has focused on smart monitoring and control systems, particularly in areas such as soil condition monitoring, farm and greenhouse environmental tracking, and automated irrigation and fertilizer management. These efforts aim to enhance productivity and resource efficiency through real-time data collection and responsive system automation. Furthermore, the integration of IoT with cloud computing has enabled the development of robust architectures that allow farmers to access timely, location-specific information through Wireless Sensor Networks (WSNs), thereby supporting informed decision-making in agricultural operations [63]. Despite these advancements, there are still several challenges and limitations that need to be addressed. The future potential of IoT in agriculture, along with these existing constraints, is discussed in detail in the following sections.

**Conclusions**

In recent years, the Internet of Things (IoT) has been actively integrated into various sectors of agricultural technology. This review provides a comprehensive overview of IoT applications in agricultural automation. The discussion begins with a brief exploration of the standard IoT architecture, including the perception, network, and application layers. Subsequently, the review categorizes and analyzes different implementations of IoT in agriculture, identifying four primary functional groups: management systems, monitoring systems, control systems, and unmanned machinery.

A significant portion of current IoT applications in agriculture focuses on monitoring soil conditions, livestock environments, and greenhouse climates, as well as controlling irrigation and other environmental parameters. The review also evaluates key communication technologies widely employed in agricultural IoT, such as Wi-Fi, LoRaWAN, mobile networks (e.g., 2G, 3G, 4G), ZigBee, and Bluetooth. Each technology differs in terms of transmission range, energy efficiency, and cost, making it essential for farmers to choose sensors and communication protocols suited to the specific environmental and operational needs of their farms.

Moreover, to ensure reliable performance in outdoor agricultural environments, IoT devices must be robust and resilient, with strong network stability and adequate data security measures in place. Based on the literature, IoT in agriculture has demonstrated the potential to resolve various long-standing challenges, enhance crop quality and yield, and increase farm profitability by reducing labor requirements and input costs.

Despite its benefits, certain limitations persist. There is a need for integrated systems that can manage the full spectrum of agricultural processes using IoT technologies. Local communication networks must also be optimized to prevent signal interference. Another area requiring advancement is the use of IoT in autonomous agricultural machinery, where current applications remain limited. To support the development and deployment of autonomous systems—especially within the context of smallholder farming typical in countries like India—improvements in GPS precision and IoT-based control technologies are essential.

On behalf of all authors, the corresponding author states that there is no conflict of interest.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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