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Recent Developments of the Internet of Things in Agriculture: A Survey

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ABSTRACT A rise in the population has immensely increased the pressure on the agriculture sector. With the advent of technology, this decade is witnessing a shift from conventional approaches to the most advanced ones. The Internet of Things (IoT) has transformed both the quality and quantity of the agriculture sector. Hybridization of species along with the real-time monitoring of the farms paved a way for resource optimization. Scientists, research institutions, academicians, and most nations across the globe are moving towards the practice and execution of collaborative projects to explore the horizon of this field for serving mankind. The tech industry is racing to provide more optimal solutions. Inclusion of IoT, along with cloud computing, big data analytics, and wireless sensor networks can provide sufficient scope to predict, process, and analyze the situations and improve the activities in the real-time scenario. The concept of heterogeneity and interoperability of the devices by providing flexible, scalable, and durable methods, models are also opening new domains in this field. Therefore, this paper contributes towards the recent IoT technologies in the agriculture sector, along with the development of hardware and software systems. The public and private sector projects and startup's started all over the globe to provide smart and sustainable solutions in precision agriculture are also discussed. The current scenario, applications, research potential, limitations, and future aspects are briefly discussed. Based on the concepts of IoT a precision farming framework is also proposed in this article.

INDEX TERMS Artificial intelligence, cloud computing, Internet of Things, precision agriculture, wireless sensor networks.

I. INTRODUCTION

The term 'Agriculture' is inferred from the Latin words '*Ager*' means 'Land' and '*Culture*' means 'Cultivation'. It is the milestone field of human civilization and is one of the benchmark areas. This field is the withstander of the economies of various nations. According to the Food and Agricultural Organization of the United Nations (FAO), more than 60% of the human population depends on agriculture for survival and around 12% of the total land area is under agricultural production [1]. Predicted by FAO, the global population will reach the mark of 8 billion people by the year 2025 and 9.6 billion by the end of 2050 (FAO, 2009) [2]. The interpretation of this data shows that to tackle this population growth, an estimated increase of 70% in food production must be achieved worldwide by 2050 [3]. Agriculture is also the second-largest greenhouse gas (GHG) emitter, because of fossil-based fertilizers, biomass, and machinery. In some of the developed and developing nations, the agriculture sector is the backbone of the economy. This field has a huge contribution in the growth of Gross Domestic Product (GDP) of developing countries, in particular, some of them are listed in TABLE 1.

In India, 53% of the population is dependent on the agriculture sector for employment and 61.5 % of the Indian population is primarily dependent on the agriculture sector for its livelihood [5]. Focusing on the market size, India is the second-largest fruit producer in the world. Based on certain data and statistics, the farming income in India is expected to double by 2022. Eyeing this change, there is an intra-state cluster development of certain states in terms of the agriculture sector. The various stats and numbers representing the impact of agriculture in the overall economic development of India as compared to other fields has been shown in Fig. 1.

At present, the demand is more than the supply generated and this curve will illustrate more unstable results in the

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TABLE 1. Nations having agriculture as a major part of their GDP [4].

S. no.	Country Name	GDP (%)
1	Liberia	76.9
2	Somalia	60.2
3	Guinea-Bissau	55.8
4	The central African Republic	53.1
5	Chad	52.7
6	Comoros	51.6
7	Sierra Leone	51.5
8	Togo	46
9	Ethiopia	41
10	Niger	39
11	Mali	38.8
12	Burma (Myanmar)	38.2
13	The Democratic Republic of the Congo	37.5
14	Benin	36
15	Nepal	34.9
16	India	23

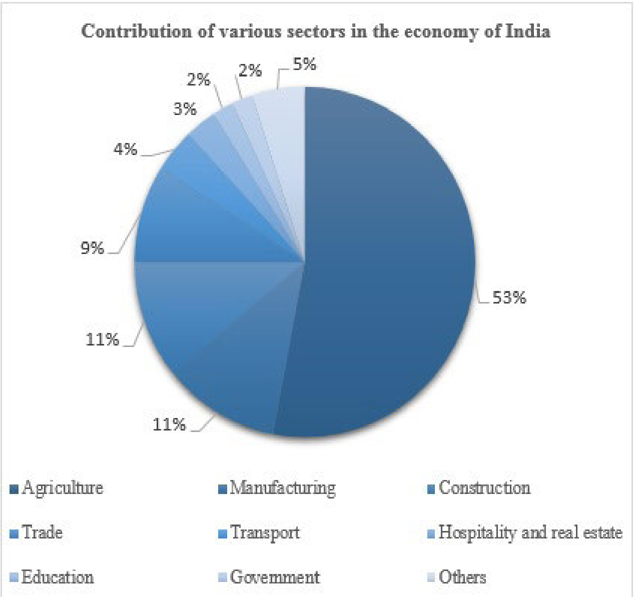

FIGURE 1. Contributions of various sectors in the Indian economy [6].

coming years, due to increase in demand with population rise. To maintain the demand-supply curve, there will be enormous stress on the agricultural sector. Global warming and changing climatic conditions are also important factors to be taken into consideration. From the past decades, due to the increase in demand and pressure on the overall structure of the field, this area is witnessing the slow but progressive shift from traditional approaches to the most advanced technology-driven methods. The use of traditional approaches and conventional methods, as well as the changes in the environment, lay stress on the agricultural sector. Some of the challenges for the agricultural sector are given as follows:

1) The use of traditional techniques of farming hinders the optimization of both cost and time.

2) Depletion of the topsoil due to floods and winds resulting in the deposition of the pollutants, sediments, nitrates, and phosphates, result in causing the eutrophication and the runoff of the soil.

3) Planting the same crop after each harvest makes the soil redundant of the essential nutrients.

4) Water scarcity due to the climatic changes lowers the level of groundwater for irrigation, thereby disturbing the water cycle.

5) Global climate changes due to the destruction of the tropical forests and the other vegetative species in agriculture result in the elevation of the carbon dioxide and other greenhouse gas levels.

6) Lack of expertise in proper recognition of the particular plant species.

7) There is no proper method to detect the disease at early stages, such that precautionary measures could be taken to prevent it.

Therefore, because of these factors, the need for the creation of modern methods and intensification of the agricultural practices to use water, soil, minerals, and other resources efficiently becomes obligatory.

The nature of the technology and devices is changing i.e. it never settles for any less. A lot of research papers addressing the challenges of agriculture in the IoT domain have been put forth. Constant developments and everlasting expectations from the existing technologies paves a great way for motivating academicians and researchers to set and attain new standards. During recent years, there has been a paradigm shift in the study and application of domains like IoT, cloud computing, machine learning, and big data, etc. Therefore, from the trends of these data sets, a constant need is felt to revisit the current standings and capacities of the new age IoT concepts. The modern-day requirements and the counteractive substitutes in the field of agriculture and changes exactly to the expectations based on the concepts of IoT must be addressed. The contribution of IoT in the agriculture field and certain gaps in resource utilization motivated us to perform a study that addresses current issues and applications of IoT in agriculture.

Agriculture is expected to get immensely fortified by the advancement of technology especially by the domain IoT. Precision agriculture is the new term appended to the agriculture filed, with all the procedures being followed, addressed, and simulated in a tech-driven manner. Incorporation of the internet has started to revolutionize this field by associating devices together, now being identified as the Internet of Things. Coined in 1999 by a British visionary "Kevin Ashton", Internet of Things is a consortium of devices connected [7]. The devices are associated with internet via Wireless Sensor Networks (WSN), Radio-frequency Identification (RIFD), Near Field Communication (NFC), Long Term Evolution (LTE), and other devices and communication technologies. This association helps the devices and the other objects transfer the information gathered to destined places all over the network. Precision agriculture, therefore, aims to optimize and improve agricultural processes to ensure optimum production with reliable, fast, and distributed dimensions thus providing growers a detailed overview of the ongoing scenarios in the cultivation stretches. This practice is followed to reduce energy consumption. The major areas where IoT can leave an everlasting impression are climate monitoring [8], data analytics [9], early disease detection [10], crop counting [11], smart irrigation [12], etc. With the spread of a network of devices, a communication channel can be established between the farmers, fields, and experts. By developing IoT based models, the field conditions can be monitored remotely on regular time intervals without any human intervention and after analyzing the data favorable and efficient decisions can be taken accordingly. This will help to ensure both field and market safety and security to the farmer. Also, with early monitoring of crops, disease detection can be done and thus preventive measures can be taken to save the crop beforehand. For producers it will also help in the analysis of consumer demands. Whether the product will be able to meet market expectations, thus creating an intelligent decision driven farming. An analysis of different existing articles addressing the research and development of precision agriculture is presented in TABLE 2.

In this article based on research gaps and findings obtained from articles analyzed below, a systematic survey is done.

Therefore in this study, the most prominent problems of the agriculture sector, and solutions provided by modern systems are addressed and discussed in detail. The major contributions of this study are as follows:

1) A comprehensive survey of the architectural, conceptual, and implementation details of IoT models adopted for Precision Agriculture has been carried out.

2) Various IoT hardware platforms and other associated devices like sensors, accumulators, etc. along with their role in agriculture have been discussed in brief. Various IoT OS supported for Precision Agriculture have been discussed. The significance and key differences of MIoT in agriculture have been discussed along with related studies.

3) Studies limited to a specific domain has been merged together for clear mapping of the domain.

4) Sensors and their role in agriculture is discussed. Various projects/ start-up's started all over the globe for tacking agricultural problems and providing intelligent and sustainable solutions to farmers have also been discussed.

5) Functional concepts like limitations, improvements, future works and applications are discussed separately.

The rest of the paper has been organized as in Section 2 various search and source methods used for the selections of relevant articles has been introduced, in Section 3 to get into the deep insight of the various concepts, theories, and devices related to the implementation of Internet of Things has been discussed, followed by Section 4 which gives the various related studies concerning different applications of Internet of Things in Agriculture, findings like challenges, limitations, improvements, future work, etc. with a short description of our proposed work has been given in Section 5, and finally, at last, the article ends with a conclusion. Table 3 gives the detailed nomenclature used throughout this article.

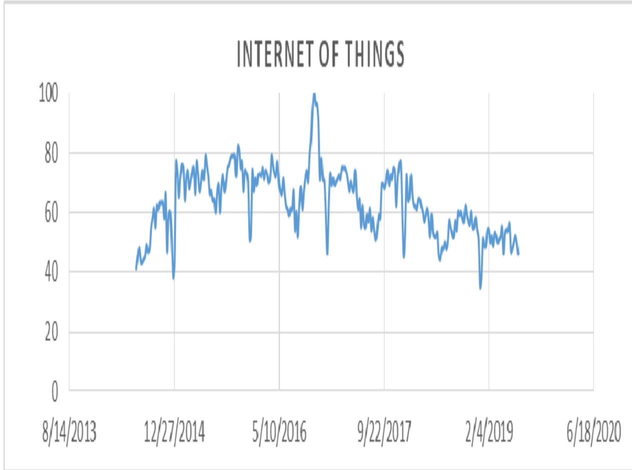

FIGURE 2. Worldwide distribution of IoT of the past eight years [19].

II. SOURCES AND SEARCH METHODS

The research methodology consists of going through articles based on the contribution of IoT and its related technologies for the advancement and development of the agriculture filed. For designing the overall structure of this article, the data and selected studies are chosen strictly based on a time frame. Most of the articles taken for study are sorted from 2015 to 2020. This time frame is chosen to visualize and understand the current impact of IoT in the field. In TABLE 4, a summary of the resources from where the papers have been selected is presented.

Given the objective of this article, research has been conducted thoroughly by examining the existing literature work related to the subject. For developing a firm foundation, the articles containing the origin of IoT, alongside current standings, recent trends, and technologies, were considered for a study concerning their contributions to the field of agriculture. By reviewing the existing literature, a sustainable framework has been developed to overcome the existing challenges in the field. The keywords mainly used to identify the literature included Precision Agriculture, Agriculture, Plant Monitoring, Internet of Things, Smart Agriculture, Smart Farming, Irrigation, Plant Pathology, Wireless Sensor Networks, etc. The eight-year trends of the different terminologies and their search significance over the years have been extracted from Google and are presented in Fig. 2 and Fig. 3.

From the figures, it can be seen that the frequency of search or usage of these two terms is somewhat stable over the past eight years. An average, 80% of people talk and search about these topics for study and other related purposes, thus establishing the growing interest worldwide in this area. So for a better understanding, in the next section, the various

TABLE 2. Alaysis of various papers in the field of precison agricuture for the current study.

Ref	Title	Year	Area	Research findings	Research gaps
[13]	Smart farming: Agriculture's shift from a labor intensive to technology native industry	2020	Smart farming	• Role of IoT in pest and disease detection • Robotic harvesting • Multi robot systems	• How to address real time monitoring not discussed • Data collection is also not discussed • Various allied fields of smart farming like field monitoring, crop monitoring, irrigation not addressed
[14]	Internet of Things (IoT) and Agricultural Unmanned Aerial Vehicles (UAVs) in Smart Farming: A Comprehensive Review	2020	Smart farming	• Role of IoT and UAV in smart farming • Focused on areas like disease detection, irrigation, fertilization, weed detection, field level phenotyping	• Role of data collection not discussed • Issues and challenges of IoT in agriculture not discussed • Economic importance of IoT in nations is also not discussed
[15]	Review of operational management in intelligent agriculture based on the Internet of Things	2020	Precision agriculture	• Presented how collaborative research in the field of agriculture across various nations • Technologies related to context awareness and context reasoning were presented	• No IoT based frameworks exiting for agriculture were discussed • IoT operating systems and communication technologies were also not discussed
[16]	Evolution of Internet of Things (IoT) and its significant impact in the field of Precision Agriculture	2019	Precision farming	• Role of IoT in agriculture discussed • Challenges and various communication technologies related to IoT in agriculture addressed	• No existing frameworks of IoT for precision agriculture discussed • Role of sensors in agriculture not discussed
[17]	Precision Agriculture Techniques and Practices: From Considerations to Applications	2019	Precision agriculture	• Wireless senor networks in agriculture discussed • Case study related to WSN-PA presented • IoT based smart solution for plant health monitoring presented	• Challenges for deployment of IoT modules in agriculture not discussed • Role of various communication technologies and their bottle necks also not addressed • Role of agriculture in the economy of nations not discussed
[18]	Role of IoT Technology in Agriculture: A Systematic Literature Review	2020	Precision agriculture	• Discussed various sensors used in IoT agricultural systems • Communication protocols and network devices in IoT were discussed • A hypothetical framework for IoT in agriculture was	• No discussion on how to make systems more capable of real time data collection • Role of data in the agriculture domain • IoT OS not discussed

terminologies related to the Internet of things concepts and devise have been discussed.

III. INTRODUCTION TO THE INTERNET OF THINGS (IoT) CONCEPTS AND THEORIES

Inspired from the technology of the internet to connect the whole world, the Internet of Things constitutes of things possessing unique identities and are connected to the internet. A cosmos of sensors, actuators, appliances, and other devices connected with each over the internet, results in making the Internet of Things (IoT). The scope of IoT is not just limited to only connecting things but to allow them to communicate and exchange data. Based on the Electronic Devices and Network Annex-IEA-4E (EDNA), by 2020 the number of connected devices will rise to 50 billion, thus resulting in the generation of high revenue. IoT works in a layered manner depending upon the problem it is addressing. Therefore, it can be define that IoT possesses a layered architecture [20]. All these layers combined are called the IoT functional blocks. Apart from the functional blocks, various communication models that aid the smooth working of an IoT model are a request-response model, publish-subscribe, push-pull, and exclusive pair [20]. Fig. 4 represents the reference architecture of IoT in agriculture and includes the following layers: device/physical layer, network layer, middleware layer, service layer, analytics layer, and end-user layer. The layered architecture includes all the hardware devices, facilities, equipment, internet, communication technologies, protocols, and data analytic algorithms. How the layers work along with each other is described below:

TABLE 3. Nomenclature.

AGB	Above Ground Biomass
ARPT	Active Reader Passive Tag
ANN	Artificial Neural Network
CNN	Convolutional Neural Network
DSS	Decision Support System
FAO	Food and Agricultural Organization of the United Nations
FCA	Front forward Communication Area
GA	Genetic Algorithms
GDP	Gross Domestic Product
GHG	Green House Gas
GPIO	General Purpose Input/output
GSM	Global Mobile Services
IoT	Internet of Things
LIDR	Light Detection and Ranging
LTE	Long Term Evolution
MSO	Met Station One
NFC	Near Field Communication
PART	Passive Reader Active Tag
PA	Precision Agriculture
PB	Potential Biomass
PNN	Probabilistic Neural Network
RIFD	Radio Frequency Identification
RGB	Red Green Blue
SOA	Service-Oriented Architecture
SOS	Sound Surveillance System
SPI	Software Platform Infrastructure
SVM	Support Vector Machine
TPC	Transmission Power Control
UART	Universal Asynchronous Receiver Transmitter
UWB	Ultra-Wide Band
VI	Vegetative Index
IoT OS	Internet of Things Operating System
IDE	Integrated Development Environment
QoS	Quality of Service
QoE	Quality of Experience
MIoT	Multimedia Internet of Things
IIoT	Industrial Internet of Things
WMSN	Wireless Multimedia Sensor Networks

TABLE 4. Summary of the e-reserves for obtaining the related research articles.

S. No.	e-Resource	Bodies
1	www.ieeexplore.ieee.org	Conferences, Journals, Transactions,
2	www.springer.link.com	Magazines and Databases, Book Chapters,
3	www.sciencedirect.com	Books, Special Issues, Proceedings
4	www.scholargoogle.com	
5	www.onlinelibrary.wiley.com	
6	www.acm.org	
7	www.webofknowledge.com	

Perception Layer: Also called physical or the device layer, this layer lies at the bottom of the architecture and constitutes of sensors, actuators, microcontrollers, gateways, routers, switches, hubs, etc. The main role of this layer is, how efficiently the sensing devices and the other equipment's can work together to gather data. The microcontroller device acts as a controller as it performs all the networking

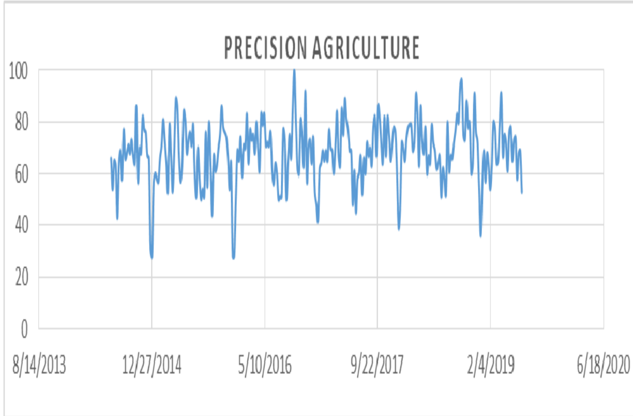

FIGURE 3. Precision Agriculture distribution worldwide of the past eight years [19].

ifunctionalities. The microcontroller also acts as a network regulating body as it regulates the networks, such that the sensors and other devices can collect data. The main aim of this layer is to capture data and transfer it to the other layer i.e., the higher abstraction layers. In terms of agriculture, the devices in the physical layer gather, soil, water, pH value, humidity, leaf wetness, and other data parameters. Also, the topology in which the devices are placed plays a major role in power consumption and efficient data collection in this layer.

Network Layer: It comprises of internet and other communication technologies. The main aim of this layer is, how to achieve better communication in the platform. In terms of agriculture, the design of this layer plays an important role in a framework due to the selection of suitable communication technologies relevant to field size or the test bed size. LTE, CDMA, GSM, Wi-Fi, ZigBee, LoRa, NFC, UWB Bluetooth, and RIFD are some of the communication technologies used for agriculture purposes.

ZigBee, LoRa, and NFC are the most used communication technologies employed depending upon the problem and the area to be addressed in the agro domain. NFC and Bluetooth are the most suitable for the greenhouses. Various protocols like HTTP, WWW, and SMTP serve for efficient communication in the agricultural scenarios.

Middleware Layer: This layer in IoT architecture is accountable for device management, context awareness, interoperability, portability, and security-related responsibilities. In terms of agriculture scenarios, HYDRA, SMEPP act as best middleware due to their context-aware functionalities.

Service Layer: Dealing with agricultural problems, cloud-assisted service layer in IoT layered architecture plays a prominent role in providing cloud storage and Software-as-a-Service (SaaS). To facilitate the function of sensing, actuation, and other activities, this layer focuses on some main areas or domains such as monitoring, detection, control, decision making, recognition, etc. The service layer offers services like device monitoring, control, discovery, and data publishing services.

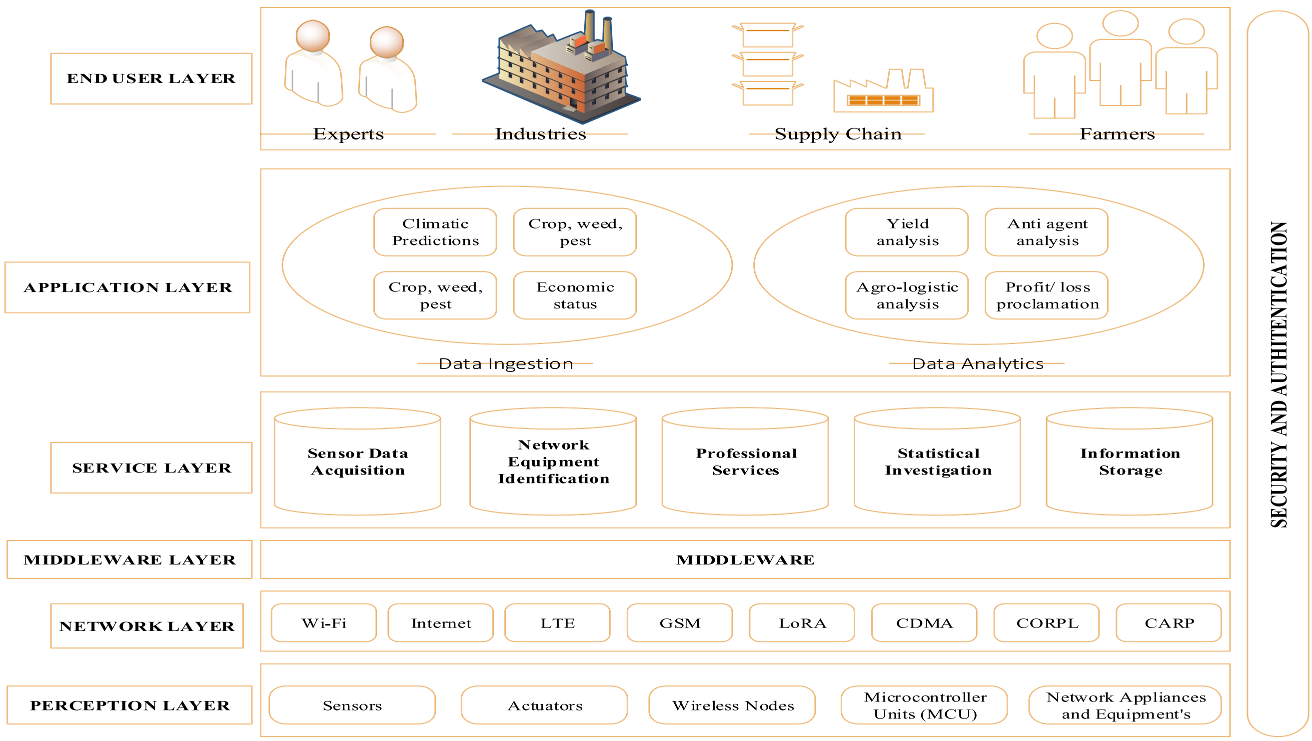

FIGURE 4. A layered ecosystem/architecture of Agro-IoT.

Analytics Layer: The layer is responsible for the processing and analysis of data. This layer works as a consortium of two steps- 1) Data ingestion, is the step that performs storage, cleansing, and streaming of data and the 2) Data analytics, which performs data reporting, mining, and learning. In the analytics layer various machine learning tools, data analytic algorithms are employed to give early predictive decisions for measuring the crop yield, crop growth, disease detection, etc. These decisions can enhance farm monitoring capacity. The predictive decisions can help in the design of better decision support systems.

End-User Layer: Being the topmost layer of the model, it serves the consumer or the user. To provide the interface to the users to control and monitor their model, this layer allows them to view the system status, analyze or process the data. In agro models, the farmer is the end-user. This layer provides a user-friendly experience and platform to the farmers. The services or applications in this layer are designed based on the behavioral study and pattern analysis of the user. Various intelligent approaches and data analytic studies are employed to understand the behavior of the users, as they come with different needs and offer a lot of diversity. Social media, Cloud computing, Mobile messaging are the platforms used to provide services to users, experts, and industries. Through this layer, the whole IoT based platform can be monitored, controlled, and run. The services generated from this layer are mostly the link between the user and the systems/platforms.

A. MULTIMEDIA INTERNET OF THINGS (MIoT) IN AGRICULTURE

Based on the working, nature of deployment, and the subject IoT concepts are used to address, traditional IoT is differentiated into various forms such as IoMT, MIoT, IIoT, etc. Without the inclusion of these concepts, IoT systems cannot successfully realize the concept of ubiquitous computing. In these paradigms, the interaction and cooperation between the heterogeneous devices is facilitated. Due to the increase in the number, diversity of devices and data with time, these concepts have become more functional and prominent to develop models and techniques for coming challenges and reflect the possibilities enabled in them. All these concepts have the same main character of availability, intelligence, and devices but they only differ in their due course of action i.e., their general usage. Being an allied branch or extension of IoT, MIoT, include smart objects that are usually resource-constrained, in terms of memory, energy, and processing power. Due to the progressive reduction in size and cost of production of these devices, MIoT models are expected to be developed and deployed on a large scale. Generally, the sensors of these models are usually designed to be battery operated or solar power operated. Due to the large data sensing and analysis, these devices require high computational power. Mostly, the multimedia data includes audio, video, and image data, which possess unstructured features and is difficult to transmit and analyze on a computationally scarce network and low bandwidth conditions. Multimedia data shows different behavior compared to the scalar data due to its computational complexity and network topology bottlenecks to the Quality of Service (QoS). A lot of work has been done in IoT and its allied fields to realize the concept of heterogeneous, low-level data transmission, and communication. In agricultural frameworks, the data is mostly in the visual form e.g., pest images, plant disease images, field images, etc. The characteristic difference in scalar and multimedia data is shown in Fig. 5.

DATA	
SCALAR	MULTIMEDIA
Linear Data	Bulky Data
Low Processing	Extensive Processing
Low Storage	Massive Storage
Low Bandwidth	High Bandwidth
Delay Tolerant	Delay Sensitive
Low Power Consumption	High Power Consumption

FIGURE 5. Key characteristic differences between IoT and MIoT data [25].

Depending upon the various parameters there are key differences between IoT and MIoT and they are discussed as:

- The IoT systems work mostly on non-heterogeneous devices while the MIoT functions well in case of heterogeneity.
- IoT data is mostly scalar, however, MIoT considers the multimedia data.
- Traditional IoT networks does not take into consideration the concept QoS while transmission and communication whereas in case of MIoT, QoS and QoE play a major role as the prime parameters.
- IoT can function well over low bandwidth channels whereas MIoT networks are in demand of high bandwidth due to bulky data.
- Node operation is predefined in IoT whereas in MIoT the node operation is adaptive in nature.

Various authors have worked on the implementation of concepts of MIoT for agriculture. Zhang *et al.* [21], worked on the concept of preserving the concept of data confidentiality while realizing the challenge of low-cost data acquisition. A measurement matrix under the control of chaos and random subsampling is employed to capture the ruptured image signals. Then these sampled sub-images are assembled to form a big master image and then encrypted based on android transform and single value diffusion. Correlation, histogram, keyspace, robustness, real-time, and entropy analysis are performed to understand and realize the concept of low-level transmission. Rani *et al.* [22], worked on the concept of bridging the gap between the scalar and multimedia data, and for this, they developed an IoMT cross-layer protocol. This protocol considered cross-communication between the physical, data link, and routing layers. The main objective of this work was to achieve energy-efficient communication with less computational time complexity. An optimal mathematical model was developed to study the cross-layer behavior in all the three layers, therefore selecting the efficient one. A comparative study was conducted on two parameters like delay and distance. Usman *et al.* [23], proposed a multilayer framework based on multilevel edge computing architecture to manage, and preserve the privacy of end devices from external attacks. Authors mainly focused on the three major challenges i.e., node management, privacy-preserving, and network protection. The proposed architecture is divided into three layers with the first layer comprising of underlying network partitioned into multiple clusters to manage end-devices and Level-One Edge Devices (LOEDs). In the second layer, the LOEDs apply an efficient aggregation technique to reduce the volumes of generated data and preserve the privacy of end-devices. Local differential privacy-based technique is applied to protect the privacy of sensitive information in aggregated data. In the last layer, the mobile sinks are registered with a level-two edge device via a handshaking mechanism to protect the underlying network from external threats. Floris and Atzori [24], addressed the issue of evaluation of Quality of Experience (QoE) for IoT applications where mostly multimedia data is involved. For designing a layered architecture, authors first tried to analyze the QoE parameters or factors with applications in the relevant scenarios. Then a layered multimedia IoT architecture was proposed for QoE analysis by combing each of the analytic and contributing factors. Zikria *et al.* [25], presented a brief overview of the MIoT along with its challenges, solutions and future opportunities. The authors discussed the data differences between the traditional IoT and MIoT, along with the role of communication technologies. The demand for realizing the dream of MIoT and its bottlenecks were also discussed. The challenge of data collection and its impact over the network traffic is also discussed along with the methodologies developed to solve it. Nauman *et al.* [26], presented a comprehensive survey on the multimedia internet of things. Authors discussed the existing role of MIoT in concern with various fields like medical, agriculture, automation, and industry, etc. The importance of QoE and QoS for multimedia transmission over IoT channels is also discussed. A better need for routing and Physical-Medium Access Control (PHY-MAC) protocols for M-IoT was also discussed. A potential discussion on open research issues related to multimedia communication in IoT was presented. Alsamhi *et al.* [27], presented a survey on the role of green IoT in greener and smart cities. The authors focused on how the environment pollution can be controlled along with other parameters for making living more sustainable and green with the aid of IoT concepts. AlSkaif *et al.* [28], presented a survey on the energy efficiency of MAC protocols in low data rate wireless multimedia sensors. The conflicting goals of WMSN were also discussed. Role and challenges of multimedia data were also discussed. A focused analysis was performed on network parameter constraints and what techniques are employed to solve them. A comparison of the energy consumption of MAC protocols in four selected application scenarios related to smart cities and environment monitoring was also presented. Libo *et al.* [29], worked on how with the use of multimedia data in the form of images can be employed to detect the plant diseases. Rape diseases were studied as a case study. Authors also discussed the challenges and bottlenecks faced for the transfer of multimedia data over low bandwidth channels. With machine intelligence, authors also proposed a diagnostic procedure via which the data can be transferred over wireless multimedia sensors networks. Psannis *et al.* [30], proposed a technique for the transfer of advanced media-based smart big data via intelligent systems. Authors in their work addressed the problem of the rapid rise of devices and heterogeneity. An encoding algorithm with HVEC standard for performance evaluation was proposed to transfer the data intelligently.

B. HARDWARE PLATFORMS FOR IoT

The hardware platform for IoT comprises a set of compatible hardware capable of running certain software. The main components of a hardware platform are machine language, sensors, wireless devices, programs, and processors, protocols, etc. The processor in a hardware platform determines how much fast a framework can work. To design certain new methodologies in IoT, various hardware platforms supported are elaborated as:

1) RASPBERRY PI

It is a series of single-board computers developed in the UK by Raspberry foundation. There are various families of raspberry i.e., Raspberry Pi 1, Raspberry Pi 2, Raspberry Pi 3, Raspberry Pi Zero, Raspberry Pi 4. All these families have different models. The Broadcom processor is used in most of the boards. It acts more like a computer system and can do multitasking [31].

2) ARDUINO UNO

Developed by Arduino.cc, it is a microcontroller board and is based on the ATMega32 processor. Arduino Uno possessing a USB port is a very valuable addition to the family of microcontrollers. Various versions of Arduino like Arduino Uno, Arduino Due, Arduino Leonardo, and Arduino Mega are present in the market. Out of these the most common versions are Arduino Uno and Arduino Mega [32].

3) NODE MCU

It is an open-source IoT platform. It generally refers to firmware rather than the development kits. It is a low-cost open-source kit/module developed for the ESP8266 Wi-Fi chip. It is developed in the Arduino IDE environment [33].

4) BEAGLEBONE

Developed by Texas Instruments, it is a low-cost open-source single-board computer. Its size measures 75 by 75 mm and possesses all the functionality of a basic computer. It requires 2W of power or a 5V separate power and can work smoothly without any cooling or sinks [34], [35].

5) BANANA PI

It is a low-cost credit-card-sized single-board computer developed by a Chinese company Shenzhen SINOVOIP Co. Ltd. The hardware design is hugely influenced by Raspberry Pi. It is compatible with Raspberry Pi boards as well. It can be developed both on Android and Linux [36].

The various hardware platforms of IoT with their functional specifications are given in TABLE 5.

C. IoT OPERATING SYSTEM (IoT OS) FOR AGRICULTURE

IoT operating system (IoT OS) is an operating system designed to perform within the constraints particular to Internet of Things devices. IoT OS are designed and developed in such a way that it can function under the restrictions of memory, size, power and processing capability. The main aim of IoT OS is to enable successful data transfer over the network via internet. The IoT OS for a particular framework is not chosen at random. Certain parameters such as footprint, scalability, portability, modularity, connectivity, and reliability are taken into consideration. As per the requirement of agriculture, a huge number of devices are connected having different features and also the devices have to withstand the different environments, the OS then to be chosen must be scalable, cost-efficient, and reliable. Various studies have been put forward for the role of IoT OS in network management and overall communication. Javed *et al.* [37], provided a detailed reviewed comparison of the operating systems designed for IoT devices based on their architecture, scheduling methods, networking technologies, programming models, power, and memory management methods, along with other features required for IoT OS applications. Musaddiq *et al.* [38], studied the role of small IoTOS in powering the scarce network devices. Authors also put light on the energy consumption of these devices. A detailed discussion on IoT devices and resource management is provided and some state of art IoT OSs such as Contiki, TinyOS, and FreeRTOS are also investigated. Baccelli *et al.* [39], a comprehensive review of RIOT is provided. The key components highlighted in this study are the kernel, hardware abstraction, software modularity for various configurations. The authors also discussed the operational aspects like system boot-up, timers, power management, and networking along with the relevant APIs. Zikria *et al.* [40], proposed a study for the management, challenges, and opportunities of IoT OS in managing IoT systems. The authors discussed the issue of interoperability, protocol functionalities to support heterogeneous deployment scenarios. Supported hardware and future research trends are also discussed. Ain *et al.* [41], proposed an efficient and

TABLE 5. Hardware platforms of IoT and their specifications.

Platform	Processor	Operating voltage	Clock speed (MHz)	Bus width	System memory	Communication supported	Developing environments	P.L	I/O
Raspberry Pi	Broadcom BCM2835 SoC-based ARM11 76JZF	5V	700	32	512 MB	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	NOOBS	Python, C, C++, Java, Ruby, Scratch	SPI, DSI, UART, SDIO, CSI, GPIO
Arduino Uno	ATMega32 8P	5V	16	8	2 KB	IEEE 802.11, b/g/n, IEEE 202.15.4, 433RF, BLE 4.0, Ethernet, Serial	Arduino IDE	Wiring	SPI, 12C, UART, GPIO
Arduino Yun	ATMega32 µ4 and Atheros AR9331	5V, 3V	16,400	8	2.5 KB, 64 MB	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	Arduino IDE	Wiring	SPI, 12C, UART, GPIO
ESP8₂66	L106 RISC	3.3V, 3.6V	80	-	32 KB	IEEE 802.11 b/g/n Wi-Fi	ESP8266 BASIC, ESP-Open-RTOS, MicroPython , PlatformIO	Lua and AT command s	SPI, UART, GPIO
Intel Edison	Intel® QuarkTMS oC X1000	3.3V	100	32	1 GB	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	Arduino IDE, Eclipse, Intel XDK	Wiring, C, C++, Node.JS, HTML5	SPI, 12C, UART, GPIO
Intel Galileo	Intel® QuarkTMS oC X1000	5V	400	32	256 MB	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	Arduino IDE	Wiring, Wyliodrin	SPI, 12C, UART, GPIO
Beagle Bone Black	Sitara AM3358B ZCZ100	3.3V	1 GHz	32	512 MB	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	Debian, Android, Ubuntu, Cloud9 IDE	C, C++, Python, Perl, Ruby, Java	SPI, 12C, UART, GPIO, McASP
Banana Pi	A20 ARM Cortex -A7 Dual-Core	5V	1.2 GHz	-	512 MB	IEEE 802.11 b/g/n	Debian, Android, Linux	OpenWrt, FreeBSD	GPIO, UART, I2C BUS, SPI BUS
NodeMCU	ESP8266, LX106	5V	80 MHz	4	128 KB	IEEE 802.11 b/g/n	Arduino IDE	Wiring	GPIO
Electric Imp 003	ARM Cortex M4F	3.3V	320	32	120 KB	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	Electric Imp IDE	Squirrel	SPI, 12C, UART, GPIO
ARMmbed NXP LPC1768	ARM Cortex M3	5V	96	32	32 KB	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	C/ C++ SDK, Online Compiler	C, C++	SPI, 12C, CAN, GPIO

TABLE 6. IoT os platforms in agriculture and their specifications.

OS Platform	Inventor/license	Launch year	Protocols	Features	Ref.
Contiki	Adam Dunkels	2002	IPv4 and IPv6	• Devices are power and memory constrained • Built in internet of protocol suite helps perform multitasking • Bandwidth used is	[43]
Android Things	Google	2015	Weave	• Open source platform • Regulates every six weeks • Run on low power and supports Bluetooth and WiFi technology	[44]
RIOT	GNU Lesser General Public License (LGPL)	-	COAP, RPL, IPv6, UDP	• Open source • Hardware independent • Energy efficient • Works on 8, 16 and 32 bit processors	[45]
TinyOS	TinyOS Alliance released under BSD license	2000	Bluetooth	• Scalable • Can handle large number of devices • Designed for low power wireless devices	[46]
Apache Mynewt	Apache Software Foundation (Apache license 2.0)	2019	HTTP, Bluetooth	• Maintains up to 32 connections simultaneously • Console, shell and boot loader support • Supports priority based scheduling, pre-emptive scheduling and memory heap and pool allocation	[47]
Zephyr	Linux Foundation, Wind River Systems	2016	IPv4, IPv6, MQTT, Bluetooth, OMA LWM2M	• Small kernel • Flexible configuration and built in system for compile time definition of required resources and responses	[48]
Raspbian	Raspberry Pi foundation	2012	-	• Highly flexible for raspberry Pi line CPUs • Offers a number of preinstalled IoT software for general and experimental use. • Kernel similar to UNIX kernel • Open source	[49]
Google Fuchsia	Google	2016	HTTP, MQTT, Bluetooth	• Open source capability OS • Microkernel called Zircon based • Software development kit Flutter is used for user interface and apps	[50]
Windows IoT	Microsoft	1999	MQTT, HTTPS, AMQP	• Hybrid kernel • Closed source • It runs on ARM processor	[51]
TizenRT	Tizen developers	2013	IPv4, IPv6, Bluetooth	• Infrastructure called Tizen common offers sustainability • Monolithic kernel • Mostly suitable for mobile applications	[52]
Snappy	GPLv3	-	TCP/IP protocol stack	• Ubuntu core IoT OS • Security of IoT devices with Ubuntu community research • Key based authentication ensures exact application run	[53]

flexible decision-making system for maintaining user thermal comfort with the help of intelligent sensors. Fuzzy based approach along with RIOT OS was developed to tackle the problem of fluctuation and adjustment. Results show that the proposed approach can perform 28% better than the existing approaches in terms of energy efficiency. Stergiou *et al.* [42], studied the transfer of metadata in the IoT networks. Authors discussed the techniques and open tools such as CC analyzers and simulators which can provide intelligent metadata transfer over a network. The experimentation was performed on CloudSim and Cooja emulator of Contiki OS for the testing of a single network segment. From the experimentation, it was found that no duplicate packet transfer occurred which is a good sign for multimedia data transmission.

The various IoT OS with their functional specifications are presented in TABLE 6.

D. SENSORS AND THEIR ROLE IN AGRICULTURE

Sensors are the devices, modules, machines or subsystems capable of detecting the changes or events in the environment. They also send signals back to the receiver end. Mostly the sensors are used with other electronics. A sensors sensitivity usually indicates how much change in sensor output occurs with respect to the change in the input quantity measurements. Most sensors possess the linear transfer function. The sensitivity of a sensor is defined as the ratio between the output signal and the measured property. The resolution of a sensor is the smallest change it can detect in the quantity it is measuring. In the area of agriculture, demand of technological solutions with high aim in rising production and quality is increasing day by day. Also the solutions are required which provide optimal analysis and sustainable methods for the field development with reduced cost and time. To sustain such challenges, sensor- based technologies have proven to be of much help to tackle the above issues and challenges. Precision agriculture is an emerging area where sensor based technologies are playing a major role.

Since the sensors are a major data collection agents, they play a dynamic role in agriculture. Also, it is very difficult to collect the data from an agricultural field due to the undulating field conditions that keep on changing over time. Sensors are selected or designed according the problem to be addressed or needs identified by the farmers. Agriculturalists generally use sensors to sense the soil conditions, humidity, crop conditions, minerals, pH value, water levels, and sunlight, etc. The nature and the characteristics of the component which needs to be sensed also plays a major role in the development of a sensing device. With the development of technology, machinery and easy-to-use microcontroller platforms, the usage of sensors has expanded beyond the traditional fields of measurement i.e., temperature, pressure and flow. However, the analog sensors such as potentiometers and force sensing resistors are still widely in use. Pajares *et al.* [54], discussed the sensors in agriculture and forestry. In the article, various related works of the sensors performed by different authors in the same domain were presented. The role and importance of the component or substance which needs to be sensed was discussed along with their characteristics and specifications. The major areas focused by authors were soil analysis, seed growth, weed detection, forest stands and reflectance, machinery for effective treatments, microorganisms, pest control, seedling breeding, growing, state of health, positioning, navigation, safety, detection and classification.

Zhu *et al.* [55], showed that LIDAR, IMU, and Encoder (x2) can be used for designing a prototype vehicle for the agricultural domain. The authors also discussed how these sensors can be used for the development and usage of that prototype in case of undulating surfaces and rough terrains. A complete review of the wireless sensors and the network applications used in agriculture is provided. The authors also addressed the importance of sensors in the field of agriculture. Along with the sensors, the communication technologies that support sensor communications are also mentioned by Rehman *et al.* [56]. The sensors used in the medical and agricultural fields have also been discussed. In the case of the agricultural field, the various conditions and circumstances affecting the data collection from sensors are addressed. The various types of sensors and their platforms used by different authors in their work are also included by Chokkareddy *et al.* [57]. Plageras *et al.* [58], used efficient IoT based sensor and big data analytics for secure collection of data and communication over a channel. In the study, smart housing or building was taken as case study, and the secure data collection with the sensors was performed and analyzed. The behavior of various sensors for data collection in different scenarios in terms of IoT and cloud computing was studied by Stergiou *et al.* [59]. The secure communication among devices was also studied along with performance bottlenecks and challenges.

The various sensors and their use in agriculture is discussed below:

1) LEVEL SENSORS

They measure the substance of liquid in a cast. The cast can be any agricultural field, pond, water tank, etc. They measure data in two methodologies 1) Point level measurements: indicate only whether the constituent or level measured is above or below the sensing point or threshold. 2) Continuous measurements: specific range measurements and exact substance amount determination are performed by these sensors. In agricultural fields, the water level sensors, humidity sensors, and moisture sensors are used to measure the water content levels in a field. The point level sensors are used when the water content in the cast i.e., soil or testbed is very less i.e. in dry and arid areas, whereas the continuous level sensors are feasible for semi-arid locations. Some of the ultrasonic level sensors are also used in water treatment plants. Blank *et al.* [60], designed a low-level senor based fusion application for agricultural machinery design.

2) TEMPERATURE SENSOR

Temperature sensors measure the temperature of the environment or surroundings. They are of different types i.e. thermistors, thermocouples, resistance temperature detectors, infrared sensors, semiconductor sensors. In agriculture they measure the temperature variants in a field. Mahan *et al.* [61] designed an optimal temperature based field monitoring system by using a low-cost infrared sensor.

3) PROXIMITY SENSORS

Detect the presence of nearby objects without any physical intervention. The sensor works by emitting an electromagnetic beam in the field and looks for any alterations in the signal. These are mainly employed in agricultural cattle grazing, counting of fruits, etc. Kim *et al.* [62] used a capacitive proximity sensor to optimize the harvest yield of fields.

4) INFRARED SENSORS

Senses the changes in the environment by emitting infrared rays. They work in two approaches i.e., active and passive. An active IR sensor can both emit and detect the radiations and constitute a light-emitting diode and a receiver. The passive IR sensors can only detect the radiation and possess only a LED. In agriculture field infrared sensors can be employed to detect the presence of rodents in the orchards, count the number of plants or trees in the field, capturing satellite images of the field. Allred *et al.* [63], used IR sensor-based satellite imagery to map the findings and results of UAV to chart agricultural drainage systems.

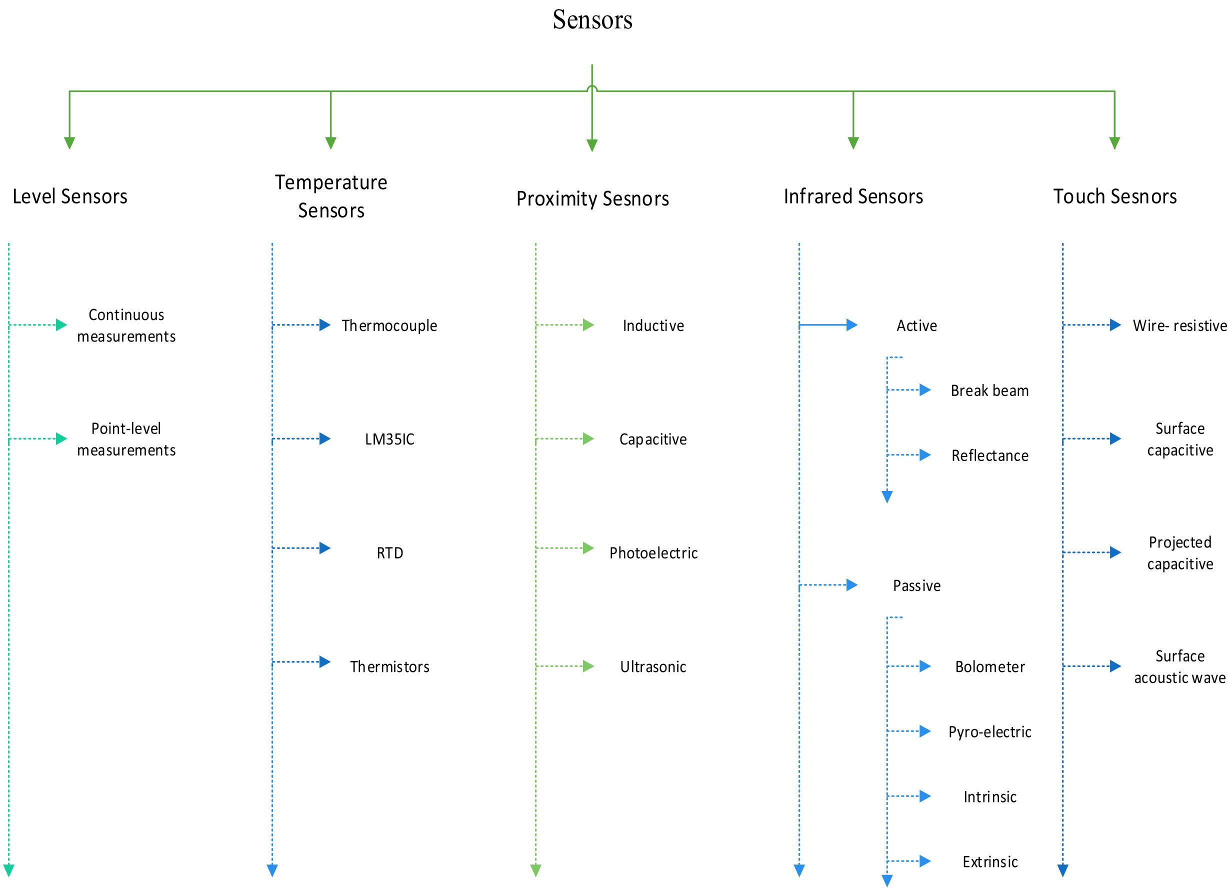

FIGURE 6. **Sensors and their types.**

5) TOUCH SENSORS

Also known as tactile sensors, work on sensing the touch. They are low-cost sensors. In the agriculture field they can be used for the detection of intrusions in the field.

Depending on the target and the range, there are different types of sensors, the same are discussed in Fig. 6 and TABLE 7 below:

IV. RELATED WORK

The advancement and role of the Internet of Things in precision agriculture along with the related areas where research is being conducted are discussed in this section. Literature including various approaches, techniques, and methodologies presented by the number of authors has been divided into different sections. Various studies are performed and put forward by various academicians and authors concerning the evolution of agriculture relating to the incubation of the concepts of the Internet of Things.

Kim *et al.* [64], reviewed different articles related to the induction of unmanned aerial vehicles in agriculture. The authors highlighted the recent trends, controls, perspectives, and platforms of UAV for agriculture. The study focused on what are the different platforms used for UAV and how those platforms can be designed. The hardware components related to the design of UAVs were also discussed. Sensor types compatible with platforms such as fixed-wing, helicopter, quadcopter, etc. were also discussed. A study on critical technologies for communication, modeling, and control was also presented. Various applications of UAVs in crop monitoring, spraying, and mapping, etc. were also presented. The authors concluded their study by providing the data on the latest technology trends and applications of UAVs in agriculture. Ayaz *et al.* [65], studied the latest trends and technologies in the field of agriculture. The potential sensors, IoT devices, communication techniques, used for soil, crop irrigation, insect, pest analysis were studied and discussed. Also, how this technology is redefining the agriculture system and boosting farmers to work, is portrayed. Authors studied the recent developments of IoT and how it is helping in providing the solutions while designing an IoT system for agriculture, what strategies and policies need to be considered. The advanced agricultural practices such as greenhouses, vertical farming, hydroponic farming, and phenotyping are also explained. All the crop stages and potential challenges are also discussed.

Farooq *et al.* [66], presented many aspects of IoT in agriculture. Authors discussed all the recent technologies associated with IoT along with big data analytics for the

TABLE 7. Sensors based on their fields of application.

Soil Related	Source	Environment Related	Source	Plant Related	Source
Pogo portable soil sensor	http://www.stevenswater.com	WXT520 compact weather station	http://www.stevenswater.com	Leaf wetness sensor	http://www.decagon.com
Hydra probe II soil sensor	http://www.stevenswater.com	CM-100 compact weather station	http://www.stevenswater.com	237-L, leaf wetness sensor	http://www.campbellsci.com
ECH2O EC-5	http://www.decagon.com	Met Station One (MSO) weather station	http://www.stevenswater.com	LW100, leaf wetness sensor	http://www.globalw.com
VH-400	http://www.vegetronix.com	All-In-One (AIO) Weather Sensor	http://www.climatronics.com	SenseH2TM hydrogen sensor	http://www.ntmsensors.com
EC-250	http://www.stevenswater.com	XFAM-115KPASR	http://www.pewatron.com	TPS-2 portable photosynthesis	http://www.ppsystems.com
THERM200	http://www.vegetronix.com	RM Young (model 5103)	http://www.stevenswater.com	CI-340 hand-held photosynthesis	http://www.solfranc.com
Tipping bucket rain gage	http://www.stevenswater.com	Met One Series 380 rain gauge	http://www.stevenswater.com	PTM-48A photosynthesis monitor	http://phyto-sensor.com
AquaTrak 5000	http://www.stevenswater.com	RG13/RG13H	http://www.vaisala.com		
WET-2	http://www.dynamax.com	LI-200 Pyranometer	http://www.stevenswater.com		

development of precision agriculture systems. Various network topologies, architectures, layers, and protocols are also presented. In context to the development of a smart farm, all the major components and relevant technologies were discussed. Also, the regulations, standardizations, and policies used by several countries to standardize IoT methods for agriculture have been discussed. Elijah *et al.* [67], gave an overview of IoT and data analytics technologies and practices in agriculture. The authors divided their study into four sections i.e., communication technology, internet, data storage, technology. The authors also provided an analysis and data on how the aforementioned sections can be employed for dealing with the diminishing agricultural resources. The pros and cons of various technologies such as cloud computing, WSN, radio frequency identification, middleware systems, etc. to their application in the agriculture field are also discussed. Studies on how these technologies can be used to develop an IoT ecosystem, with technical and business scenarios were also presented. Misra *et al.* [68], discussed the concepts and role of IoT, AI and big data in the field of agriculture. In the review, focus was laid on green- house monitoring, disease detection, usage UAV machines and drones agriculture and supply chain modernization, social media in food industry, food quality assessment and modernization for food traceability. Thakur *et al.* [69], reviewed articles of repute in the context of the employability of WSN in agriculture. The authors highlighted the different communication technologies and WSN technologies adopted for precision agriculture. The authors also discussed various sensors and their role in agriculture. The influence of various techniques for designing the models is also discussed at length. Damos [70], presented a review on the pest control in precision agriculture. The author discussed the various computer-aided technologies employed for forecasting and designing decision support systems. The challenges and constraints of designing the decision support system were highlighted. The most available and published data present online in terms of pest management was also discussed. A differentiation between the documented and existing decision support systems was highlighted. The advancement and role of the internet of things in precision agriculture along with the related areas where research is being conducted are discussed in this section.

Literature including various approaches, techniques, and methodologies presented by the number of authors has been divided into different sections and are discussed as follows:

A. IoT IN FARM MANAGEMENT

Farm management refers to the construction and implementation of decisions for obtaining the maximum production and profit via organizational operation of decisions. This area is most benefitted by automation and the implementation of new technological methods. With farm management agricultural practices are made informative by evaluation and comparison with the other developed approaches and methods. Diedrichs *et al.* [71], with the aid of machine learning and IoT sensing devices, predicted the occurrence of frost events. Authors designed their system based on three layers i.e., a group of internet-enabled devices for water data collection. The authors augmented the data using the synthetic minority oversampling technique due to its capability of reducing the occurrence of errors with the ML approaches. The humidity and temperature sensors were employed to collect data from five meteorological stations of the Mendoza Province of Argentina. For each station, the existing sensor data spanning from a period 2001 to 2016 was taken as a reference to collect the daily data. The data was divided into two sets i.e., locally available is the config-local and the one available globally is the config-all. Bayesian Networks were employed along with SMOTE and recursive portioning, to train the system. Jawad *et al.* [72], designed a wireless power transfer technology based on a drone charging system for smart agriculture. The authors used the concepts of magnetic resonator coupling and sleep/active modes of charge transfer system for designing the model. Authors mainly focused on how to charge wirelessly the drones and other equipment employed in agricultural field monitoring. The magnetic resonant coupling technique was considered due to its capability of high power transfer and efficiency. In the experimentation, authors found that the FSC coil with 150 coil turns in the transmitter circuit and the MTC comprising of 60 coil turns in the receiver (i.e. drone) accomplish the maximum transfer power and efficiency. For finding the accurate efficiency, the model was tested based on different load, and how to load misalignment changes the model behavior was also noted. Drone flight time was also taken into consideration and was estimated based on the adopted battery capacity and payload of the drone.

Tseng *et al.* [73], proposed an intelligent IoT based platform for farm management. The authors took the data based on different plants i.e., beans, spinach, celery via sensors, and used 3D normalization on that data to extract the optimal/useful data. The average and variance were moved to obtain user data without making any visible changes in the actual data. Farmer's behavior was analyzed for the application of pesticides and fertilizers. For the platform development SIM5320E, IoT Development Board is used along with the BH1750 illumination sensor and BME280 temperature and moisture sensor. Bacco *et al.* [74], designed a model based on air-ground UAV communications for smart farming. Authors empirically and analytically developed a real test-bed implementation of IEEE 802.15.4 based communication between unmanned aerial vehicle and ground sensors. The focus was laid on how to transfer data between sensors and other devices present on the ground in an optimized manner to ensure fewer transmission losses. From the experimentation, and result analysis authors found the Gilbert-Elliot model to be suitable to approximate the packet loss in the link at low transmission speeds. The authors used approximately 80,000 datasets from the testbed. Ahmed *et al.* [75], based on the concepts of fog computing and Wi-Fi-based long-distance networks proposed a system for smart monitoring. In comparison to the existing traditional models, a scalable and flexible model was designed for monitoring and controlling agro farms in rural areas. Authors introduced a WiLD network and fog computing in the existing WSN-based solutions to cover long ranges with fewer delays. A cross-layer based MAC and routing solution for sensing and actuating were proposed to reduce the network latency. Throughput, coverage range, and network latency of the network structure were analyzed.

Liu *et al.* [76], by hybridizing the concepts of IoT, cloud computing, and data mining proposed an integrated framework for the agricultural field. China was considered as the territory to design and devise mechanisms to enhance modern agriculture as compared to the conventional one. Quality, safety, management, and pollution are were taken into consideration while designing the model. NoSql database, DynamoDB, relational database Oracle, and file object storage Amazon S3, were employed to provide the hybrid data storage design. Bai *et al.* [77], due to the issue of frequently changing environmental conditions addressed the issue of estimation and control in the greenhouse. The authors studied how to collaboratively deploy WSNs and actuator schemes for agriculture. Sensor nodes were used to conduct a local estimation with Kalman filters to enhance the stability and transmission of data ensuring energy optimization. Using the concepts of collective clustering and mutual effect, the actuator node based scheme is designed for the improvement of estimation speed and conversion accuracy. Parameter optimization is achieved through fuzzy neural networks along with the PID control algorithm.

Jinbo *et al.* [78], performed research on developing a platform for the monitoring of a field with agricultural modernization. A system named DEMO was proposed by using the SpringMVC framework, MyBatis, Spring Data DynamoDB Stored Procedure, Paho, and other related technologies grounded on the J2EE platform. Open-source elements such as raspberry, IoT gateway integrated with the ZigBee module were used for the development of the platform and were chosen due to their stable and cost-efficient properties. The proposed system is capable of massive data processing and analysis for agricultural monitoring. RESTful interface service system developed on a cloud platform, ExtJs client technology, and WeChat were applied to develop the Demo system of an application layer. Mukherjee *et al.* [79], worked on the challenges of a decentralized and heterogeneous UAV swarm deployment. The work is focused on how to design and deploy a UAV in resource-constrained, harsh, and challenging environments. Swarm edge due to its heterogeneous nature and unequal data generation within its member's results in under-utilization of the available computational resources. To solve this issue, the authors proposed a Nash bargaining-based weighted intra edge processing offload scheme which can reduce the problem of heavy processing in some swarm members. The proposed method achieves better scalability and reduced processing delays. Chen *et al.* [80], developed an IoT based inexpensive platform named 'AgriTalk' for precision soil farming. Turmeric plant was considered for cultivation and experiments were conducted to enhance its growth and production. Authors employed AgriTalk in developing several other IoT based models for the fields of Mountain Bao in Taiwan. For the study authors grew turmeric in three fields. The proposed model is capable of addressing dynamic changes in the field conditions for plants grown via in-soil cultivation. Automated devices like sensors, actuators with desired farming intelligence were employed to design the model. Manual delays for automatic control and switching over long distances were also addressed. From experim-entation it was found that the curcumin concentration in turmeric leaves after six months was elevated to 6685.6 μM as compared to 72.1 μM thus witnessing a fivefold increase. Lopez *et al.* [81], proposed a smart system for estimation of soil parameters using an autonomous wireless sensor network. Phosphorus content in the soil was measured. For power optimization and maintaining a balance between change rate phenomena of soil throughout the day for phosphorous estimation, authors developed a dynamic power management approach. DPM was tested on both the circuit level and the system level. ANN was used to find the significant correlations between the soil parameters such as electrical conductivity, phosphorous, temperature, and humidity. Also, energy harvesting with the help of IoT and cloud services is proposed.

Chen and Yang [82], provided a detailed analysis of how efficiently the systems can be developed for agriculture based on the techniques of data visualization, clustering, etc. The authors studied the significance of various parameters in the same environment and effects. For the promotion of efficient development of agriculture, the authors proved that data visualization and cluster analysis pave a way for finding the key technologies to be applied in modern agriculture. For time and cost optimization, functions such as sensing, monitoring, identification, transmission, and feedback can be realized using IOT platforms and they can serve as an impetus for intelligent agriculture. To test and develop their methodology, authors took the agriculture situation in the Jhinsa river basin which lies in the upper reaches of the Yangtze River as a testbed. This area has become the most abundant area of biological communities in Eurasia. For the study, the authors collected precipitation and temperature data. Since data was large, k-means clustering is used to analyze the data. Leng *et al.* [83], presented a study for the application of IoT in agricultural products supply chain management. Authors discussed in length what to take into consideration, while designing a structural model for the supply chain management. RIFD technology was considered as the key constituent for designing the model.

Pereira *et al.* [84], based on the concepts of IoT developed an instrument capable of performing environment monitoring in a poultry farm. The authors focused on designing a cost efficient prototype for the poultry monitoring which provides affordable benefits compared to the commercial products available in the market. DHT22 sensors were used to collect air pressure and temperature details and CPU such as Wemos Mini D1with chipset ESP-8266EXwith standard Wi-Fi 2.4 Ghz connectivity were used to calibrate the whole model. Singh *et al.* [85], developed a cloud based autonomic system for delivering agriculture as a service via web and mobile based applications. For data collection IoT and other devices were used for communication and coordination. Fuzzy logic was used to automatically analyze agriculture. An architecture named Agri-info was developed to provide user services. Kolipaka [86], proposed a predictive analysis using cross media references for precision farming. Authors focused on the usage of sensors and MEMS integrated IoT for precision farming. The crop growth parameters such as soil state, water, weed state, crop quality and seed quality were also discussed. ML and big data approaches were applied to perform predictive analysis and thus finding method to provide optimal solutions to farmers. Further based upon the certain characteristics we have tabularized the major findings in TABLE 8.

B. IoT IN IRRIGATION

Irrigation is the method of application of controlled water to the farming fields, at needed intervals. Irrigation has been a constant area where a lot of energy, money, and labor is invested in the case of farming. Detection and knowledge of water level can reduce the cost of production by half. For increasing crop yield, smart irrigation management is essential. Various optimized and precise methods have been developed by various academicians. Klein *et al.* [96], with the help of satellite images, worked on the implementation of closed-loop irrigation. The authors designed a real-time water requirement system, which can optimize water delivery for 140 cells located in four hectares of land. Vegetative indexes were calculated for analyzing the total water consumption and how via loops this facility can be automated. Through this study and experimentation it was found that with the integration of closed-loop strategy and advanced water analysis, the overall water consumption efficiency can be improved. Alahi *et al.* [97], extended research to design and develop a smart nitrate monitoring system for the monitoring nitrate content in the surface and groundwater. The authors proposed a portable sensing system with the help of a planar inter-digital sensor, associated electronics, instrumentation, and electrochemical impedance spectroscopy-based analysis. Through real-time monitoring and sending data directly to the IoT web server, the proposed system possesses the capacity to monitor the impact of industrial, urban, and agricultural activity on water content and quality. The system also ensures distributed monitoring. Daskalakis *et al.* [98], used leaf sensing technology instead of ground soil monitoring for knowing the plant water stress. The authors proposed a low cost and low power consumption leaf moisture sensing model by sensing the leaves with the new plant backscatter sensor node/tag. The developed tag collects the information from a leaf via analog and digital conversions and then the data is transferred via remote communication to a low-cost software-defined radio reader using monostatic backscatter architecture. The data collected from this node is then connected to the irrigation system. The proposed system is powered by a flexible solar panel.

TABLE 8. Summary of developed methods for farm management.

Authors	Purpose	Tools / Technique/ Communication Technology	Location	Future scope
Pankaj Mohan Gupta et al. [87]	System for improved agricultural practices using IoT is designed	Autonomous sensors, web interface, automation interface, GPRS interface, LoRaWAN, microcontroller, memory Cloud, ZigBee	India	The fusion of IoT for the development of multi-domain self-sufficient agricultural practices system
Foughali Karim et al. [88]	An application prototype for precision farming is proposed	WSN, IoT, cloud, local server, store, gateway, GPRS 802.15.4 protocol	Tunisia	Improvement in the current designed application for performing sophisticated tasks
Qiulan Wu et al. [89]	Developed a model to estimate the acquisition of organic carbon compounds in farmland for farm management	I/O, Solar cell panel, battery, IoT, sensors, GPRS Module, JTAG interface, ZigBee. Z-stack protocol stack, TCP/IP protocol stack	China	Eradication of the technical bottleneck sensors. Optimization of the overall cost.
F. De Rango et al.[90]	Designed a lightweight bio-inspired coordination protocol for model communication in farming	UAV, drones, pesticide, path energy, TTL, data length. Link state routing protocol with recruiting strategy	-	To design a joint approach for the performance enhancement of the bio-inspired algorithms
Manishkumar Dholu and Mrs. K. A. Ghodinde [91]	Developed an IoT based precision model for agricultural applications	IoT, MCU, Wi-Fi module, router, temperature, and humidity sensor Cloud, MCU, and Wi-Fi	India	Improvement in the usage of the mobile app by adding alarms for controlling of a particular parameter
Nik Hisham Nik Ibrahim et al. [92]	An advanced climate monitoring system for the agricultural farm is designed	Controller, memory, wireless transceiver, sensor, interface circuit, power module, LoRa node, AP/ router LoRa, M2M	Malaysia	Development of scalable design which can withstand harsh climate conditions-resistant greenhouse for mushrooms
N. Pavon Pulido et al. [93]	A novel cloud-based system for enabling automated precision agricultural tasks is designed	WSN, GPRS, UAV, MEWiN platform, microcontroller, solar panel charger, WiFi Rosbridge package	Murcia Spain	Design a flexible architecture capable of adapting different climate scenarios
Terteil A. A. Ali et al. [94]	Based on green IoT, a precision agriculture monitoring system is designed	Autonomous sensors, LoRa transceiver module, PC, smartphone, buzzer, BeagleBone Black, ZigBee IEEE and GSM protocols	India	To develop a flexible real-time precision agriculture system
Rama Krushna Das et al. [95]	Development and design of a smart agriculture system	Motor driver, wireless autonomous sensors, pest sensors, motor, sprinkler, raspberry pi 3, power supply, alarm TCP/IP Stack	India	Development of models that are more efficient and cost-optimized

Jayalakshmi and Gomathi [99], proposed a sensor-cloud based precision agriculture for intelligent water management, to enhance crop production. For the model design, moisture and stress levels of different plant organs were considered along with the behavior vegetative and reproductive organs cell growth, and its effects on the water requirement were studied. The dimensionality reduction technique was employed to choose the optimal parameters. For the case study, the wheat plant was taken. The effect of soil temperature and water suction rate was studied in the case of the plant growth. The non-adsorbing testbed was prepared by exploding the sand grains at high temperatures. With the aid of WSN, it was monitored when the plant needs to be irrigated. Angelopoulos *et al.* [100], developed a small scale smart irrigation prototype for a strawberry greenhouse. The prototype possesses off the shelf hardware and software requirements and was tested on large farms having multiple crops to get a data gain. The reference architecture also targets edge data distribution. The model was tested in Greece and its performance was compared against the traditional existing strawberry greenhouse methods for irrigation. Compared to the cloud-based approaches, and their incompetence to handle network traffic, security challenges, and data sharing with the third party, this model is secure and reliable and can handle large datasets. Dominguez-Nino *et al.* [101], worked on how to integrate sensors for developing automated software tools to undertake the routine tasks and decision-making involved in scheduling irrigation. The authors also focused on the suitability of capacitance approach soil moisture sensors and how to automatically interpret them and providing feedback to the scheduling algorithm. The proposed approach was tested in the apple orchards located at the IRTA-Lleida Experimental Station in Mollerussa, Lleida, Spain. For the study, both the physiological and agronomic properties were taken into consideration while experimentation. Krishnan *et al.* [102], designed an automated irrigation method. The authors developed a fuzzy logic-based system for precision irrigation by using Global System for Mobile Communication (GSM) service to enable farmers to water the fields. Soil and temperature, humidity, and motor status parameters were monitored and taken for the study. For the efficiency evaluation of the system, a comparison was done between the proposed system, drip irrigation, and manual flooding. Harun *et al.* [103], designed an environment-friendly system named "Greenhouse Irrigation Management System" for precision irrigation in agriculture. Some critical environmental parameters such as soil moisture, pH, temperature, humidity are measured with the use of WSNs to make decisions. The sensors measure the data and based on certain threshold value result, the fields are irrigated.

Olivo [104], focused on the problems associated with device growth and its effects on the control decisions. To address this issue, an architecture named "Rules Engine and Context Event Processor (RECEP)" is proposed for the dynamic processing of events originated in the context of IoT and PA. In this model the concept if optimization was used to optimize the resources to increase agricultural production. The experimental setup was set in a banana field located in Machala-Ecuador. The given model was designed for operating in low-cost infrastructures for both small and large producers. Marcelino *et al.* [105], based on the work and issues of small family farmers, proposed a low-cost system for control, monitoring, and automation of agricultural greenhouse. The proposed model was designed by prototyping Raspberry Pi and Arduino along with sensors. Temperature, humidity, and light sensors are used for the field data collection. The web human interface was developed for interaction between the system and the farmers. Koksal and Tekinerdogan [106], developed an automatic farm management information system capable of performing data acquisition, processing, monitoring, planning, and decision making and managing the farm fields. The authors tested their models on two case studies on smart farming in Turkey, one for smart wheat in Konya and other greenhouses in Antalya. The feature-driven domain analysis model is designed based on IoT reference architectures and data modeling approaches. The system was capable of performing all farming related functions, such as irrigation, crop monitoring, etc. Hate *et al.* [107], designed a vegetable traceability system with smart irrigation. The field parameters like soil moisture, humidity, water supply control, and temperature of particular farmland are monitored with sensors such as water level, humidity, soil moisture, and temperature sensors. With IoT, the cost is reduced and efficiency is improved. Agale and Gaikwad [108], focused on the problem of water reduction in farmlands. An IoT based automatic system is designed to collect, analyze, and monitor the real-time sensor data every 10 seconds from soil and environment and provide irrigation solutions based on that. The parameters like temperature, humidity, soil moisture were considered for data collection. The proposed method achieved 92.24 % accuracy in water-saving strategy.

Huan *et al.* [109], designed a system for monitoring of water in aquaculture ponds. To design the system authors used the concept of narrowband IoT (NB-IoT). The system used STM32L151C8 microcontroller, sensors and other devices for real time data collection and other services. The system was implemented and tested in ChangZhou, JiangSu Province, China and performed with low error rate. Vij *et al.* [110], developed a smart precision irrigation system based on the concepts of IoT and machine learning. The main aim of authors was to develop a computationally efficient and low cost system. Raspberry Pi and Arduino Mega 3 were used as microcontroller and other sensors were used to fabricate the system. Compared to the existing systems, the proposed system is computationally efficient. The various findings of this section have been tabularized in TABLE 9.

C. IoT IN CROP MONITORING

Crop monitoring is the process or method of observing the farm fields and crops for enhancing productivity and reducing cost. This can be performed with satellites, drones, sensors, and other methods. Vegetative indexes of an area can also play a major role in crop monitoring by providing the data related to the exact area of land under cultivation etc. With crop monitoring the estimated time of harvest can be predicted. de Souza *et al.* [118], proposed an integrated framework with the combination of hardware, software, middleware, and other equipment to monitor the testbed. The authors also recorded the testing of each equipment in the seed test labs. An IoT based system was developed where soil sensors provided the relevant information/data for the growth of seeds. Testing was performed in the Official Seed Analysis Laboratory (OSTL) of the Brazilian Agricultural Research Corporation. Rekha *et al.* [119], developed a WSN based framework for sensing agricultural characteristics and then provide decisions to the farmers. Based on the data collected, the model will provide decisions for irrigation and crop monitoring. For the case study, India was taken into consideration due to its large farming area and population dependence on agriculture. Groundnut farming was studied in this work. Becker Reshef *et al.* [120], proposed a remote sensing analysis based crop monitoring system for strengthening agricultural decisions and improving crop security. The authors named this model as "GEOGLAM" model which ensures the decision support of all the necessary steps for crop security and analysis.

Kamath *et al.* [121], proposed a wireless sensor-based model for monitoring the growth of weeds in paddy crop. The authors performed a study on how Raspberry Pi and WSN can be modeled for precision agriculture. Raspberry Pi based model was deployed to monitor crop along with the integration of Bluetooth 4.0 to send signals from visual sensors to the base station. A solar cell battery was used to provide power to the system. At the remote station, the images of the crops were processed to extract the background and foreground objects. Classification between weeds and paddy crop was performed with SVM.

Rao and Sridhar [122], Developed an automatic irrigation system by prototyping Raspberry Pi and other IoT devices to enhance crop productivity. A cloud-based data collection system supported by sensors used for data collection is employed to collect the field data. The data collected is sent to the base station and based on that data, the decisions are made. Parameters like humidity, soil temperature, and sunlight availability

TABLE 9. Summary of IoT based developed methods for irrigation.

Authors	Purpose	Site/location	Parameters	Tools/ Techniques	Dataset
Bright Keswan et al. [111]	IoT based precision irrigation system is developed considering the weather conditions	Bhubaneswar, India	Soil temperature, soil type sunlight intensity, sunlight time, airflow time	Fuzzy logic, neural networks, ZigBee	Self
Prasad M. P ujar et al. [112]	Developed a statistical model for monitoring real-time water quality of river on IoT concepts	River Krishna, India	pH level, conductivity, dissolved oxygen, biochemical oxygen demand, temperature, nitrate, total dissolved solids	One way ANOVA, two-way ANOVA, Arduino MEGA 2560, Esp8266, sensors	Self-collected data from different banks of river Krishna
Nestor Michael Tiglao et al. [113]	A low-cost wireless system named 'Agrinex' is designed for smart irrigation	-	Soil moisture, temperature, humidity	ATMEGA328P, Raspberry Pi, Wi-Fi, HTTP, Sqlite3 w	Self senor based
Brooke Mason et al. [114]	An intelligent irrigation system is developed for enhancing crop yield and save water	USA	Soil moisture, rooting depth, rain infiltration rate, maximum crop	CROPWAT Model, Conventional-Scenario Intelligent-Scenario (CSIS)	CLIMWAT, NOAA's online data portal
Neha K. Nawandar and Vishal R. Satpute [115]	Designed an IoT based low cost and intelligent system for precision irrigation	India	Crop water requirement, total plant area, pipelining	SIU: sensor information unit, NN, MQTT protocol, Wi-Fi, HTTP,	Self-sensor based
Freddy Canales Ide et al. [116]	Performed a case study for developing a smart irrigation system for cities with water scarcity	Madrid, Spain	Climate data, plantation density	WUCOLS III methodology,	Data is collected from a system connected to the local weather station
Gerardo M. Spinelli and Zach L. Gottesman [117]	Developed an Arduino based low-cost data logger for precision irrigation in crop monitoring	USA	Environmental parameters, soil moisture, humidity	Arduino MEGA, FONA shield battery, FONA cellular shield, Adafruit datalogger, Raspberry Pi,	Self-sensor based

are measured. Geng *et al.* [123], for greenhouse environment monitoring proposed a four-layer IoT based mobile system. To design the system, the authors proposed integration of both Raspberry Pi and Arduino chip in the design where the former serves as the data server and later as the master chip for a mobile system. Fabrication of all the sensors, actuators, and other devices was done on a single board, thereby reducing the device's physical distances for better performance due to serial communication. A dedicated communication protocol with CYC was designed to reduce transmission errors and data loss. Shadrin *et al.* [124], designed an intelligent agriculture IoT equipment to monitor the crop. The authors designed the system using the test case of monitoring the seed germination. The proposed model was fabricated with the integration of low power embedding wireless sensor nodes with artificial intelligence. CNN was used to train the model along with the collection of data via sensor nodes of the different stages of germinated seeds. A 3D clustering analysis was used to analyze the relationship between environmental factors and farmer issues.

Uddin *et al.* [125], focused on developing a system for monitoring crops from the stage of seed germination to harvest. For this authors proposed a resource optimized fast health crop monitoring system. Saudi Arabian agriculture was taken into consideration as a case study. IoT and drones were harnessed to make an efficient agricultural monitoring system. Data collection methods were used to collect data from heterogeneous devices arranged in localized clusters. The system was designed to withstand a harsh environment with agility and feasibility. Feng *et al.* [126], proposed a crop growth and nutrition diagnostic system based on hyperspectral remote sensing. Color canopies obtained from images captured with satellites, UAV, and remote sensing were used to determine the index of yield. To determine the color canopy of plants, the color correlation was employed. Cen *et al.* [127], discussed the usage of UAV with dual image frame cameras to estimate the aboveground biomass and panicle biomass of rice. The authors conducted their study at different growth stages of the crop. The field investigations were made on the variations in typical vegetation indices. The accuracy of the model was obtained with the extraction of RGB images at two different stages. Random forest was employed to obtain AGB as well as the PB.

Khan and Kumar [128], proposed a framework for the monitoring the crop field. To make their study reliable, the authors monitored weather in real-time to get an idea of how to provide an ambient condition to farm. Production increase techniques are also proposed for precision farming. To overcome the problems of delay in information transfer from the field to the farmer, the context-based agricultural mobile sink is designed in WSN. Thus the mobile sink node introduction improves the overall efficiency and energy consumption of the model. Frontward communication area (FCA) based route selection is proposed to reduce energy consumption and delay. Min and Kuang [129], designed a system for monitoring the rice crop field. The analysis of the growth of rice and rice duck in real-time is done by obtaining the data via the Internet of Things. Authors comprehensively viewed the rice and rice duck plant species and the ambient farm conditions required for their growth.

Qiulan *et al.* [130], estimated the production of carbon from the crop growth. The authors provided a framework for the estimation of organic carbon compounds in the farmland soil. The wheat plant was taken as a test case in this study. The model provided the real monitoring of the farm for carbon production with the aid of IoT and other devices. The real-time data was collected from the Yanzhou District of Jining City, Shandong Province, China. Harun *et al.* [131], proposed an improved crop monitoring system based on IoT concepts. Brassica Chinensis is the plant taken for study and was subjected to four different light treatments such as pulse treatment, continuous treatment, high intensity, and artificial control for enhancing the plant growth. The authors also analyzed parameters such as leaf count, height, dry weight, and chlorophyll a and b. An intelligent embedded system was developed to monitor and capture real-time data.

Alonso *et al.* [132], designed an intelligent edge IoT based platform for precision livestock and crop monitoring in a dairy farming scenario. In their study, authors used the concepts of AI, blockchain technology, edge computing and IoT concepts for designing the platform. The architecture named Global Edge Computing Architecture (GCEA) was tried and tested in real time in a dairy farm. Castellanos *et al.* [133], proposed a narrowband IoT (NB-IoT) system for collection of soil parameters to monitor the potato crop health and growth. A UAV aided network is used to support the purpose. The architecture proposed accessed the real filed scenario of a potato filed near Bogota, Columbia. The main achievement of this work was the energy harnessing due to optimal topology applied for the deployment of sensors across the field and thus making the battery last for 82 hours for above ground sensors and 77 months for the deep buried sensors. Shafi *et al.* [134], presented a multimodal for crop health monitoring based on the concepts remote sensing, IoT and ML. Authors conducted their research in Pakistan. Sensors were deployed in fields to collect the real time data. Multispectral data from drones presented a NDVI and was used to analyze the crop based on its chlorophyll content. Variable length time series data captured from IoT devices and sensors were used to generate crop health maps. Deep neural networks were implemented for classification and provided the optimal classification.

Some studies of the articles incorporating IoT in fields related to crop monitoring are presented in TABLE 10.

D. IoT IN DISEASE DETECTION

Diseases play a vital role in the economic and food crisis of a country. So to avoid this, disease detection is employed. This involves the detection of various diseases whether fungal, viral, bacterial, etc. from the stages of early to the post-harvest. Incubation of IoT has revolutionized the disease detection area in plant phenotyping resulting in major control resources available to avoid disease occurrence. Wang *et al.* [146], focused on addressing the problem of pests and insects. Authors proposed an IoT based model that can detect the early occurrence of the pests and diseases from visual references. Rough set theory algorithm and NN were used to model design. The proposed model was compared with existing models for accuracy and efficiency. Pandiyan *et al.* [147], applied the concepts of image segmentation and IoT, to develop a system/platform that can detect the diseases in plants. Authors proposed a novel platform having an Advanced Segmented Dimension Extraction (ASDE) with Heterogeneous Internet of Things procedural (HIoT) aspects, to detect the apple leaf diseases. A sign based plant disease identification model for real-time resembling of leaf diseases namely bacteria, fungi, microorganisms, and viruses is presented. Three levels i.e. connectivity level, platform level, and service level were employed for performing data aggregation, transmission, and automatic identity identification. Leaf gestures were studied to identify the diseases in leaves.

Zhao *et al.* [148], developed an automatic crop disease detection system capable of identifying and recognizing the leaves from a cluttered background. Combining IoT concepts and CNN, authors designed a novel approach named "Multi-Context Fusion Network (MCFN)" along with IoT deployments for crop diseased detection in wild. Kale and Sonavane [149], developed a smart and optimized smart fertilizing decision support system for smart farming. The authors addressed the problem of disproportion due to lack of judgment. Concepts of IoT and GA were used to design the system. An improved GA based multilevel parameter

TABLE 10. Summary of developed methods crop monitoring.

Authors	Plant	Tools/ Techniques	Parameters	Applications
Ayush Kapoor et al. [135]	Philodendron	Soil moisture sensor, DHT11 temperature, and humidity sensor, serial JPEG camera module, SD card, Arduino UNO board	Fertilizer ratio, sunlight, temperature, humidity	By combined IoT and image processing concepts, an approach is developed to determine the environmental factor or man-made factor (pesticides/fertilizers) specifically hindering the growth of the plant
Jerrin James and Manu Maheshwar P [136]	Tubers	Sensors DHT-11, SHT- 11, heavyweight measuring apparatus, raspberry pi, Bluetooth	Atmospheric temperature, soil temperature, relative humidity, soil moisture, plant height	Cost-effective automatic prototype to measure the vertical height of a plant and correlation with the surroundings is proposed
Andrey Somov et al.[137]	Tomato	WSN, IoT, Artificial intelligence	Seed propagation and seedling growth, water, nutrient content, light	To monitor and control the growth of a tomato plant, an IOT based greenhouse is designed
Boonsit Yimwadsana et al. [138]	Sunflower Sprout and Morning Glory Sprout	Air, light, humidity sensors, actuators like a relay, motor gear dc, water pump, microcontrollers, Raspberry Pi 3 Model B, Arduino Uno R3, LED	Air temperature, air humidity, light intensity, soil moisture	An automated controlled system for precision farming despite conventional farming is designed
Kuei-Chung Chang et al. [139]	Persimmon	Wifi camera, rainfall sensors, illumination sensor, temperature sensor, gateway, weather boxes	Hough lines and white regions, dormancy, sprout, luxuriant leaves, flowering, unripe fruit, ripe fruit	Farmland with IoT and embedded technology with weather boxes is proposed for agricultural monitoring
Manju. M et al. [140]	Varied aquaponic species	pH sensor, ammonia sensor, water level sensor, moisture sensor	pH level, ammonia, and humidity	A real-time system is developed for aquaponics system for monitoring the environmental parameters
Susan Nnedimpka Nnadi and Francis E Idachaba [141]	Gafan Tomato	Arduino, soil moisture sensor, DHT 11 temperature and humidity sensor, 12VDCFROM solar panel, heating bulb, cooling fan, exhaust, water pump, LCD, Bluetooth	Temperature, light, water level, and humidity	Sustainable greenhouse farming prototype is designed and implemented for automating and remotely controlling a farm
Jun Yang et al. [142]		Temperature sensor, illumination sensor, air sensor, data storage, and analysis service	Temperature, illumination, humidity, mineral content, CO2 content	An indoor intelligent agricultural system with the capability of parallel extension is designed to optimize the plant growth in a controlled environment
Mahammad Shareef Mekala and P. Viswanathan [143]		ThingSpeck cloud, Wi-Fi, microcontroller, power supply, sensors, Arduino board	CMMi index, temperature, and humidity	A cloud-enabled CLAY-MIST measurement (CMM) index model is proposed to assess the comfort levels of a crop and its changes related to environmental effects
Miguel A. Zamora-Izquierdo et al. [144]	Potato (Solanum Lycopersicu m)	FIWARE platform, ORION Context Broker, Comet, CPS, level controller, liquid counter, flow meter	Climate, nutrients, and micro-nutrients, drainage volume, pH level, electrical conductivity	A pilot system greenhouse for crop monitoring is proposed considering extreme agriculture conditions
Theerayod Wiangtong and Phaophak Sirisuk [145]	Cordyceps Militaries, Abalone mushroom types	Actuators, Arduino Mega2560, ESP 2866 WiFi, TFT 3.5 GUI, Xively, ThingSpeak	Temperature, relative humidity	A versatile controller is designed to monitor and control temperature and relative humidity to serve different scenarios in a greenhouse

optimized feature selection algorithm for ELM classifier along with IoT was proposed in the designed system. The proposed system focuses on plant disease detection in a real-time environment. Khattab *et al.* [150], developed an IoT based cognitive automatic monitoring system for detecting the epidemic diseases in plants. By combining the concepts of artificial intelligence and prediction algorithms to develop the expert system, capable of predicting, analyzing, and decision making. A layered approach was used to design the model. Soil, leaf wetness, wind speed, and wind direction sensors were employed to gather the data. The model was tested on detection of the diseases like Late Blight, Early Blight, and Powdery Mildew in tomato and potato crops. Chen *et al.* [151], based on AI technologies and IoT, developed a system named "RiceTalk" for the detection of Blight diseases in the rice plant. AgriTalk model was used as a base model in this work to develop this system. Compared to AgriTalk, the authors used non-image IoT devices to design this model for disease detection. Devi *et al.* [152], proposed a simple and efficient IoT enabled solution for developing a system for automatic disease detection. Bunchy top of banana and Sigatoka diseases in the wild banana plant were detected and classified. Environmental parameters like soil moisture, temperature were measured with sensors and the IoT model was framed using the Raspberry PI hardware model. Data were classified using GLCM and RFC for disease detection.

Kitpo and Inoue [153], developed an early disease detection system for rice crops disease detection. The drones based IoT architecture with real-time data collection capabilities was designed. For the mapping of drones on the fields, GPS sensors were used. The designed system is capable of displaying the analytical results and the position of the plant where the disease is present. Pawara *et al.* [154], studied the pomegranate diseases such as Bacterial Blight, Fruit Spot, Fruit Rot, and Leaf Spot. Developed a HMM and senor based model to early detect the disease and provide the solutions. Parameters like air temperature, leaf wetness, air humidity, and soil wetness were considered and studied for model design. For digital communication between field and farm GSM module was used. Truong *et al.* [155], real-time data monitoring capable system was designed with IoT and cloud storage for disease detection and recognition. The fungal diseases of rural crop fields with detected. Environmental data conditions such as humidity, temperature, wind speed, and rainfall were employed for designing decision support. A Support Vector Machine Regression (SVMr) model was used to classify the data. Jumat *et al.* [156], developed a cost-efficient and affordable smart farming prototype capable of detecting plant disease and proving decisions. For study and experimentation, Septoria plant disease was taken and studied for different stages right from outbreak to spread maturity. The system also possesses the web-enabled facilities for farmer support.

Some studies of the articles incorporating IoT in fields related to disease detection are presented in TABLE 11.

V. FINDINGS

Several research articles related to the role and responses of the Internet of Things in agriculture have been studied. From the literature and studies, it can be seen that immense contribution has made by IoT in the field of agriculture starting from micro areas and moving over to macro environments. Internet of Things along with the concepts of cloud computing, cluster computing, wireless sensor networks and computer vision has revolutionized the field of monitoring, crop production, disease detection, and supply chain management. Since the domain of agriculture itself is a wide domain so considering the impact IoT has or can make on this field, the search was not restricted or limited to any area.

The data acquisition for agriculture systems is a multi-dimensional approach. There are several fields in agriculture where IoT is applied e.g., crop monitoring, diseased detection, precision irrigation, supply chain, cattle grazing, and raising, etc. To design a precision approach, the target plays a very important role in data collection. From the existing studies it is found that mostly overall 90% of the data is self-acquired by the authors with the use of wireless sensors. This data included soil data, pH values, light, water, humidity, and images. In the case of crop disease detection, leaves were taken as the primary subject of study due to their ease of availability and quantity. Nearly 80% of the leaf data was self-acquired using digital cameras and web-enabled devices. However in some studies to validate their models, authors also used the existing standard ground truth databases available. Satellite imaging and remote sensing images were also taken to understand the demography and vegetative indexes of a region. UAV drones were the most used devices along with web-enabled digital cameras and mobile devices to capture the data in the form of images and also acted for providing real-time monitoring of device location in the fields. Certain issues and challenges are faced by the authors while capturing real-time images due to environmental and lighting conditions. To avoid these issues, laboratory-based testbeds such as greenhouses were developed and their data was acquired in a closed environment.

From the literature, it is seen that, to develop the prototypes certain common parameters were taken for conducting the study irrespective of the problem to be addressed. Theses parameters included soil data, pH value, humidity level, moisture content, water content. After the analysis of the studies it was found that for any agricultural system to flourish all these parameters play a combined role. These parameters were most common for the problems addressing farm management, crop monitoring, and irrigation. However in certain other parameters like leaf wetness, salinity, disease severity, fertilizer ratio, plant height, CO_2 content, mineral content, and conductivity were considered while addressing the specific problems like plant disease detection, smart irrigation, seedling germination, etc.

These were the devices employed to collect the data. Depending upon the problem the authors addressed, different type of sensors were employed. For soil data collection, the contact method sensors such as hygrometers, or electrodes which penetrate the soil were used to collect soil information. While as in the case of the collection of soil information via tractors or vehicles non-contact soil sensors were employed. But for the studies it can be seen that contact method sensors are the most common devices used for soil data collection. In case of soil pH value and salinity electrochemical sensors are employed. In the case of soil nitrates, CO_2, and fertilizer content, topsoil depth, biomass content, organic matter are measured.

For water data collection, parameters like relative humidity, leakage of pipes, dissolved oxygen, nitrates, and other oxides were measured by the authors. To accomplish this various water sensors like ultrasonic sensors were employed to measure the water levels in the tanks, ponds, and farms. Temperature and humidity sensors were used to measure the temperature of water and humidity of soil for water content. In the case of plant leaves, the leaf wetness sensors were

TABLE 11. Summary of IoT based developed methods for disease detection.

Author	Purpose	Application	Disease	Hardware	Dataset	Network Type	Parameters
Amogh Jayaraj Rau et al. [157]	Monitoring of weather conditions along with over and under irrigation	Devised a means for cost-effective automated irrigation and fertilization of rice fields	Bacteria blight, brown leaf spot and nutrient deficiencies of magnesium and nitrogen	Raspberry Pi+ DHT11 temperature and humidity sensor and solenoid valves	Self	IOT+ Embedded system	-
Apeksha Thorat et al. [158]	Smart solution for leaf disease detection	Designed leaf disease detection server-based remote monitoring system	Botrytis blight, black spot, powdery mildew, rust	Raspberry PI (RPI) + DHT11 sensors.	Self with GSM	Embedded + wireless	-
Karim Foughali et al. [159]	Disease prevention in precision agriculture	SIMCAST prediction model is proposed for risk analysis of plants	Late blight of potato	Wasp mote nodes (Wasp mote 868 SMA 4.5 DBI), XBee 802.15.4 Pro SMA 5dBi	Self	cloud-IoT	Temperature , humidity, pressure
Ms.Yasha swini L S et al. [160]	Automated smart irrigation system with disease prediction	Designed a smart system working in an automatable manner to detect diseases and drought conditions	Bacterial leaf Spot, Powdery Mildew, Downy Mildew, Anthracnose, Bacterial Cancer, Rust	Arduino Uno, GSM module,	Self with sensors	Embedded_ IOT	Humidity, leaf wetness, soil moisture, temperature
P.R.Harsh ani et al. [161]	Smart system for crop production and nutrient level monitoring	Designed an IoT based system for soil parameter and nutrient level monitoring in plants	-	Raspberry Pi + sensors	Sensor data	Wireless_ IOT	pH level, soil moisture, temperature and humidity
Santosh Sam Koshy et al. [162]	An automatic system for smart farming taking the case study of the castor and groundnut crops	Application of IoT in smart farming for disease detection and forewarning	Leaf miner pest, late leaf spot and gray mold in castor plant	Rainfall sensor, solar radiation sensor, canopy sensor, solar power unit	Sensor	Wireless + IoT	Leaf wetness index, rainfall index, climatic conditions
Sergio Trilles et al.[163]	Developed an open sensorized platform in the context of smart agriculture	Monitoring support for vineyard fields	Mildew disease of vine	Arduino, grove temperature and humidity sensors, GPRS module, Shield grove, microcontrollers	Self-sensor based	Embedded + Cloud	Weather, humidity, temperature
S. Aasha Nandhini et al. [164]	Proposed a web-enabled disease detection system	Designed a wireless multimedia sensor-based disease analysis system	Anthracnose and Alternaria Alternata in the pomegranate leaves, Phytophthora blight, and Alternaria leaf spot in the brinjal leaves, Early blight and Septoria leaf spot in tomato leaves	Raspberry pi 3 board, USB camera, and SD card.	Self of 3 plants	Wireless+ IOT+ Cloud	Weather, temperature, leaf shape, textural features
Suyash S. Patil and Sandeep A. Thorat 2016[165]	Early detection of diseases	Designed an automated for early grape disease detection	Bacterial Leaf Spot, Powdery Mildew, Downy Mildew, Anthracnose, Bacterial Cancer, Rust	ZigBee module, Arduino board, sensors	Self	WSN + IoT	Texture, shape, color, humidity, temperature

employed to understand the moisture content of the plants. Other than these sensors, neutron sensors, time travels sensors, and capacitance sensors are also employed by some authors for measuring the water levels. In the case of supply chain and cattle grazing, tags and biosensors were employed to gather the data.

To develop the prototypes, the authors used the devices based on functional capabilities. From all the devices, Arduino and Raspberry Pi were the most desirable hardware platforms for the authors. Arduino was employed to tackle simple or sequential issues that do not require complex solutions. In the case of scenarios with complex environments, Raspberry Pi boards were employed due to their capability of addressing multiple problems at the same time. For functionalities that faced time issues, Raspberry Pi boards were employed. In the case of communication technologies, LoRa and ZigBee are the most commonly used communication technologies by the authors in the platform designs due to their capabilities of handling a multitude of solutions. Lora and ZigBee use GPS to enable and detect geo-locations. They are low cost and secure for data transmission. Other than these technologies, authors also made use of cloud and cluster computing to handle a large mass of data and provide on-spot solutions to the consumers.

The authors performed the processing of data in different stages. At first preprocessing on data was performed to remove any kind of outliers or anomalies in the data.

1) To remove the imperfect data, algorithms such as noise removal with Gaussian noise, salt and pepper noise, histogram equalization were commonly used for the preprocessing of image data. However in the case of numerical data missing value imputation, the banana dataset for noise reduction was employed.

2) To obtain the optimal data from a given set of data, data reduction was performed. The data reduction approaches e.g., dimensionality reduction, attribute subset selection, numerosity reduction, etc. were employed by various authors.

3) To make systems capable of taking decisions, several learning algorithms like GA, CNN, NN, SVM, PNN, GANs were used to train and test the models.

From the literature, it is seen that most studies and experiments were performed in countries that have agricultural economies like the USA, China, India, Brazil, Australia, etc. Most of these countries are economically stable and first world countries. They have better infrastructure and service availability. Also only 20% of the studies were focused on real-time implementation of their prototypes which indicates that most of the experimentation was conducted in a closed environment. This pattern raises concerns on how these studies can be employed in real-time environments with low infrastructure and maintenance costs. The problem of power consumption was also addressed by some studies. However there were no comparisons and reasons given on how the dream of IoT can be made real for poor and self-financing farmers. Along with this, a few studies provided the cost estimation for the deployment of the models. In the Fig. 7, the percentage distribution and contribution of IoT in different fields of agriculture are shown. From the figure it can be seen that more extensive studies are conducted in the field of crop monitoring.

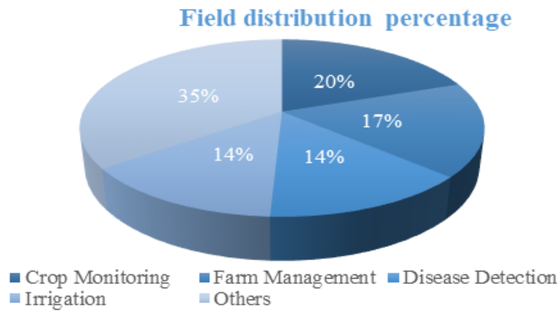

FIGURE 7. Percentage contribution of IoT in different fields of agriculture.

These studies and analysis put forth by different articles show that current/existing solutions have incorporated IoT to solve several challenges in the agricultural domain. With the incorporation of these technologies, a large number of challenges/factors for improvement have emerged. Along with the study of factors for improvement, future research directions, applications are also highlighted. The sections below explain the factors for improvement and the futuristic research directions.

A. CHALLENGES

Despite the growth achieved by IoT over the past few decades, there still exist some conceptual, fundamental, and developmental issues.

1) COST

Designing a cost-optimized model is still a difficulty faced by many authors. Scientists are focusing on developing cost-efficient systems by reducing the hardware and software requirements in IoT deployments. Economic differences of countries make it difficult for farmers to deploy devices and technology. So, it is important to develop some economic models.

2) STANDARDIZATION

To fully utilize the technology for large range of applications, standardization of devices is essential. The present or current mechanisms do not confirm any standardization formats either for the data and process representation. Deprived of the cordial use of the semantic ontologies, machine-readable codes result in output differences due to misinterpretation and alterations from time to time. With standardization the interoperability issues of the devices, applications, systems and products can be solved.

3) HETEROGENEITY

While designing a system, heterogeneous devices are used. Every device differs in processes and services requirements.

In the case of agriculture, most models perform with heterogeneous devices, so it is important to create interaction between heterogeneous modules and communication technologies. Because of heterogeneity, the complexity of the network increases, and sometimes falsified results may appear.

4) ACCESSIBILITY

For developing any farming decision support system based on IoT technology and other devices, the demand for availability of existing software and hardware to be present anywhere any time is a must thing. These problems need to be addressed to ensure the availability of services anywhere and anytime. Lack of availability of the required equipment can result in chaos and delay in the services.

5) ADAPTABILITY

While designing a model, especially for precision farming, it is pertinent for the devices to be adaptable with the other devices and the surroundings. Since the environmental conditions keep varying and also sometimes due to certain communication or hardware issues certain devices are not adaptable with each other.

6) ENERGY OPTIMIZATION

Energy is the most emerging issue in IoT systems, WSNs, and other devices for their communication. Till now conventional sources of energy have been supporting the designing and working models. But due to an increase in devices, the consumption of conventional energy is not a reliable solution. Non-conventional sources of energy like solar, wind, water energy harvesting schemes should also be tested, but they haven't been of much success and new methodologies should be developed to employ them for model development.

7) COMPATIBILITY

To achieve the standards of fragmentation and scalability, the developed models or software should be flexible and should run on any machine.

8) RELIABILITY

For successful and smooth working, reliability is a major concern for IoT devices in terms of data transmission. The devices need to gather and transfer reliable data as based on the data received and interpreted, the decisions are made. Reliability is still a challenge due to system failures, node failures, battery issues, or other interventions.

9) MOBILITY

Generally the systems or models developed are static. For smooth implementation of the framework, there should be mobility as most of the devices and applications are mobile. In mobile models, the issue of maintaining connectivity is still a difficult task.

10) ENVIRONMENTAL CONDITIONS

In agriculture there are different landforms. So it becomes difficult to adapt to those changes, and this also jeopardizes data and services. This alters the accuracy of a system.

11) REAL-TIME DEPLOYMENT

Most of the studies put forward are not employed or tested in a real-time testbed. So before deploying a system or model, real-time analysis is a must, to avoid post-deployment losses.

B. IMPROVEMENTS

Since the growth of IoT is remarkable in the field of agriculture, certain improvements can be included in the growth and developmental state to make the systems and models more efficient, reliable, and business-oriented.

1) WARDING OFF THE PERFORMANCE DEGRADATION

Generally while developing systems, customer interaction or input is not taken. As the models serve a variety of customers from dynamic backgrounds, therefore their input must be taken while developing the models. This way the performance hazards and chaos that occurs on the filed can be avoided.

2) SHARING RICH DATA GLOBALLY

In almost all, the IoT based models designed for precision farming, the data sharing while integrating and mapping the system design should be encouraged. This can lead to the development of an interactive model globally. This feature can also help in understanding the topographic and demographic challenges of various regions on a global level. Thus the suitable solutions can be designed with those working in resource-constrained environments.

3) MOVING TOWARDS HIGH-SPEED COMMUNICATION

The communication domain itself is witnessing a progressive and dynamic shift. Since the IoT models are remotely located, so better communication is a prerequisite. Therefore it is important to consider high-speed communication strategies like 5G, for making the devices more reachable with lesser delays.

4) COST ANALYTIC STUDIES FOR MODEL DESIGN

With the incumbent of IoT in agriculture, a variety of models are designed for addressing different domains such as irrigation, farm management, disease detection, and crop monitoring, etc. While designing the models various case studies are performed. As the development cost of models for these cases varies from country to country i.e., in first world countries there will be the different cost of devices and in second and third world countries it will be different. Therefore a model cost analysis will provide an idea of the purchasing power and investment a farmer from these varied economic regions can invest to develop a model. Also this can result in seeking or considering other cheaper and efficient ways to develop models.

C. FUTURE RESEARCH DIRECTIONS

With the advancement in the development of precision agriculture platforms with IoT and other technologies, the development of new applications or research areas is envisioned. After the study of the literature, certain potential concepts and futuristic research directions are listed and discussed below:

1) Design of platforms in a user-friendly manner (from farmers' perspective and ease of using) using Artificial Intelligence and other learning tools. Farmer's perspective here means that an audit should be done well before designing the prototype. From this study a clear insight and differences between the requirements of the farmers and farming systems across the globe can be understood.

2) To develop concepts and methodologies based on multidimensional aspects like science, expertise, experience, industry, etc.

3) Energy harvesting or power optimization methodologies should be developed to reduce the cost of production, maintenance, and fault tolerance. It is evident that mostly the farms be it small or large, require power and energy for the working of devices. In most of the cases, the power to the devices is supplied from the main line or the power grid. But this is not a sustainable and efficient method. Thus in order to make farms self-reliant, the energy harvesting or power optimization approaches should be developed or incorporated while designing of the models.

4) Induction of cloud sources for data gathering and processing in a reliable, systematic, and scientific manner.

5) Develop systems that can withstand variable soil and environmental conditions. Since the agricultural environments are harsh and keep on changing with change in climatic conditions or seasons. So it is essential to develop systems which can be robust and sustainable to the changes in the external as well as internal factors.

6) Development of user or farmer friendly apps for monitoring crop and plant health. Mostly farmers come different ethnic and linguistic backgrounds. So due to this their level of understanding and ways to perform agricultural tasks is also different. It is important to develop frameworks considering the native language of a region into consideration so the farmer and machine interaction can be improved. This will enhance enable the acceptance of precision farming methods easy as it can be seen some areas are reluctant to adopt due to this linguistic and understanding problems.

7) Development of efficient sensor-based systems for high elevation areas. High elevation areas mostly have undulating surfaces and also in most of the countries, supply of power to these areas is still a dream. Form the literature, it can be seen that these areas have not been targeted for precision farming instead of being resource deficient. Therefore deployment and design of sensor based systems in these areas opens a scope in future of precision farming.

8) Usage of previous and existential scientific data for the development of decision support systems in farming. Generally for designing the precision farming models, the primary data is considered. However for designing cost efficient and reliable models, the previous case studies and deployment models should be considered for the study. This means a collaborative model development methodology should be developed for understanding the nature of the work.

9) To recognize various plant species using mixed data sets or heterogeneous data.

10) Design of a portable and sustainable farming equipment control systems for large as well as small farms. Mostly from the study it can be seen that first world countries are welcoming in PA approaches while as in most third world and other nations, this concept is still in avoidance due to cost and shelf life of products and equipment's.

11) Development of reliable supply chain management methods for precision farming.

D. APPLICATIONS OF IoT IN AGRICULTURE

IoT has revolutionized the world of agriculture, and a manifold of application can be derivative of implementation of the Internet of Things in agriculture. These applications are a resultant of the architectural design chosen. These applications have been categorized and differentiated based on the subject they focus on and also the service they provide. The major sectional areas where IoT is applicable in agriculture are- observation, data collection and corroboration, governing, and management. Most of these fields work collaboratively, and all the applications involve at least two of these sections. All these sections are described below and TABLE 12 presents various IoT applications in agriculture.

1) OBSERVATION

It is also called monitoring as the main aim of this section is to discern the working of various models, devices, applications, etc. With the incubation of the concept of IoT, it is the first and foremost stage to be smeared. In this phase, all the devices and equipment that are placed strategically are monitored for their work. Sensors, are the major deployment and data collection tools engaged in this phase for data collection of various field and non-field parameters. Monitoring the certain parameters, like soil salinity, pH value, volumetric water content by using various soil sensors and other essential parameters such leaf wetness sensors, color, humidity, etc. helps in the development of systems capable of performing following operations e.g., calculation of leaf area index, leaf health, leaf color, plant growth and aid in the development of automatic plant recognition systems. Other devices like water sensors aid in the monitoring of irrigation levels and requirements of the fields. Thus with such devices, smart irrigation scheduling systems are developed. Also with the gas sensors, remote monitoring devices such as UAV devices or images with hyperspectral reflectance properties, help in the estimation of biomass, nitrogen, carbon, and other essential gases content. This data can also be used to find the vegetative indexes of the filed or large demography. Heavy-duty vehicles such as thrashers, tractors, trucks etc., also need supervision and can use data analytics for farm management. Robots, autonomous vehicles, agricultural drones other equipment also need to be

TABLE 12. applications of IoT in agriculture.

Author	Purpose	Application	Disease	Hardware	Dataset	Network Type	Parameters
Amogh Jayaraj Rau et al. [157]	Monitoring of weather conditions along with over and under irrigation	Devised a means for cost-effective automated irrigation and fertilization of rice fields	Bacteria blight, brown leaf spot and nutrient deficiencies of magnesium and nitrogen	Raspberry Pi+ DHT11 temperature and humidity sensor and solenoid valves	Self	IOT+ Embedded system	-
Apeksha Thorat et al. [158]	Smart solution for leaf disease detection	Designed leaf disease detection server-based remote monitoring system	Botrytis blight, black spot, powdery mildew, rust	Raspberry PI (RPI) + DHT11 sensors.	Self with GSM	Embedded + wireless	-
Karim Foughali et al. [159]	Disease prevention in precision agriculture	SIMCAST prediction model is proposed for risk analysis of plants	Late blight of potato	Wasp mote nodes (Wasp mote 868 SMA 4.5 DBI), XBee 802.15.4 Pro SMA 5dBi	Self	cloud-IoT	Temperature , humidity, pressure
Ms.Yasha swini L S et al. [160]	Automated smart irrigation system with disease prediction	Designed a smart system working in an automatable manner to detect diseases and drought conditions	Bacterial leaf Spot, Powdery Mildew, Downy Mildew, Anthracnose, Bacterial Cancer, Rust	Arduino Uno, GSM module,	Self with sensors	Embedded_ IOT	Humidity, leaf wetness, soil moisture, temperature
P.R.Harsh ani et al. [161]	Smart system for crop production and nutrient level monitoring	Designed an IoT based system for soil parameter and nutrient level monitoring in plants	-	Raspberry Pi + sensors	Sensor data	Wireless_ IOT	pH level, soil moisture, temperature and humidity
Santosh Sam Koshy et al. [162]	An automatic system for smart farming taking the case study of the castor and groundnut crops	Application of IoT in smart farming for disease detection and forewarning	Leaf miner pest, late leaf spot and gray mold in castor plant	Rainfall sensor, solar radiation sensor, canopy sensor, solar power unit	Sensor	Wireless + IoT	Leaf wetness index, rainfall index, climatic conditions
Sergio Trilles et al.[163]	Developed an open sensorized platform in the context of smart agriculture	Monitoring support for vineyard fields	Mildew disease of vine	Arduino, grove temperature and humidity sensors, GPRS module, Shield grove, microcontrollers	Self-sensor based	Embedded + Cloud	Weather, humidity, temperature
S. Aasha Nandhini et al. [164]	Proposed a web-enabled disease detection system	Designed a wireless multimedia sensor-based disease analysis system	Anthracnose and Alternaria Alternata in the pomegranate leaves, Phytophthora blight, and Alternaria leaf spot in the brinjal leaves, Early blight and Septoria leaf spot in tomato leaves	Raspberry pi 3 board, USB camera, and SD card.	Self of 3 plants	Wireless+ IOT+ Cloud	Weather, temperature, leaf shape, textural features
Suyash S. Patil and Sandeep A. Thorat 2016[165]	Early detection of diseases	Designed an automated for early grape disease detection	Bacterial Leaf Spot, Powdery Mildew, Downy Mildew, Anthracnose, Bacterial Cancer, Rust	ZigBee module, Arduino board, sensors	Self	WSN + IoT	Texture, shape, color, humidity, temperature

monitored remotely for better farm supervision. Livestock monitoring with the aid of IoT is also an important subject for precision farming. It includes cattle monitoring remotely using tags. Labour is also a major area of concern for precision farming. Since human intervention is generally prone to errors due to differences in understanding, decision making, and methodologies applied to solve a particular problem. Also the induction of human labor is cost-intensive. Therefore, with the application of IoT, human interference can be minimized and a network can be set up for monitoring thus reducing the errors and cost.

2) DATA COLLECTION AND CORROBORATION

Data is the main constituent of precision farming. It acts as both base and catalyst in the whole process. With IoT, a large number of data is collected in varying forms and formats. Sensors, cameras, and various other nodes aid in the collection of data. In precision agriculture, based on the nature of the problem, the IoT network can be designed and formulated to collect different types of data. After the data is collected, the corroboration also called documentation of the data is very important for better understanding. Corroboration is a natural application of collected data, but certain additions of different samples such as manual or machine integration are also seen. Data once collected needs to be refined and understood, labeled, and thus documented in a certain format. Documentation or corroboration of data helps in formulating statistical analysis and developing the decision support systems. Remote sensing charts and other crop assessing tools can be employed to understand the total crop yield of a particular region. Crop management can also be optimized using corroborating data. A yearly or term analysis can be performed on this data to improve precision farming. Food chain supply management can use the predictive analysis of this data for optimizing and designing new efficient strategies. The major areas where its application is seen are yield mapping for fertilization planning, field planning, agrofood traceability, site-specific measurements based on soil and water analysis, and remote vehicle monitoring for supply chains, etc.

3) FORETELLING

Also called forecasting is one of the major attributes or applications for decision making that is brought in agriculture with the introduction of IoT. With the IoT devices and network, real-time data analysis along with the comparison to the previously available datasets helps in the forecasting of the upcoming events in much advance. With this foretelling, various decision support systems can be designed capable of taking optimal and real time-decisions. It can also act as a preventive measure mechanism for avoiding or dealing with various upcoming unprecedented situations. With monitoring, data collection, and corroboration, foretelling can help in early disease detection, pest growth, weeding, drought, smart irrigation, and harvesting. Artificial intelligence can be employed for designing these learning systems. With IoT, a predictive analysis could be made way earlier than the harvest period for assessing crop production and consumption. Pre and post-harvest crop monitoring along with behavioral sciences and market analysis can also be employed to help site-specific farming and production increase in precision agriculture in the context of IoT.

4) GOVERNING AND MANAGEMENT

It is an outcome of the monitoring device. Governing helps in controlling the whole system. Foretelling also plays a major role in governing. With IoT, it is important to govern the farm. Thresholds play a major role in designing a controlling strategy. Controlling is a major addendum of IoT in agriculture. Applications of controlling can be easily seen in site-specific management, working of smart irrigation models, plant growth monitoring models, and early crop analysis models and also in supply chain and smart vehicular navigation, interaction, optimization, and logistics control of farms.

With governing, all the new strategies, formulae, practices and methods employed to solve the problems occurring on daily basis in farms can be monitored. These strategies can then be compared and analysed with the previous existential strategies. Therefore a knowledge base can be maintained. From the data analysis of that knowledge base, the best or the optimal strategies that can be employed to design or mould the system can be fetched. Various case studies can be performed to gather and test such information. From this the redundant techniques can be withdrawn and robust ones can be prioritised. With these methodologies and experiments, the management can be made more flexible, scalable and reliable. Also governing and management can be employed to find the best suited solutions.

Due to the growth in agriculture sector, various public and private sector projects and startups are being started in various countries across the world. All these projects use artificial intelligence and IoT concepts to provide support and solutions to the growing industry of agriculture. All these projects or startups are explained in the TABLE 13.

E. OUR PROPOSED WORK

Inspired by the contribution of IoT in the field of agriculture, we proposed an architecture for precision farming. The layout of the architecture to be designed is proposed and shown in Fig. 8. The structure proposed for precision farming in case of farm management will constitute of different layers. The first layer would be the sensing layer, in which different types of sensors like soil, humidity, water, light, proximity, and conductive sensors will be deployed in the region of experimentation. All data from the sensors will be sent to the base station. The second layer is the network layer, which consists of gateways, internet, and other devices. This layer manages the traffic of the whole architecture. This layer collects data from the sensing layer and transfers it to the decision layer and the application layer. The third layer is the decision layer, which processes the data, manipulates it, and generates alerts or actions. The next layer is the application

TABLE 13. IoT based public and private sector projects/ startups for precision agriculture.

Ref	Project/ startup	Origin/ Place	Description
[178]	Opencube Labs (OCL)	Bengaluru, India	An open source farmer friendly organization working on the design of systems to measure NDVI and get real time crop health
[179]	AgNext Technologies	Punjab, India	An IoT based firm which performs imagery analysis from drones and satellites for farm monitoring and helping the farmers by data harvesting
[180]	CropX	USA	Analytics company, developed on cloud based software solutions in integration with sensors to provide services for crop yield by saving energy and water
[181]	Arable	USA	Agricultural data analytics company offers IoT based irrigation management tool, weather station and crop monitoring
[182]	Gamaya	Brazil	A Swiss startup which helps farmers for early pest and disease diagnosis
[183]	Aker Technologies	USA	An agro data company providing crop intelligence and in season analytics
[184]	AgEagle Aerial Systems	USA	Designs, develops and distributes drone enabled software devices for advanced imaging and analysis for precision agriculture
[185]	PrecisionHawk	USA	An information delivery company that combines UAV and remote sensing technologies and data analytics for precision farming
[186]	Smartbell	Mexico	An AI and IoT based solution for livestock monitoring. Performs operations for animal hearth monitoring by designing tags and sensors
[187]	Agrostar	India	Develops real time solutions for farmers on the need to know basis
[188]	Driptech	USA	Develops and designs affordable, high quality and easy to use equipment's for irrigation of the fields
[189]	Kheyti	India	Helps small farmers battle income variability by providing low cost and affordable technology and services
[190]	EnergyBots Private Limited	Gurgaon, India	Based on GSM technologies, this startup has come up with smart watering system
[191]	Ceres Imaging	Oakland	An aerial spectral imaging company providing solutions to farmers for optimized water and fertilization application
[192]	Mothive	UK	Autonomous agronomy service to help farmers with farm management. Their device such as Mothive Ladybird helps farmers in logistically predict diseases and improve yields
[193]	AgriData	USA	Provides asset tracking system for permanent crops like trees and vines for yield prediction and pest detection
[194]	Aggrowatcher	Israel	Uses computer vision and multispectral imaging to identify and detect water stress, pests and diseases
[195]	Farmbeats	USA	Developed by Microsoft, provides data driven methodologies and solutions for precision farming
[196]	Kamal Kisan	India	Design, develop and manufacture affordable and relevant equipment's for farmers to help them in precision farming
[197]	Cropin	Bengaluru, India	Provides full suite for farm management, monitoring and analytics solutions
[198]	Whirlybird	Maharashtra, India	Works on curbing post-harvest losses by providing farm management solutions to the farmers based on the soil, and meteorological sensing in real time as well as in customized scenarios

layer, which constitutes the firmware and the users. It receives all the inputs from other layers and the outputs are made visible to users. It also manages how the whole architecture will work or look.

Our proposed architecture aims to observe and monitor the farm in real-time. Optimize the resource utilization, early detection of the diseases, and identification of the plant species, optimize irrigation facilities, and make definite use of pesticides and other manures. Monitor the growth of plants in each stage and take the necessary actions for the betterment of plants. The model to be designed will take into consideration the earning and investment of the small scale farmer. A scalable and cost efficient model will be designed by considering the reusability and recycling of the materials used. From the literature, it is found that the issue of interoperability and robustness is still not achieved. So, while designing the model these issues will be prioritized. Also, power supply and power consumption is a bottleneck for each model. So, from the literature it is found that energy harnessing approaches can be used to address this issue. In the proposed model, main focus will be on incorporating the concepts of energy harnessing approaches like solar energy and wind flow energy for power optimization. Harnessing solar energy for regions which have different season's e.g., Kashmir, which has four seasons like spring, summer, autumn and winter throughout the year. So for these regions depending only on solar energy will be a bottle neck. Therefore, in the proposed work, a hybrid approach based on consumption of both wind and solar energy for reducing power consumption will be proposed.

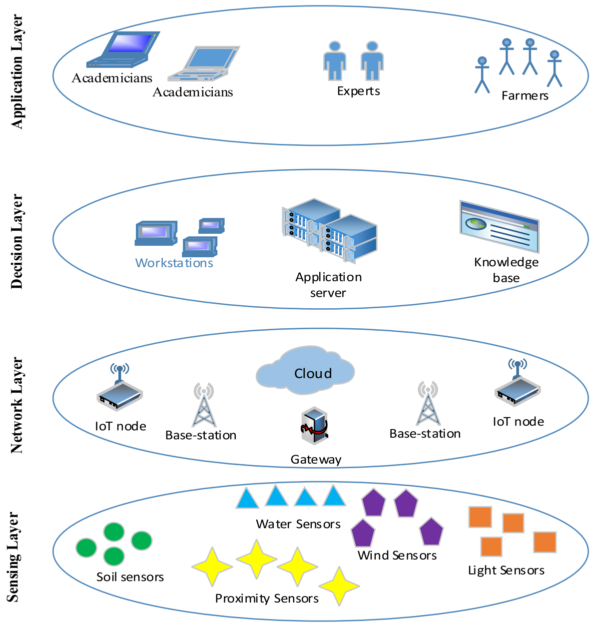

FIGURE 8. **Proposed layered architecture for Precision Agriculture.**

Some of the major findings of the proposed work will be:

1) A scalable and cost efficient model will be designed by considering the reusability and recycling of materials used.

2) The issues of interoperability and robustness issues of heterogeneous devices will be targeted.

3) Power supply and power consumption being the bottleneck of each model will be targeted. To tackle such issues, energy conservation and energy harnessing approaches like solar and wind energy will be used.

4) Harnessing solar energy for regions which have different season's e.g., Kashmir, which has four seasons like spring, summer, autumn and winter throughout the year. So for these regions depending only on solar energy will be a bottle neck. Therefore in the proposed work, a hybrid approach based on consumption of both wind and solar energy for reducing power consumption will be proposed.

5) Small scale farmers will be targeted for the development of sustainable and robust model.

VI. CONCLUSION

The Internet is revolutionizing our world. Communication via connective devices has become the countenance of survival. Agriculture is growing from precision farming to micro-farming. IoT has added more potential to communication by enabling the communication between humans and objects along with the environmental aspects. Seeking the vision of omnipresence i.e., anytime, anything, anywhere, everywhere, IoT should be considered a core for the development of new architectural concepts. Resource scarcity is a must address issue in precision agriculture and models should be developed to optimize resource utilization. Inclusion of monitoring in food supply chains, farms, greenhouses equipped with tags, WSN, etc. at each stage in the growth of the product/plant, making automatic reasoning via intelligent analysis and responses is moving towards much safer, secure, and trustworthy systems. In the article, firstly the agriculture sector along with its challenges and economic importance is presented. The domain of IoT along with the communication technologies and goals, protocols, architectures are studied and put forward. The various IoT OS, their specifications and features with respect to agriculture are discussed. An analytic study of various articles in the field of agriculture is presented, highlighting their most focused sections and gaps or areas not addressed. The sensors based on their field of application are also discussed. A systematic review of different articles focusing especially on crop monitoring, irrigation, disease detection, and farm management is offered. The articles considered for study range from the time frame of the year 2015 to 2020. From the studies, certain issues are put forward that demand research and experimentation in the future. Various existing public and private sector platforms or start-ups which work for precision farming are also presented and discussed with their specifications and applications. Making precision farming a base, a layout of an IoT based architecture is proposed. The communication technologies and the hardware platforms of IoT are also discussed. The applications of IoT in agriculture are also discussed. The issues, challenges, and future research directions are also highlighted. As a whole, the in-depth description of various aspects of IoT for agriculture has been discussed and how these studies should be catered in a way to create efficient and smart agricultural scenarios.

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