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Review

# Review of the internet of things communication technologies in smart agriculture and challenges

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ABSTRACT

The advent of Internet of Things (IoT) spurred a new direction of research in agriculture, and various IoT communication technologies are used to connect with different devices in different layers. With the rapid increasing number of studies and projects about IoT-based smart agriculture, information got scattered and the involved communication technologies were not been analyzed and discussed before in other reviews. Intending to identify and review scientifically validated literature on IoT communication technologies in smart agriculture, this study critically summarizes the recent research pertinent to the smart agriculture with IoT communication technologies. The employed method was a thorough search from these three databases, namely: ScienceDirect, IEEE Xplore, and Scopus. Total 94 research articles were reviewed after the total of 886 titles being scanned for relevance. The monitored parameters by sensors and communication technologies associated with IoT-based smart agriculture applications are analyzed comprehensively, as well as some specific issues, challenges, and recommendations in IoT applications in agriculture. The study provides reference for researchers, and more burgeoning communication technologies should be applied in agriculture to realize the great-leap forward development in smart agriculture.

## 1. Introduction

Agriculture is the basis of human life, the fundament of survival, and the primary condition of all productions. The area is the backbone of national economies (Yang et al., 2021a; Yang et al., 2021b; Chirico and Bonavolonta, 2020). According to the ‘Agriculture in 2050 Project’, the Food and Agricultural Organization of the United Nations (FAO) predicted that the global population will reach about 10 billion by the end of 2050 (Friha et al., 2021). Consequently, food production should have a least 70% increase to accommodate this population growth (Hunter et al., 2017). It is a big challenge to satisfy the food demand within limited field resources (Mumtaz et al., 2017). Hence there is an urgent need to improve the crop productivity, so the precision farming and smart agriculture have gained much importance in today’s world. In smart agriculture, technologies like robotics, Artificial Intelligence (AI), Information and Communications Technologies (ICT), Unmanned Aerial Vehicles (UAVs), Deep learning (DL), Internet of Things (IoT) and related big data analytics can effectively address relevant challenges, including food shortage and waste of resources (Yin et al., 2021; Gupta et al., 2020; Islam et al., 2021; Alfred et al., 2021; Terence and Purushothaman, 2020). Smart agriculture is a promising field having broad prospects.

In modern wireless communications, IoT can be seen as one of the most revolutionary technologies (Atzori et al., 2017). Basically, IoT is a huge internet-based network to connect devices together for the better work (Manogaran et al., 2020; Santiteerakul et al., 2020). IoT technology has pervasively penetrated various markets such as smart health care, smart city, industry, transport, agriculture and so on. In agriculture, IoT platforms provide monitored data and useful solutions for farmers to tackle real problems (Nukala et al., 2016). And Wireless sensor network (WSN) is of paramount importance since operations can be supported by various IoT devices.

The agricultural sector is undergoing a fourth revolution named Farming 4.0 by integrating ICT towards a new era of agriculture (Lezoche et al., 2020). During the past few years, various combinations of emerging technologies in smart agriculture have been widely analyzed, including UAV technology (Kim et al., 2019; Boursianis et al., 2020), WSN (Ojha et al., 2015; Kochhar and Kumar, 2019), AI (Jha

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et al., 2019), big data (Wolfert et al., 2017), data analytics (Elijah et al., 2018a,b), and IoT (Tzounis et al., 2017; Ayaz et al., 2019; GarcÃ-a et al., 2020; Kour and Arora, 2020), ect.

With the rapidly increasing number of studies, projects and grey literature based on smart agriculture, information got scattered. Although there are some publications related to IoT based smart agriculture (Sadowski et al., 2020; Shi et al., 2019a,b; Farooq et al., 2019; Chen and Yang, 2019; Jayaraman et al., 2016; Khanna and Kaur, 2019), they highlighted more on evolution and IoT's role in agriculture, or had more emphasis on the platform and the architecture of IoT. Undoubtedly, IoT communication technologies play (now and in the future) a pivotal role in agriculture industry. As far as the authors' knowledge goes, there were no studies published before focusing on the characteristics of IoT communication technologies development in agricultural environment, such as: i) the developing process of IoT communication technologies in smart agriculture; ii) the analysis of communication technologies in different agricultural scenarios; iii) relevant monitoring parameters under diverse agriculture contexts; iv) the further direction of communication technologies applied in smart farm system; and v) challenges and relative recommendations in IoT-based smart agriculture applications. The development of IoT communication technologies in agriculture is a crucial but overlooked gap in the literature. Therefore, this systematic review intends to identify scientifically-validated literature on the development of IoT communication technologies in agriculture with emphasis on the referred points.

The rest of this paper is organized as follows. Section 2 describes the review methodology; Section 3 presents the distribution results of reviewed articles, which are divided into three parts: category, the year of publication, and the author's nationality; Section 4 describes the relative monitoring parameters and communication technologies in section 4.1 and 4.2, respectively; challenges about cost, system, device, and data are discussed in Section 5; Section 6 explains corresponding recommendations; and conclusions and future directions are presented in Section 7.

## 2. Methodology

The objective of this review is to correctly analyze and summarize the current standings of IoT communication technologies in smart agriculture. Research has been done throughout by examining the existing literature work. The present review includes studies published from 2007 to 2021 in the following databases: ScienceDirect, IEEE Xplore, and Scopus. Although no language restrictions were imposed during the search, all publications mentioned below were in English. We used a series keywords containing "smart agriculture", "smart farming", "smart farm", "smart irrigation", "precision agriculture", "smart greenhouse", "automation agriculture", "automation irrigation" in different variations and combined with "OR" and "AND" followed by "Internet of Things" or "IoT". Because most of the articles would not mention specific IoT communication technologies in title, abstract, or keywords, it's difficult to choose specific communication technologies to search papers. Therefore, the keywords do not contain communication technologies, and relative information needs further filtering. A total of 886 publications were found with potential interest from the initial search and their titles were screened based on their context of research. As an example, publications which fail to delve into relative agricultural IoT systems were eliminated. From those, 160 publications remained and their abstracts were appropriately reviewed. After this, exclusions were performed based on the following criteria: i) publications that do not mention their communication technologies were excluded: ii) system architectures or platforms which are not based on IoT or WSN were excluded; and iii) publications focusing on other fields except agriculture were excluded. Using these criteria, 68 abstracts were excluded. Five additional relevant articles were found while reading the selected 92 articles. After rejecting three publications that focusing on the same water quality monitoring system with similar monitoring parameters and IoT communication technologies, 94 total projects were reviewed in detail. And the 94 projects were divided into three major parts: agri-food supply chain traceability, plant management and animal farming. Fig. 1 shows the flowchart with the number of studies identified and included/excluded.

## 3. Distribution results

A detailed summary for various IoT-based agriculture projects has been presented in chronological order as shown in Table 1, including descriptions of project objectives, monitoring parameters, and used communication technologies.

### 3.1. Distribution by category

Selected references were clustered into three application domains, corresponding to plant management, animal farming and agri-food supply chain traceability. Plant management includes relative irrigation management applications, field monitoring applications, crop disease risk evaluation systems and greenhouse management. Animal farming contains different systems and applications applied in fish farms, water management, and livestock. And agri-food supply chain traceability contains traceability platforms for meat, milk, fish and agri-food products based on IoT. The total number of selected published articles is 94, consisting of 69 articles for plant management, 20 for animal farming, and 5 for agri-food supply chain traceability. Fig. 2 shows the percentage distribution of studies in three different categories. It's clear that the majority published articles are focusing on plant management, while agri-food supply chain traceability accounts for a small proportion.

### 3.2. Distribution by year of publication

Fig. 3 indicates the number of included articles in three categories according to the year of publication. The distribution of scholarly papers from 2011 to 2021 is shown, although relevant projects were from 2007 onwards. Because there are only 1 paper about agri-food supply chain traceability in 2007, 3 articles about plant management and 1 about animal farming in 2008, and no paper in 2009 and 2010, the analysis from 2011 is more representative.

Exactly 3 papers included in this review were published in 2011. None were published in 2012, while 1 were published in 2013. 8 articles were published in 2015, and both 4 articles were published in 2014 and 2016. Exactly 7 and 12 papers were published in 2017 and 2018, respectively. Among the selected articles, 14 were published in 2019, and 17 were published in 2020, as well as 19 were published in 2021. The majority of projects, i.e., 62 out of 94, were published in the last few years (2018–2021).

### 3.3. Distribution by authors' nationality

The reviewed studies were globally distributed and not concentrated in a specific region. Fig. 4 shows the geographical distribution of reviewed projects. These articles generally involve study cases conducted in 32 countries.

The value n = 94. In particular, the geographical distribution of the selected articles about IoT communication technology in smart agriculture in terms of numbers shows that the most productive authors are from India, with 25 study cases. This was followed by China with 15 study cases; the U.S.A and Korea with 5 and 4 study cases each; Mexico, Spain, Italy, Pakistan, Vietnam and Malaysia with 3 each; U.K., Tunisia, Indonesia, Brazil and Turkey with 2 each; and Portugal, South Africa, Australia, Ireland, Macedonia, Greece, Thailand, Egypt, Nigeria, Norway, Colombia, Algeria, Saudi Arabia, Romania, Russia, Kuwait, and Bangladesh with 1 study case each.

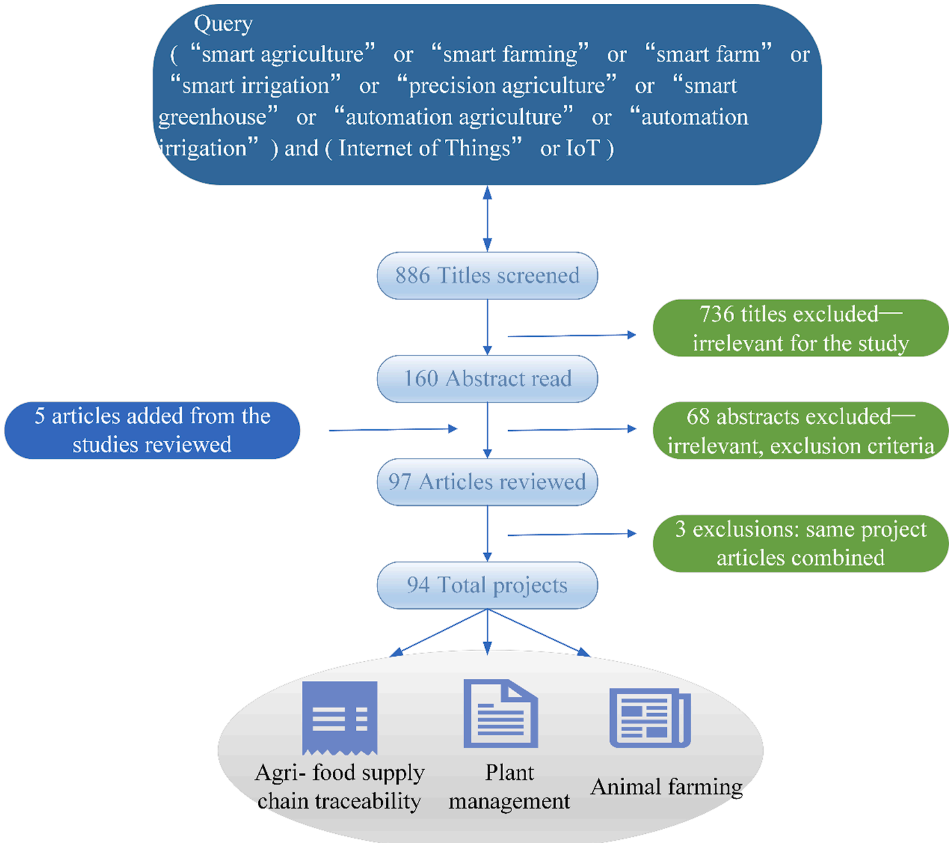


**Fig. 1.** Systematic review flowchart.

## 4. Discussion

IoT agriculture systems are applied in a wide variety of fields, as shown in Fig. 5, and particularly in irrigation management, soil management, precision agriculture, and smart farming. It's clear that the irrigation management accounts for the largest proportion. By monitoring weather conditions and soil conditions, modern irrigation system facilitates farmers by installing multiple sensors, reducing farmers' monthly irrigation cost, and save water resources. And soil management increases crop productivity and recommends some appropriate fertilization solutions to farmers. Precision agriculture and smart farming help farmers to improve and optimize all feasible directions in order to enhance the agricultural productivity and make cropping system more intelligent. Meanwhile, pest and crop disease monitoring has also been combined with IoT technologies, which assists farmers to generate more revenue by saving crop from pest attracts at early prediction stages.

### 4.1. IoT sensors in agriculture

The smart agriculture system parameters monitored varied from study to study. Fig. 6 and Fig. 7 represent the number of projects about plant management and animal farming respectively, involving parameters which have occurred twice or more, and parameters that only monitored once do not been discussed in figures. The majority of projects utilized sensors to monitor temperature, humidity, soil moisture, and light intensity. Soil temperature plays an important role in the productivity of crop. The change about soil temperature directly effects soil moisture and soil nutrient absorption. And the measured air temperature can be used to monitor crop environment in fields or in greenhouse. The humidity sensors including relative humidity, air humidity, or soli humidity are utilized to sense and measure the comparative humidity level. The humidity directly and indirectly affects plants' leaf growth, pollination, and photosynthesis in in multiple ways. As for soil moisture, it's used to measure the moisture content and water quality in the soil. Resistance of soil moisture sensor is inversely proportional to moisture content which is the major factor to determine plant growth. Soil moisture is used in all over the field to maintain the water quantity and any other automated measures that are required. Light intensity has direct influence on the photosynthesis of plants, and then effects the growth of crops. Additionally, PH is necessary for irrigation which is used to monitor the accurate amount of nutrients in the soil. And wind speed and precipitation are widely used in order to expect the chances of rainfall and to control the water flow.

In Fig. 7, the importance of the measurement about humidity and temperature is the same as in plant management systems. But in animal farming, the majority of projects also monitor PH, dissolved oxygen, for the reason that some articles focus on recirculation aquaculture systems, which can be used in fish farms. The monitored turbidity and water level have a strong relationship with water quality, which are precious factors in agriculture management.

### 4.2. IoT communication technologies

Sensors need to send the sensed data to control center. The connectivity can be divided into wired, wireless and hybrid wired-wireless. From the Fig. 8, the majority of involved communication technologies are wireless, except one project used CAN technology (Zamora-Izquierdo et al., 2019). Table 2 summarizes the comparison of existing wireless communication technologies. And technologies used for connectivity in agriculture system are surveyed.

#### 4.2.1. WiFi

There are about one fourth of studies used WiFi in architecture of the system. WiFi stands for wireless fidelity. WiFi is based on IEEE 802.11

**Table 1**
Summary of the IoT communication technologies in agriculture.

| Time | Location | Category | Objectives | Monitoring parameters | Type of communication | Communicationtechnology |
|---|---|---|---|---|---|---|
| 2007 | UK | Agri-food supply chain traceability | To propose an information infrastructure for RFID enabled traceability in a supply chain to provide full and verifiable traceability across a supply chain in a cost effective and efficient way for the chain's partners. | P | Wireless | RFID |
| 2008 | China | Plant management | To design and implement a real-time prediction system of soil moisture based on GPRS and wireless sensor network. | PR, W, SG, SM | Wireless | ZigBee & GPRS |
| 2008 | USA | Plant management | To describe details of the design and instrumentation of variable rate irrigation, a wireless sensor network, and software for real-time in-field sensing and control of a site-specific precision linear-move irrigation system. | SM, Ts, Ta, RH, PR, WS, WD, R | Wireless | Bluetooth |
| 2008 | Portugal | Plant management | To present a ZigBee multi-powered wireless acquisition device for remote sensing applications in precision viticulture. | Ta, Ts, RH, R, W, WS | Wireless | ZigBee |
| 2008 | Australia | Animal farming | To present how an RFID-enabled dairy farm can leverage mobile network infrastructure towards achieving total farm management. | WG, T | Wireless | RFID |
| 2011 | Mexico | Animal Farming | To develop an automated recirculation aquaculture system based on fuzzy logic control to integrate into novel automated equipment for recirculation aquaculture systems used for fish production under intensive conditions. | TB, T, DO, F, TAN, PH | Wireless | ZigBee |
| 2011 | Spain | Agri-food supply chain traceability | To develop and test a novel RFID tracking technology to measure the burrow emergence rhythm of a commercially important marine crustacean species. | PA | Wireless | RFID |
| 2011 | China | Plant management | To develop an IOT system application with crop growth models in facility agriculture to make the system more intelligent and adaptive. | Ts, Hs, Ta, Ha, L | Wireless | 433 MHz |
| 2013 | Spain | Plant management | To propose an IoT multiplatform networking to monitor and control wineries and vineyards. | Ta, RH, PD, WS, WD, Ts, SM, LW, U, BP | Wireless | Mobile communication |
| 2014 | South Africa | Plant management | To present an energy efficient wireless environment monitoring system with a capability to monitor a wide range of greenhouse gases with environmental parameters. | Ta, RH, O, C1, C2, S2, N2 | Wireless | ZigBee |
| 2014 | Mexico | Plant management | To develop an automated irrigation system to optimize water use for agricultural crop. | Ts, SM, W | Wireless | GPRS & ZigBee |
| 2014 | Tunisia | Plant management | To develop a monitoring Web-based decision support system communication with a wireless sensor network for irrigation scheduling in developing countries context. | WS, WD, Ta, Ha, R, PR | Wireless | ZigBee |
| 2014 | India | Animal farming | A wireless sensor network based on precision animal management system developed by us called Moosense in order to maximize the comfort level (of animals) through accurate climate control, detect diseases through feed and fluid monitoring, and detect heat with activity monitoring. | WG, Ta, Ha, F, FC, AN | Wireless | WiFi |
| 2015 | USA | Animal farming | To propose an IoT-based framework which enables dairies to minimize the economic impact of heat stress and capture the higher Return on Assets & Return on Investment by improving operational efficiencies. | RH, T, Ta, BP, A, PA | Wireless | Bluetooth |
| 2015 | Taiwan | Animal farming | To develop an automated monitoring system of wireless sensor networks for a fish farm Environment Simulation. | PH, T, W, DO | Wireless | ZigBee & WiFi |
| 2015 | India | Animal farming | To present a design and development of a low-cost system for real time monitoring of the water quality in IoT. | T, PH, DO, TB | Wireless | WiFi |
| 2015 | Indonesia | Animal farming | To present a continuous water quality monitoring system based on a PCDuino microcontroller, a sample collection unit, and PC based graphical display. | PH, DO | Wireless | ZigBee |
| 2015 | China | Agri- food supply chain traceability | To develop a real-time perishable food supply chain monitoring system based on ZigBee-standard wireless sensornetwork | Ta, RH, A, C2 | Wireless | ZigBee & GPRS & WiFi |
| 2015 | Macedonia | Plant management | To develop a system for monitoring and controlof crop production which would be tailored to the needs of farms | Ta, Ha, SM, PH | W | ZigBee |
| 2015 | Greece | Plant management | To propose a scheme based on the collaboration of an integrated system for automated irrigation management with an advanced novel routing protocol for wireless sensor networks. | Ta, Ts, Ha, Hs, WS, R | wireless | ZigBee |
| 2015 | India | Plant management | To design an irrigation system which is automated by using controllable parameter in e in wireless sensor network. | Ts, SM, Ha | wireless | ZigBee |

(*continued on next page*)

**Table 1** (*continued*)

| Time | Location | Category | Objectives | Monitoring parameters | Type of communication | Communicationtechnology |
|---|---|---|---|---|---|---|
| 2016 | China | Agri- food supply chain traceability | To formulate an IoT–based framework for monitoring fruit e-commerce deliveries using scenario analysis and interval number approaches. | Ta, Ha, L, C2, SM | Wireless | RFID |
| 2017 | Taiwan | Plant management | To develop an IoT-based system to monitor the environmental factors of an orchid greenhouse and the growth status of Phalaenopsis at the same time | Ta, RH, L | Wireless | ZigBee & WiFi |
| 2017 | Mexico | Animal farming | To present the prototype and proof of concept of a distributed monitoring system of the most important variables in aquaculture water quality. | T, DO, PH | Wireless | ZigBee |
| 2017 | Italy | Agri- food supply chain traceability | To propose a solution to gather information throughout the entire food supply chain based on NFC tags and bring it directly to the consumer | P | Wireless | NFC |
| 2017 | India | Plant management | To develop an interoperable agri-meteorological observation and analysis platform for precision agriculture. | Ta, Ha, Ts, Hs | Wireless | WiFi |
| 2017 | Republic of Korea | Animal farming | To propose a wireless sensor network application for irrigation facilities management based on radio frequency identification and quick response codes. | W, PA, | Wireless | RFID & ZigBee |
| 2017 | India | Animal farming | To develop a wireless sensor node which will contain several sensors to sense the chemical contents of water. | PH, T, TB, DO, SP, AM, NI | Wireless | Heterogeneity (GSM, 4G, LoRaWAN, ZigBee |
| 2017 | India | Plant management | The paper aims making use of evolving technology i.e. IoT and smart agriculture using automation, which can give the information about the temperature, humidity of the air in agricultural field through MMS to the farmer, if it fallout from optimal range. | Ts, Hs, RH | wireless | WiFi & GPRS |
| 2018 | China | Plant management | To design a complete remote monitoring system on the basis of Agricultural IoT and to improve energy efficiency, reliability, safety and customer experience. | Ta, Ha, Ts, Hs, L | Wireless | LoRa |
| 2018 | Tunisia | Plant management | To present a new prototype of late blight prevention decision support system based on sensor network and cloud IOT. | Ts, Hs | Wireless | ZigBee & multi-protocol router |
| 2018 | Vietnam | Plant management | To present the design of automatic irrigation system for the greenhouse agriculture based on LoRa technology with outstanding advantages in terms of transmission range and power consumption. | Ts, Hs, SM, | Wireless | LoRa & WiFi & GPRS |
| 2018 | Korea | Plant management | The cloud-based technology capable of handling the collection, analysis, and prediction of agricultural environment information in one common platform was developed. | Ts, Hs, C2, L, EC, PH | Heterogeneous | LoRa & CAN & RS485 |
| 2018 | England | Plant management | To propose a creative service process to improve the integration of the current cloud-to-physical networking and to improve the computing speed of the IoT. | Ts, Hs, PH, L, DI | Wireless | WiFi |
| 2018 | India | Plant management | This paper proposes an IoT based smart irrigation architecture along with a hybrid machine learning based approach to predict the soil moisture. | Ta, Ts, Hs, UV, RH | Wireless | WiFi & ZigBee |
| 2018 | China | Plant management | To present an agricultural cyber-physical-social system serving agricultural production management, with a case study on the solar greenhouse. | Ta, Ha, Ts, Hs, L | Wireless | Mobile communication |
| 2018 | India | Plant management | To develop a Raspberry Pi based automatic irrigation IoT system to modernization and improves productivity of the crop. | Ta, Ha, Ts, Hs, L | Wireless | WiFi &Bluetooth&4G |
| 2018 | China | Animal farming | To propose an IoT-enabled smart nitrate sensor and sensing system to monitor the nitrate concentration in real-time. | NI | Wireless | LoRa & WiFi |
| 2018 | India | Plant management | To propose a scalable network architecture for monitoring and controlling agriculture and farms in rural areas. | SM, L, Ta, RH, BP | Wireless | WiFi |
| 2018 | USA | Plant management | To propose a wireless sensor network (WSN) system for smart estimation of soil conditions. | Ts, Hs, EC, | Wireless | ZigBee |
| 2018 | USA | Plant management | To report a disposable IoT gardening soil sheet, capable of analyzing real–time soil nitrate concentration during leaching and irrigation events. | NI | Wireless | ZigBee |
| 2019 | Thailand | Plant management | To design and develop a control system using node sensors in the crop field with data management via smartphone and a web application. | Ts, Hs, SM | Wireless | WiFi |
| 2019 | India | Plant management | To develop an IoT based system by designing a novel Nitrogen-Phosphorus-Potassium sensor to provide the farmer regarding the deficiency of major soil nutrients namely nitrogen, phosphorous and potassium through SMS. | NT, PS, PO | Wireless | WiFi |
| 2019 | Egypt | Plant management | To present the design of an IoT-based monitoring system for epidemic disease control: a key precision agriculture application. | Ta, Ha, Ts, EC, WS, WD, PR, LW, SV, DP, R, IR | Wireless | Mobile communication |
| 2019 | India | Plant management | | PA, FC, WC | Wireless | ZigBee |

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**Table 1** (*continued*)

| Time | Location | Category | Objectives | Monitoring parameters | Type of communication | Communicationtechnology |
|---|---|---|---|---|---|---|
| | | | To propose a user-centric IoT architecture for addressing the various issues faced in the agricultural domain. | | | |
| 2019 | Nigeria | Plant management | To develop the architectural design and performance evaluation of an adaptive sprinkler irrigation robot. | SM, IR | Wireless | ZigBee |
| 2019 | Brazil | Plant management | To represent an integrated hardware and software automated system designed to use in continuous monitoring and recording operations in seed testing laboratories. | Ta, RH, L | Wireless | WiFi |
| 2019 | Norway | Animal farming | To develop and test the feasibility of a concept called Internet of Fish and its potential use in marine aquaculture monitoringapplications. | LK, AM, TD, SA | Wireless | LoRa |
| 2019 | India | Plant management | To propose an adapting weather conditions based IoT enabled smart irrigation to realize the optimum usage of irrigation by the precise management of water value using neural network-based prediction of soil water requirement in 1 h ahead. | SM, Ts, Ta, Ha, C2, L, MC | Wireless | ZigBee & WiFi |
| 2019 | China | Animal farming | To present a mobile measuring system that could acquire the real-time data in large-scale farm to measure the body components of pigs ranging from 23.1 to 116.2 cm automatically. | BL, BW, HW, HH, BH | Wireless | RFID |
| 2019 | Spain | Plant management | To propose a flexible platform able to cope with soilless culture needs in full recirculation greenhouses using moderately saline water. | Ts, Hs, PH, EC, R, W, C2, LC, FM | Wired | CAN |
| 2019 | Brazil | Plant management | To propose a smart water management platform architecture, pilots and deployment scenarios for the four pilots using FIWARE as the underlying IoT platform. | SM, Ts, EC | Wireless | WiFi & LoRa |
| 2019 | India | Plant management | To propose a framework for infinite lifetime solar energy harvesting-WSN for smart agriculture monitoring applications. | Ts, Hs, A, BP | Wireless | ZigBee & WiFi |
| 2019 | India | Plant management | To propose a cloud-enabled CLAY-MIST measurement (CMM) index based on temperature and relative humidity to assess the comfort levels of a crop. | RH, T | Wireless | WiFi |
| 2019 | India | Plant management | To develop a low-cost intelligent system for smart irrigation supporting one-time setup for irrigation schedule estimation and neural based decision making for intelligent support and remote data monitoring. | Ta, Ha, Hs | Wireless | WiFi |
| 2020 | Colombia | Plant management | To propose a (Narrow Band IoT) NB-IoT system for collecting underground soil parameters in potato crops using a UAV-aided network. | Ha, Hs, Ts, R, C, PH, C2, O, PR, U | Wireless | NB-IoT |
| 2020 | Malaysia | Plant management | To detail a portable and wireless sensor network system to remotely monitor the environmental parameters in an agriculture field and provide field managers with alerts and information regarding current conditions. | Ta, Ha, L, SM, PH, UV | Wireless | WiFi |
| 2020 | Korea | Plant management | To develop a smart garden system environment which can auto-monitor relative data and have the capability of automating the irrigation process. | SM, Ta, Ha, CG | Wireless | WiFi |
| 2020 | Malaysia | Animal farming | To present a prototype on aquaponics and goat stall that implement the concepts of the internet of things for monitoring, controlling, or automation system. | Ta, Ha, PR, L, UV, WG, | Wireless | WiFi |
| 2020 | Taiwan | Plant management | To develop an IoT-based smart agricultural system for pest detection with the artificial intelligence and image recognition technologies. | SM, BP, L, Ta, Ha | Wireless | LoRa |
| 2020 | Turkey | Plant management | To design a long-range context-aware platform for rural monitoring with IoT in precision agriculture. | Ta, Ts, Hs, SM, | Wireless | LoRa |
| 2020 | Pakistan | Plant management | To provide a low-cost information monitoring system to fulfill the requirements of information monitoring for actual large-scale agricultural farms. | SM | Wireless | Mobile communication |
| 2020 | Italy | Animal farming | To develop a low-cost, modular, and LoRaWAN-based IoT platform to improve the management of generic farms in a highly customizable way. | SM, Hs, Ts, Ta, Ha | Wireless | LoRa |
| 2020 | Saudi Arabia | Plant management | To develop an IoT-based smart palm monitoring prototype as a proof-of-concept which allows monitoring palms remotely using smart agriculture sensors and contribute to the early detection of red palm weevil infestation. | Ts, Hs, PH, A | Wireless | LoRa |
| 2020 | Romania | Plant management | To describe a multi-sensor IoT system for agriculture and provide an analytics platform that provides advices to the farmer about the fertilization strategy. | Ta, Ha, BP, UV, CG, W, SN, MD | Wireless | Bluetooth & LoRa |
| 2020 | Russia | Animal farming | To develop a system of automated control of business processes for an agricultural enterprise allowing for remote collection and processing of data on technical and economic performance of the farming enterprise. | BP, PR, MD, Ta, Ha, PH, SM, | Wireless | WiFi & GSM |
| 2020 | Taiwan | Animal farming | | | Wireless | Mobile communication |

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**Table 1** (*continued*)

| Time | Location | Category | Objectives | Monitoring parameters | Type of communication | Communicationtechnology |
|---|---|---|---|---|---|---|
| 2020 | South Korea | Plant management | To establish a smart farm-scale piggery wastewater treatment system with the IoT applications. To propose a smart urban farming model which modifies tele-communication technology association smart greenhouse standard such that cloud service us integrated with IoT sensors. | PH, T, DO, MLSS, BOD, SS, EC, COD C2, Ta, Ha, WS, WD, EC, Ts, PH, PR | Heterogeneous | RS485 & WiFi & Bluetooth |
| 2020 | India | Plant management | To develop a smart application with modern agricultural methods involving the concept of AI and IoT will definitely help farmers worldwide in taking better decisions and help them in increasing the overall crop yield and efficiency. | PH, Ta, RH, SM, SV, SPS, Ts | Wireless | ZigBee |
| 2020 | Malaysia | Plant management | To design smart irrigation and fertilization system for chili plant using Fuzzy Logic, which can administer the flowrate of water, alkali and acid solutions into the soil in order to maintain its moisture and pH level. | PH, SM, FM | Wireless | WiFi |
| 2020 | Italy | Animal farming | The paper provides a comprehensive description about the design, development, and assessment of a monitoring application for IoT animal repelling devices. | ARD | Wireless | LoRa |
| 2020 | USA | Plant management | To introduce a smart drone for crop management where the real-time drone data coupled with IoT and cloud computing technologies help in building a sustainable smart agriculture. | FS, NS | Wireless | Mobile communication |
| 2021 | Algeria | Plant management | To develop a zoning irrigation system, where the main objectives are the optimization of plant growing conditions and the reduction of water use and energy consumption. | SM, Ta | Wireless | WiFi |
| 2021 | China | Plant management | To design a LoRa-based wireless sensor network to provide the remote data sensing functions for the planned smart agricultural recycling rapid processing factory. | EC, PH, VC, SM, | Wireless | LoRa |
| 2021 | Turkey | Plant management | A low-power agriculture IoT system with LoRaprototype has been built for tracking goods in open field storage. | C2, Ta, Ha | Wireless | LoRa |
| 2021 | China | Plant management | A framework for agricultural field monitoring and irrigation control is proposed using the concept of IoT. | SM, Ts, Hs, WD, WS | Wireless | WiFi & GSM |
| 2021 | China | Plant management | In accordance with the practical application requirements of agriculture in China, an agricultural monitoring system that can collect and share information of agricultural environment in real time is designed. | PH, SM, Ts, Hs, L | Wireless | WiFi |
| 2021 | India | Plant management | To propose a real-time automated dynamic and manual irrigation system for heterogeneous crop fields using IoT. | SM, W | Wireless | Zigbee & GPRS |
| 2021 | Pakistan | Plant management | To present an intelligent and smart irrigation system using edge computing and IoT o predict the watering requirements for a field of crops, and display the result by using an android application edge. | SM, Ha, L, Ta | Wireless | GSM |
| 2021 | Indonesia | Plant management | An Internet of Things (IoT) based automatic remote plant sprinkler with sun light cover was designed to monitor soil moisture and sun light. | SM, L | Wireless | WiFi |
| 2021 | India | Plant management | To develop an IoT-based smart drip irrigation system to minimize the water utilization for paddy crop by detecting the optimum environmental conditions using a neural network. | SM, Ta, Ha, L, PR | Wireless | WiFi |
| 2021 | India | Plant management | To design an advanced agriculture system for irrigating the plants smartly and remotely and checking the plants disease by seeing the leaf image of plant with image processing technique. | SM, CS, | Wireless | WiFi |
| 2021 | India | Plant management | To present an automated irrigation system for agriculture-based out of several low-cost sensors that monitor and maintain the soil moisture based on real-time data from the field with very low form factor compared to the existing systems. | SM, Ta, Ha | Wireless | WiFi |
| 2021 | India | Plant management | To realize the IIoT (Industrial Internet of Things) based monitoring procedure for farm safety against animal attacks and climate change conditions. | Ta, Ha, U, IR, SM, L | Wireless | WiFi |
| 2021 | India | Plant management | To develop a smart irrigation system by detecting the moisture level in the crop with a crucial parameter called evapotranspiration for the reinforcement of Precision agriculture using prediction algorithm. | PH, SM, Ta, Ha | Wireless | WiFi |
| 2021 | Vietnam | Plant management | To propose a real-time IoT system with a built-in hardware security function, allows the ambient environment monitoring and control actuators via a wireless network. | C2, Ha, Ta | Wireless | WiFi |

(*continued on next page*)

**Table 1** (*continued*)

| Time | Location | Category | Objectives | Monitoring parameters | Type of communication | Communicationtechnology |
|---|---|---|---|---|---|---|
| 2021 | Vietnam | Plant management | To present the design of a low-cost remote monitoring and control network for household cultivation, in which peripherals connected to each sensor-node can be re-configured remotely from the internet via a master node without any changing on the system firmware. | SM, Ta, Ha, U, IR | Wireless | LoRa & WiFi |
| 2021 | Kuwait | Plant management | A smart irrigation system equipped with LoRa has been proposed in this paper in order to increase the quality of the irrigation systems. | SM, PR, Ta, Ha, WD | Wireless | LoRa |
| 2021 | Bangladesh | Plant management | A completely unique IoT based smart robotic system is developed using which more output can be generated from identical amount of input. | SM, PR, Ta, Ha, AQ | Wireless | Bluetooth |
| 2021 | India | Plant management | To design a solar-powered smart agriculture and irrigation monitoring system over cloud with an efficient and eco-friendly method for effective crop production by farms in rural areas. | L, PR, Ta, SM, W | Wireless | WiFi |
| 2021 | India | Plant management | To develop an IoT device for smart crop field monitoring system and automated irrigation system using the wireless sensor networks. | SM, Ta, Ha, W, IR | Wireless | WiFi |

Abbreviations: Ta-air temperature; T-objective temperature; Ts-soil temperature; Ha- air humidity; Hs- soli humidity; RH-relative humidity; R-solar radiation; C-compaction; L-light intensity; SM-soil moisture; UV-ultraviolet light intensity; C2-carbon dioxide; C1-carbon monoxide; O-oxygen sensor; S2-sulfur dioxide; N2-nitrogen dioxide; PR- precipitation; U-ultrasonic sensor; P-production information; W-water level; SG-sluice gate level; WS-wind speed; WD-wind direction; TB-turbidity; DO-dissolved oxygen; F-feeding amount; TAN-total ammonia nitrogen; PA-position; EC- electric conductivity; LW-leaf wetness; PD-plant diameter; BP-barometric pressure; A-acceleration; B-biogas; F-fire sensor; CG-contaminant gases; SP-sulphate; AM-ammonia; NI-nitrate; DI-disease information; NT-nitrogen; PS-phosphorous; PO-potassium; HI-global horizontal irradiance; SV-soil volumetric water content; DP-soil relative dielectric permittivity; FC-field condition; WC-weather condition; IR-infrared introduction; LK-link length; AM-overall acoustic message rate; TD-telemetry data; SA-size of a single acoustic; BL-body length; BW-body width; BH-body height; HW-hip width; HH-hip height; LC-liquid counter; FM-flow meter; WG-weight; SN-soil nutrient concentrations; MD-motion detection; MLSS-mixed liquid suspended solids; BOD-biochemical oxygen demand; SS-suspended solids; COD-chemical oxygen demand; SPS-soil porosity; ARD-animal repelling devices; FS-flight sensor; NS-navigation sensor; CS-camera sensor; AN-ankle-bound node; VC-viscosity values; AQ-air quality.

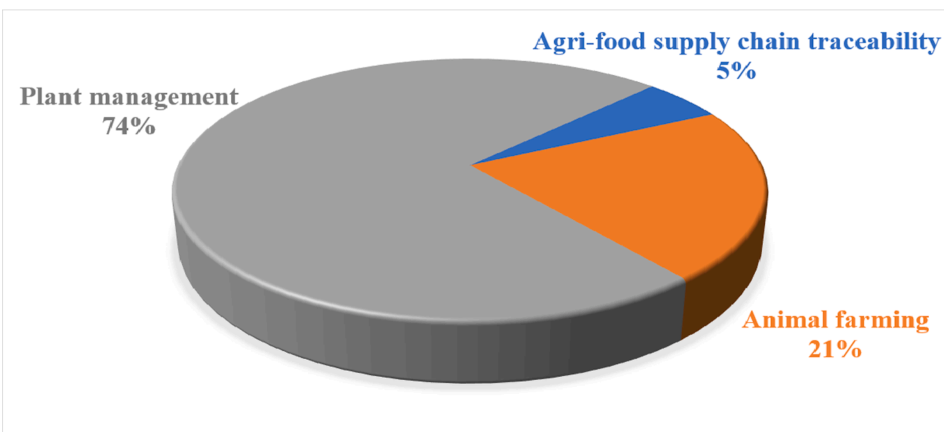


**Fig. 2.** Distribution of included studies in three categories.

and utilizes radio frequency band. WiFi has a communication range of 20–100 m, which is mostly used for communication from gateway to central server or cloud communication (Memon et al. 2016; Hsu et al., 2020; Muangprathub et al. 2019; Mekala and Viswanathan, 2019; Nawandar and Satpute, 2019; Benyezza et al., 2021; Hu et al., 2021). Vijayakumar and Ramya, (2015) proposed an IoT module which supported WiFi for accessing mobile devices, in order to realize the real-time monitoring of water quality. Using WiFi for sensor-to-sensor communication can be energy consuming and affect lifetime of network. Lavanya et al., (2020) and Sarangi et al. (2014) used low energy WiFi in data link layer, because it possesses qualities such as low energy, less overhead, power friendly communication, better synchronization, and short MAC fame of 30 bytes. Some smart agriculture systems Gsangaya et al., (2020), Song, (2020), Effendi et al., (2020), Elakkiya et al., (2021), Karthikkumar et al., (2021), Sirisha and Sahitya, (2021) and Ahmed et al., (2021) used the ESP8266 module as communication medium for using the internet, which is a low-cost WiFi microchip. And other agricultural platforms chose WiFi as the means of connection medium between the controller and smart phone or cloud (Pezol et al., 2020; Pokala and Bini, 2021). Sawant et al., (2017) used WiFi to realize the communication between the child nodes and base station. Jonathan and Widjaja, (2021), Bharti et al., (2021), Nanda et al., (2021) and Le et al., (2021) used a built-in WiFi module to access to the internet. And WiFi can also be used to form the WiFi based long distance (WiLD) network, which can successfully been used to connect the rural regions with low cost. Ahmedet al., (2018) used the WiLD network to connect the rural regions from a remote location situated far from the point of internet connectivity. Compared with SigFox and NB-IoT that are designed for long-range connection, WiLD network is suitable for carrying a huge amount of data and running fog computation, and avoids the very low data-rates as well as low processing capabilities.

#### 4.2.2. ZigBee

ZigBee is also a kind of wireless communication technology gaining

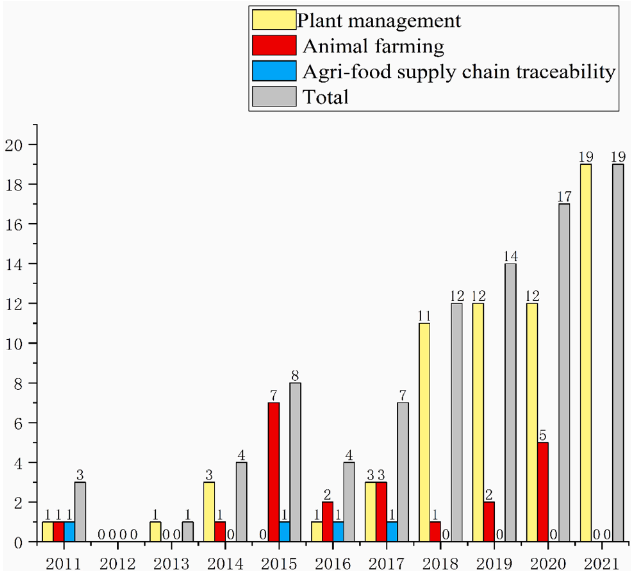


**Fig. 3.** Number of included articles in different categories by year of publication.

popularity majorly in smart agriculture, and about one sixth of researches used ZigBee in the IoT systems. ZigBee is based on IEEE 802.15.4 standard and operates in 2.4 GHz ISM (Industrial, Scientific and Medica) band. Three types of devices are defined in ZigBee: ZigBee end devices, ZigBee routers and ZigBee coordinators. Sensors are ZigBee end devices that don't have any routing capability but can send the data to parent nodes. Morais et al., (2008) used two MPWiNodeZ (Multi-Powered Wireless Node ZigBee) devices as end devices to form a small ZigBee network. Kumar and Hancke, (2014) and Fourati et al., (2014) selected Xbee modules to transfer data for both indoor and outdoor line of sights. Compared with other technologies, ZigBee has high scalability and also offers easier maintenance of the connected sensor nodes which canintercommunicate with each other (Encinas et al., 2017; Nikolidakis et al., 2015; Chikankar et al., 2015). Estrada-Lopez et al., (2018), Burton et al., (2018) and Srbinovska et al., (2015) used ZigBee radio models to receive data between nodes. Then information is collected from various sensor nodes to base station. The base station receives all data, monitors each connected sensor and serves as the ZigBee coordinator. ZigBee coordinator is the core and single control station of the network. (Sinha et al., 2019) and Patil and Thorat (2016) used ZigBee coordinator for establishing network.

For most water quality monitoring applications where sensors must be installed in the field, ZigBee technology has been widely used as wireless communication (Soto-Zarazúa et al., 2011; Wiranto et al.,2015). Because Xbee module can transmit data to 100 ft indoor and 300 ft outdoor (with line-of-sight), so this wireless communication coverage should be sufficient to give the flexibility of locating the data logger in a secured location. ZigBee is also most widely used technology for intra-sensor communication in a greenhouse or irrigation system (Bodunde et al., 2019; Dasgupta et al., 2020) due to its low-duty cycle and low power consumption.

### *4.2.3. LoRa*

LoRa is another communication enabling technology for agriculture. Because of its long range, LoRa can be used to support remote

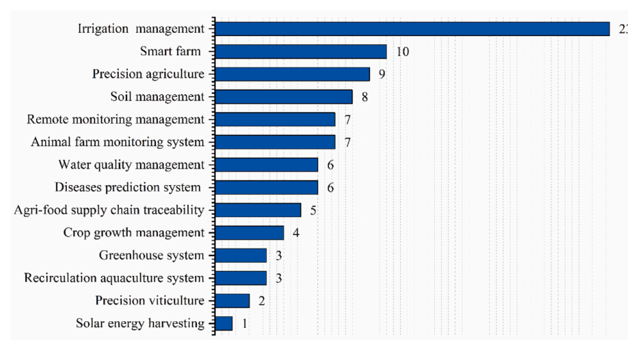


**Fig. 5.** Numbers of articles on smart agriculture applications.

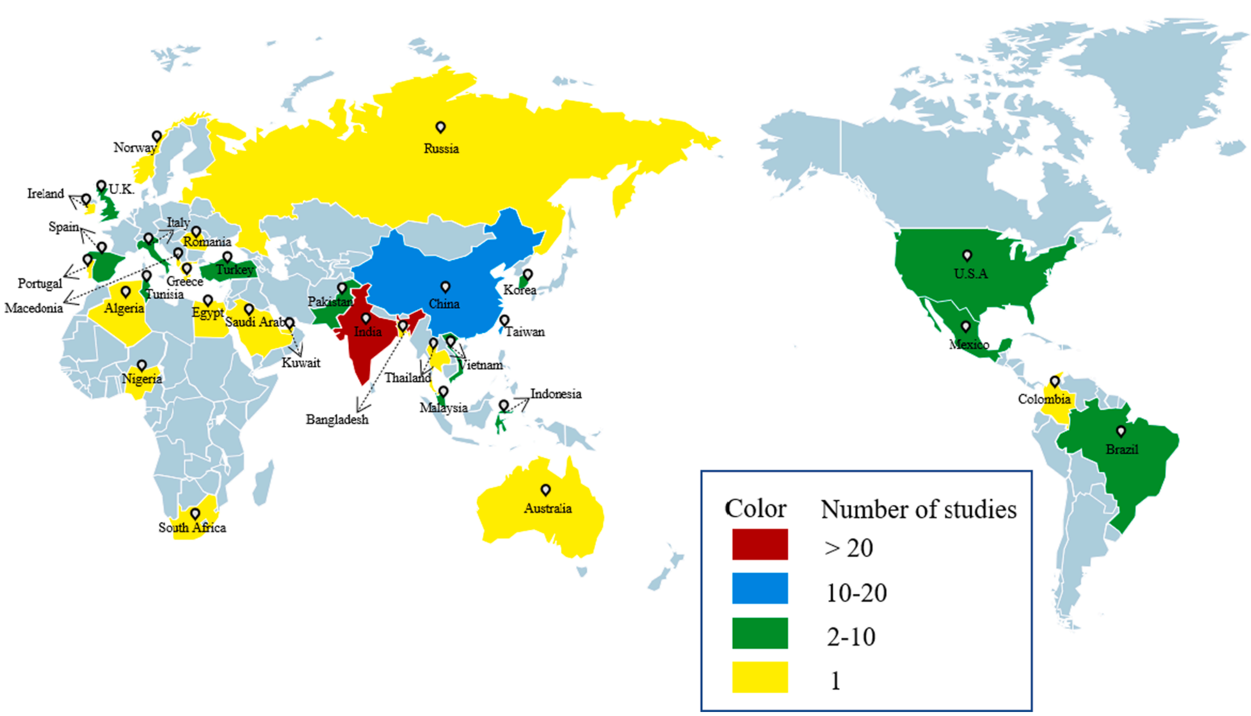


**Fig. 4.** Distribution of studies from different locations in the world.

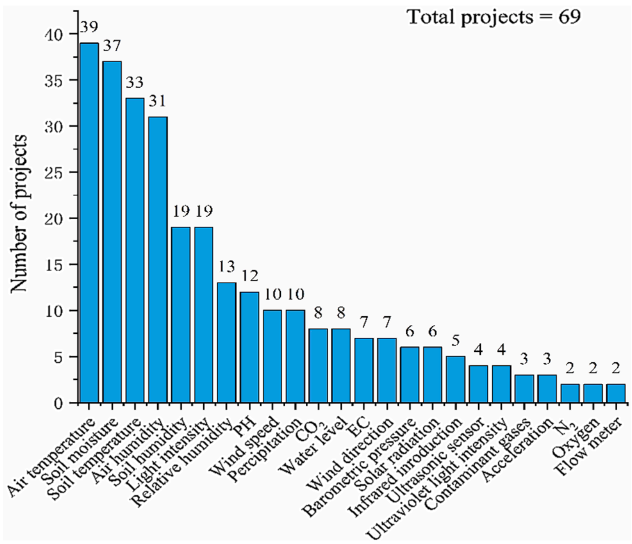


**Fig. 6.** Partial monitoring parameters included in 65 plant management projects.

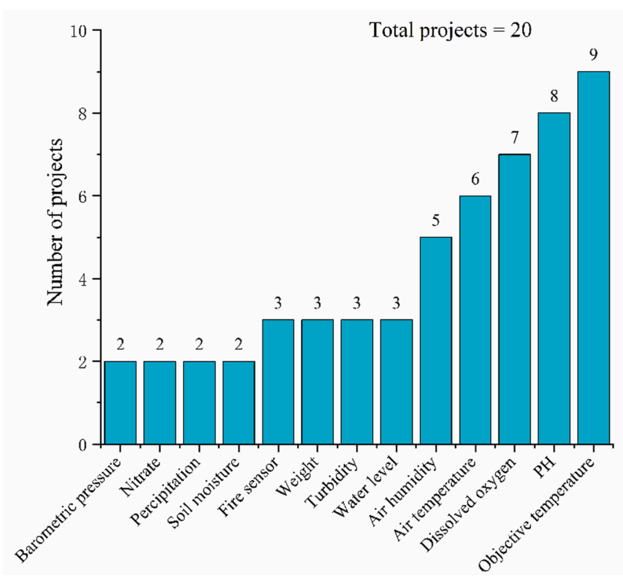


**Fig. 7.** Partial monitoring parameters included in 20 animal farming projects.

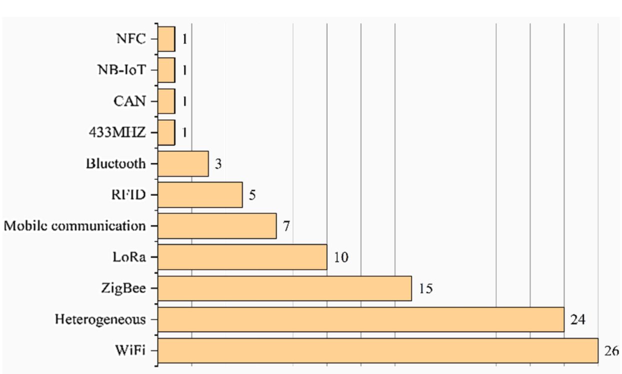


**Fig. 8.** IoT communication technologies in 94 reviewed projects.

monitoring applications like greenhouse monitoring, pest detection, and acoustic fish telemetry. In Changqing et al., (2018) LoRa wireless network for communication is realized in greenhouse. And the sensor collection points are supplied with solar power so that they can be positioned anywhere inside the greenhouse. In Chen et al., (2020), LoRa module SX1276 was used to transmit data to the Raspberry Pi on the server station in a pest detection system. LoRa has a unique feature named Spreading Factor (SF) which can be chosen as a trade-off between coverage area, data rates and radio packet size. This makes LoRa an ideal candidate as a wireless communication interface for acoustic fish telemetry (Hassan et al., 2019). LoRaWAN (LoRa Wide Area Network) is a network based on LoRa technology. It can provide connectivity over large agricultural fields, yet with low energy requirements (at the cost of a low data rate). Taşkın and Yazar, (2020), Codeluppi et al., (2020) and Adami et al., (2020) proposed the IoT-oriented platform based on the LoRaWAN architecture, due to its inherit simplicity, modularity and possibility to be deployed almost everywhere. LoRa gateways receive the data from LoRa end devices and direct it to LoRa servers. Koubaa et al., (2020) proposed a smart palm architecture with LoRa gateway layer to collect data, and Wang et al. (2021), Kökten et al., (2021) and Catak (2020) used LoRa transceiver module to transfer data. Compared to other wireless communication technologies such as Bluetooth, ZigBee, and Wi-Fi, LoRa technology has advantages in terms of low energy consumption.

#### *4.2.4. **RFID***

RFID works on the principal by assigning a unique number individually to each object in order to record information. RFID consists of readers, host and tags where tags receive and transmit radio waves. Tags have a unique ID number and environmental information, and these tags are transmitted by chip to a reader to identity object. RFID technology has been extensively used for a diversity of applications in agriculture, ranging from livestock management systems, supply chain management systems and so on. For example, Shi et al., (2019) provided a mobile measuring system to measure the body components of pigs, and images of pigs were acquired when the RFID reader was triggered by pigs in drinking area. And Trevarthen and Michael, (2008) presented how an RFID- enabled dairy farm can leverage mobile network infrastructure towards achieving total farm management. In Aguzzi et al., (2011), researches developed and tested a novel RFID tracking technology to measure the burrow emergence rhythm of a commercially important marine crustacean species. Kelepouris et al, (2007) and Ruan and Shi, (2016) used RFID to realize traceability in food supply chain.

#### *4.2.5. Mobile communication*

There are multiple generations of mobile communication standards consist of second generation (2G), third generation (3G), fourth generation (4G) and GPRS. IoT devices communicate with cellular networks by using these standards. Saqib et al., (2020) used a 2G module to collect weather data from the Internet and establish connection with the cloud using the GSM/GPRS protocol to develop a low-cost information monitoring system for smart farming applications. And Munir et al., (2021) placed GSM module SIM808 at transport layer to transfer data to edge server. Compared with 3G or 4G, 2G module is more suitable for agricultural applications because most agricultural farms are located in the countryside, where 3G or 4G are not yet established. Even data rate is relatively slower than the latest technologies, the amount of collected data is extremely small and the transmitted data is not a significant factor. Su et al., (2020) and Namani and Gonen, (2020) used 4G to realize communication between controller and server. Through the use of mobile communication, users can detect changes and abnormal data at any time. Khattab et al., (2019) selected cellular services to develop an IoT-based cognitive monitoring system for early plant disease forecast, due to its relatively long-range wireless communication and its robust communication links.

GPRS as one of mobile communication technologies is also been

**Table 2**
Comparison of existing communication technologies.

| Parameters | Standard | Frequency Band | Data Rate | Transmission Range | Energy Consumption | Cost |
|---|---|---|---|---|---|---|
| WiFi | IEEE 802.11a/c/b/d/g/n | 5 GHz-60 GHz | 1 Mb/s-7 Gb/s | 20–100 *m* | High | High |
| ZigBee | IEEE 802.15.4 | 2.4 GHz | 20–250 kb/s | 10–20 *m* | Low | Low |
| LoRa | LoRaWAN R1.0 | 868/900 MHz | 0.3–50 kb/s | < 30 Km | Very low | High |
| RFID | ISO 18000-6C | 860–960 MHz | 40 to 160 kb/s | 1–5 *m* | Low | Low |
| Mobile communication | 2G-GSM, CDMA 3G-UMTS, CDMA2000, 4G-LTE, GPRS | 865 MHz, 2.4 GHz | 2G: 50–100 kb/s<br>3G: 200 kb/s<br>4G: 0.1–1 Gb/s | Entire Celluar Area | Low | Low |
| Bluetooth | IEEE 802.15.1 | 24 GHz | 1–24 Mb/s | 8–10 *m* | Very low | Low |

mentioned in several agricultural platforms. It stands for General Packet Radio Service, and doesn't have a range limitation. GPRS is a cellular standard designed to transmit voice and data, and ease the Machine to Machine (M2M) communication. Medela et al., (2013) proposed an IoT multiplatform networking to monitor and control wineries and vineyards using GPRS. Because there are cellular networks base stations on the vicinity of the crop, GPRS is the most appropriate communication option in this scenario, which allows convenient data transmission. Mostly GPRS is used for sensor to base station or gateway to base station communication. It's suitable for remote monitoring of greenhouse also. Kang et al., (2018) used GPRS to realize data transmission in a solar greenhouse due to its connectivity without requiring the installation of a web cable. GPRS's main advantage is its wide availability over the world but soon it may phase out for acquisition of higher data rate services like 4G and 5G. GPRS is cost effective and has high consumption in low data rate applications like greenhouse monitoring but 4G and 5G may not be.

#### 4.2.6. Bluetooth

Bluetooth is a low power and low range personal area network which is the best for short range mobile communication. Kim et al., (2008) utilized Bluetooth technology for sensor-based variable rate irrigation systems. For the application in this paper, accommodating existing data loggers and sensors required plug-and-play compatibility to serial devices with cost-effective wireless communication modules. Hence the Bluetooth module was selected for wireless data communication between in-field sensing stations to a base station. Ilapakurti and Vuppalapati, (2015) and Hasan et al., (2021) focused on Bluetooth low energy framework to connect to sensors. Bluetooth low energy, marked as Bluetooth Smart, is intended to provide considerably reduced power consumption and cost while maintaining a similar communication range.

Compared with other technologies, the limitations about Bluetooth applications in agricultural systems can be solved or minimized by a system design optimization. For example, power shortages can be solved by using solar panels that recharge the battery, and radio range can be improved by upgrading the power class and antennas.

#### 4.2.7. Heterogeneous communications

As mentioned before, different technologies have different characteristics, and are suitable for different scenes. In an IoT-based system, power consumption and transmission range are two factors which need to be considered when proposing solutions for smart farming. Therefore, the combination of more than one technology in the architecture system may have better effect. In these 24 researches, ZigBee accounts for a large proportion due to its long battery life and low duty cycle. With deployed sensors communicating with IoT gateways over the 100 m range, ZigBee has been commonly used for farm management (Nam et al., 2017). Chen et al., (2015), Liao et al., (2017), Goap et al., (2018), Keswani et al., (2019), Sharma et al., (2019) and Wang et al., (2015) selected ZigBee and WiFi as the communication technologies in systems. ZigBee is used to transmit sensing data from wireless sensor network to gateway or central processing core, and WiFi module is used to transfer data to user terminal devices, including personal computers and mobile phones. Liang et al., 2008 and Gutierrez rt al., (2014) selected ZigBee and GPRS to realize communication, and GPRS module was for transmitting the data to a web server via the public mobile network. Roy et al., (2021) used ZigBee to sense environmental parameters and forward the data to gateway, and the gateway nodes transmit the data to remote server in the packet format of GPRS. Compared with the two different combinations, WiFi is used to provide self-organization communication supporting remote data transmission between 20 and 100 m, while GPRS is more used for smart irrigation and environmental monitoring.

However, WiFi combined with GPRS can take advantages of both. Prathibha et al., (2017) developed an IoT-based monitoring system, and current images of the particular field were captured by a camera sensor and were sent to the farmer through GPRS, with a high performance Wi-Fi wireless microcontroller to process data. As for long range, a data packet service for the GSM cellular network is used (Butsenko et al., 2020). In Yang et al., (2021a,b), the communication layer is compromised of the GSM module. Collected data is transferred to the base station through this gateway wirelessly, and this module is also WiFi-enabled and communicates the information wirelessly.

LoRa provides wide communication range with low data rate. So, LoRa is also valuable for widely spread smart agriculture. Vu et al., (2018) and Kamienski et al. (2019) chose LoRa communication to enable the concentrator to connect to field-level devices, and chose WiFi to provide internet service for connecting the system to the web server. Hoan et al., (2021) used LoRa to build communication between master node and slaves, with a built-in WiFi module ESP8266 to access to the internet. Mobile communication is more suitable for systems spanning a wide agricultural area. Edwards-Murphy et al., (2016) used ZigBee to send collected data to the base and data were transmitted by a 3G radio to a server (cloud storage). The Bluetooth wireless communication technology is popular with applications for soil moisture and temperature monitoring, with shortrange communications up to 10 m. Balan et al. (2020) selected a Bluetooth5 module enabling the link to a mobile device, and the data logger becomes an endpoint, connecting to the back-end server through a LoRa gateway.

Other systems chose a heterogeneous communication subsystem to collect data and realize communication. On the one hand, systems with different communication interfaces can collect data from various sensors (Kim et al., 2018) . Foughali et al., (2018) used a multi-protocol router which has five interfaces (2.4 GHz WiFi, 5 GHz WiFi, Bluetooth, ZigBee and 3G / GPRS) to collect all data from sensor nodes and store them in the cloud. On the other hand, Menon et al. (2017) developed a wireless sensor node network which contains several sensors to sense the chemical contents of water. Because river flows through different areas like urban, semi-urban and rural areas, the used communication can be varied. GSM, 3G, 4G and Wi-Fi are more prominent in urban areas and ZigBee provides better signal strength for communication in rural areas.

## 5. Challenges

In an agricultural environment, although IoT devices provide useful information on a wide range of physical parameters to enhance cultivation practices and crop productivity, there are still some challenges and limitations in IoT-based agricultural systems. The main challenges in adopting smart agriculture applications are listed below. The challenges are classified according to their nature, as shown in Fig.9.

### 5.1. Concerns on cost

There are several cost associated with the deployment of IoT in agriculture which can be categorized into hardware cost and software cost (Elijah et al., 2018a,b). The hardware cost includes the purchases of IoT devices, modules, base station infrastructure and so on. Meanwhile, in order to realize real-time monitoring of multiple parameters and precision agriculture, the high-quality and high-precision sensors and devices are another high-cost situation (Shi et al., 2019a,b). The software cost involves the high development, maintenance and deployment cost of smart agriculture systems, and the running cost including continuous subscription for use of centralized services or IoT platforms (Elijah et al., 2018a,b). The high hardware and software cost make it difficult for farmers to deploy devices and technology, so Bringing down the system cost is still a big challenge faced by many researchers. To realize the wide spread of the IoT-based smart agriculture applications, it's important to reduce the system cost further and develop some economic models (Chen and Yang, 2019). Energy management as one of the most emerging issues also plays a vital role in any WSN-based systems. Till now, because of the increasement in devices, conventional energy consumption is not a reliable and sustainable solution. Therefore, potential energy harvesting solutions such as solar, wind, water, biomass, and vibration energy harvesting schemes should also be tested while designing IoT-based smart agriculture applications (Kour and Arora, 2020).

### 5.2. Concerns on system

On the one hand, in agriculture, there are different landforms, systems should adapt to various environment conditions. On the other hand, sensor nodes deployed in the field are sensitive to environmental variations, and hence the accuracy of collected real-time data can be easily affected. Especially in precision agriculture, devices are adaptable with other devices and surroundings. While sometimes devices cannot adopt to each other due to consistent varying environment conditions or hardware problems. And communication between wireless nodes and the cloud may be interrupted because of the disturbed wireless communication channels. Therefore, the development of advanced techniques for atmospheric correction and cloud detection should be paid attention to reduce the influence of environmental variations. In addition, for systems with a large-scale deployment, hierarchical architecture has a better perform than the plane network architecture. Hence authors need to design and deploy such agriculture system in a planned and proportional way, which can also reduce the average cost keeping the performance intact. And the usability of developed platforms and solutions should be simplified because farmers accounts for a large proportion of the end-users of these agriculture applications. In this regard, the simplicity of operation and interface is required to be taken care of. Meanwhile, real-time analysis is imperative before deploying the system to avoid post-deployment losses.

### 5.3. Concerns on data

Reliability is a major concern for IoT devices in terms of data transmission. Devices need to gather and transfer reliable data in order to make appropriate decisions when necessary. False reading will greatly reduce system reliability. Therefore, the integrity of data is still a challenge due to system failures, battery issues and other interventions. At the same time, data storage is another challenge. Sensors constantly generate data, and a large amount of data requires enough resources to preform data analysis. Consequently, the increasing requirements for storage result in advanced new software platforms and facilities for scalable management of big data sources. Fault tolerance is also an important feature of wireless sensor networks. There are various faults that may occur in an IoT-based agriculture system, such as node failure because of the depleted battery or other reasons, erroneous value, communication failure and faulty sensor calibration. Therefore, solutions for tolerating fault should be considered.

### 5.4. Concerns on devices

Standardization of devices is essential to realize the wide use of technology in large range of applications. However, there are none standardization formats about the data process. And outputs can be different due to the misinterpretation of the mismatched code. The standardization of machines can solve the interoperability issues of systems, applications, equipment and products. Additionally, with the development of 5G network, the communication between devices and servers is 100-times faster than 4G. 5G can carry much more data which is an ideal technology for transferring information from remote sensors. Therefore, the use of 5G as the new communication network is a must for more secure users' requirements and more rapid data transfer rate. And the lack of interoperability is one of the biggest problems in smart agriculture. Heterogeneous devices are used while designing a system,

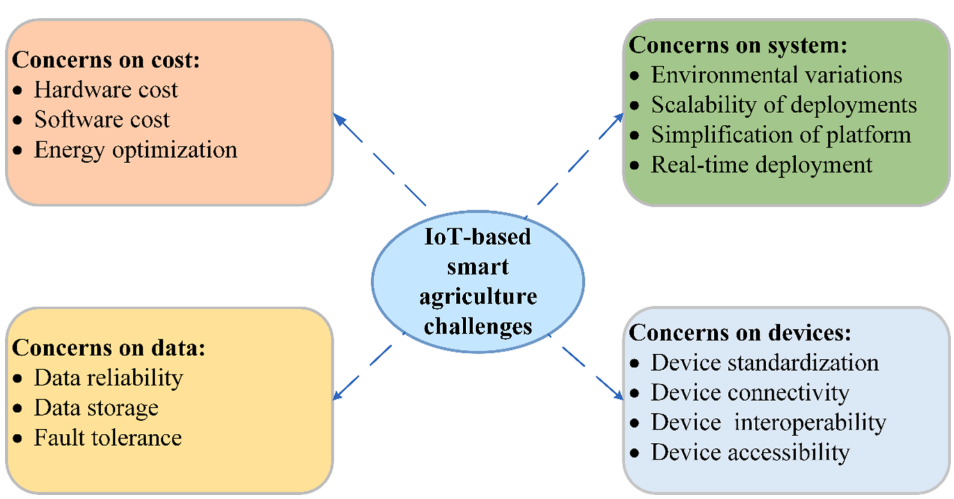


**Fig. 9.** Categories of challenges in smart agriculture applications based on IoT

so it is significant to integrate different machine communication standards for interaction between heterogeneous modules. Otherwise, lack of interoperability not only inhibits the adoption of new technology, but also influences the productivity of crops. As a result, the interoperability of efficient communication and data sharing between machines is important. In addition, the applications of agriculture are applied not only in indoor environments, but also in other difficult outdoor environments. The developed smart farming monitoring systems should realize the availability of existing software and hardware in order to present anywhere. The availability of required equipment can ensure services anywhere and anytime, and avoid chaos and delay of the service.

## 6. Recommendations

This section provides a summary of some important recommendations to mitigate the challenges, which can make the IoT-based smart agriculture applications more efficient, reliable and business-oriented, as shown in Fig. 10.

### 6.1. Data recommendations

Data sharing should be encouraged while designing and integrating agriculture systems. The acceleration of economic globalization and the arrival of the era of sharing lead to the development of global interactive mode. Global data sharing is not only good for further understanding the whole agriculture status worldwide, but also helps to better understand the terrain and population challenges in different parts of the world. Thus, environments with constrained resources can attain more suitable solutions to realize automated and smart agriculture. Simultaneously, the era of data explosion needs a more reliable, systematic, and scientific manner to process the exploring data. Data mining and cloud storage are both valid means to gather and store data, which should be played maximum attention in the future. Meanwhile, the existing data has a great reference value for designing smart farming systems. With the development of IoT in agriculture, a variety of models are designed to meet different need including irrigation systems, farm management, pest and diseases detection, and precision agriculture. Therefore, previous case studies and deployment models are valuable for developing cost efficient and reliable models.

### 6.2. Device recommendations

The communication domain has gone through a progressive shift. Once 5G technology enables various connected services, agricultural sectors can see explosive growth in data traffic. Since IoT-based smart agriculture models are remotely located, high-speed communication is a prerequisite. The integration of 5G and smart agriculture can realize remote consultation of agriculture production problems and remote control of agricultural productions. The relative users or farmers friendly apps for monitoring crop and plant health should also be developed in the future, since globalization is inevitable and users of targeted applications may come from different countries. Various ethnic and linguistic backgrounds can result in different levels of understanding and methods to perform agriculture tasks. The consideration of native language and regional custom during the design of systems can improve interaction between farmers and machines, and enhance the acceptable of people to smart agriculture. Furthermore, portable and sustainable farming equipment is of great significance for large or small farms. Because different countries have different economic conditions. From relative studies, many third world countries and other nations are rejecting the concept of smart agriculture due to equipment's high cost and short life time. And the input cost of smart agriculture models varies from country to country. There is no doubt that the cost of devices in second and third world is different compared with cost in first world. Therefore, device cost analysis provides the concept of purchasing power, and can result in seeking other more cheaper and efficient models for farmers in developed countries. The interoperability between different components and communication technologies can reduce unnecessary cost as well as enhance the function of the system. Furthermore, lack of equipment's interoperability obstructs the popularization of IoT technologies in agricultural production management.

### 6.3. System recommendations

Platform should be designed from farmers' perspective and be ease of using. Because farmers all over the world have different farming habits, and different soil environments lead to different farming systems. Before designing prototype, there should be a clear sight of various requirements, which is helpful to design a user-friendly system. In the meantime, energy management should be kept in mind while designing system components and algorithms. It is evident that no matter how small the farm is, it needs power and energy for normal working of devices. Conventional power generation is the mainstream in agriculture, which is not sustainable. Thus, making full use of characteristics of some special areas to develop non-conventional sources of energy like wind energy and solar energy is a great solution. Because many agricultural environments always change with season or outside conditions,

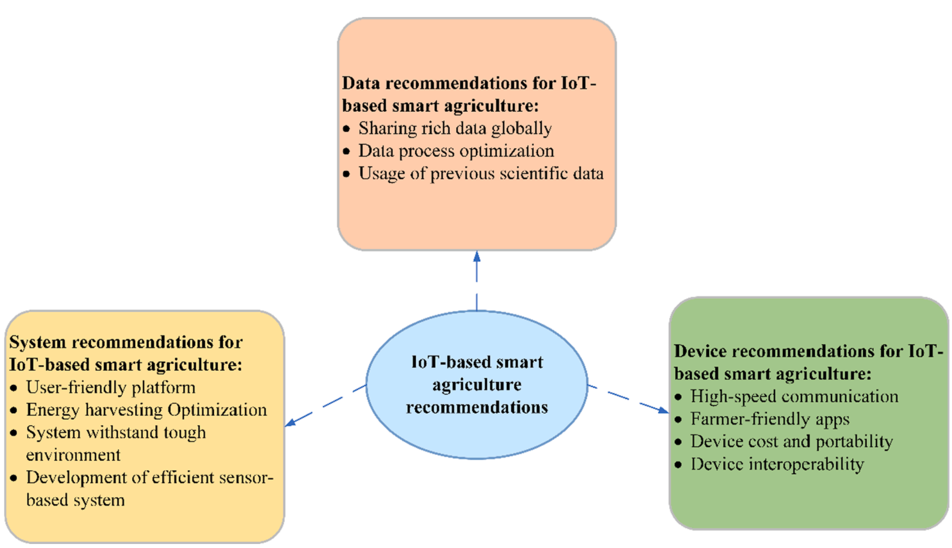


**Fig. 10.** Categories of recommendations for IoT applications in smart agriculture.

and some conditions are even harsh, systems which can withstand soil erosion and other destruction are essential. It's still a great task to develop systems which are sustainable to external and internal changes. At the same time, the more efficient sensors-based system can realize a more precise investment in agriculture. Firstly, sensor network composed of a certain number of sensor nodes can accurately obtain real-time information of soil environment and crop growth. Secondly, high-precision wireless sensor networks can water, fertilize, spray in time according to the needs of crop growth, so as to avoid the problem of obtaining crop growth information by visual observation and subjective experience in the past, and the waste and pollution caused by overuse are avoided.

## 7. Conclusions and future directions

A recent disruptive trend has emerged in the use of IoT based applications in smart agriculture. The reform about relevant IoT communication technologies is ongoing, and obtaining insights into this emerging trend as well as integrating with agricultural sector are important. Therefore, this review compiled scientific literature on the development of communication technologies in IoT-based smart agriculture systems and studied relevant challenges in IoT-based smart agriculture applications. Relative 94 articles were reviewed, classified by category, year, and authors' nationality. Then we analyzed partial monitoring parameters in 65 plant management projects, and 20 animal farming projects, respectively. The communication technologies between sensor networks and gateway or servers are discussed. Other common communication technologies like Zigbee, Bluetooth, WiFi, and many other technologies and heterogeneous systems are also explored. Results indicate that each technology has its own advantages and limitations, and different wireless communication technologies are suitable for different scenarios. An in-depth analysis of these articles helps identify and describe challenges and recommendations relevant to IoT applications in smart agriculture. We presented the challenges associated with existing IoT-based smart agriculture applications from 4 aspects, namely cost, data, system and device. Finally, we listed relevant recommendations which can solve the challenges of IoT applications in smart agriculture and open up opportunities for researches in this area.

Intending to tackle the growing grey literature and scattered information about IoT communication technologies in smart agriculture, a summary of previously published studies about IoT communication technologies in smart agriculture is presented. The review of these works may serve as a reference for researchers. People will continue to adopt new technologies, and thus, researchers must learn about emerging trends and technologies in IoT-based smart agriculture. The review of these existing works gives us some new directions in the further development of IoT-based smart agriculture. Current state-of-the-art offers IoT-based solutions for irrigation management, soil management, crop disease prediction, animal farming mostly. Therefore, other fields such like agri-food supply chain traceability need more attention and have big potentials in applying IoT technologies. Meanwhile involved IoT communication technologies in these articles are mostly LoRa, ZigBee, and WiFi, and the emerging high-speed communication technologies like 5G and NB-IoT are supposed to be widely used to promote the modernization and intelligence of agricultural production. With the advent of modern technologies, there is a lot of scope for innovating new and efficient systems in IoT-based agriculture. Specifically, low-cost solutions with features like autonomous operation, low maintenance, energy-efficiency, ease of operation, and robust architecture are in demand. Overall, futuristic pre-planning is required for the success of IoT-based smart agriculture applications, specifically to overcome these problems.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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