Role of IoT Technology in Agriculture: A Systematic Literature Review

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Abstract: The growing demand for food in terms of quality and quantity has increased the need for industrialization and intensification in the agriculture field. Internet of Things (IoT) is a highly promising technology that is offering many innovative solutions to modernize the agriculture sector. Research institutions and scientific groups are continuously working to deliver solutions and products using IoT to address different domains of agriculture. This paper presents a systematic literature review (SLR) by conducting a survey of IoT technologies and their current utilization in different application domains of the agriculture sector. The underlying SLR has been compiled by reviewing research articles published in well-reputed venues between 2006 and 2019. A total of 67 papers were carefully selected through a systematic process and classified accordingly. The primary objective of this systematic study is the collection of all relevant research on IoT agricultural applications, sensors/devices, communication protocols, and network types. Furthermore, it also discusses the main issues and challenges that are being investigated in the field of agriculture. Moreover, an IoT agriculture framework has been presented that contextualizes the representation of a wide range of current solutions in the field of agriculture. Similarly, country policies for IoT-based agriculture have also been presented. Lastly, open issues and challenges have been presented to provide the researchers promising future directions in the domain of IoT agriculture.

Keywords: internet of things; agriculture; devices/sensors; agricultural applications; communication protocols

1. Introduction

The widespread of the internet from the last two decades has brought unlimited benefits for organizations and citizens over the globe. The major benefit of this innovation was the capability to producer and consumer services in real time. Recently, Internet of Things (IoT) is promising to provide the same benefit through its innovative technologies and giving a way to enhance the user's perception and ability by modifying the working environment. IoT offers multiple solutions in different domains such as healthcare, retail, traffic, security, smart homes, smart cities, and agriculture. IoT deployment in agriculture is considered the ideal solution because in this area there is a need for continuous monitoring and controlling. In the field of agriculture, IoT is used at different levels in the agriculture industrial production chain [1]. The main applications of IoT in agriculture are Precision Farming, Livestock, and Greenhouses, which are grouped into different monitoring domains. All these applications are monitored with the help of different IoT-based sensors/devices by using wireless

sensor networks (WSNs) that helps the farmers collect relevant data through sensing devices. Some IoT-based setups analyze and process the remote data by applying cloud services, which helps the researchers and agriculturists make better decisions. Nowadays, with the advancement of current technology, environment monitoring solutions offer additional facilities in terms of management and decision making. A custom-made landslide risk monitoring system has been developed that allows quick implementations in hostile environments without user intervention [2]. What is more interesting about the developed system is that it deals with node failures and reorganizes the poor quality communication links on the network by itself. An IoT management is proposed in [3] that monitors the elements such as wind, soil, atmosphere, and water over a large area. Moreover, IoT-based agricultural monitoring solutions have been identified based on the sub-domains to which they belong. The identified sub-domains are soil monitoring, air monitoring, temperature monitoring, water monitoring, disease monitoring, location monitoring, environmental conditions monitoring, pest monitoring, and fertilization monitoring. Further, the IoT paradigm improves human interaction in the physical world through low-cost electronic devices and communication protocols. IoT also monitors different environmental conditions to create dense and real-time maps of noise level, air, water pollution, temperature, and damaging radiations [4,5]. Besides, data collected about different environmental parameters is transmitted to the user by trigger alerts or sending recommendations to authorities via messages [6].

In the last few decades, a large number of studies have been presented in the IoT-based agriculture domain. Therefore, it is important to collect, summarize, analyze, and classify the state-of-the-art research in this area. The purpose of this research is to present a comprehensive systematic literature review in the field of IoT agriculture. The contributions of this paper related to the IoT agriculture domain are as follows. In Section 2, we present a background of IoT agriculture technology. In Section 3, we present the research methodology by defining research questions, inclusion/exclusion criteria, and search string to collect effective studies relevant to the IoT agriculture domain and focused on different publication channels. In Section 4, we present the research results in the form of tables by synthesizing the selected papers. Besides, some IoT-based agricultural applications, sensors/devices, communication protocols, and country policies are also presented in this section. In Section 5, we present a summary of our findings through a research hierarchy and designed an IoT-based smart farming framework. In Section 6, open issues and challenges in IoT agriculture have been discussed from many different perspectives. Moreover, research validity threats are presented in Section 8. Section 9 presents the conclusions of the article.

2. Background

Researchers have proposed different IoT-based technologies in the agriculture field that are increasing the production with less workforce effort. Researchers have also worked on different IoT-based agriculture projects to improve the quality and increase agricultural productivity. Some IoT-based agricultural techniques have been identified from the literature, which have been summarized in this section. Carnegie Melon University has worked on a plant nursery by using wireless sensors technology [7]. In [8], a WSN-based polyhouse monitoring system has been presented that makes use of carbon dioxide, humidity, temperature and light detection modules. By using GPS technology and ZigBee protocol a WSN-based system has been proposed that monitors different agricultural parameters [9]. A real-time rice crop monitoring system has been designed to increase the productivity [10]. The crop monitoring system has been presented in [11], which collects the information of rainfall and temperature and analyzes it to mitigate the risk of crop loss and enhance crop productivity. A low-cost Bluetooth-based system has been proposed in [12] for monitoring various agricultural variables such as temperature by using a microcontroller that works as a weather station. The proposed system is best for monitoring real-time field data. Moreover, the disadvantage of this system is its limited communication range and required Bluetooth configuration with smartphones for continuous monitoring. A smart sensing platform based on ZigBee has developed by [13] for

monitoring different environmental conditions such as humidity, temperature, sunlight, and pressure. The developed platform provides a fast data rate, low-cost hardware, and an accurate sensor working on mesh network so that each node can communicate with each other effectively. A Global System for Mobile Communications (GSM) based irrigation monitoring system has been developed that uses an android app for measuring different environmental conditions such as humidity, temperature, and control of the water level. The basic purpose of this system is to develop a low-cost wireless system, whereas the negative aspect of the system is to know the operating command to actuate the field motor and agriculture parameters [14]. To measure the greenhouse parameters such as humidity and temperature, a system has been proposed on the basis of GSM and Field Programmable Gate Array (FPGA). The proposed system provides cost-effective and timely monitoring solutions to monitor crop and soil conditions [15]. In [16], a simple, flexible networking low-cost system has been proposed that uses a fuzzy control system to monitor different greenhouse parameters. The operation and design methodologies for WSN have been proposed in [17] for a more advanced monitoring and controlling system in the greenhouse. Multiple environmental problems related to greenhouses have also been addressed such as WSN components standardization, wireless node packaging, and electromagnetic field interference. In [18], a system has been proposed that monitors the animal's health as well as identifies the widespread diseases, whether it originates from biological attacks or natural causes. A low-cost animal health monitoring system is presented in [19] that measures the heart rate, postures, and body temperature.

3. Research Methodology

A systematic literature review (SLR) is selected as the research methodology for this paper. The goal of this research is to investigate and provide a review of existing IoT-based agricultural monitoring applications, sensors/devices, and communication protocols. We have followed the methodology proposed by [20] to make research impartial in the context of information selection and results in representations. The research methodology for this systematic mapping study has been illustrated in Figure 1.
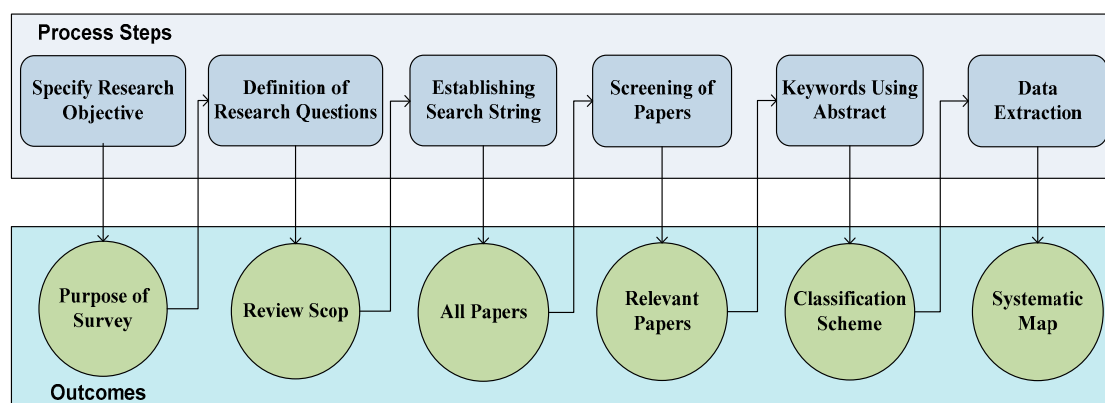

Figure 1. Research methodology.

3.1. Research Objectives

This research comprised on the following objectives:

O1: More focused state-of-the-art research work has been identified in the field of IoT agriculture.

O2: Characterize the existing IoT agriculture applications, sensors/devices, and communication protocols.

O3: Proposed a taxonomy that further highlights the adopted IoT agriculture methods and approaches.

O4: An IoT-based smart farming framework has been proposed that consists of basic IoT agriculture terms to identify the existing IoT solutions for the purpose of smart farming.

O5: Identify the research gaps in terms of challenges and open issues.

3.2. Research Questions

The first step of this SLR is the definition of research questions and provision of the current research status on IoT-based agriculture. This SLR addresses eight research questions with their corresponding motivation represented in Table 1.

Table 1. Research questions. IoT: Internet of Things.

No	Research Question	Main Motivation
RQ1	What are the major targeted primary publication channels for IoT agricultural research?	In order to identify where IoT agricultural research can be found as well as good publication sources for future studies.
RQ2	How has the frequency of approaches been changed related to IoT agriculture over time?	Identify the publication with the time related to IoT in agriculture.
RQ3	What approaches are used to address problems related IoT agriculture?	To find out existing IoT agriculture approaches reported in the existing IoT agriculture literature.
RQ4	What are the main application domains of IoT in agriculture?	Identify the main areas of agriculture where IoT technology is being utilized for monitoring, controlling, and tracking purposes.
RQ5	What are the primary focuses of the selected studies?	To identify the significant proposed solutions.
RQ6	What type of IoT devices/sensors have been used in agriculture?	To identify the role of primary IoT devices/sensors.
RQ7	Which IoT network/communication protocols are used in agriculture?	To identify the role of network and communication protocols.
RQ8	Which IoT agricultural policy have been implemented in different countries?	To measure the potential of IoT in the agriculture field in the different countries.

3.3. Search String

The second phase of SLR is to search for relevant studies on the research topics. A search string has been defined that is used to gather published articles related to the research topics. We conducted a pilot search based on the specific keywords, and we decided to use only IoT applications in the agriculture search string. However, in the pilot search, we have also used IoT sensors/devices and communication protocols in agriculture. Internet research has been performed by using multiple search engines and digital libraries to collect information. The obtained results were compiled manually to get the best sources for information to answer the defined research questions. Selected search engines and digital libraries have been chosen based on their scientific contents and closely related to the objective of this paper. The chosen databases were Springer, Elsevier, IEEE, MDPI, and IGI Global. The next step is to identify the consistent procedures and search terms to seek out technical and scientific documentation in search engines and digital libraries. The set of keywords selected to define the search string from the research questions is given in Table 2.

Table 2. Search string.

Sources	Search String	Context
IEEE Xplore, Science Direct, Springer Link, MDPI, and IGI Global	("Internet of Things" OR "IoT") AND ("IoT agricultural Applications" OR "Devices/Sensors" OR "IoT agricultural devices/sensors") OR ("IoT agricultural protocols" OR "IoT Communication Protocols")	Agriculture

3.4. Screening of Relevant Papers

All the papers in the search were not precisely relevant to research questions; therefore, they needed to be assessed according to the actual relevancy. For this purpose, we used the search process

defined by Dybå and Dingsøyr [21] for the screening of relevant papers. In the first screening phase, papers were selected based on their titles, and we excluded those studies that were irrelevant to the research area. For example, the keyword protocol returns articles relevant to IoT in other fields that have different meanings than the IoT technology used in agriculture. These papers were totally out of scope, so we excluded them. In the second phase of screening, we read the abstract of each article that was selected in the first screening phase. Furthermore, inclusion and exclusion criteria also used to screen papers.

We decided to exclude the following types of papers:

- Articles not presenting new and emerging ideas.
- Papers published other than conferences, journals, patents, and technical reports.
- Articles without defining data sources or where the data collection procedure was unclear.
- Articles not published in the English language.
- Papers published before 2006.
- Papers that are not relevant to the search string.

Papers have been selected on the basis of the given exclusion criteria and after examining the abstract of selected studies, we have decided to include it in the next screening phase.

3.5. Keywording Using Abstract

To find the relevant papers through keywording by using the abstract, we used a process defined by Petersen et al. [22]. Keywording has been done in two phases. In the first phase, we have examined the abstract and identified the concepts and keywords that reflected the contribution of the studies. In the second phase, a higher level of understanding is developed on the basis of these keywords. For the mapping of reviews, we have used keywords to form and cluster the categories.

3.6. Quality Assessment

In an SLR, generally, quality assessment (QA) is carried out to assess the quality of selected papers. In this SLR, a questionnaire has been designed to measure the quality of the selected papers. The QA in this SLR is carried out by following the previous mapping study [23].

(a) The study contributes to IoT in agriculture. The possible answers for this research question were "Yes (+1)" and "No (0)".
(b) The study represents a clear solution in the field of agriculture by using IoT. The possible answers for this research question were "Yes (+1)", "partially (0.5)", and "No (0)".
(c) The published studies that have been cited by other articles and possible answers for this research question were: "partially (0)" if the citation count is 1 to 5, "No (−1)" if paper is not being cited by any author, and "Yes (+1)" if citation count is more than five.
(d) The published study is from a stable and recognized publication source. The answer to this question has been evaluated by considering the Journal Citation Reports (JCR) lists and CORE ranking computer science conferences.

Possible answers for journals and conferences are presented in Table 3.

Table 3. Quality criteria. JCR: Journal Citation Reports.

Sources	Ranking	Score
Journal	Q1	2
	Q2	1.5
	Q3 or Q4	1
	If paper is not in a JCR ranking	0
Conference	CORE A	1.5
	CORE B	1
	CORE C	0.5
	If paper is not in a CORE ranking	0

Selected studies have a score for each question, and the calculated sum of scores is presented in the form of an integer between −1 and 5.

3.7. Study Selection Process

The selection and search processes results are presented in Table 4. Initially, 3179 papers were selected when the search protocol was applied on the selected repositories. A screening process has been applied on the basis of the exclusion criteria, keywords, titles, abstracts, and full articles of retrieved papers. One author retrieved all these papers; then, two authors examined the papers, which led to the selection of a total 240 papers. After that, we eliminated the duplicate titles and the titles that were not relevant to the review. For example, most of the excluded papers were related to general IoT such as privacy, security, healthcare, retail, and smart cities. To determine the assessment agreement between two authors, a Cohen's kappa coefficient of 0.91 was used, which indicates that the evaluation made by authors is a perfect measurement [24]. Furthermore, after reading the full abstracts of the selected 171 papers in the duplication phase, we have selected 104 papers on the basis of their abstracts. In the end, 67 studies were selected out of 3179.

Table 4. Primary selection process for retrieved articles.

Phase	Process	Selection Criteria	IEEE Xplore	Springer	Science Direct	MDPI	IGI Global	Total
1	Search	Keywords	1900	601	402	255	21	3179
2	Screening	Title	111	63	27	31	8	240
3	Screening	Duplication Removal	72	53	29	11	6	171
4	Screening	Abstract	45	24	21	9	5	104
5	Inspection	Full Article	47	6	7	6	1	67

3.8. Data Extraction Method

The data extraction strategy has been applied to providing a set of possible answers to the defined research questions.

RQ1: The answer to this question is given by identifying the publication channels and sources for all papers.

RQ2: To identify the frequency of approaches of each article, which has been classified according to the publication year.

RQ3: Research approaches have been classified according to developing techniques in the selected studies such as whether they proposed a system, solution, method, model, application, survey, platform, architecture, ecosystem, review, and framework.

RQ4: To identify the primary IoT solution for agriculture, different monitoring, controlling, and tracking applications have been investigated.

RQ5: The defined research question identifies the primary focus of the selected studies in the IoT agricultural field.

RQ6: This research question has been designed to measure the utilization of devices/sensors used by selected IoT agricultural solutions.

RQ7: Which communication protocol or network system has been designed or implemented to provide an IoT-based agricultural solution.

RQ8: Different country policies have been discussed to measure the value of IoT in agriculture.

4. Analysis

In this section, findings related to the SLR questions that are presented in Table 1 are described. Research studies after choosing the screening process have been used to illustrate each research question answer to make an essential contribution to the IoT agriculture field.

4.1. Selection of Results

Analysis of the state-of-the-art IoT-based smart farming studies is a key challenge due to the coverage of multiple application domains, communication protocols, sensors/devices, and protocols. According to our research questions, we have gathered 67 primary studies in this section. After analyzing the selected studies, we have addressed each question according to the extracted information. Quality assessment and the overall classification results of the selected papers have been presented in Table 5.

Table 5. Classification and quality assessment scores. WSN: wireless sensor networks.

| | | | | | Classification | | | | | | | Quality Assessment | |
Reference	P. Channel	Years	Research Approaches	Applications Domain	Major Focus	Sensors and Devices	Protocols/ Network Type	a	b	c	d	Scores
[25]	Journal	2009	Method	Monitoring	Proposed a method to measure the environmental conditions in a vast area such as air humidity and temperature.	Microclimate Sensor	ZigBee/WSN	1	1	1	2	4.5
[26]	Conference	2014	Platform	Monitoring	Designed a platform to monitor the soil moisture and temperature all over the field.	Core Ship CC2530	WSN	1	1	0	0	2
[27]	Conference	2014	Architecture	Controlling	A WSN-based irrigation solution has been presented.	Water Quality Sensing Node	WSN	1	1	1	0	3
[28]	Conference	2009	Method	Controlling	A low-cost wireless irrigation system has been proposed.	Sensor Node and Microcontroller	GPRS/WSN	1	1	1	0	3
[29]	Colloquium	2014	Method	Controlling	A web-based decision support system has been developed for irrigation scheduling.	Weather Station	WSN	1	1	1	0	3
[30]	Symposium	2006	Architecture	Monitoring	A preliminary investigation system is presented on a large-scale sensor network for precision agriculture.	LOFAR-agro	WSN	1	1	1	0	3
[31]	Conference	2015	Platform	Monitoring	Proposed an intrusion detection system to monitor the field.	AVR Microcontroller	WSN	1	1	1	0	3
[32]	Conference	2008	Method	Tracking	Designed a method to track the behavior of animals in the field.	Wild CENSE Node	GPS/WSN	1	1	1	1.5	4.5
[33]	Journal	2013	Method	Controlling	Developed a climate controlling method for greenhouses.	Sensor Nodes	ZigBee/WSN	1	1	0	0	2
[34]	Conference	2009	Method	Monitoring	A sensor network is designed to measure the soil moisture.	Soil Moisture Sensor	ZigBee/WSN	1	1	0	0	2
[35]	Conference	2015	Architecture	Monitoring	Developed a system to monitor the drought and irrigation level.	No	No	1	0.5	0	0	1.5
[36]	Conference	2017	Proposed System	Monitoring and Controlling	A wireless mobile robot system has been developed to perform multiple monitoring and controlling tasks.	Various Sensors/Raspberry PI	WIFI, ZigBee	1	1	1	0	3
[37]	Conference	2015	Proposed System	Monitoring	Proposed a system to monitor the field and greenhouse gas.	Various Sensors	WSN	1	0.5	0	0	1.5

Table 5. *Cont.*

			Classification									Quality Assessment
Reference	P. Channel	Years	Research Approaches	Applications Domain	Major Focus	Sensors and Devices	Protocols/ Network Type	a	b	c	d	Scores
[38]	Journal	2012	Proposed System	Tracking	Proposed a design to measure the animal movement.	No	GPS	1	1	1	2	5
[39]	Conference	2018	Proposed System	Monitoring	An innovative and scalable system has been proposed for monitoring the agricultural system.	Humidity and Temperature Sensor	LoraWAN	1	0.5	1	0	2.5
[40]	Journal	2019	Model	Monitoring	Proposed a model to measure the crop productivity and anticipate the problems.	Various Sensors	Lora	1	1	0	2	4
[41]	Conference	2017	Proposed System	Monitoring	An IoT-based agricultural production system has been developed to monitor the field of environmental parameters.	Temperature and Moisture Sensor	RFID	1	1	1	0	3
[42]	Symposium	2017	Proposed System	Monitoring	Developed a low-cost irrigation monitoring system.	Soil Moisture Sensor	MQTT	1	1	1	0	3
[43]	Conference	2015	Proposed System	Monitoring	Developed an animal pastures monitoring system.	Collars and Geolocation Devices	GPS, SigFox	1	1	1	0	3
[44]	Conference	2011	Proposed System	Monitoring	Developed a WiFi-based wireless sensor network for field and smart grid monitoring.	WiFi Sensor	ZigBee, WIFI, WSN	1	1	1	0	3
[45]	Journal	2009	Review	Monitoring	Presented a review on the role of WSN for precision agriculture.	Sensor Nodes/Gateway	RFID, WSN ZigBee	1	1	1	1.5	4.5
[46]	Journal	2011	Method	No	Integrated WiFi and WiMAX for agri IoT users.	No	WIFI, WIMAX	1	1	1	1	4
[47]	Journal	2018	Ecosystem	Monitoring	Several IoT agricultural benefits and challenges have been discussed for monitoring air, temperature, humidity, and moisture level.	Multiple Sensors and Devices	Sigfox, Lora, NB-IoT, Wifi	1	1	1	2	5
[48]	Journal	2019	Framework	Monitoring	An experimental framework has been designed to monitor different agricultural applications such as water, fertilization, heat, and gas	Various Sensors/Gateway	ZigBee, MQTT/WSN	1	1	0	2	4

Table 5. *Cont.*

					Classification							Quality Assessment		
Reference	P. Channel	Years	Research Approaches	Applications Domain	Major Focus	Sensors and Devices	Protocols/ Network Type	a	b	c	d	Scores
[49]	Journal	2019	Platform	Controlling	Proposed a low-cost agri talk IoT-based platform for the precision farming of soil cultivation.	Soil and Insects Sensor, Actuators	Network Time Protocol (NTP)	1	1	0	2	4
[50]	Conference	2010	Proposed system	Controlling	A system has been proposed to control the environmental parameters such as humidity and temperature.	Temperature and Humidity Sensor	SMS, Wireless application protocol (WAP)	1	1	1	0	3
[51]	Journal	2018	Model	Tracking	A tracking and record-keeping model has been presented that traces the growth level of plants in a greenhouse.	Various sensors and Raspberry Pi 3	WIFI	1	1	−1	2	3
[52]	Conference	2018	Application proposed	Monitoring	Cloud-based IoT application is developed to monitor different agricultural parameters, which are water, light humidity, and pesticides.	Soil Moisture, Temperature, and Humidity Sensor/Microcontroller	GPS, WIFI	1	0.5	0	0	1.5
[53]	Conference	2018	Proposed model	Controlling	The author collects poly houses data about crop productivity and uses WiFi to transmit data over the network to control insects and pesticides.	Soil moisture, PH Humidity and Water Sensor	WIFI	1	0.5	0	0	1.5
[54]	Conference	2017	Proposed system	Monitoring	A remote sensing system has been proposed to monitor different greenhouse parameters such as soil moisture, temperature, and light.	Various Sensors, Actuators, and Embedded System	WSN	1	1	0	0	2
[55]	Conference	2018	Proposed system	Monitoring	Low power and the prolonged network has been proposed in the agriculture field to monitor soil moisture content.	Soil Moisture Sensor	Lora	1	1	1	0	3
[56]	Conference	2012	Platform	Controlling	System captures the data of growing fruits, control plants environment, water, and fertilizers.	Various Sensors	RFID/WSN	1	0.5	1	0	3.5

Table 5. *Cont.*

Classification								**Quality Assessment**					
Reference	**P. Channel**	**Years**	**Research Approaches**	**Applications Domain**	**Major Focus**	**Sensors and Devices**	**Protocols/ Network Type**	**a**	**b**	**c**	**d**	**Scores**
[57]	Conference	2019	Proposed system	Controlling	Designed a system to test and self-power IoT devices for precision agriculture to control fertilization.	Various Sensors/Gateway, Microcontroller	Ultra-low power (ULP), MQTT, Bluetooth	1	1	−1	0	1
[58]	Conference	2016	Architecture	Monitoring	An IoT-based three-layered architecture has been proposed to monitor different precision agricultural applications such as wind detection, rain volume, air temperature, and humidity.	Multiple Sensors	nRF24L01 ultra-low-power transceiver	1	0.5	1	0	2.5
[59]	Conference	2018	Method	Monitoring	A method has been proposed to monitor multiple field parameters such as soil humidity and temperature.	Various Sensors/Microcontroller, Gateway	WiFi	1	0.5	0	0	1.5
[60]	Conference	2017	Survey	Monitoring	A survey of different monitoring applications and communication protocols.	Various Sensors	Multiple Protocols	1	0.5	1	0	2.5
[61]	Conference	2018	Platform	Monitoring	An IoT-based animal's behavior monitoring platform has been developed.	Various Sensors/Gateway	GPS	1	1	1	0	3
[62]	Conference	2015	Framework	Controlling	Developed an innovative project to facilitate the farmers and improve the farm productivity by controlling water.	Radar Level Sensor	GSM	1	1	1	0	3
[63]	Conference	2017	Solution Proposal	Monitoring	Paper presents a remote monitoring leaf disease detection scenario.	Temperature, Soil Moisture, Humidity/Raspberry PI	WiFi	1	1	0	0	2
[64]	Conference	2018	Proposed System	Controlling	A system has been developed to increase crop productivity by low water consumption.	Temperature, Soil Moisture Sensors/Raspberry PI	4G mobile network	1	0.5	1	0	1.5
[65]	Conference	2017	Model	Controlling	Proposed a model to minimize the use of fungicides and pesticides in plants.	Weather Station	No	1	0.5	0	0	1.5

Table 5. *Cont.*

	Classification							**Quality Assessment**				
Reference	**P. Channel**	**Years**	**Research Approaches**	**Applications Domain**	**Major Focus**	**Sensors and Devices**	**Protocols/ Network Type**	**a**	**b**	**c**	**d**	**Scores**
[66]	Conference	2018	Proposed System	Controlling	A repelling system is provided to prevent the crop from wild animal attacks.	Microcontroller, Gateway	6LowPAN	1	1	0	0	2
[67]	Conference	2018	Proposed System	Controlling	A web and android app-based power efficient irrigation control system has been developed.	Temperature, Moisture, and Humidity Sensors	Lora	1	1	−1	0	1
[68]	Journal	2019	Architecture	Monitoring	Developed an agricultural watering system on the basis of WSN.	Temperature and Humidity/Node MCU	WSN	1	1	1	2	5
[69]	Conference	2018	Application	Controlling	Developed an application for disease detection at early stages.	Sensor Nodes/Gateway	WIFI, Bluetooth, ZigBee, GPRS	1	1	1	0	3
[70]	Conference	2016	Application	Monitoring	An e-Agriculture application has been developed to monitor crop productivity.	Temperature and Humidity sensor	3G, WIFI	1	1	1	0	3
[71]	Journal	2019	Proposed System	Monitoring	An intelligent and low-cost irrigation monitoring system is developed.	Unified Sensor Poled	HTTP, MQTT	1	1	−1	2	3
[72]	Journal	2018	Architecture	Monitoring	Proposed an architecture to monitor multiple agricultural parameters such as temperature, humidity, and soil moisture.	Multiple Sensors	WSN	1	1	−1	2	3
[73]	Journal	2018	Proposed System	Monitoring	A smart irrigation system is developed by using open source technologies and machine learning.	Multiple Sensors	WSN, HTTP, WIFI	1	1	1	2	5
[74]	Workshop	2017	Proposed System	Monitoring	A greenhouse monitoring system has been developed to monitor the different parameters such as light, temperature, humidity, and pressure.	MicaZ	WSN	1	1	1	0	3
[75]	Journal	2017	Method	Monitoring	Proposed a method that monitors the soil moisture and nutrients level.	Various Sensors	Zigbee	1	1	1	1	4
[76]	Journal	2016	Platform	Monitoring	To automate the environment condition, soil conditions, and fertilization, a smart net platform is proposed.	Various Sensors/Cameras, Weather Stations	No	1	1	1	1	4

Table 5. *Cont.*

| | Classification | | | | | | | Quality Assessment | | | | |
Reference	P. Channel	Years	Research Approaches	Applications Domain	Major Focus	Sensors and Devices	Protocols/ Network Type	a	b	c	d	Scores
[77]	Journal	2016	Platform	Monitoring	A monitoring platform has been proposed for the suitability of FIWARE precision agriculture.	Sensors/Gateway	FIWARE/WSN	1	1	1	1	4
[78]	Journal	2019	Platform	Monitoring	IoT-based smart irrigation system has been developed.	Various Sensors	FIWARE	1	1	1	1	4
[79]	Journal	2018	Proposed System	Monitoring	Analyzed and measured the environmental variables and crop disease. Proposed cloud-based technology.	Growth, Nutrients and Environmental Sensors	LORA	1	1	0	1	3
[80]	Journal	2019	Method	Monitoring	Introduced the augmented reality use and integrating it with IoT to update precision farming.	Various Sensors/Camera	RFID	1	1	−1	1	2
[81]	Journal	2011	Method	Monitoring	An ontology-based approach has been presented for smart farming to solve the semantic interoperate problem.	No	No	1	0.5	1	0	2.5
[82]	Conference	2016	Survey	Monitoring	IoT technology status and IoT agriculture such as precision seeding and irrigation have been investigated.	Sensors Module	RFID	1	0.5	0	0	1.5
[83]	Journal	2013	Method	Monitoring	Discussed the practical applications and theoretical research gap of IoT agriculture.	No	RFID/Information Network System	1	0.5	1	0	2.5
[84]	Journal	2018	Framework	Controlling	Proposed a solution for the efficient usage of water.	Various Sensors	WSN	1	1	1	1.5	
[85]	Journal	2015	Proposed Solution	Monitoring	Discussed agricultural challenges and proposed a solution to monitor oil moisture.	Soil Sensor	WSN	1	1	1	1	4
[86]	Symposium	2016	Proposed Solution	Monitoring	A methodology has been proposed to monitor the quantity and quality of grains in soil.	Various Sensors and Devices	WSN	1	1	1	0	3
[87]	Journal	2017	Proposed Solution	Monitoring	Proposed a cloud-based information system to deliver agricultural solutions.	Various Sensors and Devices	WSN	1	1	1	1	4

Table 5. *Cont.*

	Classification							Quality Assessment				
Reference	P. Channel	Years	Research Approaches	Applications Domain	Major Focus	Sensors and Devices	Protocols/ Network Type	a	b	c	d	Scores
[88]	Journal	2013	Architecture	Monitoring	Proposed an architecture on the basis of Routing Protocol for Low-Power and Lossy Networks (RPL) protocol to meet specific requirements for precision agriculture.	No	RPL	1	1	0	1	3
[89]	Conference	2017	Proposed System	Monitoring	A system has been proposed to monitor animal diseases by using data mining techniques.	Temperature Humidity and Heart Rate Sensors	WSN, WiFi, HTTP, GPRS	1	0.5	1	0	2.5
[90]	Conference	2015	Proposed System	Monitoring	Environment monitoring system has been developed for animal shelters.	Environmental Sensor, Aurdino, UHF Reader	RFID, WSN	1	1	1	0	3
[91]	Conference	2017	Proposed System	Monitoring	To monitor the behavior of small animals, a system has been proposed by using multiple IoT sensors.	IFR, Humidity and Temperature sensors, Raspberry PI, Camera	WSN, Bluetooth	1	1	0	0	2

4.1.1. Assessment of RQ1: What Are the Major Targeted Primary Publication Channels for IoT Agricultural Research?

Table 5 shows the different publications channels and several articles that have been published on these channels. Five different publication channels have been identified, in which 45% of the papers were presented in conferences, 1% of the papers were presented in workshops, 5% of the papers appeared in symposiums, 1% of the papers appeared in a colloquium, and 48% of the papers were published in journals. Note that 39% of the papers have been published in IEEE conferences, as shown in Table 6.

Table 6. Publication channels.

Publication Sources	References	Channel	NO	%
Sensors	[25,45,76–79]	Journal	7	10.44%
International Conference on Wireless Communication and Sensor Network	[26]	Conference	1	1.49%
IET Science, Measurement, and Technology	[27]	Journal	1	1.49%
International Conference on Networks Security, Wireless Communications, and Trusted Computing	[28]	Conference	1	1.49%
International Colloquium in Information Science and Technology	[29]	Colloquium	1	1.49%
International Parallel and Distributed Processing Symposium	[30]	Symposium	1	1.49%
International Conference on Communications	[31]	Conference	1	1.49%
International Conference on Intelligent Sensors, Sensor Networks, and Information Processing	[32]	Conference	1	1.49%
Pervasive Computing	[33]	Journal	1	1.49%
Annual Conference on Information Sciences and Systems	[34]	Conference	1	1.49%
International Conference on Geo informatics	[35]	Conference	1	1.49%
International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)	[36]	Conference	1	1.49%
International Conference on Intelligent Robots and Systems	[37]	Conference	1	1.49%
Transactions on Wireless Communications	[42]	Journal	1	1.49%
International Workshop on Factory Communication Systems	[39]	Conference	1	1.49%
Computers and Electronics in Agriculture	[40,68,71–73]	Journal	5	7.45%
International Conference on Smart Technologies for Smart Nation (SmartTechCon)	[41]	Conference	1	1.49%
Region 10 Symposium (TENSYMP)	[42]	Symposium	1	1.49%
International Conference on Industrial Technology	[43]	Conference	1	1.49%
Conference on Industrial Electronics and Applications	[44]	Conference	1	1.49%
Research journal of applied sciences, engineering and technology	[46]	Journal	1	1.49%
IEEE Internet of Things Journal	[47,48]	Journal	2	3%
IEEE Access	[48,51]	Journal	2	3%
International Conference on Computer Science and Information Technology	[50]	Conference	1	1.49%
International Conference on Trends in Electronics and Informatics	[52]	Conference	1	1.49%

Table 6. *Cont.*

Publication Sources	References	Channel	NO	%
International Conference on Inventive Research in Computing Applications	[53]	Conference	1	1.49%
International Conference on Big Data, IoT, and Data Science	[54,63]	Conference	2	3%
World Forum on Internet of Things (WF-IoT)	[55,57]	Conference	2	3%
International Conference on Image Analysis and Signal Processing	[56]	Conference	1	1.49%
International Conference on Microelectronics (ICM)	[58]	Conference	1	1.49%
International Conference on Cloud Computing, Data Science and Engineering (Confluence)	[59]	Conference	1	1.49%
International Conference on Microelectronic Devices, Circuits, and Systems (ICMDCS)	[60]	Conference	1	1.49%
IoT Vertical and Topical Summit on Agriculture—Tuscany (IOT Tuscany)	[61]	Conference	1	1.49%
IEEE Technological Innovation in ICT for Agriculture and Rural Development (TIAR)	[62]	Conference	1	1.49%
International Conference on Inventive Systems and Control (ICISC)	[64]	Conference	1	1.49%
International Conference on Ubiquitous and Future Networks (ICUFN)	[65,90]	Conference	2	3%
International Conference on Environmental Engineering (EE)	[66]	Conference	1	1.49%
International Conference on Innovations in Science, Engineering, and Technology (ICISET)	[67]	Conference	1	1.49%
International Conference on Ambient Systems, Networks, and Technologies	[69]	Conference	1	1.49%
International Conference on Advances in Computing and Communications, ICACC	[70]	Conference	1	1.49%
International Workshop on IoT, M2M, and Healthcare	[74]	Workshop	1	1.49%
Sustainability	[80]	Journal	1	1.49%
International Conference on Computer and Computing Technologies in Agriculture	[81]	Conference	1	1.49%
International Conference on Electrical Engineering and Automatic Control	[82]	Conference	1	1.49%
Informatics and Management Science	[83]	Journal	1	1.49%
Neural Computing and Applications	[84]	Journal	1	1.49%
In Interoperability and Open-Source Solutions for the Internet of Things	[85]	Journal	1	1.49%
International Symposium on Intelligent Systems Technologies and Applications	[86]	Symposium	1	1.49%
Journal of Organizational and End User Computing	[87]	Journal	1	1.49%
International Journal of Agricultural and Environmental Information Systems	[88]	Journal	1	1.49%
IJETT	[89]	Conference	1	1.49%
International Conference on Intelligent Informatics and Biomedical Sciences (ICIIBMS)	[91]	Conference	1	1.49%

4.1.2. Assessment of RQ2: How Has the Frequency of Approaches Been Changed Related to IoT Agriculture over Time?

The selected articles published between 2006 and 2009 are shown in Figure 2. It can be seen that most of the papers have been published between 2015 and 2019 and there are few papers that have been published in 2019, because the initial search process was made in July of that year. This shows that each year number of publication are increasing, which indicates the growing interest of IoT in agriculture.
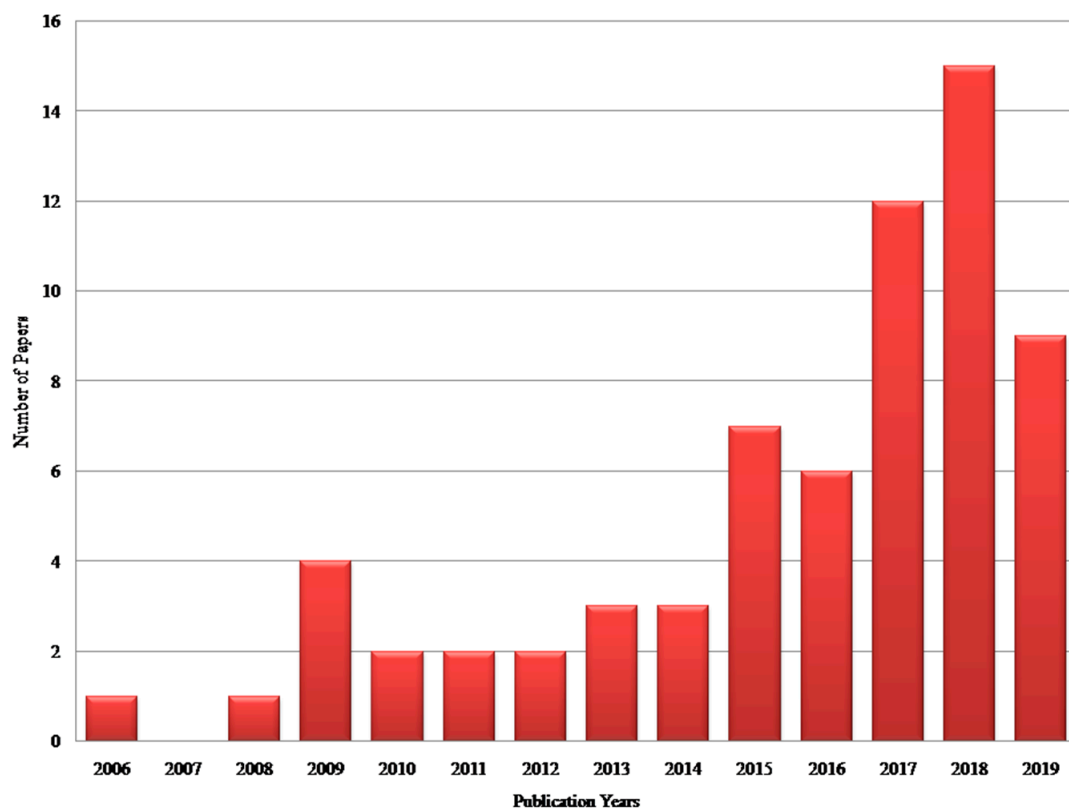
Figure 2. Distribution of selected papers by year.

4.1.3. Assessment of RQ3: What Approaches Are Used to Address Problems Related to IoT Agriculture?

There are multiple research approaches in the field of IoT agriculture, as shown in Figure 3. Each approach has been investigated in this section.

(a) Proposed method or solution: There may be single or multiple systems, and solutions have been proposed to investigate the phenomenon within its actual context. In [36], a wireless robotic system has been proposed to control and monitor the different agricultural tasks. Furthermore, several IoT-based systems have been proposed to monitor the animals' behavior such as monitoring health conditions and weather parameters [89–91]. IoT technologies have been utilized to provide different agricultural solutions such as monitoring the soil quality, grains quality, and quantity in the soil [85–87].

(b) Survey/Review: A method that collects quantitative information relevant to IoT agriculture. Authors presented a survey on multiple IoT agricultural applications and communication protocols [92]. In [93], a survey has been presented on IoT-based precision seeding and irrigation.

(c) Platforms: Different IoT-based platforms have been developed under the controlled environment to examine its effect on agriculture. A smart network platform has been developed to monitor

the environmental conditions, soil conditions, and fertilizations [54]. In addition, different water, temperature, irrigation, and moisture monitoring platforms have been designed [45].

(d) Architecture: Multiple IoT agricultural architecture designed to collect the data from devices/sensors and store the collected data for proper analysis [68,72,88].

(e) Application: Mobile apps provide a connection for many IoT devices and facilitate the farmer having better control over different agricultural applications. Several applications have been developed to monitor the crop productivity and disease detections at early stages [69,70]. In [52], a cloud-based IoT application has been developed to measure the farm variables such as light, humidity, water, and pesticides.

(f) Method: A series of steps taken to acquire knowledge about IoT agriculture. Several methods have been designed to integrate the communication technologies such as WiFi and WiAX and measure the field parameters such as water quantity, soil humidity, temperature. etc. [32,33,46].

(g) Framework: A conceptual structure that is intended to guide or support for building something that explores the guidelines and conceptual structure in useful manners in IoT agriculture [48,62,84].

(h) Model: A representation of the developed system that investigates the designed properties of IoT agriculture. The model proposed in [51] tracks and traces the growth level of plants in a greenhouse.

(i) Ecosystem: Ecosystems are designed to address the several IoT agricultural solutions and challenges. In [53], IoT-based smart farming benefits and challenges have been presented to monitor the air, temperature, and humidity.
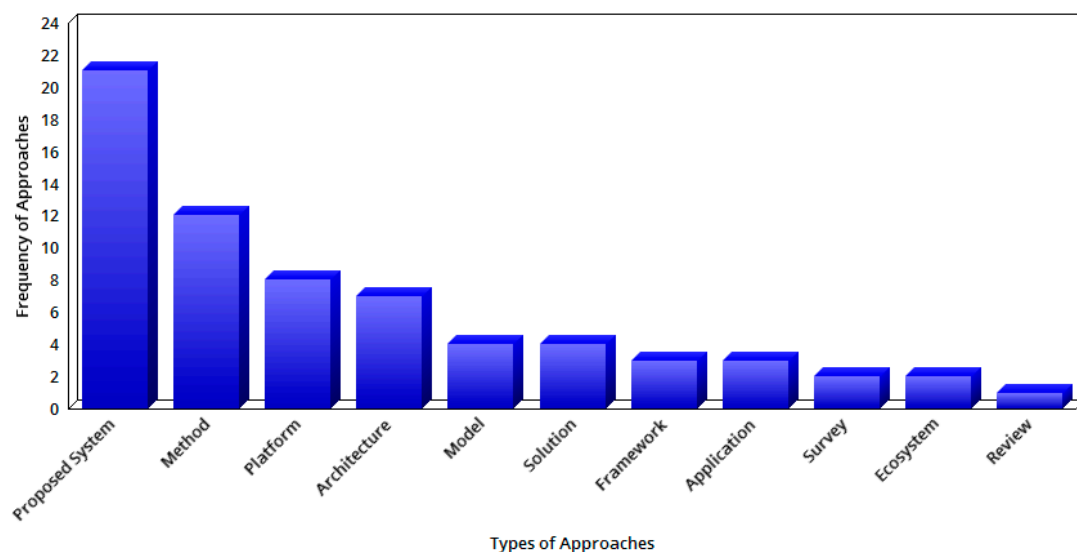
Figure 3. Research Approaches in IoT Agriculture.

4.1.4. Assessment of Q4: What Are the Main Application Domains of IoT in Agriculture?

IoT agricultural solutions consist of multiple monitoring, controlling, and tracking applications that measure several types of variables such as air monitoring, temperature monitoring, humidity monitoring, soil monitoring, water monitoring, fertilization, pest control, illumination control, and location tracking. The selected mainstream application domains in this SLR are monitoring, tracking, and controlling, as shown in Figure 4. Most of the studies have focused on monitoring (70%), controlling (25%), and tracking (5%), as shown in Figure 4.
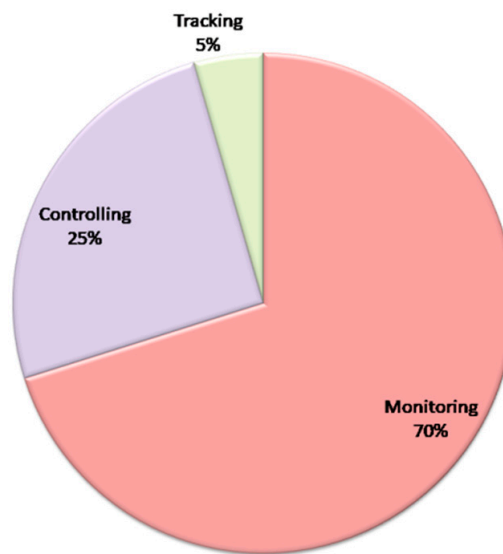
Figure 4. Application Domains.

4.1.5. Assessment of RQ5: What Are the Major Focuses of the Selected Studies?

The primary focus of each IoT agricultural application concerning their domains (monitoring, controlling, and tracking) is discussed in this section. The main classification of these applications are Irrigation Monitoring and Controlling (16%), Precision Farming (16%), Soil Monitoring (13%), Temperature Monitoring (12%), Humidity Monitoring (11%), Animal Monitoring and Tracking (11%), Water Monitoring and Controlling (7%), Disease Monitoring (5%), Air Monitoring (5%), and Fertilization Monitoring (4%), as shown in Figure 5. It can be seen that most of the selected papers have focused on precision farming, irrigation monitoring, and controlling. Some representative examples of IoT agriculture applications are discussed in this Section.
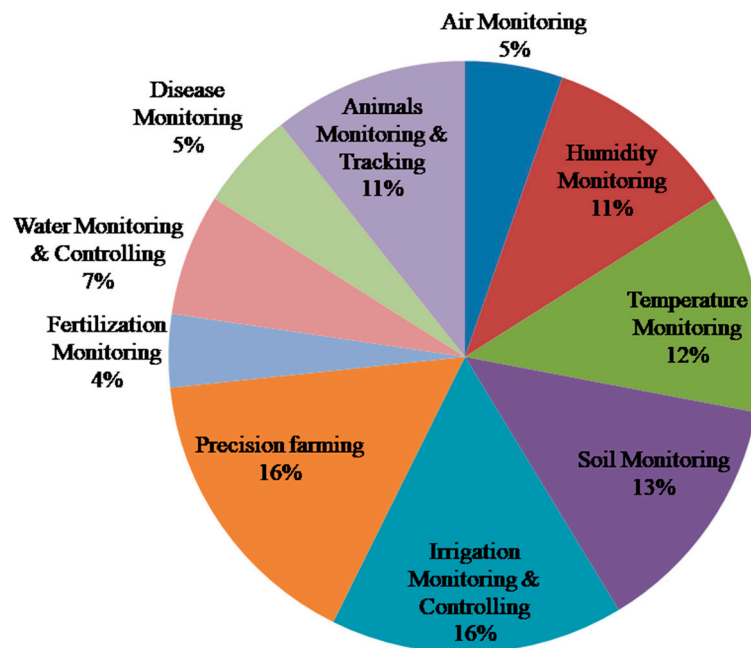
Figure 5. IoT agriculture applications.

Air Monitoring

The aim of this sub-domain is to evaluate and determine the air condition in order to prevent from damaging effects. In [25] an IoT-based agricultural air, humidity, and temperature monitoring system has been proposed. This system offers a real-time microclimate monitoring solution that is based on WSNs. The system consists of a temperature and humidity sensor that is supported by a communication technology called ZigBee and powered by solar panels.

Soil Monitoring

Paper categorized in this sub-domain [26] proposed solutions for soil moisture and temperature monitoring in the fields using WSN. Both of these systems are maintained through multiple communication technologies such as GPRS, ZigBee, and the internet, where the user interacts with the system through web applications [63,85].

Water Monitoring

The studies that have been categorized in this sub-domain intend to monitor water quality or water pollution by sensing PH, temperature, and chemicals, which can change the normal conditions of water. In [27], an IoT-based solution has been presented to monitor the water quality by measuring temperature, conductivity, and turbidity. This solution based on WSN combines sensing devices and monitors the multiple parameters of water in urban areas. Moreover, [28] developed a WSN-based system to monitor the rainfall and water level in irrigation systems. A web-based decision support system has been proposed in [29] that use sensors to measure temperature, solar radiations, humidity, and rainfall for irrigation monitoring in olive fields.

Disease Monitoring

The LOFAR-agro Project is the best example for crop or plant monitoring [30]. This project protects the potato crop by monitoring different climate conditions such as temperature and humidity through WSN. The proposed system protects the crop by analyzing the collected data from fungal diseases.

Environmental Condition Monitoring

An environmental condition monitoring system is proposed in [34] that measures the spatial sampling of humidity sensors using WSN. To determine the behavior of 2D correlation, a historical database is being used in the proposed system. Moreover, another environmental conditions monitoring system is proposed in [35] that integrates forecasting and drought monitoring musing IoT.

Crop and Plant Growth Monitoring

In this sub-domain, farmlands have been analyzed by using the mobile sensors presented in [94]. The essential purpose of this proposed system is to monitor the growth of grapes and control plans for viticulture activities. To monitor apple orchards, researchers proposed an efficient and intelligent monitoring system that provides suggestions based on the sensed data [95]. The basic purpose of this proposed system is to decrease the management costs, improve the quality of apples, and protect from pest attacks. It is a WSN-based system that is designed by using ZigBee and GPRS to monitor the growth of apples.

Temperature Monitoring

Soil temperature plays a vital role in crop productivity. In [96], a system has been proposed to monitor the amount of nutrients between surface and ground water. To measure the quantity of nutrients in soil, electrochemical impedance was applied. Soil test results are monitored through an inductance (L), capacitance (C), and resistance (R) (LCR) meter, and the results are calculated via standard library measurements.

Humidity Monitoring

The humidity level is measured in air by using multiple humidity sensors. An inappropriate amount of humidity leaves a negative impact on plants regarding cell growth [36].

Monitoring Gases in Greenhouse

Agriculture and greenhouse gases are related to each other. The excessive amount of gases in a greenhouse increases the temperature, which directly impacts the agriculture productivity. To monitor the greenhouse gases and CH4, a WSN and solar powered Unmanned Aerial Vehicle (UAV) system has been presented [37].

Fertilization and Pest Control

In this domain, an IoT solution provides conservation approaches to improve the quality of the crops and amount of nutrients usage. An online climate monitoring system has been presented for greenhouses to monitor pests, irrigation, fertilization, and climate [33]. The system use WSN to gather and analyze sensed data for efficient analysis.

Greenhouse Illumination Control

An automated agriculture system is developed to monitor the growth of cabbages and melons in greenhouses [38]. The designed system monitors the crop growing process and controls the greenhouse environmental conditions such as temperature, ambient light, and humidity.

Location Tracking

This sub-domain referred to the tracking and tracing of animal locations and any unwanted movement all over the field. Different monitoring devices and sensors have been deployed in the field to save the crop from theft and wild attacks. For agriculture, an intrusion detection solution is presented in [31] that generates an alarm and sends a text message to the farmer's mobile when an unwanted movement happens in the crop field. Moreover, for livestock, different monitoring devices are implemented to track the animals' locations and monitor their activities. In [32], an IoT-based animal monitoring solution is presented that monitors the behavior of swamp deer. Moreover, a herd of cattle grazing in the field can be monitored and tracked by using RFID and WSN [97]. In this way ranchers can get real time monitoring of cattle's.

4.1.6. Assessment of RQ6: What Is the Role of IoT-Based Devices/Sensors in Agriculture

Multiple organizations and industries are using different kinds of devices/sensors for a long time, but an invention of IoT has taken advancements of devices/sensors totally at a different level. An IoT device consists of an embedded system that interacts with actuators, sensors, and the required WSN. Embedded systems consist of a microprocessor, memory, communication modules, and input/output components. Sensors monitor the different environmental parameters and farm variables in the field of agriculture and dynamic data that is obtained through facilities intervention.

Commonly used sensors are temperature sensors, humidity sensor, soil pattern monitoring sensor, airflow sensor, a location sensor, CO_2 sensor, pressure sensor and moisture sensor. The significant characteristics of IoT devices/sensors that make them suitable for agriculture are their (1) portability; (2) reliability; (3) memory; (4) durability; (5) power and computational efficiency; and (6) coverage. This systematic study shows that many researchers have been focused on temperature monitoring (19%), humidity (17%), and soil moisture (14%). Twenty types of data have been collected through different monitoring and sensing devices, as shown in Figure 6.
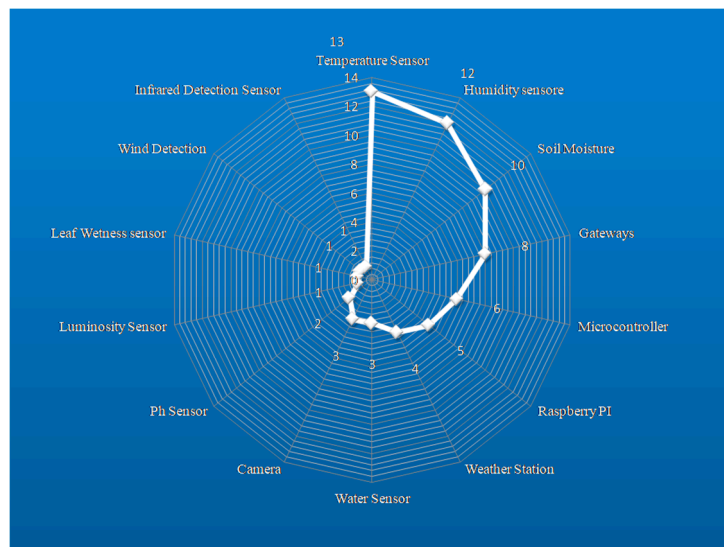
Figure 6. Sensors/devices distribution.

Temperature, humidity, and soil moisture are considered the most critical variables for smart farming, as shown in Figure 6. Meanwhile, Table 7 represents the operations of different sensors and devices in the field of IoT agriculture.

Table 7. Sensor/devices operation.

Infirmity	Sensor/Devices Operations
PH Sensor	To monitor the exact amount of nutrients in soil, PH sensors are used, which is efficient for the healthy growth of plants and crops [98].
Gas Sensor	Through the observation of infrared radiations this sensor measures the exact amount of toxic gases in livestock and greenhouses [99]. A sensor node called Waspmote Plug & Sense! Smart Agriculture Xtreme has been designed to monitor the gas level water content in the soil.
Motion Detector Sensor	The sensor is used to track/trace the location of animals and field, moreover it also detect the motion of an unwanted object in the field or farm and generate alerts to farmer for timely action and preventing crop loss [100].
Ultra Violet Sensor and Passive Infrared (PIR) Sensors	An ultra violet sensor monitors the UV rays for the effective growth of crops [101]. In the PIR sensor, a motion detector is fixed that traces the range of a person's movement in the field. The sensor also has a light detection property: while tracking an object, it changes the rising temperature into voltage for analyzing crop growth [102].
Soil Moisture Sensor	The soil sensor measures the quantity of water and level of moisture all over the field [103]. In [104], a wireless moisture sensor has been implemented to monitor the greenhouse irrigation system. CropX Starter Kit–Soil Temperature 24/7 is cellular connection sensor that is used to monitor the multiple soil conditions [105].
Temperature Sensor	Changes in the soil temperature affect the absorption soil nutrients and moisture. A novel sensing approach has been presented to map the exact amount of nutrients in soil and the water surface [12]. A 3D crop sensor Array with Photosynthetically Active Radiation (PAR) technology can be deployed at any location of field to monitor the temperature, CO_2, and humidity [106].
Humidity Sensor	Humidity leaves a negative impact on the growth of plant leaves, photosynthesis, and pollination. Therefore, to sense the level of humidity in air, this sensor directly measures the temperature and moisture content in the air [107]. Grofit provides different climate monitoring devices that can monitor the air temperature, air humidity, and sun radiation. The data transmission range of the device is up to 200 m and stores the measurement for a maximum of 30 days [108].

4.1.7. Assessment of Q7: What Is the Role of IoT Communication Protocols and Standards in Agriculture?

A large number of IoT communication technologies are being utilized within IoT applications due to their low cost, wide coverage range, and low energy requirements as compared to other long-range communication technologies. All the communication technologies that have been identified in this mapping study are shown in Figure 7. WSN (29%) has been identified as the widely used technology, whereas WIFI (15%) and ZigBee (10%) are also used to transfer data to a lesser extent [109].
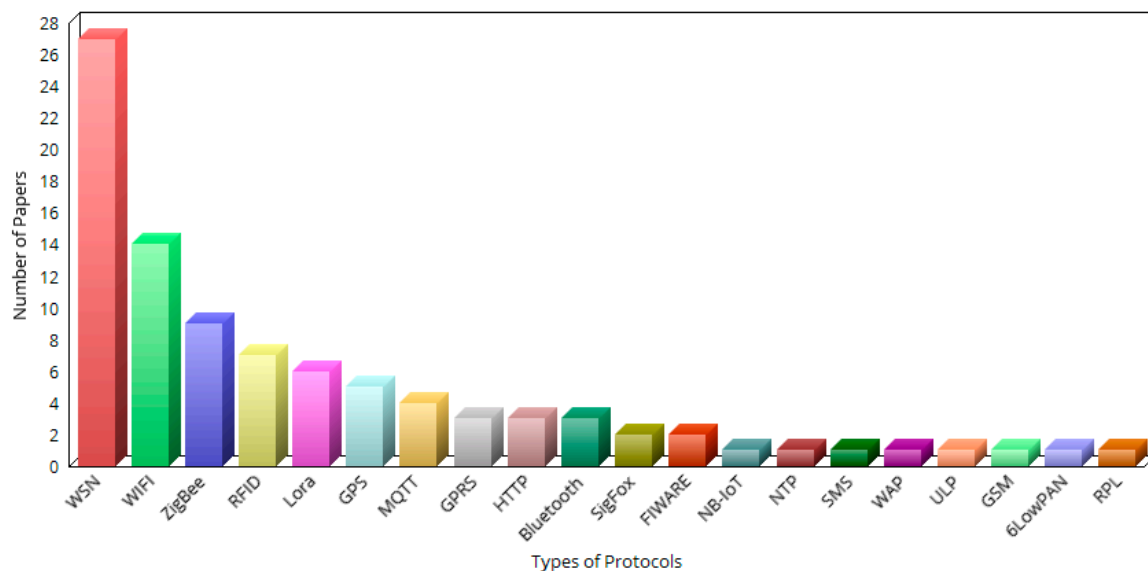
Figure 7. Communication protocols.

Low Range Wide Area Network Protocol (LoraWan)

An organization called Lora TM Alliance has developed a low-range wide area network protocol. The primary aim of this protocol is to ensure interoperability among multiple operators [39]. A framework has been developed in [40] that enhances the crop productivity and mitigates risks.

Message Queue Telemetry Transport Protocol (MQTT)

MQTT is used to send and receive sensor information. In [42], a MQTT protocol has been used to solve the irrigation problem that controls the water pump action and transmits the status of water pump and soil moisture conditions to a user's mobile application and web page.

Radio-Frequency Identification (RFID)

RFID records information by assigning a unique number to each object individually and tracking their location. This protocol identifies environmental conditions such as moisture level and temperature conditions. To track crop information and identify the object location, an RFID tag has been used in [41]. In [42], RFID technology and sensors have been integrated for identification that help the farmers in multiple ways, such as saving time, money, and power.

SigFox

Sigfox is a wireless cellular network that is suitable for long-range communications. In [43,110], SigFox has been used, which localizes animal pastures for the whole summer. Moreover, the system proposed in [43] helps the ranchers track their cattle's positions.

ZigBee

One of the top IEEE 802 standards developed by the ZigBee alliance has a long-range battery life. This technology fulfills the demand for quick throughput by offering high-speed data transfer for applications such as agriculture [111].

WiFi

WiFi is a standard part of a wireless local area network (WLAN) that is used to exchange information over the internet wirelessly (IEEE Standard for Information technology, 2005, 2012a). The communication range of WiFi is 20–100 m and the data transmission range is 2–54 mbs. In the field of agriculture over an ad hoc network, WiFi broadens the utilization of heterogeneous architectures connecting different types of devices [44].

Bluetooth

Bluetooth is a low-cost, low-power technology that is based on IEEE 802.15.1 standard and used for communication over short ranges i.e., 8–10 m (IEEE Standard for Information technology, 2012b; Bluetooth Technology Special Interest Group). This technology is suitable for multi-tier agricultural applications due to its ubiquitous nature [45].

Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is a wireless communication that is based on an IEEE 802.16 standard whose transmission range is 50 km and the data rate is 0.4–1 Gbps (IEEE Standard for Local and metropolitan area networks, 2011). WiMAX is suitable for monitoring and controlling different agricultural applications such as monitoring farming systems, crop area border monitoring, and controlling gates, lights, water pumps, and the remote diagnosis of the farming systems. The Ministry of Food and Agriculture, Ghana (MOFA) has utilized WiMax and WiFi technologies so that user has choice of selecting WiFi or WiMax to establish network connections [46].

4.1.8. Assessment of Q8: Which IoT Agricultural Policies Have Been Implemented in Different Countries?

Technologies and evidence-based policies have become the driver in all cases of practical implementations. Similarly, regulations and policies play a vital role in order to transform the agriculture sector in a more innovative way over the next several decades. Although existing policies accommodate IoT agricultural services, these policies and regulations are the key goals for a large number of initiatives over the globe. This section describes the IoT-based agricultural policies that have been adopted by different countries as shown in Table 8.

Table 8. IoT-based agriculture success stories.

Countries	Application Sub-Domains	Success Stories
Thailand	Water management	A water control system has been developed on the basis of WSN to measure the water consumption in whole field. The developed system has been tested and implemented at three different fields in Thailand. After implementation, results indicated that for the efficient growth of lemons, the level of humidity should be 70–80% and the temperature should be between 29 °C and 32 °C for the high productivity of lemons and vegetables [68].
Taiwan	Soil cultivation	For precision farming, a low-cost AgriTalk IoT-based platform has been implemented in Taiwan to monitor soil parameters [49]. The developed platform has been tested by implementing it in three different fields for turmeric cultivation. After using the developed AgriTalk solution, the chlorophyll amount was increased up to 40–60%, which is more than existing methods, and 70% of water was also saved. Furthermore, 140,000 USD revenue was generated by 14,000 USD investments, which was big revenue compared to old cultivation methods.

Table 8. *Cont.*

Countries	Application Sub-Domains	Success Stories
Brazil	Soil humidity and temperature monitoring.	An IoT-based Agri Prediction model is presented in [40] that provides low-cost prediction methods to measure the soil humidity and temperature. After the implementation of the proposed model, the weight (up to 14.29%) and size (up to 17.94%) of arugula leaf was increased.
India	Monitor moisture content, temperature, humidity, pesticides, animals CO_2, and light.	An IoT-based robotic has been presented in [36] to measure the agricultural parameters such as pesticides, moisture, and animals movement. When the system was practically implemented, the obtained results were very satisfactory, which shows that the system is user friendly, robust, and reduces the labor cost. Moreover, a remote sensing control system is developed in [54] to monitor the greenhouse gas, temperature, soil moisture, and light. These variables were monitored for bell paper plants and the obtained results indicate the yield increment and facilitate the farmer to monitor the farm remotely.
China	Environment monitoring	To monitor the greenhouse environment conditions, a low-power and low-cost system is developed [112]. Implementations of the developed system show that the system is reliable and reduces the labor cost. Furthermore, IoT technologies implemented in the Shandong Province demonstration park of Zhongyi show that the fertilization and pesticides cost reduced up to 60% and 80%. Whereas, to deal with the 300-mu park, 60 laborers were required, but the utilization of IoT technology reduced the labor cost by approximately 60% [113].
Africa	Monitoring animal's location, behavior and pasture grazing.	Authors proposed an animal behavior monitoring system that traces the animals' movement all over the field and monitors their pasture grazing [61]. The designed platform is implemented in Africa to evaluate and track the animals' conditions.
Malaysia	Fruit traceability	The Minister of Science, Technology, and Innovation (MOSTI) of Malaysia proposed IoT agricultural solutions for tracking purposes called Mi-Trace and My Traceability SdnBhd (MTSB) to ensure the quality of fruits sellers and exporters are utilizing these two solutions [114].

Australia

The Australian Government has invested AU$134 million to improve their current farming method. As a result of this large investment by a private company in Sydney, the local government created a center for the implementation of IoT technologies in agriculture fields [115]. An innovative network was established in 2014 for the purpose of precision farming to create a collaborative framework in the agriculture fields of Australia. Moreover, in terms of security and privacy, an American farm bureau established a security and privacy set for farm/field data in 2015 [116].

Ireland

A program has been launched by Irish Farmers Association (IFA) to decrease the smart farming implementation costs and improve the soil quality by providing guidance to the famer regarding how to save the water and power by utilizing IoT technology [92]. The farming community enthusiastically followed these guidelines and obtained results that were very encouraging and positive. Companies saved approximately 8700 euro, 21% savings were achieved in pasture management; there was also a 10% reduction in greenhouses gas emission and 47% savings in soil fertility. To track and trace the farm assets, Ireland VT-Networks launched a SigFox network [117].

France

In France, the ministry of agriculture has become the partner of the Agriculture Innovation Project 2025, whose basic purpose is to increase the strength of agriculture land, monitor weather parameters, and improve the field conditions by creating incubators. Moreover, the ministry of agriculture shares benchmarked farm data with farmers to develop innovative solutions in agriculture [118].

China

To integrate IoT technology in agriculture fields, China has launched their 13th Five-Year Plan [119]. The project has started in eight provinces of China to collect data from different sources such as national data centers. Furthermore, the Huawei Company in China developed an NB-IoT app to transform the agriculture field in a more innovative way. NB-IoT provides excellent agricultural solutions at low cost without any gateway implementation as compared to other cellular networks. NB-IoT provides a wide range of coverage with a large number of connections to resolve the issues of the scattered agricultural data [120].

Malaysia

The Malaysian Institute of Microelectronic System (MIMOS) has created several agricultural solutions to enhance the crop productivity and reduce the poverty. The Mi-MSCANT PH sensor has been developed by MIMOS to collect the data regarding environmental conditions. MIMOS has developed an integrated IoT technology framework that creates a strong bond among the traders, suppliers, and agriculturists in cohesive manners. The developed framework utilizes the WSN and Micro Electro Mechanical System (MEMS) technologies to gather environmental data [121].

USA

In order to fulfill the basic requirements of food and energy, the USA government has initiated many research and development projects related to agricultural technologies. The National Institute of Food and Agriculture is working on a project called the Internet-of-Ag-Things and developed sensing technologies for agricultural practices. The major aim of the project is to provide precision farming techniques to increase the agricultural productivity and make better use of the fertilizers, water, and organic food [122]. A project namely has been started by Department of Agriculture (USDA) to resolve the water management issues and design new techniques to overcome the challenges that are affecting agriculture. Moreover, technologists are using the datasets of the USDA to improve and design the existing agriculture services for water distribution [123].

Thailand

The National Electronics and Computer Technology Center (NECTEC) in Thailand is implementing IoT technology to develop the smart farming, and their main focus is on four agriculture products, namely: rice, rubber, cassava, and sugar [124]. The basic aim of this movement by the Thailand government is to facilitate the farmers in all rural areas for the efficient growth of crops [125].

India

The Indian government has made several IoT policies to boost up their agriculture over the globe. Their major focus is to measure the soil conditions, parameters, temperature, and earth density in order to help the farmers control the pest and crop diseases. The Ministry of Communication and Information Technology released a policy in 2015 to transform the agricultural field by utilizing IoT [126].

Philippines

The Philippines used remote sensing techniques in order to boost the rice production and satellite imaginary techniques to get information about multiple agricultural conditions. The University of Southeastern Philippines (USeP) developed a smart solution to measure the crop heat stress through IoT technology by collaborating with Western Mindanao State University (WMSU) [127].

4.2. Quality Assessment Score

A quality assessment score has been presented in Table 9 where 9% of the papers have an average score, 64% of papers have an above average score, and 27% of selected studies are below average.

The quality assessment criteria defined in the previous section help the IoT agriculture researchers and scientists choose the relevant papers according to their tier requirements.

Table 9. Quality assessment score.

References	Score	Total
[57,67]	1	2
[35,37,52,53,59,63,65,82]	1.5	8
[26,33,34,54,64,66,80,91]	2	8
[39,58,60,81,83,89]	2.5	6
[27–31,36,41–44,50,51,55,61,62,69–72,74,79,86,88,90]	3	24
[45,56]	3.5	2
[40,46,48,49,75–78,85,87]	4	10
[25,32,84]	4.5	3
[47,68,73,97]	5	4

5. Discussion

A detailed discussion about different IoT agriculture applications, sensors, and devices has been presented in this section. An agriculture hierarchy has been proposed to summarize the findings of this research as shown in Figure 8. Moreover, an IoT-based smart farming framework has also been proposed as shown in Figure 9.
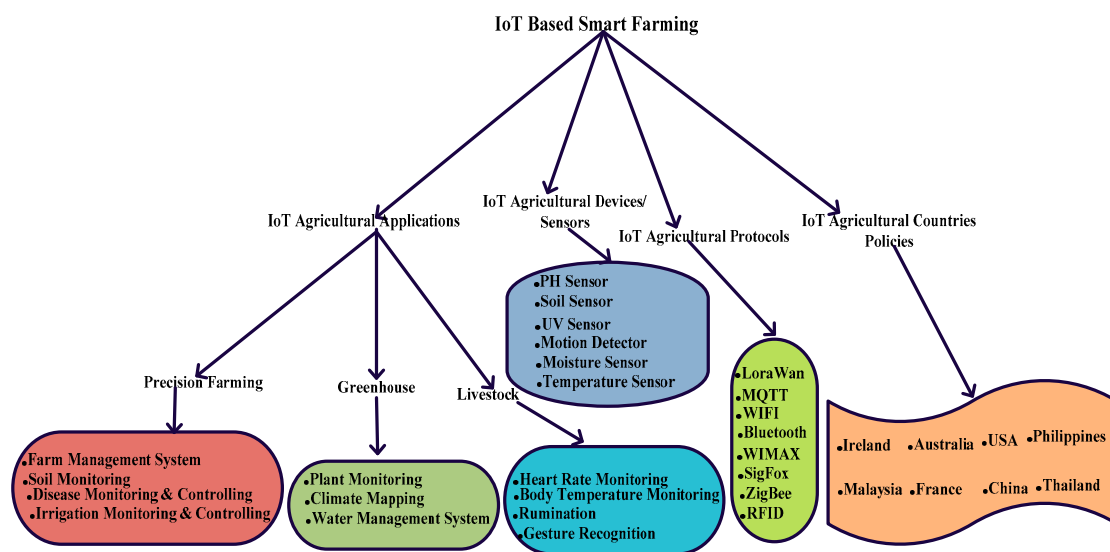
Figure 8. IoT agricultural hierarchy.

5.1. IoT Agricultural Hierarchy

The findings of this research have been summarized by developing an IoT-based agricultural hierarchy, as shown in Figure 8. The designed hierarchy consists of four primary activities. These are IoT agricultural applications, sensors/devices, communication protocols, and country policies, which encapsulate most of the findings that are analyzed in this paper. IoT agricultural applications monitor, control, and track the different precision farming, greenhouse, and animal-related parameters. IoT-based agricultural applications with their sub-domains have been discussed in Section 4 (RQ4). Sensors/devices produce valuable data by sensing and monitoring multiple field variables through WSN. The data generated through sensing and monitoring devices are transferred through the

communication protocols (LoraWan, Sigfox, ZigBee, RFID, Bluetooth, WiMax, MQTT, WiFi) on other platforms for a user or farmer view. Moreover, for the standardization of IoT-based agriculture, different countries have been made various IoT agricultural policies, which are presented in Section 4 (RQ8) Furthermore, the success stories of IoT-based smart farming have also been presented by discussing some pilot projects implemented in different countries.
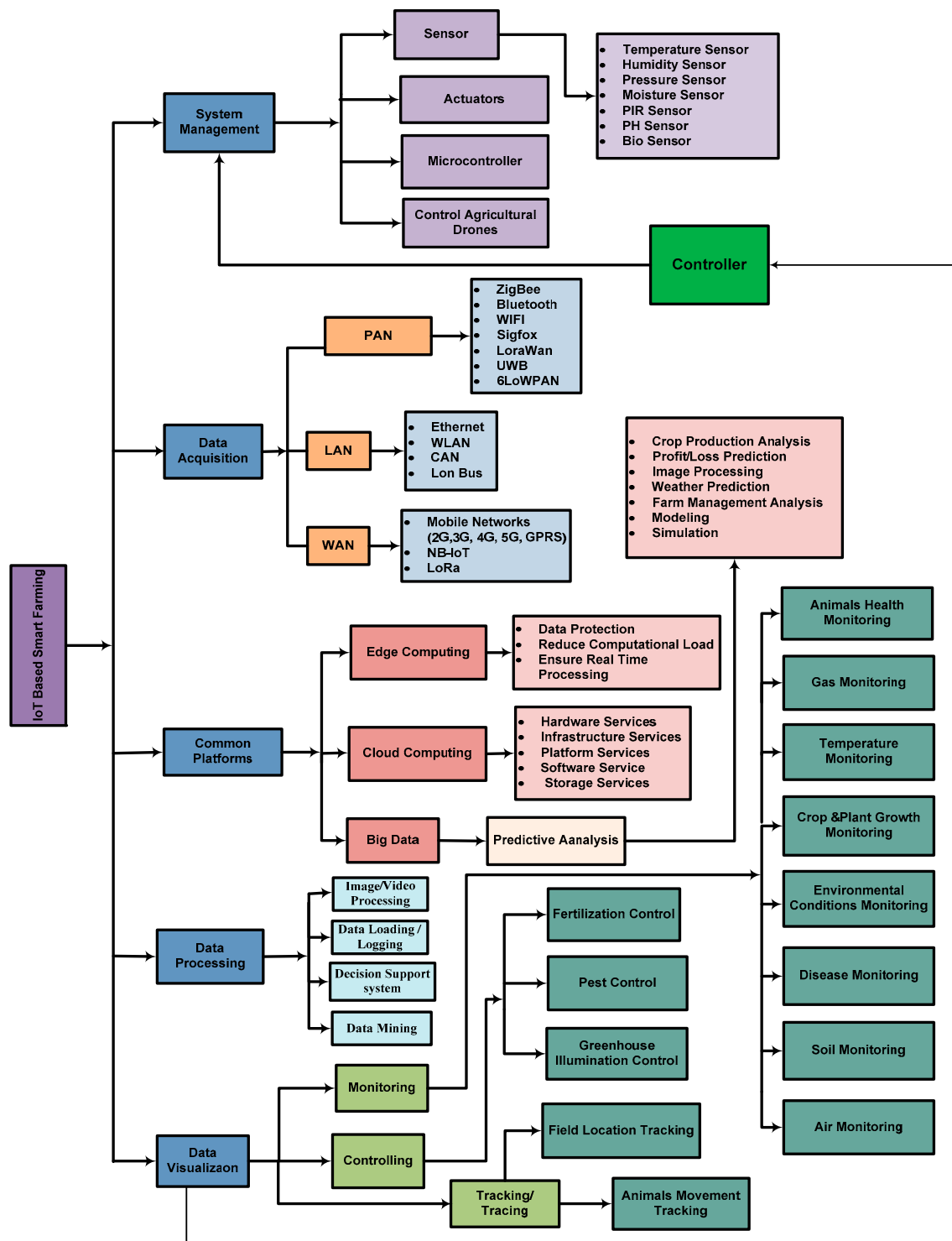

Figure 9. IoT smart farming framework.

5.2. IoT Smart Farming Agricultural Framework

An IoT smart farming agricultural framework has been proposed in Figure 9 that consists of five major components, which are data acquisition, common platform, data processing, data visualization, and system management. The data acquisition component consists of the converged network that is formed by multiple communications networks. The transmission media may be wired technology such as a controller area network (CAN) or wireless technology such as LoRa, Zigbee, NB-IoT, and Bluetooth. Meanwhile, a wide area network (WAN) component is further divided into sub-components that are mobile communication technologies. The cellular communication technology consist of four generations of technology, whereas 5G technology was announced in 2016, which will revolutionize the agriculture monitoring process by providing high-speed data transmission, network control, and energy consumption. Moreover, the data acquisition component not only transmits the agricultural related information collected from the data visualization component, but also sends the control commands to the system management.

A common platforms component is responsible for decision making, data storage, and statistical analysis on agricultural data by implementing various models and algorithms for the agricultural production process. The component has been further divided into sub-components, namely: (i) Edge Computing, (ii) Cloud Computing, and (iii) Big Data. Big data technology makes predictive analysis by finding the internal links among the data, which are collected through information mining and other resources.

Moreover, it also provides data support for new operations and performs multiple processing techniques such as image processing, statistical analysis, simulation, prediction, early warning, and modeling [93]. Cloud Computing provides software services, hardware services, infrastructure services, and platform services to different IoT agricultural applications. The cloud platform offers cheap data storage services to the farmers such as image, text, videos, and other agricultural data, which facilitates the agricultural enterprises by reducing storage cost [42]. Moreover, it is a difficult task to make the direct use of raw agricultural data for decision making on the basis of farmers' technical expertise. In contrast, agricultural experts can also give suggestions and make accurate judgments based on quantitative analysis. Therefore, only cloud computing provides an intelligent and secure platform for monitoring crop [128] Although the cloud platform helps the farmer through its advance techniques, still, there are some limitations due to which farmers face technology losses related to internet connectivity and low power. Edge computing is one of the new computing models that perform the calculations at the edge of the network. This platform also reduces the computational load by improving data transmission speed and protects agricultural data because processing in edge computing occurs more compared to cloud computing [76,129].

Data processing consists of audio, video, text image processing, and many other processing techniques. These features may be added or removed according to the system requirements.

Data visualization is one of the most visible components in the IoT agricultural field, which consists of monitoring, controlling, and tracking/tracing. The monitoring function includes environmental conditions monitoring, crop and plants growth monitoring, disease monitoring, soil monitoring, and animal health monitoring. The controlling function controls the different agricultural parameters such as pest, fertilization, and greenhouse illumination control. Moreover the tracking/tracing sub-component tracks the animals and field location. The whole monitoring, controlling, and tracking process is controlled is through a controller and managed through the system management component.

The system management component includes various kinds of actuators, sensors, microcontrollers, and drone controllers. The most commonly used sensors/devices are environmental conditions monitoring sensors, crop/plant monitoring sensors, and animal health monitoring sensors/devices. These sensors collect information about different agricultural variables, and this collected information is processed through embedded devices to make the proper analysis for smart farming.

5.3. State-of-the-Art IoT Agricultural Solutions in the Market

According to the report of Finistere Ventures, more than 2 billion dollars have been invested around the globe in AgTech, which is expected to increase in the coming years [130]. As IoT is gaining is importance in different applications of smart farming, almost all of the top technology firms are investing and supporting this technology in their own way to develop innovation in the agriculture field. Table 10 represents the different IoT agricultural solutions proposed by the top technologies firms.

Table 10. Available solutions and initiatives regarding IoT in agriculture.

Industries	Initiatives and Solutions
Samsung	Samsung takes the initiative in the field of IoT by providing its Samsung Data Systems (SDS) IoT Platform, which connects the multiple IoT devices and communication protocols such as Modbus, Zigbee, Bluetooth Low Energy (BLE), MQTT, and LoRaWAN [131].
AeroFarms	AeroFarms provides indoor farming solutions by analyzing data related to plants into data through big data, imaging, and artificial intelligence technologies [132].
Microsoft	Microsoft also works on data-driven farming techniques by resolving the issues from cloud to sensor [133]. The Bosch technology firm provides different sensors analytics techniques and IoT-based data management techniques to monitor the crop productivity and diseases [134].
R- Style Lab	R- Style Lab is the top IoT software-providing company that offers multiple software solutions such as predictive maintenance, drone's inspections, and crop/animal monitoring solutions, and it provides some embedded software that can easily be integrated into portable trackers [135,136].
IBM	IBM has provide an AI-based service called Watson Decision, which is best solution to improve the sustainability, harvesting, and quality of smart farming by using IoT and AI technologies [137].
Intel	Intel has been developed an IoT-based platform Infiswift, which helps increase the efficiency of agricultural solutions through advanced connected services [138].
Google	Google has suggested a vision for advanced agricultural solutions by joining the MIT Media Lab Open Agriculture Initiative to provide a healthier food system [139].

6. Open Issues and Challenges

There are many open issues and challenges that are associated with the implementation of IoT applications. Some of the challenges that are identified from the literature have been discussed in this section.

6.1. Security

Security issues arise at a different level of IoT-based agricultural systems, which need to be addressed. Due to low security, users face many difficulties such as loss of data and other on-field parameters. IoT privacy and security issues have been discussed in [140–142] broadly. In the agriculture field, IoT devices are at risk due to physical interference such as attack by animals and predators or modification in physical address [142,143]. Moreover, due to low energy consumption and limited memory, it is hard to implement sophisticated and complex algorithms. The precision farming services such as IoT-enabled location information and location-based services are exposed to hackers that may use this information for device capturing [141,142,144]. Attackers attack the IoT device and take out cryptographic implementations. Other communication layers also undergo some vulnerable denial-of-service (DoS) attacks and wireless signal blocking [142]. Major security threats to the cloud infrastructure are hijacking attacks, session hijacking, database issues, and denial of service attack [142].

6.2. Cost

While deploying IoT in agriculture, several cost-related issues arise such as setup and running costs. The setup costs consist of hardware costs such as IoT devices/sensors, base station infrastructure, and gateways. Moreover, running costs includes an uninterrupted subscription for the management of IoT devices, the exchange of information among other services, and centralized services that provide information/data collection [47].

6.3. Lack Knowledge of Technology

Poor understanding of technology is the main barrier among the farmers who are living in rural areas. This problem is common in developing countries, where most farmers are uneducated [145]. The implementation of IoT in agriculture is a big challenge, because a lot of investment is required in farmer's training before deploying IoT infrastructure.

6.4. Reliability

In the field of agriculture, IoT devices are deployed in an open environment due to which harsh environmental conditions may cause communication failure and the humiliation of deployed sensors. Therefore, it is important to ensure the physical safety of deployed IoT devices/sensors to protect them from severe climate conditions [146].

6.5. Scalability

A large number of IoT devices and sensors are deployed in the agriculture field, due to which an intelligent IoT management system is required for the identification and controlling of each node [147].

6.6. Localization

There are many factors that need to be considered while deploying devices/sensors. Such devices should have the ability to provide functionality and support to the rest of the world without deploying additional devices with overhead configuration [148]. Moreover, it is important to select the best deployment position so that devices can communicate and exchange information without any interference.

6.7. Interoperability

There are billions of IoT devices, standards, and protocols that are needed to interoperate. Interoperability involves semantic, syntactic, technical, and organizational policy. Semantic interoperability is the ability to deal with the interpretation of content exchanged among humans. Syntactical interoperability is related to data formats, such as java script object notation (JSON), data interchanged electronically, extensible markup language (XML), and variables separated by a comma. Technical interoperability is associated with the development of infrastructure, protocols, and hardware/software components that enable the IoT devices' communication. Organizational interoperability is related to policies for communicating and transferring data effectively across the different geographic regions and infrastructure. Whereas, in [149], three methods have been proposed through which interoperability can also be obtained, which are (i) two standards open and close, (ii) partnership among services and product developers, and (iii) mediator and adaptors services. More research work is expected to obtain a high interoperability among multiple IoT devices.

7. Integration Challenges of IoT and Cloud Computing in Agriculture

The aim of the cloud-based IoT paradigm is to analyze and integrate the data that is coming from the real world into IoT objects. This paradigm requires interacting with millions of end devices that are thoroughly distributed [110]. Although the cloud platform helps the farmer through its advance techniques, still, there are some limitations due to which farmers face technology loss related to internet

connectivity, low-power communication devices, and many other integration challenges. Moreover, the monitoring and controlling processes have made the data sharing of IoT devices more difficult, because IoT communication devices face connectivity issues and latency problems [111]. Some of the networking challenges that users face while assessing and uploading the information on cloud are given in Table 11.

Table 11. Mapping problems and solutions regarding IoT and cloud computing integration.

Year	Reference	Problems	Solutions
2016	[150]	It has become very difficult to handle the data-generating devices and power-constrained sensors, in order to obtain the more valuable services.	The cloud of things (CoTs) solution has been presented to handle the increasing demand of data-generating devices and other communication resources underlying the WSNs.
2016	[151]	IoT consist of millions of interconnected devices such as WSAN, RFID etc. in order to exchange the agricultural information; therefore, cloud computing technology is necessary due to the connectivity limitations in this field.	Authors presented a survey on cloud infrastructures, cloud platforms, and IoT middleware for the integration of devices and communication protocols.
2013	[152]	Due to the adaptation of a large number of wireless technologies, IoT has stepped out to create a fully integrated future network.	Implemented cloud solutions by using Aneka, which is a centric vision for the convergence of internet, WSN, and distributed computing.
2013	[153]	The integration of IoT and cloud computing has become a primary need over the last few years to manage different power connectivity issues.	The author designed a framework to procure data from decentralized, heterogeneous, highly distributed, and virtual devices that can be controlled, analyzed, and managed automatically.
2014	[154]	The IoT has become more persistent due to which its integration with cloud computing is very important.	The integration of both technologies is not simple, because different key issues occur that people face while accessing the communication network to retrieve or upload information to the cloud. A survey has been presented that highlights the main challenges and provides their respective solutions.

8. Threats to Validity

There have been four kinds of threats to validity identified in this section.

8.1. Construct Validity

In the SLR, construct validity threats are relevant to the classification of selected studies [147,148]. Search keywords have been proposed and identified by two authors, and seven terms related to IoT agriculture have been used in the search string. However, the list is not complete; some alternative and additional terms may alter the list of final selected papers [84]. A search string was performed by using IEEE Xplore, Science Direct, Springer, MDPI, and IGI Global. According to the statistics of the search engines, we have found most of the research papers related to IoT agriculture in these electronics libraries. To mitigate the risk of missing essential and related publications, we have sought out the related papers in major IoT agriculture research venues. Although the standard of the primary studies decreased by including publications that are not from top journals and conferences, it indicates that the studies relevant to IoT have increased.

8.2. Internal Validity

This type of validity handles the extraction data analysis process, in which two authors have identified the classification of selected papers and the data extraction process, whereas one author reviewed the final results. Data collection and paper classification have been made on the judgment of

two authors. The kappa coefficient value was 0.91, which indicates that there has been a high level of agreement among the authors and reduces the dissimilarity threats significantly by showing a similar understanding of relevance.

8.3. External Validity

External validity is related to the generalization of this study. The mapping results have been considered regarding the IoT domain, and the validity of the results presented in this paper concerns only the IoT agriculture domain. The classification of the papers and search string presented in this research may help the practitioners as a starting point for IoT agriculture research, and researchers can categorize the addition studies accordingly.

8.4. Conclusion Validity

The conclusion validity threat is related to the identification of improper relationships that may generate an incorrect conclusion. In the mapping study, a conclusion validity threat refers to the different elements such as incorrect data extraction and missing studies. To decrease this threat, the data extraction and selection process have been clearly defined in the previous paragraph on internal validity. The traceability among the extracted data and the conclusion has been strengthened through the direct generation of frequency plots and bubble plots generated from the collected data by applying statistical analysis.

9. Conclusions

This article has presented a systematic literature review that presents a discussion on selective high-quality research articles published in the domain of IoT-based agriculture. The survey has been conducted by employing a systematic methodology to select 67 studies. Thereafter, an analysis of different IoT agriculture applications, sensors/devices, and communication protocols has been presented. The most promising fact is that this area of research is being patronized by the governments of various countries, and many countries have their IoT agriculture policies. Apart from this, all the major components of IoT-based agriculture have been contextualized in a framework. Lastly, the promising future directions have been discussed for the researchers working in the domain of IoT-based agriculture.

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