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Smart Agriculture through IoT: Innovations and Challenges

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Abstract

The growth trendy the worldwide population coupled with a decline in herbal resources, farmland, and the increase in unpredictable environmental situations leads to meals protection is becoming a major concern for all countries worldwide. These issues are motivators which are driving the rural enterprise to transition to clever agriculture with the application cutting-edge the net contemporary (IoT) and huge information solutions to improve operational efficiency and productivity. The IoT integrates a series cutting-edge current solutions and technology, consisting of wireless sensor networks, cognitive radio ad hoc networks, cloud computing, large statistics, and cease-person packages. This take a look at presents a survey today's IoT solutions and demonstrates how IoT can be integrated into the clever agriculture region. To obtain this objective, we discuss the imaginative and prescient modern-day IoT-enabled clever agriculture ecosystems by way of comparing their architecture (IoT gadgets, conversation technology, massive statistics storage, and processing), their programs, and studies timeline. Similarly, we talk developments and opportunities cutting-edge IoT packages for smart agriculture and also indicate the open issues and demanding situations modern IoT software in clever agriculture. we are hoping that the findings latest this examine will represent crucial guidelines in research and merchandising modern IoT solutions aiming to improve the productivity and quality today's the agriculture zone in addition to facilitating the transition cutting-edge a future sustainable surroundings with an agro ecological method.

Keywords: Sustainable Agriculture, Green Technologies, Internet Of Things, Natural Resources; Iot Ecosystem

Introduction:

The intention to meet the cutting-edge worldwide desires of humanity, new solutions and technology are constantly being proposed and carried out. This has caused the advent of the net of things (IoT) IoT is defined as the community of all objects that are embedded inside devices, sensors, machines, software program and people thru the net environment to communicate, exchange data and have interaction for you to provide a complete solution among the actual global and the virtual global In recent years, IoT has been applied in a chain of domains, such as smart houses clever cities smart power independent cars clever agriculture, campus management, healthcare , and logistics collection of different IoT applications. As we recognize we're living within the era of smart computing and superior era that impacts many domains including the education region too. In this paper we're seeking to put some light on the adaptability of Augmented reality (AR) and digital fact (VR) technology and their packages in agricultural education. Several research discovered that the AR/VR have the capacity to enhance the student's capabilities, know-how and system of mastering. It could trade the learning and teaching stories in a completely effective and attractive way. The intention of this paper is to offer a short creation with admire to within the previous few years, the research community has been inquisitive about adapting new technology in education. one of the latest technology which can be explored and adopted by means of the schooling area is Augmented reality (AR) and digital fact (VR). It brought a good sized contribution to a study room environment of these technology from an educational view that is majorly targeted on students or newbies. AR is an emerging technology which is used to experience a unique experience of the actual global with the assist of computer-generated content that combines into our perception of the real global for a selected vicinity or sports. It isn't always a brand new technology but demand inside the schooling zone has been increasing over the previous few years. The studies community takes an hobby to apply this generation and its application inside the education area. The demand for ICT has multiplied hastily after covid-19 pandemic and technical improvement allows to use this technology because of its powerful and wonderful functions and outcomes inside the training sector.

Figure 1. IoT applications for smart agriculture

The demand for agricultural products continues to increase. However, arable land is decreasing, natural resources are increasingly depleted, and food security has become the biggest problem facing all countries around the world due to the increase in unpredictable natural problems such as global warming, salinization, and floods. In recent years, new solutions and technologies have been introduced in the agricultural sector with the aim of increasing agricultural production [1]. A new trend is the application of IoT and big data. A considerable number of studies have focused on research, experimentation, and application [2, 3]. According to Cisco's prediction, by 2030, more than 500 billion IoT devices will be connected to the Internet [4]. The use of IoT and big data is expected to enable smart agriculture and improve efficiency and productivity [5]. For many years, wireless sensor networks (WSNs) have been widely used in the agricultural field and have formed the basis for the development of smart agriculture [6]. The unique characteristics of WSNs, such as their ability to self-organize, self-configure, self-create, and self-heal, make them suitable for smart agriculture [7]. The sensing device consists of a radio frequency (RF) transceiver, a sensor, a microcontroller, and a battery power source [8]. WSNs focus on applications such as environmental monitoring, automation of machine control, and traceability [9]. The development of science and technology, as well as the urgent need for breakthrough solutions and technologies to improve productivity and efficiency in the agricultural sector, have led to the introduction of IoT. The main motivation for their application is the breakthrough in smart agriculture and its inevitable role as the future of smart and sustainable environmental management. IoT integrates many existing solutions and technologies, including WSNs, cognitive radio, ad-hoc networks, cloud computing, and end-user applications [10]. In the smart agricultural sector, automation solutions and technologies, machine machinery, knowledge, decision support, services, and software are seamlessly integrated to help farmers improve productivity, product quality, and profitability [11]. This study provides a comprehensive study of IoT applications for smart agriculture. An analysis of 135 relevant papers published between 2017 and 2022 was conducted. First, 550 relevant papers published during this period (2017-2022) were searched from major scientific databases, including IEEE Xplore Digital Library, Science Direct, MDPI, and Springer, using keywords such as IoT-enabled smart agriculture, smart agriculture, Internet of Things, aquaponics, IoT-based forestry monitoring, tracking and tracing, smart precision agriculture, greenhouse production, Sigfox, LoRa, Wi-Fi, LoRa WAN, and IoT ecosystem.

Figure 2.IoT applications for smart agriculture

We analyzed and discussed the benefits and challenges, open questions, trends and opportunities of IoT in the field of smart agriculture.

2. IoT Ecosystem Architecture for Smart Agriculture

This architecture consists of three main components: IoT devices, communication technology, and data storage and big data processes. Introduces IoT applications in agriculture, including (1) monitoring, (2) tracking and traceability, (3) precision agriculture, and (4) greenhouses. Section 4 presents some open questions and future research issues on IoT for smart agricultureThe general architecture of an IoT device consists of sensors that collect information from the environment, actuators based on wired or wireless connections, an embedded system with a processor, memory, communication modules, input/output interfaces, and battery power [12]. The general architecture of a typical smart agriculture IoT device .The sensor devices are specifically designed for use in open environments, nature, soil, water, and air, and measure and record environmental parameters that affect production, such as soil nutrients, moisture, and temperature. Smart farming solutions are an agricultural technique that is frequently used in large outdoor farmlands. Therefore, the devices that support the solution must have some unique characteristics, such as the ability to withstand the effects of weather, humidity, and temperature fluctuations throughout their lifetime. Some of its key features make IoT devices suitable for smart agriculture solutions [13]. In the field of smart agriculture, several representative sensors are used depending on the required operation.

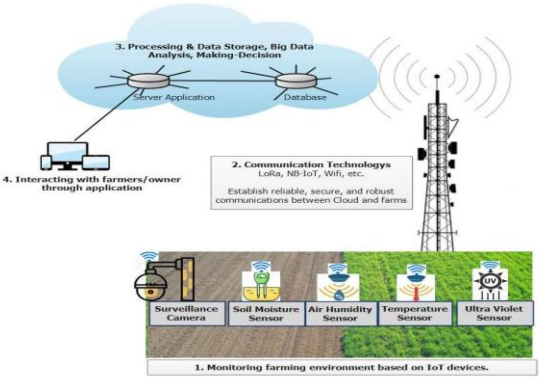

Figure 3. IoT ecosystems' architecture for smart agriculture.

2.1 IoT Devices:The common architecture of an IoT device consists of sensors to collect information from the environment, actuators based on wired or wireless connections, and an embedded system that has a processor, memory, communication modules, input–output interfaces, Embedded systems are interactive modules that can be programmed, like FPGAs (field programmable gate arrays).Sensor devices are made to work in open environments like nature, soil, water, and air to measure and gather environmental factors that impact production, such as soil nutrients, humidity, and temperature .Smart farming solutions are used in large outdoor agricultural operations, so the devices need to have special features to handle weather, humidity, and temperature changes over time.

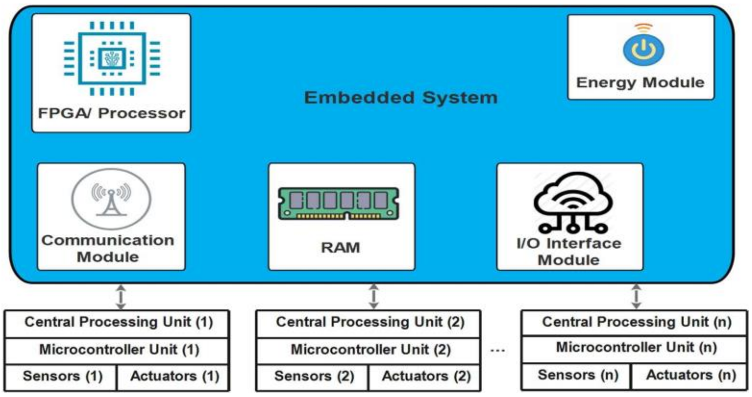

Figure 4. architecture of an IoT device.

Sensors can be divided into several typical categories, such as: (1) Position sensors, (2) Optical sensors, (3) Mechanical sensors, (4) Electrochemical sensors, (5) Airflow sensors. These sensors are used to collect information such as air temperature, soil temperature, humidity, soil moisture, leaf moisture, precipitation, wind speed, wind direction, solar radiation, and air pressure [14,15].

2.2 Communication Technology : Research on communication technology for IoT [16] has revealed that in order to integrate IoT into the field of smart agriculture, communication technology needs to gradually improve the development of IoT devices. They play an important role in the development of

IoT systems. Existing communication solutions can be categorized into protocols, spectrum, and topology.

Protocols: Many wireless communication protocols have been proposed for the smart agriculture field. Based on these protocols, devices in smart agriculture systems can interact, exchange information, monitor and control agricultural conditions, and make decisions to improve yield and production efficiency. A number of typical low-power communication protocols commonly used in smart agriculture can be categorized into short-range and long-range categories based on communication range.

Type	Spectrum	Transmission Distance	Type of Network	Frequency	Data Rate
802.11a/b/g/n/ac	Unlicensed	100m	WLAN	2.4-5Ghz	2-700 mbps
802.11p	Licensed	1 km	WLAN	5.9 GHz	3–27 Mbps
SigFox	Licensed	Rural: 50 km Urban:10 km	LPWA	Zwave	100–600 bps
LoRaWAN	Licensed	20 km	LPWA	Several Sub-GHz	0.3–100 kbps
NB-IoT	Licensed	35 km	LPWA	Zwave	250kbps
Bluetooth	Unlicensed	100 m	WPAN	2.4 GHz	2–26 Mbps
NFC	Unlicensed	20 cm	D2D	13.56 MHz	424 kbps

Table 1 shows some representative communication technologies for the smart agriculture field

The values in Table 1 show that short-range communication technologies have a transmission range of less than 20 (m), are energy efficient, and have low data rates. These protocols are widely used in sensor networks, while long-range communication technologies have a transmission range of tens of kilometers, consume more energy, and are installed in the backhaul communication between devices. A diverse review of low-power communication technologies for IoT, [17].

Spectrum: Each radio uses a specific frequency band for communication. The FCC (Federal Communications Commission) has defined license-free frequency bands for license-free operation in scientific, industrial, and medical fields [18]. These frequency bands are often used for low-power, short-range applications. As a result, many common technologies in the smart agriculture field, ranging from wireless machine control and UAVs to communication technologies such as Wi-Fi and Bluetooth, use license-free frequency bands [19]. However, the use of royalty-free frequency bands comes with several challenges, including ensuring quality of service, initial infrastructure setup costs, and

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interference caused by a large number of IoT devices [20]. Licensed spectrum is usually allocated to mobile networks, which ensures efficient network traffic, improves reliability, improves quality of service (QoS), provides security, provides comprehensive coverage, and reduces the initialization costs of the infrastructure for users. However, the use of licensed frequency bands has several limitations, including: B. High data transmission costs and low energy efficiency of IoT devices [21]. Several recent studies have demonstrated the efficiency of unlicensed frequency bands in the mm Wave range, which consume very little power but achieve long transmission distances and high data rates. A limitation of mm Wave spectrum is that data rates are highly affected by weather conditions, especially rain [22]. Topology: The communication spectrum and operating protocol setup of IoT devices depends on the structure in which IoT devices are deployed for smart agriculture applications. There are usually two main types of nodes in a smart agriculture network structure: sensor nodes and backhaul nodes . The common characteristics of IoT sensor nodes are short communication range, low data rate, and energy efficiency. In contrast, IoT backhaul nodes often require long transmission range, high throughput, and high data rate. Therefore, the sensor node or backhaul node will select and install the appropriate communication technology based on the role of each IoT network node [23]. Figure 5 shows a typical low-power network topology designed to measure and monitor elements in a smart farm. The system includes: 2.3. Data analysis and storage solutions In the field of smart agriculture, in addition to the main problems of sensing, data collection, and equipment control to meet the real agricultural environment, data storage and processing are also important issues and face several challenges . In reality, the amount of data collected is huge, and traditional solutions for data storage, organization, and processing are not practical. Therefore, it is necessary to study big data processing solutions and apply them to smart agriculture. The complexity of storing and processing data is due to the unique characteristics of the smart agriculture field, which includes unstructured data and a variety of formats such as text, images, audio, video, economic figures, and market information. Recent solutions and technologies have introduced the use of cloud platforms for storage and analysis of data collected from farms [24]. In addition, cloud-based big data analytics solutions such as edge computing and fog computing have also been proposed to reduce latency and costs and support QoS.

Research results show that many management information systems have been proposed for intelligent agriculture in recent years.

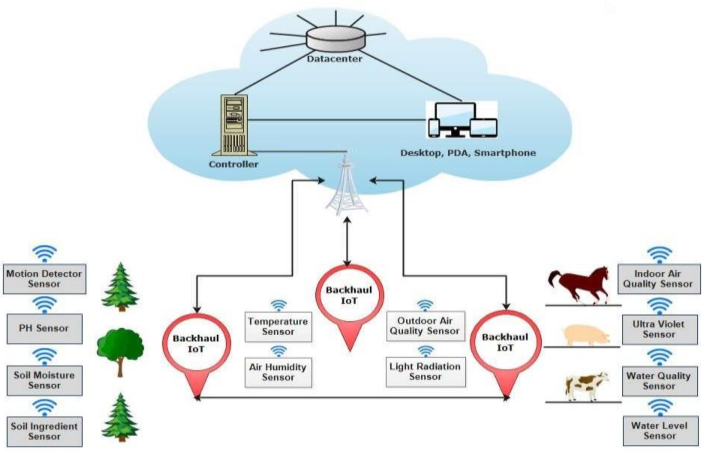

Figure 5. IoT-based smart agriculture topology.

Currently, solutions have been developed and commercialized that have the potential to provide farmers with farm and field management solutions and services with the aim of increasing productivity, reducing labor, and improving agricultural efficiency. - OnFarm [25]: Part of the SWIM family, it is specialized in providing smart farming solutions and technologies. OnFarm is a technology platform that allows farmers to manage and use data in the easiest way. It is also a comprehensive solution for managing, using and controlling water in smart farms. - Farmobile A commercialized online smart farm management platform that allows farmers, traders, scientists and insurance companies to work and communicate centrally on an online platform. - Silent Herdsman Platform : A platform that allows monitoring the activity of cow colonies and predicting milk production. - CropX : A platform that allows monitoring and control of arable soil nutrients based on sensor systems and big data analytics solutions. - FarmX : It is an all-in-one arboriculture platform. FarmX offers various agricultural management solutions such as irrigation, fertilization, farm management system, environmental monitoring, crop forecasting, etc. - Easy f arm: It is a platform that provides software to help farmers manage and account for their farms. Easyfarm provides visual figures such as input and output management, production forecasting, and market connection, allowing farmers to have full control over their farms. - KAA [26]: It is a cloud-based IoT platform that aims to provide farmers with a comprehensive end-to-end solution to: (1) connect and manage IoT devices on the farm or field; (2) monitor and control the operation of devices based on data analysis results. - Farmlogs : This is a platform that provides tools and solutions to: (1) Automate the production cost accounting process; (2) Manage the daily activities of the farm in real time; (3) Support marketing and increase product sales. 3. Representative applications of IoT in smart agriculture In recent years, many IoT applications for agriculture have been introduced. According to the survey results, we classified these applications into categories based on their purpose, such as monitoring, tracking and traceability, and greenhouse production. Detailed results are presented in the following subsections.

3. Monitoring:

In the agricultural sector, factors that affect the cultivation and production process can be monitored and recorded, such as soil moisture, air humidity, temperature, pH, etc.Aquaponics: It is an integration of aquaculture and hydroponics. Aquaponics is an aquaculture technique that converts fish waste into nutrients for plants. One of the most important issues in such farms is to continuously monitor the water quality, water level, temperature, salinity, pH, sunlight, etc. According to this line of research, the authors of [27] developed an IoT system to monitor the temperature and pH of water in an aquaponics farm. In addition, it has a water reading control system to keep the fish habitat stable and an automatic feeding function to increase fish productivity. The results show that the IoT system worked stably and provided real-time monitoring parameters. The system recommends the correct ratio of fish to plants. As a result, the system reduces feed consumption and reduces carbon emissions to the environment. The main objective of this proposal is to balance the self-sustaining ability of the aquaponics system. Experimental results show that the number of fish was reduced from 30 to 15 and the number of plants was increased from 20 to 30, while the crop yield increased by more than 50%. A detailed and comprehensive review of IoT systems and devices for controlling and monitoring aquaponics farms is presented in. Monitoring based on the obtained data allows to improve the production of fish and plants by controlling, replenishing and adjusting nutrients in the water. The collected data is also used to automate the management of aquaponics farms and reduce labour costs. Forests: Humans depend on forests for survival. Moreover, forests play a key role in the carbon cycle and provide habitat for more than two-thirds of all animal species worldwide. Forests also protect watersheds, limit floods, and mitigate climate change. The most important factors to monitor in forests are soil composition, temperature, humidity, oxygen, and the concentration of various gases such as methane, ammonia, and hydrogen sulfide. [28] present a set of forest management systems and solutions based on IoT and big data analytics. These forest areas play a very important role in Brunei's tropical rainforest ecosystem. However, these peat forests are highly vulnerable to fire. In this study, they developed an IoT system to monitor environmental conditions such as temperature, humidity, wind direction, and air pressure in preparation for disasters. To increase feasibility, the IoT devices use a solar power system and communicate with the monitoring center through a LoRa network. The solution has been used commercially in several German states to detect leaf diseases in pest-infested pine forests. Findings show that monitoring in the forestry sector focuses on providing an early warning system for forest fires, pest control, and deforestation. Livestock: It is the process of raising livestock such as cows, pigs, sheep, goats, and chickens in an agricultural environment to produce and produce products such as meat, eggs, milk, fur, and leather. In this sector, the factors to be monitored depend on the type and number of livestock system for the diagnosis, prevention, and treatment of livestock diseases called VetLink[29]. The system can provide animal health recommendations to rural farmers who have difficulty in immediately contacting a veterinarian Monitoring data on livestock water, feed, and animal health in the farming process can help farmers plan livestock breeding, reduce labour costs, and increase production efficiency. Many solutions have been introduced to monitor large-scale farms, but their application in small and medium-sized farms, especially in developing countries, is very limited. This is likely due to the high costs required to set up, manage, and operate IoT systems, as well as a lack of knowledge. Therefore, we have an effective and cost-effective solution for this. Agricultural IoT has many possibilities.

3.1. Tracking and Tracing

In the future, to meet consumer needs and increase profits, farms need to demonstrate that the products offered on the market are clean and can be conveniently tracked and traced, thereby increasing consumer confidence in product safety and health-related issues. To solve this problem, a series of track-and-trace based problems have been proposed for the smart agriculture sector, including: In [30], the authors developed an information system called SISTABENE that allows tracking and tracing of agricultural products and food products such as dairy products and vegetables. The system helps suppliers to track errors that occur in the production process and supply chain, and helps end consumers to trace the origin of food. In [31], the authors proposed a food supply chain traceability system based on blockchain technology. It helps trace the production process in the agricultural and food supply chain and trace the origin of agricultural products. The findings show that IoT components in the smart agriculture field, including hardware and software, have been the focus of research and many breakthroughs have been achieved. Several IoT solutions have been deployed in large-scale farms/fields. However, there are still some challenges for the large-scale use of IoT in the agricultural field. We identified two main issues: economic and technical. We consider these issues in relation to policies to advance the integration of IoT technologies in agriculture.

3.2. Economics

One of the most important features in agricultural economics is the low rate of return on investment projects, which involve many risks due to natural conditions. The cost-effectiveness of new technologies used in agriculture needs to be carefully calculated to ensure a trade-off between the costs of introducing the technology and the potential benefits. Therefore, we discuss the economic aspects related to the implementation of IoT in smart agriculture. The introduction of IoT in agriculture incurs different types of costs. We will introduce these costs in two parts: (1) system initialization costs, and (2) system operation costs. System initialization costs include hardware purchases (IoT devices, gateways, and base station infrastructure). System operation costs include service registration fees and labor costs for managing IoT devices. In addition, additional operation costs include energy consumption, maintenance, and costs incurred for data exchange between IoT devices, gateways, and cloud servers. According to Turgut and Boloni [32] the deployment of IoT technology will be successful only if the customer value provided by the IoT system (customers must be aware of the benefits and possibilities) exceeds the costs of physical value and data protection. Companies that are active in the IoT field will benefit and succeed. This process can be described as follows using two conditions:

Success of IoT application = Vservice > Cpri + Cuser + Cpay, farmers' benefits (1)

Vin fo + Rpay > Cbusiness, businesses' benefits (2)

Where

Vservice is the expected value received by users of the IoT service.

Cpri is the cost of privacy loss.

Cuser is the cost of devices and hardware paid by users.

Cpay is the service fee payment.

Vin fo is the value of information received.

Rpay is the direct payment received. C business is a portion of the company's hardware and maintenance costs.

According to the service user (farmer or farm owner), equation (1) shows that the value of the service perceived by the user (Vservice) must be higher than the total cost, including the cost of privacy loss (Cpri). The user incurs the cost of equipment and hardware (Cuser) and the payment of service fees (Cpay), but as shown in equation (2), the opinion of the service provider is that the value of the information received (Vin fo) and the direct payment received (Rpay) must be higher than the proportion of the company's hardware and maintenance costs (Cbusiness). There is still a gap between the service provider and the service user (farmer or farm owner), which results in the delayed adoption of IoT applications in smart agriculture. Regarding the economic aspect, the analysis results show that it can meet the need for a supportive policy by regulators and governments to enable service providers and service users to use IoT-based smart agriculture applications at an early stage. As discussed in [33], to promote smart agriculture, the European Union has adopted a supportive economic policy, the so-called European CAP (Common Agricultural Policy), whose annual budget reaches about 59 billion euros and is funded by EU countries. We believe that in order to reduce the cost of IoT services for farmers, in order to utilize IoT in the smart agriculture field, the service cost (Cpay) and the IoT operation and system initialization costs (Cuser) need to be continuously improved and optimized. Also, IoT companies (service providers) need to maximize the value of the received information (Vin fo) to improve the profitability of the service provider. In practice, service providers can commercially exploit the information (Vin fo) obtained during the provision of services to farms to promote the use of IoT applications in smart agriculture. Currently, some IoT platform providers allow free registration and use of their services, with some limitations on the service's functionality and processing power, the number of connected IoT devices, and the amount of data stored, while premium features and services are paid for.

In addition, one of the key factors slowing down the adoption of IoT in agriculture is farmers' knowledge and ability to use IoT devices. In developed countries, this problem is easily solved because new technologies are available to farmers. However, in developing countries, the majority of rural farmers have very limited access to advanced technologies, making this a significant challenge[34].

4. Technical Issues Interference:

The use of a large number of IoT devices in smart agriculture can cause interference in various network systems, especially in some IoT networks that use short frequency bands such as ZigBee, Wi-Fi, Sigfox, and LoRa (see Table 1). Interference can affect system performance and reduce the reliability of the IoT ecosystem. IoT networks that use cognitive technologies to reuse unlicensed spectrum will increase the cost of devices. In our opinion, the introduction of 6G networks [35] will allow a large number of devices to connect to the Internet with very high access speeds and very wide bandwidth. The entire interference problem of IoT networks will be solved. Security and Privacy: One of the most important issues in applying IoT in smart agriculture is security issues, such as protecting data and systems from attacks from the Internet. From the perspective of system security, the limited capacity and performance of IoT devices leads to complex encryption algorithms that cannot be implemented on IoT devices. As a result, IoT systems can be attacked via the Internet and gain system control. IoT gateways can also be attacked by denial of service attacks In addition, cloud servers can be attacked through data spoofing to perform fraudulent tasks that interfere with the autonomous agricultural process of the farm. Cloud infrastructure can also be controlled by attackers some questions regarding detailed privacy and security measures for IoT devices were discussed. According to Neschenko et al., the issue of IoT data security is one of the biggest issues slowing down the adoption of IoT in smart agriculture [36].

From the data security point of view, information obtained from farm IoT systems is collected, processed and commercially exploited by service providers to various degrees. Therefore, one of the most important issues in the guidelines concerns the validity and legal status of agricultural data [37]. In practice, this data is very valuable when aggregated and analyzed for large-scale agricultural activities. Without policies, farm privacy and data security could undermine farmers' competitive advantage. In our opinion, the use of encryption in combination with access keys is a possible solution to solve this problem. Keys can be provided based on local user groups and users who have contributed to the database. In more complex cases, secure multi-party computation can be used. In that case, homomorphic encryption methods [38] or a combination of this method and blockchain can be applied to balance privacy and data utility. In our opinion, the security problem of IoT systems will be an exciting research topic and will attract attention in both academic and industrial research. A detailed study of threats and solutions to improve the robustness, reliability and privacy of future IoT systems. Reliability: Most IoT devices are expected to be used outdoors (in fields and farms). Harsh working environments can lead to a rapid deterioration of the quality of IoT devices and lead to unexpected failures by the manufacturer. The mechanical safety of IoT devices and systems must be ensured to withstand extreme weather conditions such as temperature, humidity, storms and floods [39]. In our opinion, new materials and technologies need to continue to be explored to improve the durability of devices. The open problems and challenges described in this section show that there are still many issues to be solved for the widespread use of IoT in the field of smart agriculture. Service providers need to reduce service costs and use the information collected on farms more effectively. Meanwhile, farmers need to improve their skills in applying IoT solutions on farms to improve productivity and agricultural efficiency. Researchers need to continuously investigate and propose optimal solutions and technologies to ensure the privacy and security of IoT systems and improve the durability of IoT devices. These are very big challenges and are interesting research topics for the future to enable the widespread use of IoT in the field of smart agriculture.

5. Conclusions

This study provided an overview of IoT and big data in the field of smart agriculture. Several issues related to promoting IoT adoption in the agricultural sector were discussed in detail. The findings showed that much research has been conducted on the application of IoT in smart agriculture with the aim of increasing productivity, reducing human labor, and improving production efficiency. The benefits of applying IoT and big data in agriculture were discussed. In addition, we also highlighted the challenges that need to be overcome to accelerate the adoption of IoT in smart agriculture. However, there are still some challenges that need to be overcome to keep IoT solutions affordable for the majority of farmers, including small and medium-sized farmers. In addition, although security technologies need to be continuously improved, we believe that the application of IoT solutions in smart agriculture is inevitable and will lead to increased productivity, providing clean and environmentally friendly food, supporting food traceability, reducing human labor, and improving production efficiency. Meanwhile, this study also points out interesting research directions on IoT security and communication technologies. We believe that these will be very interesting research directions in the future.

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