

RESEARCH ARTICLE

IoT Based Smart Greenhouse Framework and Control Strategies for Sustainable Agriculture

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ABSTRACT In recent years, the Internet of Things (IoT) has become one of the most familiar names creating a benchmark and scaling new heights. IoT an indeed future of the communication that has transformed the objects (things) of the real world into smarter devices. With the advent of IoT technology, this decade is witnessing a transformation from traditional agriculture approaches to the most advanced ones. In perspective to the current standing of IoT in agriculture, identification of the most prominent application of IoT-based smart farming i.e. greenhouse has been highlighted and presented a systematic analysis and investigated the high quality research work for the implementation of greenhouse farming. The primary objective of this study is to propose an IoT-based network framework for a sustainable greenhouse environment and implement control strategies for efficient resources management. A rigorous discussion on IoT-based greenhouse applications, sensors/devices, and communication protocols have been presented. Furthermore, this research also presents an inclusive review of IoT-based greenhouse sensors/devices and communication protocols. Moreover, we have also presented a rigorous discussion on smart greenhouse farming challenges and security issues as well as identified future research directions to overcome these challenges. This research has explained many aspects of the technologies involved in IoT-based greenhouse and proposed network architecture, topology, and platforms. In the end, research results have been summarized by developing an IoT-based greenhouse farm management taxonomy and attacks taxonomy.

INDEX TERMS Internet of Things (IoT), greenhouse, applications, sensors, communication protocols, cloud computing, big data analytics, security attacks.

I. INTRODUCTION

The increasing population, growing industrialization, and continuous climate changes are reducing arable land across the globe every year [1]. Therefore, the growing demand for the production of food and crop is highly substantial and significant. United Nation of Food and Agriculture Organization (FAO) predicted that more cropland and water will be required to encounter the future food demands due to increasing the world population up to 9.73 billion in 2050 [2]. Besides, there are many other farming challenges including

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lack of labor, water, and abrupt climate changes spiral the pressure on farmers and agriculturists [3]. Therefore, traditional greenhouse farming methods are not enough and needed to change for sustainable food production. Greenhouse farming practice is considered to be the best alternate solution to overcome food crises and ensure sustainability [4].

The first-time greenhouse farming technology was initiated in the 19th century in Netherlands and France [5]. Afterward, the greenhouse farming approach has become a popular and fastest-growing industry [6]. The greenhouse is mainly designed to cultivate crops in any season by adjusting the growing conditions of plants. In traditional greenhouse farming solutions, crop parameters and all other

growing conditions depend upon the grower assessment which demands enough time and labor cost [7]. However, technology-enabled greenhouse monitors and controls the farming variables effectively and efficiently by using smart devices and specific standards [8].

IoT technology offers high potential for smart application development and innovative farming solutions to transform the agriculture domain. So, the integration of IoT in the greenhouse is considered to be one of the ideal and foremost solutions to enhance crop production with minimum labor cost [9]. IoT-based greenhouse farming can assist farmers and agriculturists to acquire knowledge about the season, soil quality, quality of water, the most suitable time for harvesting, and the required amount of nutrients for the healthy growth of plants. Thus, IoT-enabled greenhouses can develop cost-effective and reliable farming solutions to boost productivity with a minimum labor cost [10]. In this way, farmers can optimize the resources effectively and manage the farm more efficiently. It is predicted that in the future the growing fruits and crops inside an IoT-based greenhouse will be fully automated and remote-controlled. Further, IoT consists of a mass system including sensors, controllers, actuators, and decision-making platforms that provides efficient scheduling of resources to maximize crop productivity.

The potential IoT-enabled greenhouse farming solutions focus on the four major applications of farming namely enhanced fertilization and irrigation, infection and disease control, maintenance of an ideal environment for healthy growth of plants, and enhanced security solutions [11]. In technology-enabled greenhouse farming security is the major problem that can be achieved by implementing IoT smart devices, sensors, cameras, and unmanned aerial vehicles for monitoring remotely [12], [13], [14]. The commercially existing smart IoT sensors/devices have proved that it was ideal to minimize costs and increased efficiency through IoT technology. Besides, the primary goal would be to improve productivity, and resource optimization, and reduce manual interventions [15]. Preliminary research indicates that IoT-based agricultural system offers great potential in greenhouse farming [16]. For example, an environmental decision support system alerts the farmers when to apply the fungicides [17]. On time, deployment of fungicides minimizes the late blight risk as well as saves approximately 500 USD/acre [17]. Similar benefits such as water balance in the soil, irrigation control, moisture content, and chlorophyll content measurement in plants were also documented.

The utilization of IoT technology, information communication technology, and wireless sensor networks addresses several technical, economic, and environmental challenges in the agriculture field [18]. Due to the interconnectivity of a large number of sensors and devices, a large amount of data is generated. This data is vital for developing a higher level of insights for better forecasting, decision-making, and reliable management of interconnected sensors/devices [19]. Therefore, Machine Learning (ML) approaches are considered compelling tools for solving non-linear problems by utilizing

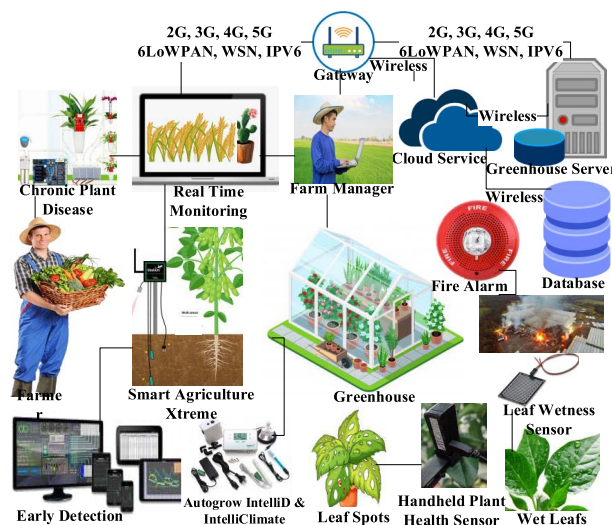


FIGURE 1. Greenhouse e farming trends.

interconnected devices. It provides better decision-making as well as more informed actions with minimum human effort [20]. Bakthavatchalam *et al.* [21] proposed a model by incorporating IoT technology to predict crop productivity and high accuracy in precision farming. A complete automated greenhouse utilizes multiple environmental sensors to track the weather conditions and keep a record of optimum climatic conditions that are necessary for plant growth. When the required environmental condition is detected then a signal is transmitted to the server immediately by using a microcontroller. In this way, the server will respond back with an appropriate decision to control the unit [22]. With the help of ML techniques, agriculturists can measure the atmospheric patterns and record water consumption for a long period in order to obtain significant results for future benefits. Farooqui *et al.* [23] presented an automated greenhouse farming system by embedding ML and artificial intelligence methods to detect early-stage diseases and real-time decision making. Furthermore, the implementation of neural network approaches enables the farmers to keep a record of plant's health status and fruit ripeness.

Moreover, the ease of interaction through secure and seamless connectivity across individual farmers, agriculturists, and greenhouse farm managers is an important trend. Figure 1 illustrates a schematic greenhouse farming trend, where the IoT enabled greenhouse networks using wireless devices to monitor and control the entire farm. Figure 1 shows that a sensor kit (Autogrow IntelliD & IntelliClimate) has been deployed to monitor and control the weather conditions and irrigation in greenhouse farms.

Whereas, two other sensors i.e. Handheld Plant Health Sensor and Leaf Wetness Sensor are used to monitor the leaf disease and leaf wetness of any plant in the greenhouse. The Smart Agriculture Xtreme is a multi-sensor device that monitors the moisture level, soil temperature, air temperature, and conductivity. Greenhouse servers, databases, and gateways

play an important role in creating greenhouse farm records and delivering on-demand services to an authorized user. The collected data through sensors and devices are stored in the cloud server automatically. The cloud system stores the data and allows farm managers or agriculturists to access it remotely for decision-making.

In IoT-based greenhouse farming, there is a number of communication protocols, applications, prototypes, architectures, platforms, topologies, and many other challenges. Therefore, an integrative collaboration between researchers, agriculturists, farmers, and technologist is hard to achieve because IoT technology is still in its experimental phase in the agriculture domain. In this regard, this review presents 5 RQs to analyze the farming trends in IoT-based greenhouse and identifies the challenges and gaps to assist the researchers, farmers, policy makers, and government. This review presents its contribution from four perspectives. Firstly, a comprehensive review of IoT-based greenhouse applications, devices/sensors, and communication protocols have been presented. Secondly, after discussing the farming applications, devices, and communication technologies rigorously we have presented state-of-the-art research challenges and future directions to overcome the current gaps. Thirdly, we discussed the IoT networks for greenhouse farming by presenting a network architecture, topology, and platforms to enable the transmission and reception of greenhouse farming data. Fourthly, proposed an IoT-based greenhouse farm management taxonomy and attacks taxonomy.

This research has been sub-divided into 6 sections. The introduction and research objective have been presented in section I. Section II presents the research methodology with relevant research questions, research objectives, search strategy, inclusion/exclusion criteria, screening & selection, and quality assessment. Research results are discussed and analyzed in section III. Section IV presents a detailed discussion on IoT networks for greenhouse farming. In addition, IoT-based greenhouse farm management taxonomy and attacks taxonomy are also presented in section IV. The conclusion of the review is presented in section V.

II. RESEARCH METHODOLOGY

A systematic literature review (SLR) is conducted by identifying the IoT-enabled greenhouse sensors, applications, communication protocols, critical challenges, and research gaps. However, an appropriate aggregation or evaluation of results related to a specific area can be done by compiling an SLR. The SLR evaluates altogether researchers commenced so for regarding specific topics, however, it demands sufficient time and effort, but a consistent methodology makes the SLR more comprehensive. The SLR was initiated by conducting a literature review on relevant topics. Defined a search string based on primary, secondary, and additional keywords to choose the relevant research articles for this SLR. Figure 2 shows a complete process of review conduction.

A. RESEARCH OBJECTIVES (ROs)

With the increased popularity of IoT in the agriculture field, it is imperative to identify how this technology is supportive and challenging in greenhouse farming for interrelated actors such as farmers, agriculturists, and technologists. The primary objective of this SLR is to develop an understanding of all those scenarios involved in IoT deployment to design a smart greenhouse. However, the major objectives of this SLR were the following:

RO1: Focused on state-of-the-art IoT-based greenhouse farming applications such as monitoring, controlling predicting, tracking, and sensing.

RO2: Identify the major challenges and gaps as well as present some future research direction to make IoT technology more robust in greenhouse farming.

RO3: Recognize the challenges, security issues, and major threats in smart farming.

RO4: Proposed IoT-based greenhouse farming taxonomy and attacks taxonomy to analyze the current standing of IoT in smart farming.

RO5: Presented a network infrastructure for IoT-based greenhouse farming by developing network architecture, topology, and platform.

B. RESEARCH QUESTIONS (RQs)

Research questions (RQs) remain always important for an SLR. The analysis process consists of designing the search protocol to fetch and extract the relevant research articles after defining the RQs. The answer to defined RQs was obtained through published research articles according to our methodology. The RQs have been presented in table 1 with their corresponding motivation to evaluate the significance of the study.

C. ELIGIBILITY CRITERIA

The primary objective of this research is to analyze the recent advances in IoT-based greenhouse farming. In addition, we implemented Petticrew and Roberts Population, Intervention, Comparison, Outcome, and Context (PICOC) criterion in order to perform all steps that are necessary in SLR. PICOC criterion was implemented to answer the defined research questions with a restricted focus. So, the criterion was as follows:

1) POPULATION

It consists of related terms, keywords, and synonyms with relevant meanings for greenhouse farming and IoT technology. As a result, we defined search string with different key terms for the relevant studies selection.

2) INTERVENTION

When the intervention is in the perspective of search that is PICOC, then we utilized different terms to filter the relevant studies such as IoT-based greenhouse, greenhouse farming,

TABLE 1. RQs and main motivations.

No.	Research Question	Major Motivation
RQ1	What are the major application domains and proposed solutions in IoT-based greenhouse farming?	To identify the proposed solutions for greenhouse farming by monitoring, tracking, predicting, and controlling
RQ2	What type of IoT Devices and sensors are addressed in the literature to revolutionize greenhouse farming?	To identify the utilization of IoT sensors and devices for crop and plant growth monitoring.
RQ3	What type of IoT-based greenhouse farming communication standards have been identified in the literature?	To identify the communication standards for greenhouse farming data transmission over networks.
RQ4	What are the open issues and challenges in current IoT-based greenhouse farming research?	To identify the open issues and challenges faced by farmers and agriculturists during greenhouse farming.
RQ5	How IoT can improve greenhouse farming in the future?	To identify the research gaps and suggested future research directions

IoT-greenhouse applications, IoT-greenhouse sensors, and IoT-greenhouse protocols.

3) COMPARISON

The comparison models have not been considered for this research.

4) OUTCOME

This step identifies which are the most relevant outcomes for answering the defined research questions. Therefore, IoT-based greenhouse applications domain, communication standards, proposed solutions, IoT deployment challenges, and security issues are stated as outcomes.

5) CONTEXT

The context is IoT-based greenhouse farming, smart greenhouse farming, security challenges, network architecture, topology and platforms.

D. SEARCH STRATEGY

The next phase was to identify and select the relevant studies. An electronic search was performed by using 5 databases including IEEE Xplore, MDPI, Springer, Elsevier, IGI Global and ACM. These databases were selected for the review process because they are closely related to researchers in IoT-based greenhouse farming. The initial search was performed in February 2022 by deploying search protocol in selected digital libraries and the string was modified until the relevant results were not obtained. Our defined search string contains two main parts that are Greenhouse and IoT. The elected keywords as well as alternate words and synonyms are presented in table 2. In table 2 “+” sign shows the carefully chosen

studies however “-” sign shows the excluded articles in this literature review.

TABLE 2. Search keywords and index terms.

Terms (Keywords)	Alternate Keywords
+Internet of Things (IoT)	IoT Greenhouse (IoTG), IoT Smart Farming (IoTSTF), IoT Protocols (IoTTP)
+IoT Greenhouse (IoTG)	IoTG Monitoring (IoTGM), IoTG Controlling (IoTGC), IoTG Tracking (IoTGT), IoTG Predicting (IoTGP)
+IoTG Monitoring (IoTGM)	IoTGM Humidity (IoTGMH), IoTGM Pest (IoTGMGP), IoTGM Soil (IoTGMST), IoTGM Temperature (IoTGMT)
+IoTG Controlling (IoTGC)	IoTGC Gases (IoTGCST), IoTGC Temperature (IoTGCT)
+IoTG Prediction (IoTGP)	IoTGP Weather (IoTGPW)
+IoTG Sensors (IoTGS)	Gas Sensor (GS), Light Sensor (LS), Heat Sensor (HS), Humidity Sensor (HMS), Temperature Sensor (TS), Moisture Sensor (MS), Tracking Sensor (TMS)
-IoT Precision Farming (IoTTF)	IoT Crop Monitoring (IoTTCM), IoT Smart Farming (IoTSTF), IoT Field Management (IoTTFM)
-IoT Livestock (IoTTL)	IoTTL Farming (IoTTLF), IoT Animal (IoTAT), IoTTL Monitoring (IoTTLM), IoTTL Controlling (IoTTLCT), IoTTL Tracking (IoTTLT)

The keywords for SLR search were identified and Boolean operators “AND” and “OR” were implemented to link the selected keywords. The Boolean operator “OR” gives further search options however, the “AND” operator is another form of a string that concatenates search phrases to identify and develop the best search options to obtain required articles. The designed search string or protocol has seven fragments. The first two fragments define the role of IoT technology in greenhouse farming as well as identify the studies related to IoT-based greenhouse applications and network technologies. Moreover, the next three fragments define how IoT monitor, control, track, and predict multiple greenhouse variables such as humidity, moisture, temperature, light, gases, pest, soil, weather, etc. Besides, the fifth fragment has been implemented to identify the most commonly used IoT sensors in greenhouse farming. The last two fragments enclose the results by excluding irrelevant search terms such as precision farming and IoT-based livestock farming. The defined search string is shown in mathematical form in equation (1).

$$\begin{aligned}
 SR = \forall &[(IoTG \vee IoTSTF \vee IoTTP) \wedge (IoTGM \vee IoTGC \\
 &\vee IoTGT \vee IoTGP) \\
 &\wedge (IoTGMH \vee IoTGMGP \vee IoTGMST \vee IoTGMT) \\
 &\wedge (IoTGCST \vee IoTGCT \wedge IoTGPW) \wedge (GS \vee LS \vee HS \\
 &\vee TS \vee MS) \neq (IoTTCM \vee IoTSTF \vee IoTTFM) \\
 &\wedge (IoTTLF \vee IoTAT \vee IoTTLM \vee IoTTLCT \vee IoTTLT)] \quad (1)
 \end{aligned}$$

In equation (1) SR stands for search results that fetch studies against a defined search string. Furthermore, “∀” symbol stands for “for all” and “∨” is another name of the “OR” operator. Moreover, “∧” symbol is representing the “AND” operator by using keywords presented in table 2.

E. INCLUSION/EXCLUSION CRITERIA

The selected papers for this SLR were examined based on the specific criteria that measured whether an article fulfil the condition for inclusion, otherwise, the study would be excluded. The most important condition for each study was to identify that each selected article is written in English and clearly understandable. Moreover, the inclusion and exclusion criteria list is shown in table 3.

TABLE 3. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Each manuscript must be written in the English language and clearly understandable.	Excluded articles are written in any other language rather than English.
Articles published between 2015-2022.	Articles published before 2015.
Articles focusing only on IoT-based greenhouse farming.	Excluded articles relevant to precision farming and IoT-enabled livestock.
Each article must be related to one of the IoT-based greenhouse monitoring, controlling, predicting, or tracking applications.	Article not specifying any IoT-based greenhouse farming application such as monitoring, controlling, predicting, or tracking.
Articles published only in journals, conferences, workshops, and symposiums.	Articles not published in well-reputed venues.

F. STUDY SELECTION PROCESS AND RISK OF BIAS ASSESSMENT

After completing the search process, selected articles were evaluated by entering them into a reference management system in order to remove duplicate studies. After that, the title and abstract of each article were screened by implementing exclusion and inclusion criteria. However, it was not possible to make a final decision after reading the title and abstract therefore, the full paper was read to create a definitive judgment. This procedure was made by 3 reviewers, the results were compared and discussed the discrepancies until the consensus was met. Data on greenhouse farming applications, proposed solutions, available outcomes, IoT deployment challenges, and security challenges were extracted by one author and validated by another senior investigator to achieve accuracy. However, the bias risk was measured by implementing Cochrane Collaboration’s Risk of Bias Assessment Tool. Although Cochrane collaboration is the widely used example of SLR in order to support the evidenced-based practices regarding healthcare intervention including policy makers patients and professionals [24]. This practice is gaining popularity to address and reduce the public healthcare issues such as food safety. Our designed SLR is also the core of evidence-based health interventions, defined as “high crop productivity and food security by implementing IoT technology” that follows the Cochrane collaboration approach. In the next step, data has been extracted from selected articles by utilizing the data extraction form. The form was specifically designed for this SLR and piloted on a sample of 3 papers. Table 4 shows the items included in the form.

TABLE 4. Extracted data items.

Data Item	Description
Reference	Author, title, published date, and type (journal, conference, workshop, symposium)
Objective	The objective of the study defined by the author
Application	Discussed or identified IoT-based greenhouse farming applications (Monitoring, tracking, predicting, or controlling)
Parameters	Identified parameters of IoT-enabled greenhouse farming such as humidity, temperature, weather, gas, light, heat, fertilization, pest, etc.
Outcomes	Evaluated results in the study

We ensure that this literature review implements the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA). The PRISMA is employed in the present study as an investigation to represent detailed information about a total number of selected studies as shown in figure 2. During the screening and selection process, 1267 articles were identified from digital libraries. Furthermore, 319 studies were selected after reading the title and abstract of each manuscript. Moreover, based on inclusion and exclusion criteria 115 articles were finalized. In the next phase of screening, 82 articles were removed after reading the manuscript completely. To make research more concrete we have concentrated on the specific information from each paper relevant to greenhouse applications such as monitoring, controlling, predicting, or tracking and finalized 32 articles. We also considered the studies that are showing state-of-the-art challenges, security issues, and gaps in smart greenhouse farming.

G. QUALITY ASSESSMENT (QA) CRITERIA

Appraising the methodological quality of selected studies is also a crucial factor in the SLR. As the selected studies were different in terms of design, therefore QA was performed by applying qualitative, quantitative, and mixed-method critical tools. The tool assesses the quality of papers by analyzing data collection, theoretical background, study design, interpretation, data analysis, and conclusions. To enhance the quality of research, a questionnaire was considered to analyze the quality of identified research articles.

QA1: Has the study developed a clear solution for greenhouse farming by using IoT technologies? The study scored +1 if the answer is yes and +0 if the answer is no.

QA2: Has the study focused on IoT-based greenhouse applications such as monitoring, controlling, predicting, or tracking? If the study met the criteria, then the answer was yes (+1) and no (+0) if the criteria was not met.

QA3: Is the research survey-based or problem-oriented? The possible answers were yes (+1) for problem-oriented and no (+0) for survey articles.

QA4: Has the article been published in a reliable and well-reputed source of publications? This criterion was evaluated by seeing the journal quartile rank (Q1, Q2, Q3, Q4) and core ranking (A, B, C) computer science conferences.

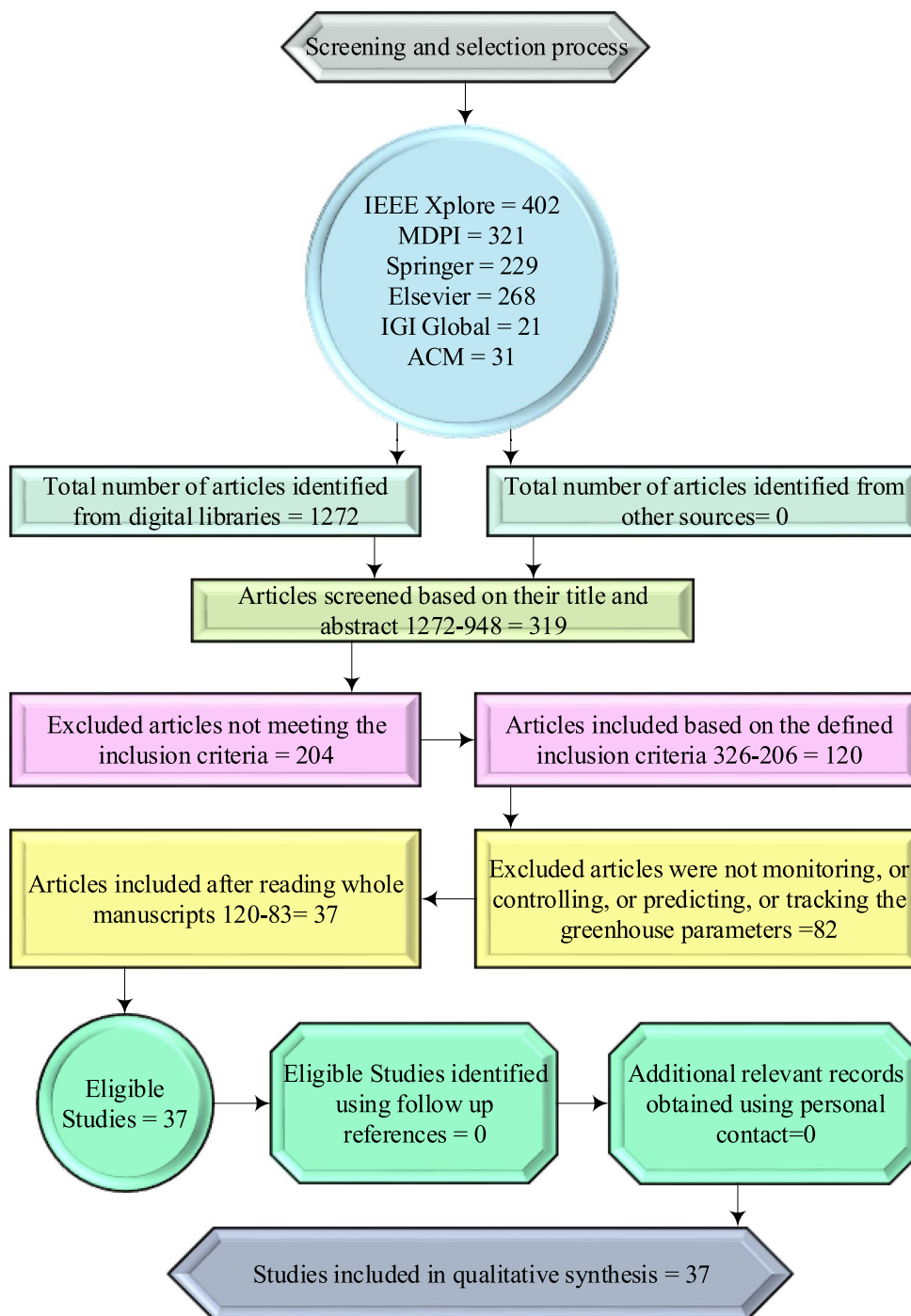


FIGURE 2. PRISMA diagram.

The possible answers for conference articles were:

- The study scored (+2) if it is ranked in CORE A
- The study scored (+1.5) if it is ranked in CORE B
- The study scored (+1) if it is ranked in CORE C
- The study scored (+0) if it is not ranked in any CORE conference

- The study scored (+1.5) if it is ranked in Q2
- The study scored (+1) if it is ranked in Q3
- The study scored (+0.5) if it is ranked in Q4
- The study scored (+0) if it is not in the JCR ranking.

The possible answers for journal articles were:

- The study scored (+2) if it is ranked in Q1

The quartile Q1, Q2, Q3, and Q4 indicates that the articles published in these journals are more valuable as compared to the articles published in conferences or workshops.

III. RESULTS AND ANALYSIS

In this section, the results of SLR were analyzed and discussed based on the search results and RQs a total of 32 articles were synthesized systematically in Table 5. These studies were selected after implementing a vigorous screening of the selected articles. In addition, studies were considered by following the inclusion and exclusion criteria strictly. From selected 32 studies a total of 22 articles (69%) were selected from journals, whereas 7 articles (22%) were selected from conferences and 3 articles (9%) were identified from the symposium as shown in Figure 3.

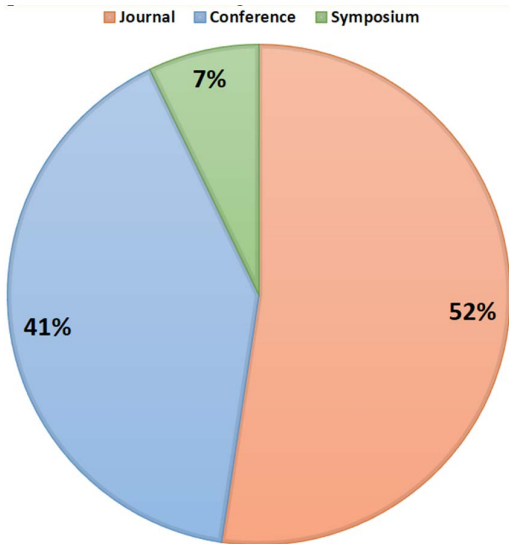


FIGURE 3. Venues for study selection.

Moreover, Figure 4 shows the yearly distribution of selected studies in their respective publication venues. It can be seen that the frequency of publication of selected articles is higher in IEEE Xplore as compared to other venues. A total of 13 articles have been published in IEEE Xplore, 5 in MDPI, 8 in Elsevier, 6 in Springer, and 5 in ACM.

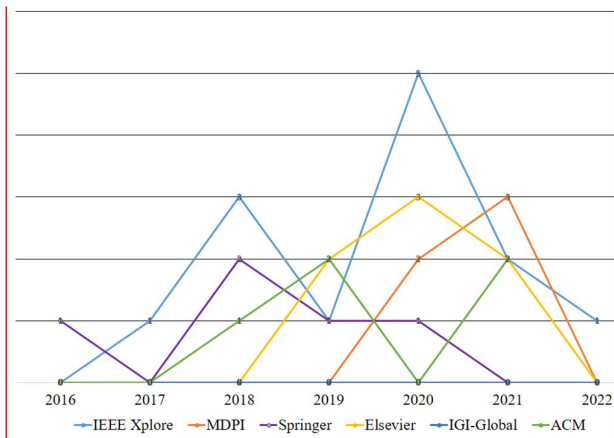


FIGURE 4. Year wise distribution in each journal.

A. ASSESSMENT OF RESEARCH QUESTIONS

The food shortage is growing day by day due to poor and traditional farming techniques therefore, agricultural technology demand has also increased in order to fulfill the food deficiency. IoT technology plays a vital role to enhance crop productivity with minimal human effort and labor cost. Based on our RQs, we have identified the 37 most effective studies improving greenhouse farming by monitoring, controlling, predicting, tracking, and sensing the multiple variables. After making a thorough analysis of selected studies, we extracted a piece of useful information from this research domain for the assessment of RQs.

1) ASSESSMENT OF RQ1: WHAT ARE THE MAJOR APPLICATION-DOMAINS AND PROPOSED SOLUTIONS IN IoT-BASED GREEN-HOUSE FARMING?

IoT enables greenhouse farmers to collect real-time data at unprecedented granularity. A farmer or agriculturist can get information about critical farming parameters such as humidity, temperature, weather, light, water, soil moisture, fertilization, pest, and carbon dioxide in a greenhouse. Each application such as monitoring, controlling, tracking, and predicting is discussed in this research question with its primary function. The frequency of utilization of each application in IoT-based greenhouse farming is shown in Figure 5.

a: HUMIDITY MONITORING

The greenhouses that use manual humidity monitoring systems are less efficient and cause uneasiness to the farmers. Furthermore, a lot of other problems occur because proper growth of plants demands constant monitoring of humidity and temperature [75]. For example, apple cultivation is one of the highest money-making activities as compared to other fruits and food crops if it is done through modern farming methods. On the other hand, the traditional way of apple farming in a greenhouse decreases the productivity of fruit due to low or excessive amounts of humidity. So, different diseases develop due to variations in soil moisture and high or low humidity. IoT technology overcomes such diseases by predicting the humidity level at an early stage and provides possible solutions for farmers. Sheel et al. [76] designed an IoT-based system to analyze and predict the different diseases and their side effect on apples. For this purpose, WIFI transceivers and IoT boards with sensors are used to detect and monitor the data for further investigation.

b: DISEASE MONITORING

IoT-enabled smart farming solutions assist the farmers in monitoring multiple plant diseases at a large scale in greenhouses with minimal labor cost. For example, grapes are a very important fruit crop over the globe and are widely used to make fresh juices and fermented wines. But the quality of grapes has been degraded in the last few years due to several reasons but the major cause is some harmful diseases

TABLE 5. Classification table.

Classification						Quality Assessment				
Ref:	Year	Application Domain	Livestock Applications and Proposed Solution	Sensor/ Device	Communication Protocol	QA1	QA2	QA3	QA4	Total Score
[37]	2020	Monitoring and controlling	A highly scalable intelligent solution has been investigated to monitor and control greenhouse parameters such as environment and temperature	Lighting, humidity, and Temperature sensor	WSN, WIFI	1	1	1	2	5
[38]	2020	Predicting	To analyze the misbehavior of integrated and embedded IoT devices in greenhouse farms, a lightweight distributed detection method has been designed	Soil moisture and temperature sensor	WIFI	1	1	1	2	5
[39]	2020	Monitoring and controlling	Presented a review on state-of-the-art greenhouse farming cultivation technologies	Moisture, humidity, temperature, CO2, air quality	WIFI, WSN	1	1	0	0	2
[40]	2018	Tracking	Designed an IoT-based traceability model for tracking the seedling as well as for recordkeeping of multiple agricultural products	Luminosity, humidity, temperature, soil, and air	WIFI	1	1	1	2	5
[41]	2019	Monitoring	An IoT-enabled greenhouse farming frame has been proposed to monitor the environmental parameters for vegetable growth	Temperature, humidity, light, moisture, and CO2 sensor	ZigBee	1	1	1	0	3
[42]	2018	Controlling	Designed an intelligent greenhouse energy control system to analyze the difficulty level	Heat Sensor	3G/4G, WIFI	1	1	1	0	3
[43]	2018	Monitoring and controlling	Developed a greenhouse monitoring and controlling system to evaluate multiple variables such as humidity, temperature, and light intensity	Temperature, humidity, and light sensor	WSN, WIFI, MQTT	1	1	1	0	3
[44]	2020	Monitoring	A smart device has been installed on a greenhouse farm to measure environmental parameters for optimum growth of plants	Temperature and humidity sensor	MQTT	1	0	1	0	2
[45]	2020	Monitoring	An Electroconductivity sensor is designed to evaluate the drainage in greenhouse farming	Electrical conductivity sensor	WIFI, 4G	1	0	1	0	2
[46]	2022	Predicting	A bot notification system has been proposed to evaluate the growing stages of tomato vegetables in a greenhouse	Temperature and humidity sensor	WIFI, WSN, 2G/3G/4G	1	1	1	0	3
[47]	2021	Monitoring	A design scheme has been presented to obtain intelligent cultivation of flowers in a greenhouse	Temperature and humidity sensor	WIFI, 2G/3G/4G	1	1	1	0	3
[48]	2015	Monitoring	In order to improve the monitoring position of a greenhouse, a multi-route and single-path protocol has been designed	Light, temperature, humidity, and PH sensor	WSN, 6LoWPAN, IEEE 802.15.4	1	1	1	0	3
[49]	2017	Management	Designed an intelligent greenhouse farm management system	Temperature, humidity, and moisture sensor	Bluetooth, WIFI, and ZigBee	1	0	1	0	2
[50]	2021	Predicting and controlling	An innovative supplemental lightening approach was developed to minimize the electricity price in a greenhouse farm	Light sensor	WSN	1	1	1	2	5
[51]	2020	Monitoring	A wireless data fusion has been incorporated for real-time monitoring of temperature, vapor pressure, and relative humidity	Temperature, humidity, and vapor pressure sensor	LoRaWAN	1	1	1	2	5
[52]	2020	Controlling	A multi-tier platform based on the cloud has been proposed to improve the microclimate of a greenhouse	PH, humidity, temperature, gas, and light sensor	WIFI	1	1	1	2	5

TABLE 5. (Continued.) Classification table.

[53]	2021	Controlling	A three-device (3D) system has been proposed to innovate the spectroscopy that can be used in open-air plots.	Relative humidity and temperature sensor	2G/3G/4G/5G	1	1	1	2	5
[54]	2021	Monitoring, controlling, and tracking	Presented a review on different greenhouse parameters such as humidity, temperature, light, gas, etc.	Multiple sensors	Multiple standards and communications protocols	1	0	1	1.5	3.5
[55]	2021	Predicting	A solution has been presented to predict the different greenhouse parameters by utilizing neural networks and artificial intelligence tools	Pest and growth sensor	WIFI, WSN, 3G/4G	1	1	1	2	5
[56]	2021	Monitoring and controlling	An IoT-based architecture was designed to monitor and control the greenhouse seedling production	Environmental sensor	WIFI	1	1	1	0	3
[57]	2020	Monitoring and controlling	Proposed a communication mechanism to monitor and control the greenhouse environment	Environmental sensor	MQTT, WIFI	1	1	1	2	5
[58]	2020	Controlling	An intelligent system was designed to control anti-frost disaster irrigation in greenhouse	Wind speed, irrigation, and rain gauge sensor	WIFI	1	1	1	2	4
[59]	2021	Monitoring and controlling	IoT technology has been implemented to automate the irrigation system in the greenhouse as well as analyzed the weather conditions	Soil humidity/moisture sensor	WSN	1	1	1	0	3
[60]	2020	Monitoring	To evaluate the microclimate variables inside two greenhouses a customized wireless sensor has been designed	Temperature, humidity, wind, and weather sensor	WIFI, 3G/4G/5G	1	1	1	2	5
[61]	2017	Monitoring and controlling	A WSN-based prototype has been proposed to monitor and control temperature humidity, and light in the greenhouse	Temperature, humidity, and light sensor	WSN	1	1	1	0	3
[62]	2019	Monitoring and controlling	Designed a solution that can maintain optimum conditions with minimal energy consumption	CO ₂ , light, and temperature sensor	Zigbee	1	1	1	0	3
[63]	2019	Management	An architecture was proposed to analyze the fault tolerance among two greenhouses for efficient farm management.	Temp, soil, humidity, light, CO ₂ , fire, and pest sensor	WSN, WIFI	1	0	1	1.5	3.5
[64]	2019	Management	An IoT-based e-business model has been proposed on the basic process of vegetables in greenhouse farming	Tracking sensor	MQTT, WIFI, 4G	1	0	1	2	4
[65]	2016	Management	An innovative energy model has been proposed that retrofits the greenhouse with various sensor nodes	Heat and light sensor	WIFI	1	0	1	0	2
[66]	2018	Controlling	A control system was intended and deployed to enhance the income and improve the labor efficiency	Multiple sensor nodes	LORA	1	1	1	0	3
[67]	2020	Controlling	The designed system controls all parameters in the greenhouse to develop an optimal microclimatic condition	Multiple sensing nodes	LoRaWAN	1	1	1	0	3
[68]	2018	Monitoring	A novel intelligent cultivation system has been proposed to modernize greenhouse farming	Pest and environmental sensors	WIFI, 3G/4G	1	1	1	1	4
[69]	2021	Monitoring	Design and developed a novel approach to building a smart indoor greenhouse system	Temperature, humidity, soil, and air quality	MQTT	1	1	1	0	3
[70]	2021	Monitoring	Designed an intelligent IoT-based greenhouse monitoring system to provide new power for agricultural intelligence	Monitoring weather conditions	WIFI, 3G/4G	1	1	1	0	3

TABLE 5. (Continued.) Classification table.

[71]	2018	Monitoring	Proposed a system that is based on simplicity and efficiency in order to enhance the use of technology in greenhouse farming	Temperature, humidity, and irrigation	WiFi, 3G/4G	1	1	0	0	2
[72]	2019	Monitoring	A user authentication scheme has been devised to deploy IoT technology in the greenhouse for monitoring environmental parameters	Temperature, light, humidity, CO ₂ , and pressure	WSNs	1	1	1	0	3
[73]	2019	Controlling	Designed and developed an agricultural cloud warehouse by using IoT and intelligent greenhouse farming technology in order to collect farm data	Controlling various sensing devices and crop breeding process	Mobile communication and ZigBee	1	1	1	0	3

■ Monitoring ■ Controlling ■ Predicting ■ Tracking

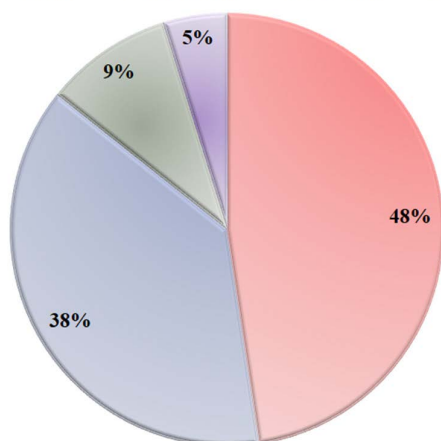


FIGURE 5. Frequency of utilization of IoT applications in greenhouse farming.

such as leaf blight, powdery mildew, and downy mildew [77]. Farmers spray a large number of pesticides in order to prevent diseases which increases the cost of yield. On the other hand, it is also difficult for farmers to identify the diseases manually in large grapes greenhouse. Further, traditional disease monitoring takes a lot of time as well as it is possible only after infection. However, IoT enables the farmers to identify the grape’s diseases at early stages in the whole greenhouse farm. IoT-based grapes monitoring solutions analyze the climate and soil conditions for disease detection and alert the farmers or experts through SMS [78], [79].

c: PEST MONITORING

The production of mango has decreased in past few years due to the extensive use of disease-causing agents and pests. In response to discovering a better solution for mango disease, Jawade *et al.* [80] proposed an alerting system by using Artificial Intelligence (AI) and IoT. The proposed system forecast the attack of mango disease by using pest weather data. The deployed sensors in the entire greenhouse collect live weather data for real-time disease prediction.

Thus, IoT-based proposed solutions forecast mango diseases effectively.

d: PLANT GROWTH MONITORING

Plant Growth cannot be monitored accurately just by analyzing the individual disease causes. It can be predicted in a digital way by using IoT through the implementation of a prototype. Proposed IoT systems and platforms collect necessary information on multiple parameters within strawberry crops such as temperature, PH, moisture content, and humidity [86], [87]. The data is received in real-time by means of communication protocols among sensors. Kim *et al.* [86] developed a cloud-based platform called farm as a service (FaaS) to monitor the strawberry crop farm. FaaS platform connects, registers, and manages all IoT devices and investigates environmental as well as growth information to predict the strawberry infectious disease.

e: TRACKING OF SEEDLING AND OTHER PRODUCTS

Different models and algorithms have been proposed based on IoT technology for record-keeping and tracking of the seedling as well as many other agricultural products at the growth stages. González-Amarillo *et al.* [81] proposed a traceability model to track the greenhouse farming products from seedling to final production. The designed model enables automated control of the internal environment in the greenhouse by using a temperature control system.

f: WEATHER CONTROLLING

In the agriculture industry, greenhouse farming has tighter constraints as compared to traditional farming. Weather variables are the most crucial and required to be controlled constantly to ensure the proper growth of a plant. However, limitations of the proposed smart solution, improvements in accuracy, and cost are the most crucial factors while implementing IoT-enabled greenhouse farming. Kodali *et al.* [82] proposed a cost-effective and reliable solution to predict the weather parameters in greenhouse farming. Furthermore, chase *et al.* [83] has been proposed a sensory platform architecture in order to monitor the environmental/weather

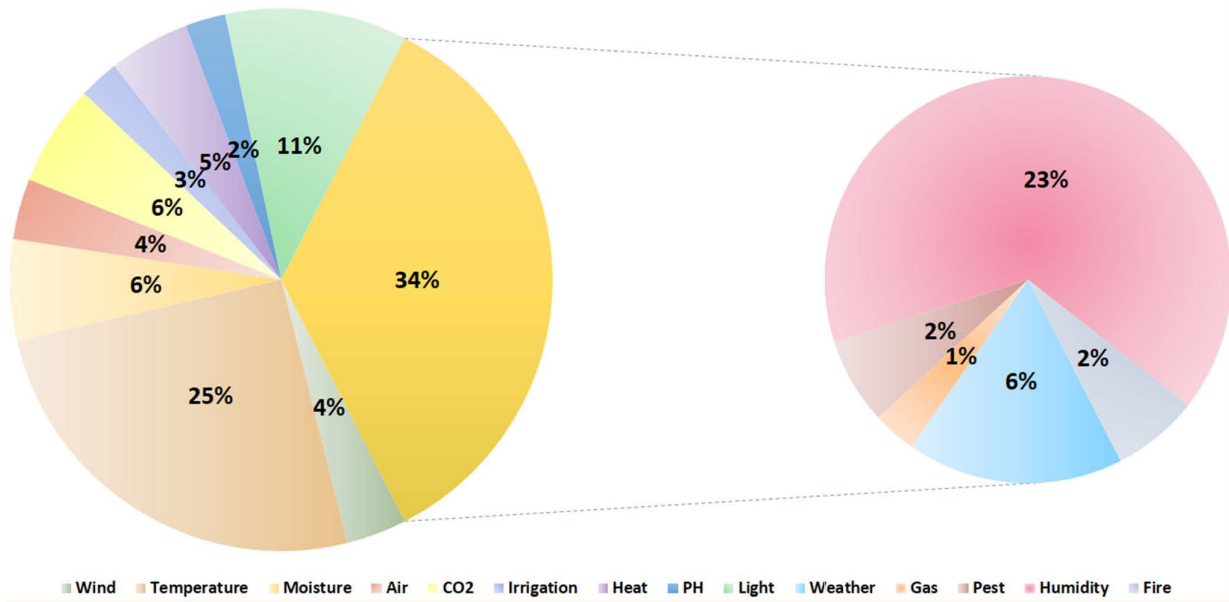


FIGURE 6. Most commonly used IoT sensors in greenhouse farming.

conditions by integrating humidity and air temperature sensor.

g: CONTROLLING LIGHT, TEMPERATURE, AND WATERING

Despite the fertile land and many other available resources, crop yields are low due to the high demand for food and an increasing amount of the world population. Therefore, the integration of technology in agriculture has become vital because it minimizes the labor cost, effort, and time. Kumar et al. [84] proposed a greenhouse monitoring and controlling system by integrating power systems and power electronics. The deployed sensors sense the greenhouse data in real-time and transmit it to the user device. In this way, farmers can control light, watering, and temperature by using their mobiles.

h: CROP GROWTH PREDICTION

IoT and machine learning (ML) based crop prediction models are deployed to identify crop growth by making a real-time observation. Kocian et al. [85] proposed a decision support system to predict crop growth by measuring environmental parameters, vapor pressure, and solar irradiance. Thus, ML and IoT-based solutions reduce the difficulties of greenhouse farmers and will enhance productivity by improving the quality of crops [88].

2) WHAT TYPE OF IoT DEVICES AND SENSORS ARE ADDRESSED IN THE LITERATURE TO REVOLUTIONIZE GREENHOUSE FARMING?

Sustainable greenhouse farming with constant sensing/monitoring, data sharing, and communication among devices is essential for disease prevention [89]. Some crop diseases such as fungi create a significant loss in extensive rainfall,

high temperature, fog, and unexpected climate conditions [90], [91]. The integration of IoT sensors with mathematical models provides an opportunity to growers to take corrective measures before an outbreak. So, the physical internal and external conditions of a greenhouse are analyzed effectively by using required sensors such as temperature, humidity, water, CO2, NH3, pH, etc. Figure 6 shows that the temperature sensor is a widely used sensor in IoT-based greenhouse farming for optimal growth and production of crops and plants. Furthermore, figure 7 shows how different kinds of sensors are utilized by farmers and researchers for different greenhouse farming applications. This section presents a detailed discussion on widely used IoT sensors in greenhouse farming applications.

a: SOIL MOISTURE SENSORS

This sensor measures the moisture content and provides a level of water in the soil and similar variables. However, the water level will be different for different crops which are determined by an agronomist. The moisture sensor contains two large pads which act as a probe for the sensor to detect moisture levels. The analog voltage will be low due to the deficiency of water in the soil and this deficiency increases the conductivity among electrodes in soil changes. This sensor is ideal for automatic watering in flower plants. Besides, soil moisture sensors are also used to monitor the air wetness and heat level in a greenhouse [92].

b: ELECTROCHEMICAL SENSORS

Nutrient content and pH values are the most important variables of soil to enable sustainable greenhouse farming. Electrochemical sensors measure the voltage level between two points to measure the level of concentration of ions including

NO₃, H⁺, K⁺, etc [93]. The traditional method is called chemical soil analysis.

Although, it is time taking and expensive, however, electrodes in this sensor contact with soil sample for quick and cost-effective analysis.

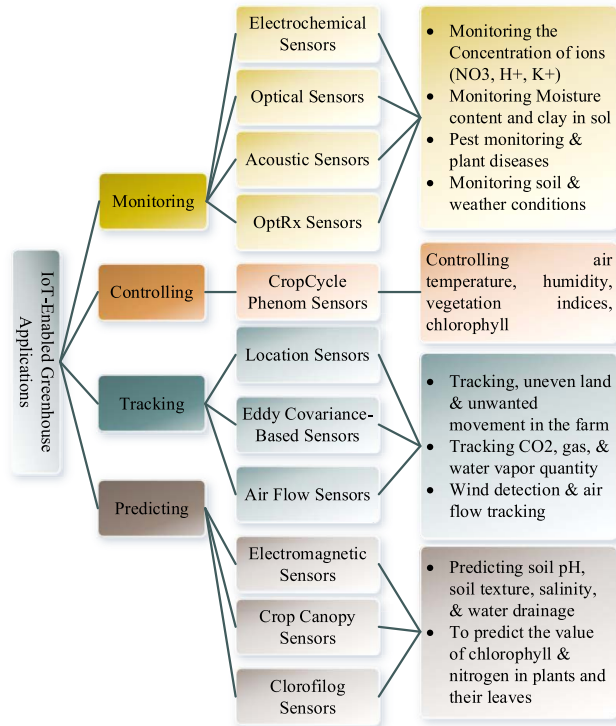


FIGURE 7. IoT-based greenhouse farming sensors taxonomy.

c: OPTICAL SENSORS

Optical sensors utilize light to measure the soil properties such as moisture content, clay in the soil, and organic matter [94]. This sensor is integrated and installed in satellites, robots, and drones for remote monitoring of a greenhouse farm. A large number of optical sensors are available which are implemented according to the soil type and nature.

d: ELECTROMAGNETIC SENSORS

Electromagnetic sensors are used to record and capture the data on various parameters such as soil pH, soil texture, the capacity of cation exchange, salinity, and water drainage [95]. These sensors can be directly implemented in soil or completely out of the soil. Furthermore, electromagnetic sensors are integrated with agricultural machinery such as tractors to track their position [96].

e: AIR FLOW SENSORS

Airflow sensors are used to calculate the permeability of air in the soil. Air permeability is an important factor to analyse the soil structure, soil type, and humidity [97]. Silicon chips are integrated into these sensors to monitor the heat and

temperature in the soil. They give a response to gas and air flowing over the soil with their speed and direction.

f: ACOUSTIC SENSORS

The acoustic sensor is used to detect the sound or any unwanted happening in the greenhouse farm [98]. The most common use of this sensor is pest detection in the greenhouse. These sensors have nodes that are mounted at a specific location in the greenhouse and they will generate a sound and report to the farmers its exact location. Pests are the major hindrance that creates damage in the greenhouses and causes plant diseases [99].

g: LOCATION SENSORS

Location sensors are used to locate the greenhouse farm accurately by using GPS [101]. These tracking and tracing devices are utilized by farmers to identify how and where to use fertilizers and pesticides in what quantity. The position sensors are also used to detect uneven land, irregular landscapes, and leveling issues which create water logging.

h: CROP CANOPY SENSORS

This sensor is used to measure the values of nitrogen and chlorophyll concentration in plants. The crop canopy sensor follows the reflectance principle while implementing pulsating laser diodes to collect the data. This sensor is installed at higher places such as roofs to minimize the damage to the greenhouse farm equipment. It enhances the yield potential by monitoring the crop over time and determines the specific rates of fertilizers [102].

i: OptRx SENSORS

OptRx sensors resolve the soil and weather-related issues in a greenhouse farm. These sensors have the ability to determine the required amount of nitrogen in the farm as well as identify the areas with an excessive amount of nitrogen. It works by utilizing the reflectance of light to measure the actual crop health. The collected data through this sensor is further processed to calculate the vegetative catalog of a plant [103].

j: CLOROFILOG SENSORS

Clorofilog is one of the most powerful sensors that calculate the amount of chlorophyll in leaves. The collected data about chlorophyll help agriculturists in determining the nutritional level of plants at their growing stages. The sensor uses a three-wavelength of light to provide instant results based on the light absorption by the leaf. In this way, farmers will know the nitrogen and fertilize farmland accurately for the efficient growth of plants in a greenhouse [104].

k: CROPCYCLE PHENOM SENSORS

CropCycle is one of the strongest sensors of a European manufacturer (Holland Scientific) which collects a wide amount of data against multiple variables such as air temperature, chlorophyll, humidity, vegetation indices, etc. It can be mounted on greenhouse farm vehicles to cover large

TABLE 6. Communication of existing IoT communication protocols/standards.

Communication Protocol	Standard(s)	Range	Data Rates	Frequency	Power
LoRaWAN	LoRaWAN	2–15 km	0.3–50 kb s ⁻¹	868/900 MHz	Very Low
Bluetooth	Bluetooth, IEEE 802.15.1	10–100 m	1–24 Mb s ⁻¹	2400–2483.5 MHz	0.1–1 W
BLE	IoT Inter-connect	10 m	1 Mb s ⁻¹	2400–2483.5 MHz	10–500 mW
Sigfox	Sigfox	30–50 km	10–1000 b s ⁻¹	908.42 MHz	N/A
WIFI	IEEE 802.11 a/c/b/d/g/n	20–100 m	1 Mb s ⁻¹ –6.75 Gb s ⁻¹	2.4, 3.6, 5, 60 GHz	1 W
ZigBee	IEEE 802.15.4	10-100m	250 kb s ⁻¹	2400–2483.5 MHz	1 mW
LR-WPAN	IEEE 802.15.4 (ZigBee)	10-20m	40–250 kb s ⁻¹	868/915 MHz, 2.4 GHz	Low
COAP	RFC 7252	-	10-20 kb s ⁻¹	1.30-2.4 GHz	Low
MQTT	OASIS	100m <	250 kbps ⁻¹	2.4 GHz	Low
RFID	Multiple standards	1m	423 kb s ⁻¹	13.56 Hz	2mW

greenhouse farms. So, landscape mapping, fertilization, and early disease detection are the common features of this sensor [105].

I: EDDY COVARIANCE-BASED SENSORS

Eddy Covariance-Based Sensors are used for evaluating and measuring the exchanges of CO₂, gases, the energy between the atmosphere, and water vapor. These sensors provide a precise way to quantify the fluxes of the surface atmosphere and track gas fluxes [100].

3) WHAT TYPE OF IoT-BASED GREENHOUSE FARMING COMMUNICATION STANDARDS HAS BEEN IDENTIFIED IN THE LITERATURE?

Fast and reliable communication, as well as timely reporting about the crop, are the most crucial factors in smart greenhouse farming. However, to obtain real monitoring, controlling, and predicting of a greenhouse farm a secure, firm, and reliable connection is necessary between connected objects. To achieve this reliability, the IoT communication protocols can play a vital role in smart greenhouse farming. On the other hand, factors like energy consumption, cost, and coverage are critical and vital to consider before selecting any communication mode. Thus, depending upon the application requirements, scalability, and reliability, multiple communication protocols and technologies are used for this purpose. The most commonly used communication technologies are addressed in this RQ. However, Table 6 shows the comparison among existing communication protocols

a: ZIGBEE

Zigbee technology is used in a large number of IoT-based greenhouse applications to replace existing non-standard communication technologies. According to application requirements, three types of devices can be integrated with this protocol including router, end nodes, and coordinator. Moreover, Zigbee also supports three topologies namely mesh, a cluster tree, and star topology [106]. On the basis of

these characteristics, Zigbee plays a major role in greenhouse farming for communication over shorter distances. During analyzing multiple variables, the data from end nodes such as sensors is transferred via Zigbee to the server. For IoT-based greenhouse applications such as fertilization and irrigation are interacted for communication in drip irrigation to monitor moisture content in the soil. In the end, a message is transmitted to the farmer to alert them about greenhouse farm data.

b: LORA

Lora is an extensively used wireless communication protocol due to its low-power and long-range properties. This protocol provides LPWAN connectivity among cloud and wireless sensors because of its low consumption. LORA has proved itself more reliable and effective as compared to WIFI, Bluetooth, etc. Zhu *et al.* [107] have presented a system to get information about traceability in the grain transportation system to maintain the quality of food by measuring humidity and temperature levels.

c: BLUETOOTH

Bluetooth is a short-range and low-power communication protocol that connects small devices together. Due to its easy use, low cost, and low power, this standard is used in multiple greenhouse farming applications. Bjarnason *et al.* [108] developed a Bluetooth-based temperature and moisture sensor to monitor environmental conditions in a greenhouse farm. Furthermore, a Bluetooth-based sensor node has been designed to analyze the temperature and ambient light for IoT-based smart farming applications [109].

d: BLUETOOTH LOW ENERGY (BLE)

Bluetooth Low-Energy (BLE) implements short-range radio with maximum power to function for a long time. Its latency time is shorter by 15 times and its coverage range is 10 times greater than classic Bluetooth [110]. Smart phone manufacturers have developed this standard very fast and now it is available in the latest smartphone models. BLE is highly

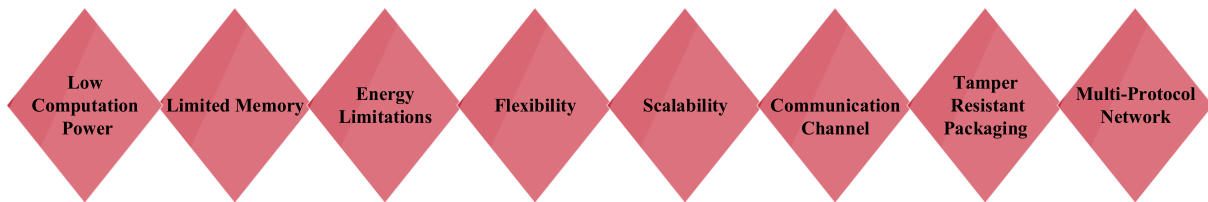


FIGURE 8. Major security challenges in IoT-based greenhouse farming.

effective and more efficient as compared to ZigBee and provides the best energy consumption as well as transmitting energy per bit.

e: CoAP

CoAP protocol is deployed on the application layer to enable smooth and faster communication between greenhouse applications [111], [112]. CoAP defines a protocol based on Representational State Transfer (REST) that makes data transfer easy between client and server over hypertext transfer protocol [113]. The aim of the CoAP protocol is to utilize low computation power and communication abilities to implement RESTful interactions in greenhouse farming. This communication protocol can be divided into further two parts i.e., the request/response layer and messaging layer. The messaging layer distinguishes duplications and makes reliable communication. On the other hand, the request/response layer controls REST communications.

f: SIGFOX

The Sigfox is an ideal standard to exchange data without maintaining and establishing the necessary network connections [115]. In this way, there will be no signaling overhead, as well as an optimized and compact protocol. Moreover, in Sigfox protocol the network complexity does not stay in devices, it stays in the cloud. The cost of the devices and power consumption are very low and making it feasible and workable for Sigfox devices to exchange data over longer distances. It has a built-in network backbone and base station in topology and longer distances.

g: WIFI

WIFI is a preferred choice of many developers, especially because it is ideal for the home environment such as greenhouse farming [116]. It is highly feasible for small, medium, and large size greenhouse farms to establish a network connection to obtain the required data. This network operates on a router, antenna, and radio signals.

h: IEEE 802.15.4

IEEE 802.15.4 standard specifies media access control (MAC) and physical layer for low-range wireless personal area networks (LR-WPANs) [117]. The original version of this standard supported 915 and 826 MHz frequency bands.

However, the basic architecture perceives communication range up to 10 m with a 250 kbit/s transfer rate.

i: LONG TERM EVOLUTION (LTE)

This wireless communication standard transfers data at high speed between mobile devices on the basis of Global System for Mobile Communication (GSM) technologies [118]. Its maximum data transfer speed is approximately 100 MHz. Data uploading and downloading encounter higher throughput and lower latency rates.

j: MQTT

it is a messaging protocol that connects embedded devices and networks with middleware and applications. MQTT consists of 3 primary components namely broker, subscriber, and publisher [119]. Numerous greenhouse farming applications are utilizing the MQTT protocol for different communication purposes. This messaging protocol is ideal for Mobile-2-Mobile communication and IoT technologies to provide routing for low-power, cheap, and small devices.

k: XMPP

XMPP is an instant messaging communication protocol that is utilized for voice and video data recording in a greenhouse farm [114]. The objective of the protocol is to support secure, open, and decentralized communication among nodes by sending instant messages. This protocol runs on a large number of internet platforms and allows new applications to add on top of core protocols [120].

4) ASSESSMENT OF RQ4: WHAT ARE THE OPEN ISSUES AND CHALLENGES IN CURRENT IoT-BASED GREENHOUSE FARMING RESEARCH?

Realization of the IoT vision of greenhouse farming is not an easy task due to a number of challenges that are necessary to be addressed. In this review, a brief discussion is presented on key challenges faced by technologists, farmers, and agriculturists while developing and deploying IoT in greenhouse farms. The challenges have been categorized into 2 basic parts which are security challenges and IoT deployment challenges in greenhouse farming.

a: SECURITY CHALLENGES

We understand that traditional and outdated security solutions are not efficient and unable to handle the IoT-based

greenhouse infrastructure requirements. Therefore, we need some innovative security solutions to address the major security concerns and challenges. Thus, to design a proper security solution, it is necessary to emphasize on security challenges shown in Figure 8.

i) LOW COMPUTATIONAL POWER

The deployed IoT sensors/devices in the greenhouse farm have the low computational power and low-speed processor. Therefore, the computational ability of such devices is low in terms of performance and speed. Thus, it is highly challenging to design and develop a security mechanism that can minimize the consumption of resources efficiently with enhanced security services [121].

ii) LIMITED MEMORY

All IoT devices deployed in the greenhouse farm have low onboard memory. Low in-device memory is already installed in smart farming IoT devices in which system software, operating system, and application libraries are already installed. Thus, we cannot implement complex security protocols or mechanisms due to insufficient space [122].

iii) ENERGY LIMITATIONS

A typical smart greenhouse farm is a framework of monitoring, controlling, sensing, and tracking devices that are compacted with minimal battery power. When the deployed node is in ideal condition, these sensing devices store energy by changing themselves into power saver mode. After that, they switch on the low speed in order to reduce the overall consumption power. So, it is very challenging to develop an energy-efficient solution that can decrease battery consumption with added security solutions [123].

iv) FLEXIBILITY

In IoT-based greenhouse farming, devices are connected and communicate from multiple networks and can be flexible in nature. All these devices are connected through the internet by using various service providers. Therefore, configurations and security settings vary in various networks and make challenging to develop efficient and flexible security mechanisms [124].

v) SCALABILITY

The rapid growth of IoT sensors and devices in greenhouse farming has been seen due to which unlimited devices are going to link globally over the network. Accordingly, it is very challenging to design a scalable security solution by fulfilling cutting-edge security requirements [124].

vi) COMMUNICATION CHANNEL

In smart farming, IoT devices are connected globally and locally through communication channels by utilizing different protocols such as 3G/4G/, GSM, BLE, WIFI, ZigBee, Z-Wave, Bluetooth, and more. Wired security mechanism becomes inappropriate with the advent of wireless solutions.

Thus, it is a big challenge to develop a comprehensive security protocol or mechanism which will be ideal for both wired and wireless technologies.

vii) FLEXIBILITY TAMPER RESISTANT PACKAGING

In IoT-based greenhouse, physical security is the prime concern of smart farming devices. The attacker can execute information tempering by hacking sensors/devices and extracting personal information. Although tamper-resistant packaging is the best solution to overcome these issues, but it is not ideal in IoT-based greenhouse farming scenarios [125].

viii) MULTI-PROTOCOL NETWORK

In greenhouse farming IoT devices connect and communicate by utilizing a proprietary network protocol. Same devices also connect with service providers by utilizing internet protocol networks. Consequently, it is difficult to design a security mechanism that will be applicable to all kinds of systems with advanced security requirements.

b: IoT DEPLOYMENT CHALLENGES IN A GREENHOUSE

In this sub-section, we have presented general challenges which are faced by farmers and agriculturists globally while implementing smart greenhouse farming solutions.

i) LACK OF STANDARDIZATION

Designing and developing a new and innovative system is always complicated and a challenging task. Furthermore, it becomes more complicated and challenging when implement without any particular standard. In the smart farming domain three aspects: safety, security, and privacy are vital and should be handled adequately. But this handling is possible only by implementing various standards. We know that in smart farming data flows among farmers, agriculturists, and technologists and is incorporated by deploying checks on each side. But the major challenge is how we can identify which security check will be implemented for data security and privacy. Thus, standardization is most important to handle these challenges efficiently [126].

ii) TIME SYNCHRONIZATION

Time synchronization is one of the most essential and complex tasks in IoT-based greenhouse farming. But it is highly complex due to a large number of heterogeneous sensors or devices and cloud integration. Time synchronization will make an accurate greenhouse application that will help the agriculturists in real-time analysis and provide various farming solutions to enhance productivity [127].

iii) ARCHITECTURAL CHALLENGES

In order to design a perfect IoT architecture for greenhouse farming, we have to handle the physical subtleties and computing complexities such as time management, data correctness, system structure, standards, and process integration [128]. Therefore, there is a need to design a generalized

architecture that can deal with physical subtleties challenges and computing complexities.

iv) LACK OF INTEROPERABILITY AMONG IoT DEVICES

The interoperability among IoT devices in smart farming is a very critical challenge that should be handled expertly. There is ongoing work on multiple standards and protocols for an unlimited number of IoT devices and sensors to interoperate [135], [136]. Technical interoperability is related to the development and deployment of infrastructure and protocols to enable communication among IoT devices [137]. It is associated with software components and hardware modules of an IoT network. Therefore, it is recommended to develop a system where heterogeneous devices can be integrated to exchange information with each other.

v) COMPLEX QUERY PROCESSING

Processing complex queries regarding power consumption is a challenging task therefore it should be handled carefully. The IoT-based greenhouse farming is a framework of heterogeneous devices interconnected with a wire or wirelessly. All wireless sensors need a battery to perform any query and drain some amount of battery while performing query tasks [138]. However, by implementing complex queries various farm monitoring variables are being retrieved to forecast any unwanted happening or possible diseases in plants or crops. Therefore, we need a complex query processing solution that can fetch the required information instead of searching whole.

vi) IMPLEMENTATION ISSUES

A large number of IoT-based greenhouse farming architectures are in their initial stage. Multiple infrastructures and frameworks are in implementation phases and some of them support minimal farming variables. The practical implementation builds advanced and effective greenhouse farming solutions and helps farmers by indicating farm-related issues [139]. However, dealing with a real-time scenario on regular basis is a very challenging task due to its very complicated nature.

vii) MARKETABILITY AND BUSINESS ISSUES

Improved power consumption of IoT sensors and devices, massive production, and reduced size drop the cost of IoT solutions for greenhouse farming. So, there is a need for the development of cheaper sensors, licensed and unlicensed communication technologies, and research on different scenarios to reduce the operating and setup cost [140]. More work is expected on policy enforcement and participation of the government to ensure the regulation of IoT in smart farming.

viii) REAL-TIME MONITORING

Millions of sensors and devices are implemented in greenhouse farms for real-time monitoring, controlling, tracking, and predicting. Therefore, a simple network protocol must

be developed to establish communication among server and object with minimum overhead. Although many protocols have been designed but they create overhead during heavy data traffic and increase power requirements for deployed IoT architecture in greenhouse farming.

ix) LOCALIZATION ISSUES

Several factors need to be acknowledged for the implementation of IoT devices/sensors in greenhouse farming. The factors include place and play functionality for IoT devices that are placed anywhere and connected across the world without any additional devices or gateway [130]. The best position to place a sensor/device is also another primary factor that can deliver adequate information with high reliability and minimum interference.

x) COST ISSUES

With the deployment of IoT several cost-related issues such as running costs and setup costs arise. Setup charges involve the cost of IoT gateways, devices, sensors, and infrastructure of the base station. Moreover, running charges includes subscription cost for the IoT platforms and services which provides device management, data collection, and information sharing among other services. Other additional charges occur due to exchanging information among gateway, cloud server, IoT devices, maintenance, and energy [131].

xi) STORAGE MANAGEMENT OF PRODUCTS

Most of the greenhouse products are misplaced or damaged due to imperfect and poor storage systems. Moreover, environmental factors, temperature, and moisture factors affect greatly due to contamination of microorganisms, rodents, food products, and insects [132]. But, IoT technology can assist farmers and agriculturists to improve and advance the storage of greenhouse products [133]. IoT sensors were also implemented to monitor environmental conditions and storage services. In addition, an alarm system can be activated to alert the farmers about extreme weather conditions or sudden pest attacks in a storage facility. Mishra *et al.* [134] proposed an IoT-based cloud storage system to facilitate the storage system by controlling temperature. But security should be a major concern while deploying such a system to protect the products from theft.

5) ASSESSMENT OF RQ5: HOW IoT CAN IMPROVE GREENHOUSE FARMING IN THE FUTURE?

After studying the literature and compiling a comprehensive review, the following research directions have been identified:

The spatial and spectral fusion of sensor data or information with multiple spatial resolutions and spectral features is an open research direction. The integration of spatial, spectral, as well as temporal domains and implementation of ML techniques for modeling and decision-making is vital in various applications of greenhouse farming.

More work is needed on greenhouse farm data and climate information to model diseases for the effective growth of plants by using artificial intelligence. Data analytics algorithms are recommended to be developed in order to process large volumes of greenhouse farm data at a higher rate.

Required an accessibility platform that can be appealing enough for service providers and facilitate stakeholders in terms of fair sharing. Accessibility platforms are highly recommended to speed up the development solution as well as to strengthen the greenhouse farm owners' position in the supply chain.

Some of the top future trends in IoT-based greenhouse farming include building a generic platform for all kinds of crops, quality of service, policies standardization, deployment advancement, and technological development.

Explainable artificial intelligence is the top concern in several areas for analyzing and understanding the hidden causes in any kind of decision [129]. It diminishes the outdated black box idea of machine learning and assists agriculturalists in understanding the reasons behind the attained results.

Deep neural network (DNN) services make deep identification models versatile to implement into rogue devices and IoT devices in the smart greenhouse. Still, more efforts are required in terms of performance Assurability and model explainability. Besides, there is limited knowledge on how DNN makes corresponding and final decision boundaries. There is no technique to ensure performance without identifying the decision boundaries and decision process. At the same time, researchers are focusing on the explanation of model behavior rather than providing surety about performance. Whereas, we can't ensure the models' performance with explainability.

The knowledge of utilizing DNNs to implement unsupervised learning for the detection and identification of IoT devices is limited. Meanwhile, only a few deep learning models have been implemented for the detection and identification of the device.

The acceptance of smart farming solutions in the greenhouse for large-scale and small-scale farmers is the biggest challenge. Moreover, the local farmers are a little bit skeptical about the adaptation of IoT-enabled smart farming solutions, considering cost, literacy, privacy, and security are the major research gap. Therefore, it is necessary to regulate privacy and transparent policies to establish the trust of farmers. It is necessary to design the average computational power devices to design cost-effective solutions for farmers.

Existing ML algorithms demand high computational power and heavy storage. Therefore, lightweight AI and ML algorithms are needed to develop with innovative automation techniques.

Crop and food wastage can be evaded by implementing forecasting of harvesting as well as mapping it along with requirements of the supply chain. So, it is an open research area where blockchain-based privacy-oriented and smart service subscription solutions are mandatory.

There is a need to develop a universal platform, not a crop-specific in greenhouse farming to deliver a required solution for any sort of crop. By implementing a universal platform, the farmers can shelter their crops and sell them in the market at a good value.

Security is the most crucial feature in IoT-based smart farming applications such as greenhouse farming. Therefore, to secure and protect the data in the network an end-to-end encryption and decryption algorithm is necessary.

Energy consumption is a highly challenging job in IoT-enabled greenhouse sensors/devices. It is essential to research in the future how energy can be saved while collecting data and how data can be transmitted over long distances on time.

It is envisioned that in the future IoT ecosystem will carry a large number of actuators and sensors for a specific application in smart farming such as a greenhouse. Therefore, the intern IC bus and the serial peripheral interface is an effective approaches to leverage the benefits of edge computing.

A practical approach is required to minimize the loss that occurs due to the wrong estimation of climate and soil conditions. ML and raspberry pi techniques utilize PH sensors, moisture sensors, and temperature and humidity sensors to overcome the pre-harvest issues.

6) QUALITY ASSESSMENT (QA) SCORE

Table 7 presents the QA score of all selected studies. There were approximately about 22% of papers below average, 0% of papers had an average score, and about 78% of papers had scores above average. The QA will help the IoT and agriculture researchers to choose closely related articles.

TABLE 7. Quality assessment score.

References	Score	Total
0	1	0
0	1.5	0
[38][43][44][48][64][71]	2	6
0	2.5	0
[40][41][42][45][46][47][55][58][60][61][65][66][69][70][72][73]	3	16
[53][62]	3.5	2
[57][63][67]	4	3
0	4.5	0
[36][37][39][49][50][51][52][54][56][59]	5	10

IV. DISCUSSION

This section provides a rigorous discussion on IoT-based greenhouse network infrastructure and presents taxonomies. After conducting a comprehensive review, we identify the major component of IoT and proposed an IoT-enabled greenhouse farm management taxonomy to identify the utilization of IoT in greenhouse farming. In addition, an attacks taxonomy was also presented by analyzing the major security challenges and issues in smart greenhouse farming.

A. IoT-ENABLED GREENHOUSE FARMING NETWORK INFRASTRUCTURE

The IoT-based greenhouse network or IoT network for greenhouse farming is a vital element of IoT in agriculture. It gives access to the IoT backbone and enables the transmission as well as the reception of greenhouse farm data. This section discusses the IoT-Greenhouse network architecture, platform, and topology. Moreover, in order to provide deeper insights into IoT networks, the architectures in [25] and [26] are considered a good starting point.

1) IoT-GREENHOUSE NETWORK ARCHITECTURE

The IoT-enabled greenhouse network architecture gives an outline to describe the physical elements of a smart greenhouse and its techniques and working principles. Nearly all the IoT applications follow four-layer network architecture i.e. application layer, transport layer, network layer, and physical layers due to interoperability and popularity as recommended by Naik [27]. After studying the protocols on these four layers we also identified two more approaches i.e. 6LoWPAN and IPv6. Each layer with its identified protocols is shown in Figure 9.

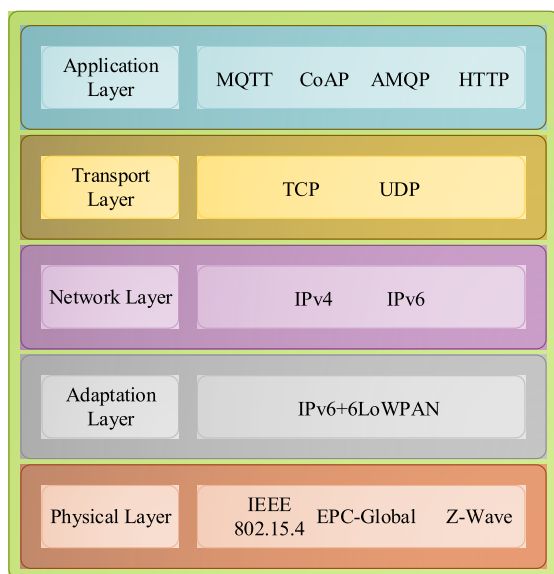


FIGURE 9. IoT-greenhouse network architecture.

a: APPLICATION LAYER

The application layer presents flexible interfaces between users and the system at the level of miscellaneous industry requirements. Due to tough computation and energy constraints incorporated by IoT devices, there are multiple lightweight protocols at the application layer such as Message Queue Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), Hypertext Transfer Protocol (HTTP), and Advanced Message Queuing Protocol (AMQP). According to system requirements, these protocols can be expanded or reduced. In IoT-enabled greenhouse farming, there are

some devices that can't use HTTP protocol directly, the CoAP protocol act as a bridge to connect such devices [28]. Further, the MQTT protocol is used to transmit information towards IoT about different greenhouse parameters such as humidity, temperature, and length intensity to take preventive measures [29]. However, AMQP and HTTP protocols are used for interfacing with the cloud and transmitting the data over the web such as environmental data [30], [31]

b: TRANSPORT LAYER

The transport layer is mainly responsible to transfer the collected greenhouse farming data from the data acquisition layer effectively. This layer contains two protocols including user datagram protocol (UDP) and transmission control protocol (TCP). The TCP protocol is responsible to transmit the data to the server as well as ensure the reliability of data. However, the UDP protocol transmits the data at a very high speed. UDP and TCP protocols are used in isolated applications according to the requirements of the application.

c: NETWORK LAYER

The network layer is responsible to transmit the greenhouse information to the application layer. This layer has many protocols, but the primary protocols are IPv4 and IPv6. IPv4 is a leading addressing technology that originates with increasing the addressable devices. An international organization IANA that assigns IP addresses over the globe has blocked IPv4 addresses. In turn, an IoT-enabled greenhouse consists of billions of nodes, each node shall be assigned a unique IP address. IPv6 has resolved this issue by assigning a unique address to each node in the entire network architecture [32].

d: ADAPTATION LAYER

The adaptation layer (AL) ensures interoperability among different communication technologies and implement compression, fragmentation, and reassembly mechanism. Despite the number of advances in AL layers still, there are many complexities for IPv6. For example, IoT sensors and devices use IPv6 for data transmission over the 802.15.4 protocol. After that data is replied back through sensor nodes by using UDP. 6LoWPAN reduces the IPv6 complexities and is responsible for collecting the sensor data in IoT-enabled greenhouse farming [33].

e: PHYSICAL LAYER

In IoT-Greenhouse network architecture physical layer is the bottom-most layer that is responsible to actuate and sense the multiple farming parameters. IEEE 802.15.4 is a highly acceptable standard due to its low complexity, low cost, and low consumption [34]. IEEE 802.15.4 standard operates between microcontroller and internet gateway if the distance is less than 100m. Further, Z-wave and EPC-Global are used as an alternative to IEEE 802.15.4 in order to exchange information from internet protocol [35], [36].

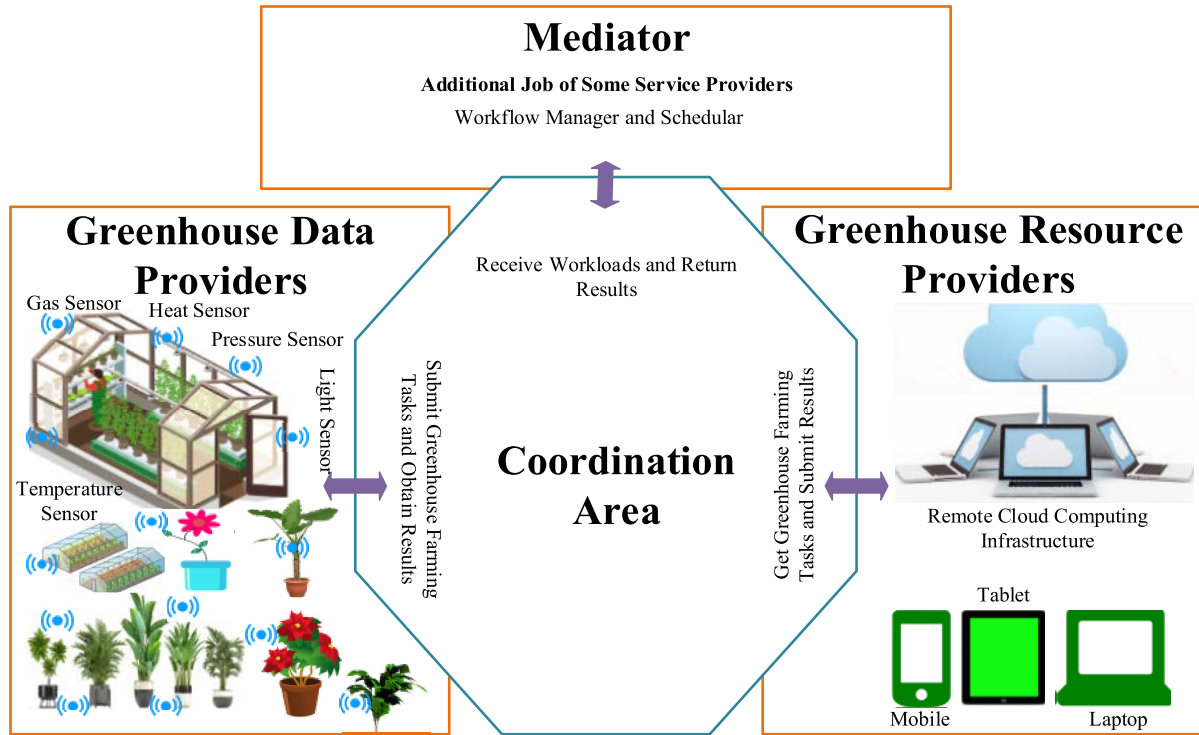


FIGURE 10. An illustration of IoT-enabled ubiquitous greenhouse farming topology.

2) IoT-GREENHOUSE NETWORK TOPOLOGY

IoT-enabled greenhouse network topology is an arrangement of multiple elements of an IoT-based greenhouse network. Figure 10 illustrates how an IoT-enabled ubiquitous greenhouse computing grid collects farming data through deployed sensors such as temperature, water pressure, heat, gas, and light. This topology transforms the diverse computing and storage capabilities of electronic devices including mobiles, tablets, laptops, and greenhouse terminals into grid computing.

3) IoT-GREENHOUSE NETWORK PLATFORM

Cloud and big data analytics platforms help to boost agricultural productivity by minimizing losses and maximizing yields. This section presents an IoT-enabled greenhouse network platform based on cloud computing and big data analytics.

a: IoT-ENABLED GREENHOUSE NETWORK PLATFORM BASED ON CLOUD COMPUTING

The existing farming methods are not enough to meet the needs of the current agro system due to the lack of availability of data storage space, processing requirements, scalability, and reliability. To overcome the existing greenhouse farming problem, there is a need to develop a cloud-based network platform. Figure 11 presents a cloud-based network platform for an IoT-enabled greenhouse. This platform ensures that the greenhouse resource manager can handle a large number

of requests as well as dynamically manage the resources. The platform has been divided into three types of cloud services i.e., Software as a service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS).

The SaaS component acts as a user interface, in which three types of users (Greenhouse expert, Greenhouse officer, and Greenhouse farmer) interact and obtain necessary information about the farm. Seven types of information for different applications in the greenhouse have been considered including crop detail, pest monitoring data, fertilizer information, yield information, irrigation information, weather details, and hardware details. The greenhouse expert answers the farmer queries based on their professional knowledge and updates the agriculture database according to their applications. Further agriculture officer provides the latest information about innovative greenhouse farming policies, rules, and schemes passed by the government.

Farmer is the primary entity in IoT-based greenhouse farming that can obtain the maximum advantage by taking the answer to their queries and getting auto-replies after analysis. Users can monitor any greenhouse farm-related data according to their applications and receive a response without visiting the greenhouse help center. The received queries from the user end are transmitted towards the cloud database for updates and send a response to a particular user based on their predefined devices (mobile, tablet, laptop).

The PaaS component consists of a data processing unit, data transformation, greenhouse expert service module, greenhouse solution reporting service module, and actuator

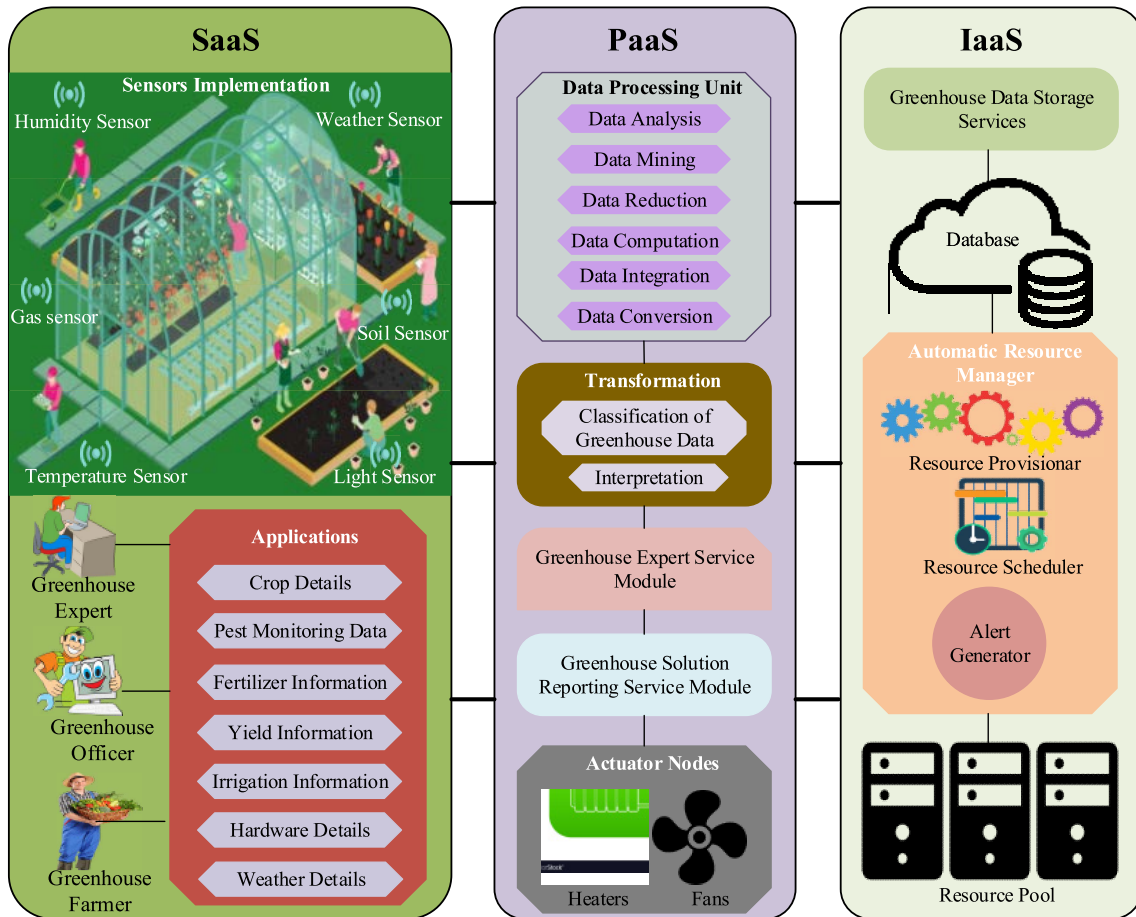


FIGURE 11. IoT-enabled greenhouse network platform based on cloud services.

nodes. The data processing unit is further divided into multiple sub-components i.e. data analysis, data integration, data mining, data conversion, data reduction, and computation. These sub-components support library modules, database infrastructure facilities, and interface services through expert knowledge to develop high-level greenhouse applications. The actuator nodes in the PaaS component operate in accordance with the action commands obtained by the decision unit. Particularly, the action commands derived by actuator nodes generate analog signals and send them to hardware devices to perform an intended action.

In the IaaS module, the automatic resource manager handles the resources automatically by identifying the quality-of-service constraints of a specific request.

b: IoT-ENABLED GREENHOUSE NETWORK PLATFORM BASED ON BIG DATA ANALYTICS

Big data provides farmers granular data about the water cycle, rainfall patterns, and fertilizer requirements. Further, it also enables the agriculturists to make smart decisions, such as which crop to plant for profitability and when to harvest. In the agriculture domain, big data is used for supply chain management (SCM) of agricultural products to reduce the

cost of production [74]. An IoT-enabled greenhouse network platform based on big data analytics is shown in Figure 12.

i) END USE

In this module end-users (Framer/Agriculturists) will interact through a mobile, tablet, laptop, or computer to share or collect greenhouse-related information. If the end-user is a farmer, then he has to share the farmland information including the total area of the greenhouse and approximate location. Farmers will also get a suggestion regarding fertilization, weather and soil conditions, irrigation, and many other crop diseases. Agriculture marketing agencies are responsible to purchase harvested crops and fruits from farmers. Therefore, periodic updates about the changes in cost are necessary to send. Moreover, agro vendors are also responsible for selling seeds, pesticides, fertilizer, and other agro equipment. Therefore, agro vendors must share the updated cost and products to aware the farmers.

ii) BIG DATA MINING & PREDICTION ANALYSIS

This unit plays a vital role in decision-making for the prediction of crop seed, disease, fertilizer, yield, and soil parameters.

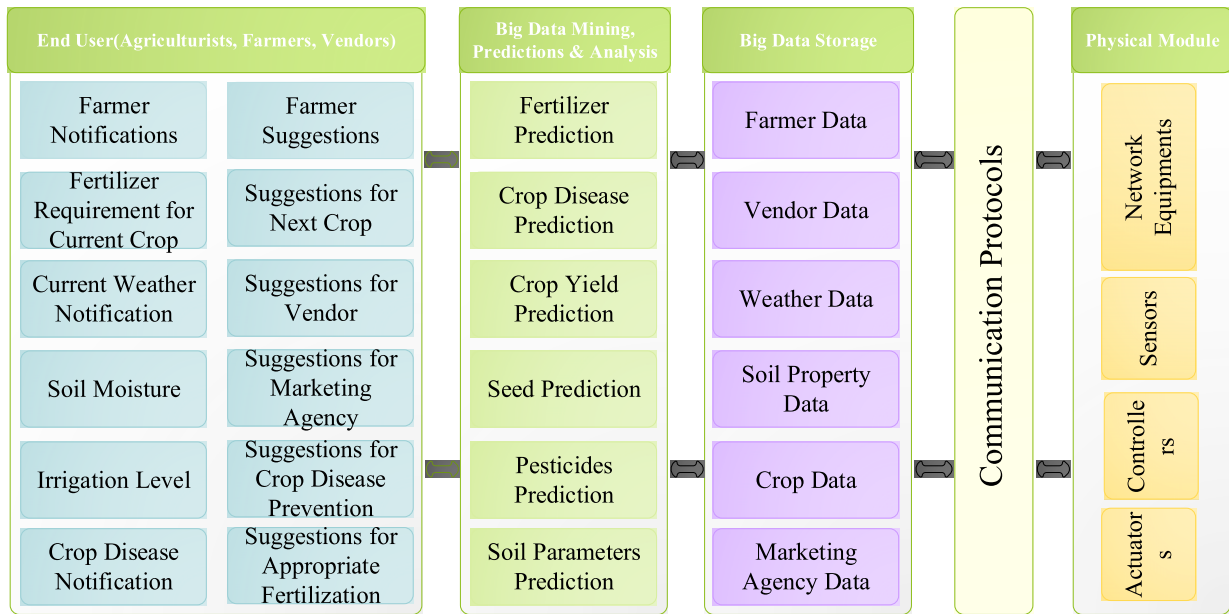


FIGURE 12. IoT-enabled greenhouse network platform based on big data.

The module identifies the proper amount of fertilizer for the current crop according to the soil conditions. This module also collects information for soil properties as well as crop details with the production cost for each greenhouse farm. The results along with data mining analysis can be calculated to preserve good soil health for better crop yield. Big data analysis is made to estimate the future production of yield and cost on the basis of previous knowledge

iii) BIG DATA STORAGE

Big data storage unit will store the details of all users related to greenhouse farming and management. This module also receives and stores the greenhouse crop and soil data. Additionally, big data storage unit will store the periodic data obtained through the environment and soil sampling. With the passage of time number of users and data size will increase rapidly resulting in big data.

iv) PHYSICAL MODULE

The soil information of each greenhouse is collected through deployed sensors. The sensors also collect and transmit the greenhouse soil information to big data storage unit when the cultivation of the crop is in progress.

B. IOT-BASED GREENHOUSE MANAGEMENT SYSTEM

The greenhouse management system is one of the core components of smart farming. The greenhouse management system collects and processes data used to manage and control farming operations thoroughly. An IoT-enabled greenhouse management system taxonomy is shown in Figure 13 with major components.

The physical measures module is an equipment monitoring module in smart greenhouse farming. The module monitors

and controls the sensors and devices deployed in the greenhouse and does create, update, delete, and retrieve operations. Users also set up an automatic monitoring rule for sensed data through data trigger action. In this way, a specified action will trigger when temperature or water reaches a certain level.

The data acquisition component consists of 8 IoT protocols namely COAP, AMQP, ISOBUS, ZigBee, MQTT, SigFox, CAN, and WIFI to support legacy systems. According to the applicable nature, one or more protocols can opt for greenhouse farm data communication. Further, the data acquisition component defines the collection of data from IoT sensors, devices, and other systems such as unmanned vehicles, tractors, and agri robots.

Data processing units mainly rely on the nature of the application and consist of data logging, data mining, and a decision support system. One or more than one features can be implemented at the same time. However, these processing units can be increased or decreased depending upon the application requirements.

The data visualization feature consists of multiple greenhouse parameters. These parameters include monitoring, controlling, tracking, and predicting greenhouse farm variables. For example, yield monitoring, humidity monitoring, pressure monitoring, weather monitoring, pest monitoring, gas controlling, light monitoring, and controlling.

The smart gateway component is divided into 3 sub-components including sensor control, actuator control, and greenhouse facilities control. This module controls the greenhouse facilities through a local program such as controlling the pest and irrigation equipment. The sub-component sensor control consists of multiple sub-features i.e. soil sensing, weather sensing, water sensing, and light sensing. The video monitoring feature monitors the greenhouse farm

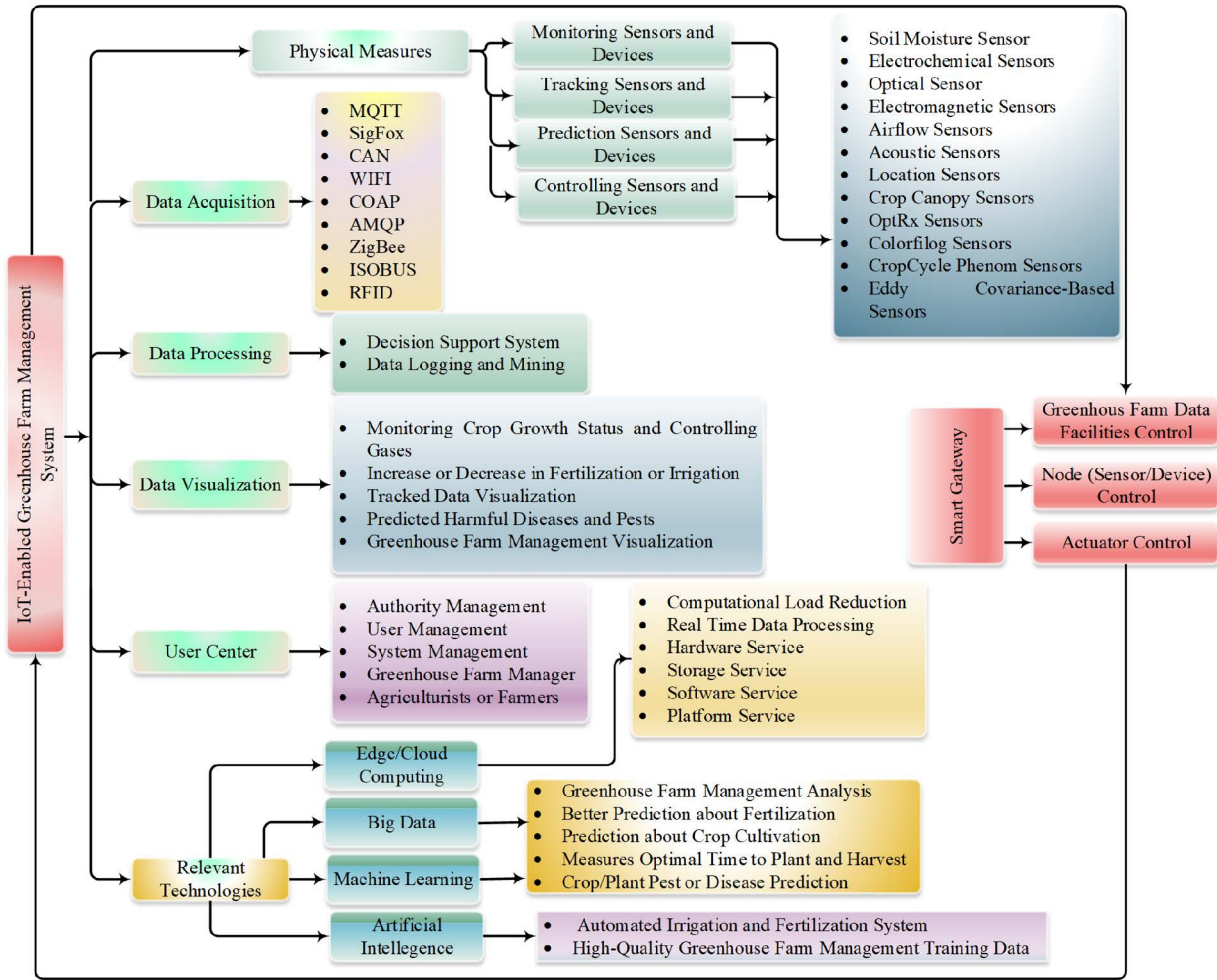


FIGURE 13. IoT-enabled greenhouse management taxonomy.

facilities and records several yield parameters such as crop growth.

Furthermore, multiple technologies are integrated with IoT to enhance system performance and crop productivity. The most commonly used technologies are cloud computing, big data analytics, machine learning, and artificial intelligence. These technologies are responsible to store data, to make more informed and intelligent, and utilize various models and algorithms to boost crop production. Although, we are already in the era of machine learning, artificial intelligence, and big data analytics but these technologies are implemented to develop improved efficiencies to make more informed farming decisions.

The integration of IoT and big data analytics provides granular data to agriculturists on different farming variables such as fertilization requirements, rainfall patterns, the optimal time to cultivate the crop, irrigation cycles, and disease detection at early stages. This enables the farmers and growers to make smarter and right decisions to enhance crop yields. In greenhouse farming, ML also has great potential to improve the yield in multiple ways from detecting diseases and weeds, yield prediction, crop quality,

data gathering, and providing predictions regarding crop productivity.

A farmer can obtain real-time insights by utilizing AI to identify the areas where pesticide treatment and fertilization monitoring are required. Furthermore, these innovative farming approaches enhance food production and quality with minimum utilization of resources. Users can get high-quality farm training data to increase profits and harvest quality with reduced cost.

User center feature generally includes system management, user management, and authority management to manage IoT-enabled greenhouse farming

C. IoT-BASED GREENHOUSE FARMING ATTACKS TAXONOMY

Technologies are increasing day by day, therefore the number of attacks also increasing on the latest technologies with the passage of time. If we talk about IoT-based greenhouse farming, networking and devices/sensors are the primary concern of attackers. Security attacks can be found anywhere across the networks. All attacks are different in nature, some are tangible, some of them are predictable, and most of them

are unpredictable. There are 3 major attacks in IoT-based greenhouse farming namely; 1) information disruption attack, 2) host properties attack, and 3) network properties-based attack as shown in Figure 14.

1) INFORMATION DISRUPTION ATTACK

Information disruption is one of the most dangerous attacks in which an adversary fetches the farm data at the storage stage. After updating or removing the information the data is manipulated.

a: INTERRUPTION

It is a denial of services attack, which makes communication channels or links to be unavailable. This attack creates an acute impact on the functionality of the network and disrupts the device functionality.

b: INTERCEPTION

In this type of attack data, privacy and confidentiality are compromised. So, in this process agricultural records or information is abstracted.

c: MODIFICATION

In this type of threat farm record is accessed in an illegal way and tempered by modifying the actual greenhouse farm data.

namely 1) user side attack; 2) software side attack, and 3) hardware side attack.

a: USER SIDE ATTACK

The attacker will attack on the user side by accessing the farm devices/sensors and network. After gaining access, the attacker will disclose sensitive data such as farm records and user passwords.

b: SOFTWARE SIDE ATTACK

An invader will outbreak the software side of the deployed system and fetch the vulnerabilities of the system and software glitches. After doing this, the devices will go into malfunction or dysfunction states.

c: HARDWARE SIDE ATTACK

An adversary will attack physical devices by removing or fetching the data, and keys, as well as modifying the code and reprogramming it.

3) NETWORK ATTACKS

This attack occurs due to specific and layer-specific compromise attacks. There are two types of network attacks i.e., standard protocol attacks and network protocol attacks.

a: STANDARD PROTOCOL ATTACK

Attacker violates or tampers standard protocols by implementing security policies such as integrity, message privacy, authenticity, and service availability.

b: NETWORK PROTOCOL ATTACK

In a network protocol attack, the attacker detects multiple glitches and forces the layers to implement malicious attacks.

V. DISCUSSION

Researchers around the globe have explored multiple technological solutions to maximize the yield of crops and fruits by mobilizing the potential of IoT. This research reviews multiple aspects of IoT-enabled greenhouse farming and presents state-of-the-art IoT-based greenhouse applications i.e., monitoring, controlling, tracking, and predicting. For deeper insights, into enabling technologies and industry trends SLR has synthesized a comprehensive review on sensors/devices and communication protocols. Furthermore, the SLR has presented a comprehensive review on IoT-based greenhouse farming challenges, security issues, and major attacks, and discovered future research directions. This research also presents diverse greenhouse network architecture, platforms, and topologies that facilitate greenhouse farming data transmission. In order to understand the IoT-based greenhouse architecture profundity, an IoT-enabled greenhouse farm management taxonomy has been proposed. In addition, an attacks taxonomy has also been presented after reviewing various farming challenges and security issues. The government patronizes IoT technology in smart farming

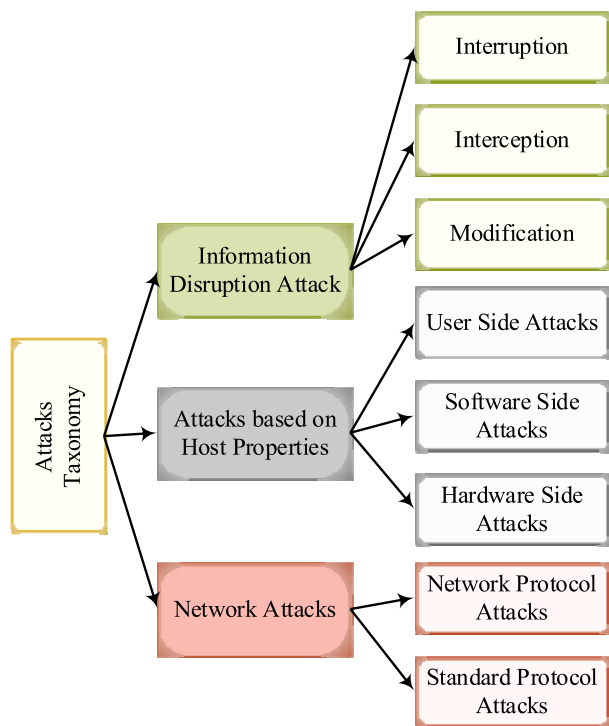


FIGURE 14. Attacks taxonomy.

2) ATTACKS BASED ON HOST PROPERTIES

In host properties, an attacker may attack on any host and destroy the entire network. It consists of three types of attacks

TABLE 8. Nomenclature.

Abbreviation	Definition
IoT	Internet of Things
FAO	Food and Agriculture Organization
SLR	Systematic Literature Review
ROs	Research Objectives
IoTG	Internet of Things Greenhouse
IoTP	Internet of Things Protocols
IoTGM	Internet of Things Greenhouse Monitoring
IoTGC	Internet of Things Greenhouse Gases
IoTGP	Internet of Things Greenhouse Prediction
IoTGS	Internet of Things Greenhouse sensor
IoTPF	Internet of Things Precision Farming
IoTL	Internet of Things Livestock
IoTGT	Internet of Things Greenhouse Tracking
IoTGMH	Internet of Things Greenhouse Monitoring Humidity
IoTGMP	Internet of Things Greenhouse Monitoring Pest
IoTGMS	Internet of Things Greenhouse Monitoring Soil
IoTGPW	Internet of Things Greenhouse Monitoring Weather
IoTGS	Internet of Things Greenhouse Sensor
IoTSF	Internet of Things Smart Farming
GS	Gas Sensor
IoTGMS	Internet of Things Greenhouse Monitoring Soil
IoTGCT	Internet of Things Greenhouse Controlling Temperature
TS	Temperature Sensor
LS	Light Sensor
HS	Heat Sensor
HS	Humidity Sensor
MS	Moisture Sensor
TS	Tracking Sensor
IoTGCT	Internet of Things Greenhouse Controlling Temperature
IoTGCG	Internet of Things Greenhouse Controlling Gases
BLE	Bluetooth Low Energy
COAP	Constrained Application Protocol
MQTT	Queue Telemetry Transport
HTTP	Hypertext Transfer Protocol
AMQP	Advanced Message Queuing Protocol
GSM	Global System for Mobile
LTE	Long Term Evolution
MAC	Media Access Control
LR-WPANs	low-range wireless personal area network
LPWAN	Low Power Wide Area Network
LORA	Low Range
RFID	Radio Frequency Identification
CAN	Controller Area Network
XMPP	Extensible Messaging and Presence Protocol
UDP	User Data Gram Protocol
TCP	Transmission Control Protocol
IoTFM	Internet of Things Field Management
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analysis
QA	Quality Assessment
AI	Artificial Intelligence
FaaS	Farm as a Service
ML	Machine Learning
REST	Representational State Transfer
DNN	Deep neural network
AL	Adaptation Layer
SaaS	Software as a Service
IaaS	Infrastructure as a Service
PaaS	Platform as a Service
SCM	Supply Chain Management

and it is expected that soon this IoT technology will modernize the conventional greenhouse farming method. In sum, it is

expected that the results of this comprehensive review will be useful for researchers, agriculturists, policy makers, and technologists in the domain of IoT and greenhouse farming.

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