International Journal of Applied Science and Engineering
Citation: *IJASE*: **11**(02): 141-155, December 2023
DOI: 10.30954/2322-0465.2.2023.5

Review Paper

INFORMATION SCIENCE

Demystifying Internet of Things (IoT) in promotion of Digital Agricultural Systems: Utilizations and Issues, and Concerns-*A Review*

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Received: 16 Sept., 2023 **Revised:** 26 Nov., 2023 **Accepted:** 03 Dec., 2023

ABSTRACT

Agricultural Informatics is integrated with agricultural systems with informatics dedicated for the best practices using ICT. For doing best Agro Informatics practice various allied technologies are employed for healthy agricultural activities required for best computation and information management. Information Technology powered with various sub-technologies such as Software Technologies, Network Technologies, Multimedia Technologies, Web Technologies, Database Technologies, and all these impacting Agricultural Systems and it is also leads the development of new-age and advanced Agricultural Systems. Additionally, emerging technologies are proving benefits in promoting healthy agricultural practices and among these Internet of Things (IoT) is considered as important for advancing traditional agricultural systems into smart and digital agricultural systems. There are ample benefits and opportunities offered by the IoT based agricultural systems which include the flexibility, productivity, advancement of agricultural systems with quality and quantity, environmental monitoring systems, remote agricultural systems, and so on. This paper highlights basics of Agricultural Informatics emphasizing IoT applications in advancing agricultural systems. This paper reveals the existing works of IoT applications in agriculture and allied fields including the issues and challenges in contemporary context.

Keywords: Agro Informatics, Development, Digital Agriculture, Smart Agriculture, Agricultural Information Technology, Internet of Things (IoT), Computing

How to cite this article: Paul, P.K., Kayyali, M., Hossain, R. and Saavedra, R. (2023). Demystifying Internet of Things (IoT) in promotion of Digital Agricultural Systems: Utilizations and Issues, and Concerns-*A Review*. *IJASE.*, **11**(02): 141-155.

Source of Support: None; **Conflict of Interest:** None

Agriculture is most important for everyone and it is required for survive, worldwide all the countries have given importance in agricultural development. For a perfect and proper economic development Agricultural development considered as most vital and required. Thus in addition to developed countries very recently developing countries are also putting effort in enhancing and modernizing ICT enable agriculture[1],[36],[47]. Though Smart Agriculture has various impacts in developing society but there are urgent needs in skilled professionals for the development of advanced Agricultural systems for new age farming and advanced cultivation methods. For effective and wider benefits of the technology, Agricultural Informatics is helpful in developing smart agriculture for various advantages like heat, cold, flood, drought, insect, pest infestations, disease identification, weather etc. Uses of ICT in computing is impactful in managing serving the food habits, required and proper nutritional requirements, etc. Further smart agriculture can also solve and attain the ecological concerns related to the agricultural systems. Information Technology is composed with various sub-fields and emerging technologies and among these IoT or Internet of Things considered as important and impactful. Internet of Things is taking care of individual's lives more efficient and smarter in different way. Smart Agriculture is dedicated in real, latest implementation of new age agro systems. Agriculture is required in all types of countries; whether developed, developing and undeveloped. This is considered as one of the oldest professions and occupation providers worldwide. Directly and indirectly variety of jobs associated with agriculture including pre agricultural and post agricultural. Thus in recent years gradual involvement of the technologies in agriculture is noticeable. Using Internet of Things (IoT) not only developed agricultural systems but also sustainable agriculture is possible effectively. Manpower development in agricultural systems is highly required and needed in modernizing agriculture leading to Digital Agricultural Systems using proper agriculture informatics and allied technologies. Internet of Things is popularly known as IoT and lies on various types of objects and sensors and therefore applicable in wearable devices to various diverse areas IoT[2],[3],[22]. The Entrepreneur Kevin Ashton in the year 1990s first coined the term Internet of Thongs and gradually it has developed drastically in many countries. Internet of Things (IoT) lies on various built-in sensors which are dedicated in collecting data. Here IP based sensors are lies on internet and network, and considered as impactful in proper, automatic heating and lighting etc. IoT is one of the promising technology for smart agriculture supported by digital society.

Objective of the Work

The paper entitled 'Demystifying Internet of Things (IoT) in promotion of Digital Agricultural Systems: Utilizations and Issues, and Concerns-*A Review'* is a review based work and dedicated in revealing following (but not limited to)—

- To know about the basic of Agricultural Informatics with its foundation, features and characteristics.
- To know about the basic and foundation of Digital Agriculture supported by Internet of Things (IoT); fundamental and emerging applications.
- To learn about the fundamental aspects of Internet of Things with features, functions and basic structure and uses.
- To learn about the issues and concern related to the Internet of Things (IoT) applications in Agricultural sector for advancement, productivity and quality.

Methods

'Demystifying Internet of Things (IoT) in promotion of Digital Agricultural Systems: Utilizations and Issues, and Concerns-*A Review'* is a scientific review based on existing sources. For completion of this work various secondary sources have consulted including books, reference books, encyclopedias, and existing journals. To understand the major issues and concerns of Digital and Smart Agriculture various websites related to Agro ICT, smart agriculture service providers have been consulted, analyzed and reported in this work. In addition to Smart agriculture service providers engaged companies in IoT also been mapped and analyzed. After gather data from different sources all are categorized in this work.

Existing Works

Different experts and researchers conducted works related to this area which are connected directly and indirectly and reported in different medias, communications, journals, etc. and here some of works reported before reaching the core of Agro Informatics in connection with IoT.

Ali, A., Hussain, T., Tantashutikun, N., Hussain, N. & Cocetta, G. (2023)[5] in this paper they have provided an overview of the creative strategies employed to mitigate the effects of climate change while maintaining adequate agricultural production. Along with clever approaches for modern crop management techniques, the technologies employed for yield prediction and enhancement are also explored. It has been shown that implementing IoT and smart farming techniques is necessary to boost agricultural productivity. Many techniques have been developed for precise crop health and water supply monitoring. These techniques include yield prediction, pest control, smart irrigation, and disease identification and classification. Yield prediction under various projected climatic conditions not only helps modify present irrigation and fertilizer management strategies, but it also results in efficient resource utilization and profitable agricultural output. With the use of clever and accurate disease management, diseases can be successfully controlled and yields can be maintained. A genetic algorithm is one image processing method that farmers can use to efficiently control leaf diseases in a variety of crops. Urbanization's impact on food production has been studied, and potential solutions—like vertical farming and its array of indoor production methods—have been put forth. A range of horticulture products require artificial illumination for improved development and growth, with the aim of providing and investigating.

Badran, A.I. & Kashmoola, M.Y. (2020)[8] discussed to give farmers information on soil, water availability, and the overall condition of the field, the authors devised a smart agriculture system. The suggested approach was designed to increase the efficiency of irrigation and agriculture while also making it simpler for farmers to make the right decisions that would boost yield. Utilizing Internet of Things (IoT) networks to track environmental variables and combining this data with a user-specific online application allows farmers to effectively apply their knowledge to maximize agricultural yields.

Gondchawar, N. and Kawitkar, R.S. (2016)[14] in this research work they suggested an Internet of Things (IoT)-based smart farm system that would use a network of devices to keep an eye on things like light intensity, temperature, humidity, and soil moisture. So that small farmers in poor countries could use it, the method was made to be cheap and simple to set up. To get the sensor data and handle it, the writers used both Arduino microcontrollers and Raspberry Pi single-board computers. The information was then sent to a cloud-based platform, where machine learning techniques were used to look at it and make suggestions for fertilization and watering. The writers also made a mobile app that farmers could use on their phones to get to the info and suggestions. They put the system to the test in the field in India and found that it could correctly track the conditions of the soil and give good advice on how to handle crops. The writers came to the conclusion that IoT could change farming in developing countries by giving farmers access to real-time data and help from experts. They did say, though, that putting IoT systems in rural places can be hard because people don't always have access to power and the internet.

Jayaraman, P. P., Yavari, A., Georgakopoulos, D., Morshed, A. & Zaslavsky, A. (2016)[19] the researches of the paper suggested an Internet of Things (IoT) system for precision agriculture that would use drones with sensors to keep an eye on the health and growth of crops. The writers said that regular ways of keeping an eye on crops, like looking at them by hand and using satellite images, can take a long time, cost a lot of money, and might not give accurate enough information for precision farming. Drones with high-resolution cameras and sensors would be used in the suggested system to take detailed pictures of crops and gather information about their health, wetness levels, and nutrient content. The data was then sent wirelessly to a site in the cloud so that machine learning methods could be used to analyze it. Based on the study of the data, the app suggested ways to water, fertilize, and get rid of pests. The authors tested the system in the field in Australia and found that it could correctly track the health of crops and make good suggestions for how to handle them. The system also cut down on the time and money needed for standard ways of tracking crops, they found. After careful research, the writers came to the conclusion that IoT and drone technology could make farming much more accurate and efficient, especially on a big scale. They did say, though, that using drones in farmland comes with some problems, such as privacy concerns, problems with the law, and the fact that people need special skills and training to use the drones properly.

Khattab, A., Abdelgawad, A. & Yelmarthi, K. (2016)[23] in this paper the authors discussed an Internet of Things (IoT) system for smart watering in farming. A network of soil moisture sensors kept an eye on the soil's level of wetness in real time. The sensor data was sent electronically to a base station. The base station used a fuzzy logic program to process the data and figure out the best time to water the plants. The system also came with a mobile app that farmers could use on their phones to watch and direct the irrigation system from afar. The writers tested the system in the field in Egypt and found that it could save up to 25% of the water that was used for regular irrigation. And they discovered that the system could raise food yields by making sure plants got the right amount of water at the right time. The writers came to the conclusion that IoT could make irrigation in farmland much more efficient and long-lasting, especially in dry areas where water is scarce. But they also said that some farmers, especially those in poor countries, might not be able to use sensors and transmission tools because they are too expensive.

Kirubanand, V.B., Rohini, V. & Laxmankumar, V. (2021)[24] in this paper the authors discuss that agriculture is crucial to producing enough food to support the world's expanding population - which is expected to reach 9.6 billion people by 2050 - but problems with the environment and climate change also need to be addressed. "Smart agriculture" refers to the application of Internet of Things (IoT) technologies to address these problems in agriculture. Vital indications like crop growth rate, pH, nutrient levels, soil moisture, and livestock health may all be monitored with IoT sensors. Data enable targeted treatments like irrigation, fertilizer application, and disease control. Drones used in agriculture can evaluate crop health across vast areas in real time. By measuring the pH of the soil, sensors can determine the ideal degrees of acidity and alkalinity for a given crop's growth.

Montoya, E.A.Q., Colorado, S.F.J., Muñoz, W.Y.C. & Golondrino, G.E.C. (2017)[28] the authors discussed the use of Internet of Things (IoT) to keep an eye on and manage the quality of water used for farming irrigation. The writers said that water quality is very important for food growth and output, and that regular ways of checking water quality take a lot of time and cost a lot of money. A network of water quality sensors kept an eye on things like pH, temperature, and dissolved oxygen levels in real time in the suggested system. The sensor data was sent wirelessly to a cloud-based platform so that it could be analyzed. The platform used machine learning techniques to find outliers and let farms know about them. The system also had motors that could change the watering system on their own based on data about the water quality. The writers did a case study on a farm in Colombia and discovered that the IoT system could correctly track the quality of the water and let them know about possible problems before they got out of hand. It was also found that the method made the irrigation system work better overall and cut down on the chance of crop loss from bad water. The writers came to the conclusion that IoT could change the way water quality is managed in agriculture, especially in places where water supplies are scarce or not very good[28]. But they also said that some farmers might not be able to use them because the water quality sensors are expensive and farmers in remote places need stable power and internet.

Tzounis, A., Katsoulas, N., Bartzanas, T. & Kittas, C. (2017)[47] in this paper the authors looked into how IoT could be used in greenhouse farming, focusing on the creation of a cloud-based system for keeping an eye on and managing greenhouse conditions. The writers planned and set up a system with a network of sensors that measured the greenhouse's temperature, humidity, light strength, and CO_2 levels. Then, this information was sent to a cloud-based platform to be studied using machine learning techniques to make the greenhouse the best place for plants to grow. The system also had actuators that could change the greenhouse's surroundings on their own based on the study of the data. One greenhouse in Greece was used as a case study by the writers. They found that the IoT system greatly increased crop yields and decreased energy use compared to standard greenhouse management methods. They came to the conclusion that IoT could change greenhouse farming by making it easier to control the growing environment precisely and lowering the need for human help. They did say, though, that the high cost of putting IoT systems in greenhouses might stop some farmers from using them.

Zhang, M., Wang, X., Feng, H., Huang, Q., Xiao, X. & Zhang, X. (2021)[49] in their study they examined how wearable IoT is being used in precision livestock farming, emphasizing the value of correct information perception, wearable IoT's biocompatibility, and sustainability monitoring in IoT-enabled precision livestock farming. The authors conclude that because most wearable IoT devices can produce precise, dynamic, and long-lasting signals, they are generally applicable to people. IoT wearables are rarely adapted or used for precision livestock farming, nonetheless, in the farming environment.

Internet of Things: Basics

The Internet of Things (IoT) is a groundbreaking device that has changed how we connect with the world around us. The Internet of Things (IoT) is a network of real devices, cars, home appliances, and other things that are linked together by electronics, software, sensors, and network connections. This lets these devices to collect and share data. This technology has made a lot of things possible by letting devices talk to and connect with each other without any problems[6],[7],[31]. This means that the real world can be more directly integrated into computer systems.

Connecting everyday things to the internet so that they can share and receive info is what IoT is all about. After this, the data can be studied and used to make smart choices, automate tasks, and make things run more smoothly. IoT has the potential to revolutionize many fields, from industry and agriculture to healthcare and transportation, by giving us real-time information and letting us watch and control things from afar. The idea of IoT is not completely new. In fact, the first programmable logic processors (PLCs), which were used in industrial automation in the early 1980s, were the first devices that could be linked together. But Kevin Ashton came up with the phrase "Internet of Things" in 1999, while he was working at MIT's Auto-ID Labs. Using radio-frequency identification (RFID) tags and devices, Ashton imagined a world where computers could learn about the real world without any help from people.

Fast changes in wireless transmission, low-cost devices, and cloud software have helped the IoT grow quickly since then. The general use of smartphones and the broad availability of high-speed internet have both helped the Internet of Things grow even faster. IoT now includes a lot of different technologies, such as Wi-Fi, Bluetooth, Zigbee, NFC, and cellular networks, which make it easy for devices to talk to each other and share data. IoT is made up of four major layers: the application layer, the processing layer, the network layer, and the sensor layer. There are sensors and devices in the sensing layer that either get information from the world or change it. These sensors can pick up on things like temperature, humidity, pressure, motion, and light, and then turn those readings into computer messages.

Architecture of IoT

The design of the Internet of Things (IoT) is a complicated system made up of many parts that work together to make it possible for devices to talk to each other and share data. The IoT architecture is made to help connect actual things like sensors and gadgets to the digital world. This lets data to be collected, processed, and analyzed in real time. In the IoT design, there are different layers, and each has its own set of tools and rules[16],[39],[46]. These are the most important parts of the IoT architecture:

Device Layer (Sensing Layer): The device layer, also known as the sensing layer, consists of physical devices, sensors, and actuators that collect data from the environment and perform actions based on the received instructions. These devices can be anything from simple temperature sensors to complex industrial machines. The device layer is responsible for converting physical parameters into digital signals that can be processed by higher layers in the architecture. Some common technologies used in the device layer include:

- RFID (Radio-Frequency Identification)
- NFC (Near Field Communication)
- Bluetooth Low Energy (BLE)
- Zigbee
- Z-Wave
- Sensors (temperature, humidity, pressure, motion, etc.)
- Actuators (motors, switches, valves, etc.)

Communication Layer (Network Layer): The communication layer, also referred to as the network layer, is responsible for connecting the devices in the device layer to the internet or other networks. This layer enables the transmission of data between devices and the cloud or edge computing systems. It includes various communication technologies and protocols that ensure reliable and secure data transfer. Some common technologies used in the communication layer include:

- Wi-Fi
- Cellular networks (2G, 3G, 4G, 5G)
- Ethernet
- LoRaWAN (Long Range Wide Area Network)
- Sigfox
- NB-IoT (Narrowband IoT)
- Satellite communication

Data Processing Layer : The data processing layer, also known as the edge or fog computing layer, is responsible for processing and analyzing data close to the source, i.e., near the devices or at the edge of the network. This layer helps to reduce latency, improve real-time decision-making, and optimize network bandwidth by processing data locally before sending it to the cloud. Edge computing devices can include:

- Gateways
- Routers
- Switches
- Industrial PCs
- Micro data centers

Application Layer: The application layer is the top level of the IoT design. It's where IoT apps and services are built and deployed using data gathered and processed by the lower layers. End users can connect with the IoT system through this layer, which also lets IoT data be shared with other business systems and services. The following are some popular uses in the IoT application layer:

- Home and building control that is smart
- Predictive repair and automation in industry
- Monitoring health and medical care
- Smart shipping and moving goods
- Controlling energy use and smart grids
- Farming and precise farming

Management and Security Layer: This is the top level of the IoT design. It connects all the other layers. The job of this layer is to make sure that the IoT system works safely and effectively. It does this by managing devices, data, and security. The control and security layer does a lot of important things, such as

- Setting up and provisioning devices
- Updating firmware and taking care of devices
- Controlling who can access what
- Data security and safe ways to talk
- Finding and stopping intrusions

Following the rules and guidelines for security:

The Internet of Things design also has other parts besides these layers, such as:

1. Manage devices and handle data with platforms and software
2. Analytic tools and machine learning models to help you understand and analyze data
3. Developers can use APIs and SDKs to build and connect apps.
4. IDEs and developer tools for writing code and testing IoT apps

In conclusion, the design of the Internet of Things is a complicated, multi-layered system that lets real-world objects connect to and talk to the digital world. From collecting and processing data to building and deploying apps, each stage in the design is very important for making sure the IoT system works smoothly and safely. As the Internet of Things (IoT) grows and changes, so will its design. It will need to adapt and grow to meet the IoT ecosystem's growing needs and challenges.

IoT in Enhancing Agricultural Systems into Smart Agriculture

Information Technology plays an important role in advancing, modernizing Agricultural systems into Smart Agriculture. Internet of Things (IoT) is emerging and also introducing digital agriculture systems powered by efficiency, reduced cost, enhanced productivity, resource minimization, and so on[9],[10],[30]. Internet of Things (IoT) in creating Digital and Smarter Agricultural Systems with following means.

Efficiency and Productivity is effectively possible with Internet of Things (IoT) by various means such as monitoring of agricultural products become easy with real-time using IoT enable drones. IoT is also helpful in the promoting need based-irrigation, effective fertilizing, intelligent harvesting, cleaning cultivating zones, etc. Further IoT is also helpful in weather prediction and climate related matters[12],[13],[19]. It is a fact that 87% of world population stays in urban areas and here IoT-is helpful to fulfill agro product need's fulfillment and thus IoT also helps in *Expansion* of Agriculture supported by smart closed-cycle agricultural systems using various Internet of Things (IoT) attributes.

Reducing the Resource supported by emerging sensors, optimization systems possible with IoT based systems and ultimately that can lead in better and effective management of corps, water, energy, land etc. Data from different sorts collected via IoT is helpful in managing pesticides, fertilizers etc, and this can lead the precision farming, and thus it reduces the resources. Further in cleaning and green strategy management and greener farming is helpful in development of organic agriculture[17],[18],[40].

Faster Agro Systems powered by Internet of Things (IoT) due to AI and ES based prediction systems and thus real-time data helps in quick agriculture and can be required in weather, humidity, soil condition management, and all these finally helps in health management of crops, weather changes using Internet of Things (IoT) and this can lead fasters and smarter agriculture.

Agro Quality and Quantity is also positively enhance with IoT Based sysyems particularly using Aerial drone monitoring systems which are connected with various types of sensors, and all these may be required in farm mapping, and ultimately can lead the quality of the crops, plants, vegetables using Internet of Things (IoT) supported systems. Such development of IoT in Agriculture leads to Agro IoT or AIoT for a quality of cultivation. IoT is helpful in managing proper temperature including get the ideas of rainfall and humidity. In managing and monitoring

Climate Systems and Monitoring attached sensors and IoT may be helpful in weather analysis and prediction, and this may lead to the effective crop productions. As IoT helps in real-time weather detection by its sensor and AI based tools; thus monitoring the crops, fields, becomes helpful and required in effective decision making and also in promotion of remote cultivation in certain cases[20],[21],[27].

Precision Cultivation is an alarming concept and here Internet of Things helpful in introducing best farming practice and ultimately helpful in following—

- Managing and monitoring Livestock of agro products.
- Easiest and effective agro related field study.
- Inventory/ budgetary management and monitoring using IoT.
- In proper and effective post agro-transportation management.

Therefore sensors are helpful in cultivation with advancement and quicker decisions to reach Smarter Precision in Cultivation[15],[29],[34].

Remote Agricultural Systems is positively possible using IoT and for this purpose agricultural drones are basically used to get pictures through the aerial view. In this regard thermal or multispectral sensors based drones are gathering of information of the health of crop health. Therefore for crop monitoring Internet of Things is required including for field work management[25],[26],[45]. This technology is separately known as drone technology for gathering real time data as well as multimedia contents. Thus it requires in pre-agricultural activities industry output. Moreover in remote water management also this is worthy and impactful.

Advanced Environmental Monitoring also positively possible using Internet of Things (IoT) for efficient energy management using different tools such as computers and other allied devices, networking switches, drones, etc. Hence in environmental protection including monitoring of air and water quality Internet of Things (IoT) is impactful. Proper wildlife management and their habitats, disaster management are useful using Internet of Things(IoT) based systems.

Data and Information Management is effectively possible with Internet of Things (IoT) for developing a of Digital Agriculture. Various allied and emerging technologies are important in regard to collection of data on large scale. Big Data with IoT dedicated in smart agricultural promotion which include managing the weather conditions, livestock management, and products, healthy and proper intelligent decision making including proper growth of the corps, seed, plants and vegetables. Predictive analytics is required in agricultural product development and here IoT and other emerging technologies responsible in building sustainable and smarter agricultural promotion.

Issues and Concern in Smart Agriculture powered by IoT

The inclusion of Internet of Things (IoT) technology into agricultural systems has gained substantial attention due to its potential to transform farming operations and handle different difficulties in food production and delivery. By integrating IoT devices, sensors, and data analytics, digital agricultural systems strive to optimize resource management, enhance production, and encourage sustainable farming practices. However, like any developing technology, the implementation of IoT in agriculture poses its own set of issues, concerns, and utilization constraints[9],[37],[43]. This detailed research digs into the utilization, benefits, challenges, and concerns surrounding the introduction of IoT in digital agricultural systems, providing a nuanced overview of the field.

Utilization of IoT in Digital Agricultural Systems

Precision Agriculture: IoT-enabled precise agriculture systems utilize sensors and data processing to monitor and manage crop health, soil moisture levels, and environmental factors in realtime. Through data collection and analysis, farmers may make informed decisions to improve irrigation, fertilization, and pest control measures, ultimately leading to enhanced crop yields and resource efficiency.

Livestock Monitoring and Management: Integrating IoT devices such as smart collars and tags provides real-time monitoring of livestock health, behavior, and location. This constant monitoring facilitates early identification of health issues, modification of breeding methods, and optimization of herd management techniques, consequently boosting both animal welfare and productivity[32],[33],[42].

Supply Chain Management: IoT technology promotes traceability and transparency throughout the agricultural supply chain, stretching from farm to fork. Integration of sensors and data analytics into storage facilities, transportation networks, and distribution channels enables stakeholders to follow the flow of agricultural products, monitor storage conditions, and maintain food safety and quality across the supply chain.

Environmental Monitoring: Deploying IoT sensors across agricultural landscapes provides significant information about environmental elements such as temperature, humidity, and rainfall. By monitoring weather patterns and soil conditions, farmers can alter cultivation operations, decrease risks associated with climate variability, and increase resilience to extreme weather occurrences, thus ensuring sustainable agricultural production.

Issues & Concerns

Data Privacy and Security: The development of IoT devices generates large amounts of data, causing data privacy and security issues. Unauthorized access, data breaches, and cyber-attacks pose major hazards to sensitive agricultural data, necessitating sophisticated cybersecurity safeguards and data encryption processes to mitigate these kinds of risks.

Compatibility and Standardization: The absence of compatibility and standardization among IoT devices and platforms is a fundamental hurdle to the seamless integration of digital agriculture systems. Incompatible technologies, proprietary procedures, and vendor lock-in difficulties hamper data exchange and collaboration across varied stakeholders in the agricultural sector.

Cost and Affordability: The initial expenses associated with establishing IoT infrastructure and sensors may be exorbitant for smallholder farmers and agricultural firms, particularly in developing nations. High equipment prices, ongoing maintenance charges, and subscription fees for IoT services may hinder uptake and limit access to technology among underprivileged areas.

Demystifying Internet of Things (IoT) in promotion of Digital Agricultural Systems: Utilizations and Issues, and Concerns-A Review Disparities in access to IoT technology and digital agricultural answers, particularly in rural and isolated locations, increase the digital divide. Limited internet connectivity, limited infrastructure, and technological illiteracy offer challenges to adoption, marginalizing smallholder farmers and limiting the equitable distribution of gains[18],[38],[44].

Data Ownership and Control: Concerns surrounding data ownership and control generate ethical and legal issues in the context of IoT-enabled agricultural systems. Farmers may cede control over their data when sharing it with third-party service providers or agricultural platforms, underlining the significance of consent, openness, and accountability in data governance frameworks.

Reliability and Maintenance: The reliability and maintenance of IoT devices and networks are essential elements impacting their efficacy in agricultural applications. Technical malfunctions, sensor failures, and power outages can disrupt data collection and transmission, reducing the accuracy and dependability of decision-making processes, hence stressing the necessity for robust maintenance routines.

Strategies for Addressing Issues and Concerns

Policy and Regulation: Governments and governing agencies should implement comprehensive policies and laws to guarantee data privacy, encourage interoperability, and provide equal access to IoT technologies. Legislative frameworks should address concerns of data ownership, consent, and accountability while driving investment in rural infrastructure and digital literacy programs.

Capacity Building and Training: Capacity-building efforts and training programs are essential for boosting farmers' digital literacy and technical abilities in IoT adoption. Extension services, farmer cooperatives, and agricultural organizations can give training on IoT technologies, data management, and cybersecurity best practices to empower farmers and agricultural stakeholders[29],[35],[41].

Public-Private Partnerships: Collaboration between government agencies, private sector enterprises, academic institutions, and civil society organizations can stimulate innovation and scale IoT usage in agriculture. Public-private partnerships can utilize resources, skills, and networks to build inexpensive IoT solutions, implement infrastructure, and provide technical support to farmers, thereby supporting inclusive and sustainable agricultural growth.

Data Governance Frameworks: Establishing transparent and accessible data governance frameworks is vital for guaranteeing responsible data management and protection in IoT-enabled agricultural systems. Multistakeholder dialogues, data-sharing agreements, and participatory decision-making procedures can encourage trust, accountability, and ethical use of agricultural data, hence boosting data-driven decision-making and innovation in agriculture[4],[36],[48].

Technology Standards and Certification: The creation of industry standards and certification systems for IoT devices and platforms can enhance interoperability, compatibility, and quality assurance. International organizations, standards agencies, and industry consortia play a significant role in creating technical specifications, testing methods, and certification requirements for IoT technology in agriculture, thereby allowing the adoption of standardized and dependable solutions.

CONCLUSION

The Internet of Things (IoT) is changing the farming business by making smart farming and precision farming possible. IoT lets farmers collect and analyze data on soil moisture, temperature, and nutrient levels by combining sensors, drones, and other devices. This lets them do better watering, fertilization, and pest control. IoT-enabled supply chain management makes sure food is safe and can be tracked from field to fork, while IoT-enabled livestock tracking improves the health and comfort of animals. Even though IoT has a lot of benefits and possibilities, it also has some big problems that need to be fixed. One of the biggest problems is privacy and security, because more and more gadgets are connecting and sending and collecting huge amounts of data. This creates new holes and risks. By resolving these difficulties and concerns through joint efforts and innovative techniques, stakeholders may harness the full potential of IoT in supporting digital agricultural systems. With responsible implementation and smart investments, IoT-enabled technologies can drive environmentally friendly agriculture, enhance food security, and improve incomes for farming communities internationally.

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