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A Comprehensive Review on the Application of Internet of Thing (IoT) in Smart Agriculture

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Abstract
IoT-based smart farming techniques have come up as one of the solutions to tackle the effect of climate change, water scarcity, etc. which are the prime reason for the decline of agricultural products and increase in their price. In recent year, many works have presented innovative ideas and prototypes which can be used for IoT-based smart farming. This article presents a comprehensive review of the cutting-edge technologies and advancements in the field of IoT-based smart farming. This article also presents a discussion on the IoT-based commercial products developed for smart farming. Based on the review of these exiting works and commercial products, some key challenges and future scope of research in this domain are found and presented in the article.

Keywords Smart farming · Internet of thing · Smart agriculture · Wireless sensor network

1 Introduction

Agriculture methods and practices have played an important role in the development of mankind. As per [1], the development of agricultural methods helped the human population to grow at a faster rate than the human population could have grown depending upon hunting and gathering methods. Agriculture not only supports the growth of mankind but also provides livelihood and employment opportunities to the people. As per [2], in 2018 more than 50% of the Indian population was dependent on agriculture for work and this alone contributed to countries 17–18% of Gross Domestic Product. In India, around 58% of the population rely on agriculture as a primary source of livelihood [2]. This shows that agriculture also plays an important role in the economic growth of any country.

In recent years, the quality and productivity of agricultural products have declined. Many factors have directly and indirectly affected crop productivity. Some of these major factors which affect crop production as listed as follows:

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- Climate changes: Climate changes and agriculture are two inter-related terms. Climate changes directly and indirectly affect the productivity of an agricultural land [3–5]. Climate change due to global warming has already affected the growth of crops. Change in average temperature, rainfall, extreme weather conditions like hail storms, dust storms, heatwaves, etc. due to global warming have directly affected the nutrition quality of the soil, pests, and diseases, water level of ground, sea, and ocean, etc. [6, 7]. According to a survey presented in [8], climate change in India has affected agricultural soil by degrading the soil. Soil degradation is primely caused by methods which include 93.7 by water erosion, 9.5 by wind erosion, 5.9 by salinity and alkalinity, etc. As per [9], further climate changes will have an adverse effect on the crop productivity in the countries at the Lower altitude and may have a positive or negative impact on the productivity of the crops of the countries in the northern altitudes.
- Scarcity of Water resources: Water is an essential resource required by the plants and for cultivation. Current farming methods heavily depend on water resources which also causes a high level of soil erosion and reduces the fertility of the soil. Also, with the changing climatic condition, the scarcity of water has been a major problem. Many areas have already faced a drought-like situation. Therefore, current and traditional farming methods can not be used for a longer duration of time, and new state of the art methods are required.
- Energy dependency: Energy also places an important role in the amount of agriculture output and profits earned by farmers on agricultural products. At present time, the majority of this energy requires in an agriculture field comes from fossil fuels. Most of the energy is directly used in the agricultural field in the form of lubricants and fuel for vehicles and machinery. Whereas, as indirect consumption, these sources of energy are used in the manufacturing of fertilizer, pesticides, and other farm machinery [10]. Concern towards the storage of fossil fuels has already started [11]. As these products decrease the price of these products will increase. This will lead to an increase in the cost of farming and a decrease in agricultural outputs.
- Use of Pesticides and fertilizer: Excessive use of fertilizer and pesticides which are used to control the weeds and other diseases in plants, may result in crop damage and diseases in crop productivity. As per the world health organization, more than three million pesticide poisoning cases were reported in 1992 which killed approximately two lakh twenty thousand [12]. Therefore, researchers suggest using alternative methods to increase the productivity of crops such as crop rotation, push-pull agricultural pest management, etc [13].
- Animal attacks: Crop damage by the animal attack and human conflicts with the wild animal is a major issue. The prime cause for the increasing conflict between animals and human is the socio-economic activity of the human [14]. Because of such activity, forest cover is slowly reducing which leaves the wild animals with smaller habitats and less food. As a replication, animals have to feed on the crops in the agricultural field. Thus increase the probability of conflicts with humans. Table 1 presents the percentage of crop damages by wild animals discussed in survey reports conducted in India, Italy, and Nepal.

Advances in the field of technology have helped to upgrade traditional agricultural methods. These advanced methods can help in optimizing the use of resources, predict the environmental condition, reduce man-power, predict heath, characterize the type and family of plant, etc. [18–21]. Hence, improve the productivity and quality of crops

Table 1 Crop damage cause by wild animals [15–17]

Country	Wild animal	Crops	% Damage
India	Elephant	Coconut, plantain, paddy	72
	Gaur	Mulberry, sandal	62
	Sambar	White sapota	17
	Wild boar	Tapioca, tubers, Paddy	16
Italy	Wild boar	Cereals	46.48
		Vineyards	13.71
		Durum Wheat	13.84
		Hazelnuts	12.92
		Grassland	11.62
		Sunflower	8.62
		Chestnuts	3.26
Nepal	Monkey, Porcupine, Goral, Deer, Bear	Maize	38.9
		Potato	29.6
		Millet	18.6
		Wheat	6.7
		Paddy	3.8
		Pulses	0.23

and reduce the cost of production. One such upcoming technology is the Internet of Things (IoT). IoT is a concept in which multiple things or objects are connected over the internet to perform a specific task by communicating with each other. IoT-based agriculture or farming is generally known as smart farming or smart agriculture. Smart farming has come up as a major solution that can help in increasing the productivity, quality, and quantity of crops at a reduced cost and damages. It could also help in optimal use of resources hence it can also be referred as 'sustainable farming'. Many works have suggested ideas, prototypes, etc. which can be used to practice smart farming.

In this article, a literature review on the advanced IoT technology based on smart farming methods presented in recent years has been conducted. An extensive review on literature from the year 2017–2020 were carried out and the work presented in these literature are discussed in brief. Apart from this literature, some commercial IoT-based smart farming products are also reviewed and their advantages, usage, and cost have been discussed in this article. Based on these reviews, some further challenges and research gaps that can be addressed in further research works are drawn out. These research gaps are also discussed in this article.

Further, this article is structured as follows: Sect. 2 presents an overview of the Internet of Things technology and its architecture. Section 3 presents a discussion on the application of IoT in smart farming followed by Sect. 4 which presents a review on the existing literature related to the works in this domain. Next, a review of some commercial products on IoT-based smart farming is presented in Sect. 5. Section 6 presents a discussion on future challenges that can be addressed. Lastly, Sect. 7 concludes this article.

2 Internet of Thing: An overview

The concept of IoT was first introduced in 1982 when a modified coke machine was connected to the internet. This machine could report the drink contained and whether the drink is cold or not [22]. Later, Mark Weiser in 1991 gave a contemporary version of IoT in ubiquitous computing [23]. In 1999, Bill joy gave a clue of the device to device communication whereas Kevin Ashton proposed the term "Internet of Thing" [24, 25].

Since then, IoT has come up as a revolutionary technology in the modern wireless communication network [26]. It has been applied to a variety of fields including industries, transportation, healthcare, vehicles, smart homes, agriculture, etc. [27]. Though there is no proper definition for IoT, but, as per International Telecommunication Union (ITU), IoT can be defined as "a technology that mainly resolves the interconnection between human to a thing, thing to thing and human to human" . In simple words "IoT is concerned as the interaction between a variety of physical objects and things using the specific addressing scheme to be connected to the internet" [28].

As the definition suggests IoT is the interconnection of things over a network, it is assumed that by 2020 more than 25 billion things will be connected to the internet [29]. The TCP/IP protocol adopted in the 1980s [29] could not handle such a big network. This caused the need for a new architecture that could provide security and quality of service apart from supporting the existing network applications. With data security and privacy in mind, a number of multi-layer security architectures were proposed. This multi-layer security architecture includes three key level [30], four key level [31], five-layer [32] and six-layer [33] architecture. Figure 2 presents the structures of these different IoT architectures. Among these different multi-layered architectures introduced for privacy and data security, a six-layer security architecture is presently being used. The six layers included in this architecture are described below (Fig. 2):

- Coding Layer: The first layer also known as the foundation layer is the coding layer. In this layer, a unique ID is provided to each object. These unique IDs help to ease the decern the objects.
- Perception layer: This layer acts as a device layer in the architecture of the IoT which gives physical meaning to each object. This layer consists of different data sensors like RFID tags, IR sensors, motion sensors, temperature sensors, etc. These sensors are able to sense useful information such as temperature, humidity, speed, location, movements, etc. of the objects. All the information of the objects gathered by these sensors is converted into digital signals which are passed on to the network layer for further actions.
- Network layer: This layer acts as a communication network between the perception layer and the middleware layer. All the useful digital information of the object gathered by the sensors are transmitted to the middleware layer using the devices used in the network layer. The most commonly used devices in this layer are WiFi, Bluetooth, WiMax, Zigbee, 3G, 4G, GSM, etc. During the transmission of the data protocols such as CoAP, XMPP, MQTT, DDS, etc. are commonly used. A comparison of different communication technologies used in IoT is presented in Table 2. Further, a comparison on the ranking of the commonly used IoT communication protocol is presented in Fig. 1
- Middleware Layer: All the information received from the sensor devices is processed in this layer using some intelligent tools. These intelligent tools included in IoT middleware layer may include systems such as Hydra, global sensor network (GSN), google

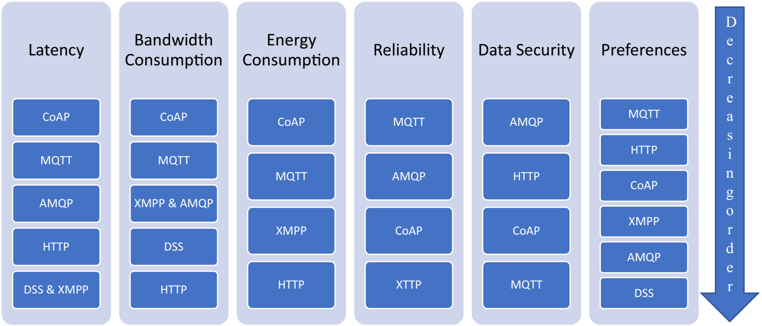

Fig. 1 Comparative analysis for communication protocols

fit, Xively calvin, UBIWARE, UBIROAD, sirena, etc. [34, 35]. Not only this layer helps in processing the information which used to generate some automated actions but also helps in device management, content awareness, security related tasks, etc. [36, 37]. This layer also includes technologies such as cloud computing and ubiquitous computing which help in accessing the database. This easy access to the database helps in storing all the processed information in a database.

- Application Layer: This layer can help in the large-scale development of the IoT network. This layer on the basis of the processed data can realize the application of IoT for different kinds of industries which includes smart farming, smart homes, smart transport, etc.
- Business Layer: All the applications, services, and research related to the IoT networks are handled by the layer.

2.1 Role of Database in IoT Application

IoT is not only about things and their interconnections. It is also about the data collected from these things [40]. Since, the concept of IoT is introduced, billions of devices have been connected with the internet to provide smart connectivity between the users and the environment [41]. Whereas, it is estimated that many more devices will be connected to internet in the coming years. With this enormous growth in the number of devices connected to the internet over the year, the amount of data generated by these devices has also increased. A simple example of this is an IoT-based ambient humidity sensors or air conditioner sensor which are installed in different smart cities to acquire the data on the humidity and temperature of the live atmosphere. These sensors have the capability to generate large amount of data in just few minutes [40]. The data generated by the sensors are generally stored processed, visualized and used for making valuable smart decisions. Like in the case of the above example, based on the data, the temperature of the air condition can be increased or decreased automatically. Further, many organizations rely on these data to provide better user experiences, to make smarter business decisions, and ultimately fuel their growth. Some example of this are organization such as amazon, google, etc. which introduced products such as Alexa (amazon) https://www.alexa.com/, Google assistance (Google) https://assistant.google.com/ provides the support of smart homes, etc.

Table 2 Comparison of different communication technologies used in IoT [28, 35, 38, 39]

Parameters	Frequency band	Data rate	Range	Energy Consumption	Cost	Security
Wi-Fi	5–60 GHz	1 Mb/s–6.75 Gb/s	20–100 m	High	High	WEP, WPS, WPA2
WiMAX	2–66 Ghz	1 Mb/s–1 Gb/s	50 Km	Medium	High	AES, 3DES
LR-WPAN	868/915 MHz	40–250 kb/s	10–20 m	Low	Low	–
Cellular	898 MHZ, 2.4 GHz	2G:50–100 Kb/s 3G: 200 Kb/s 4G:0.1–zGb/s	Cellular area	Medium	Medium	RC4
Bluetooth	2.4 GHz	1–24 Mb/s	8–10 m	Very low	Low	EO Stream AES 128
LoRa	868/900 MHz	0.3–50 kb/s	30 Km	Very low	High	AES
SigFox	868/902/902 MHz	0.1–0.6 Kb/s	High	Very low	Medium	Partially addressed
NB-IoT	800/900/1800 MHz	26–66 Kb/s	High	Low	High	UDP
Z-wave	800–900 MHz	40 kb/s	100 m	Medium	Medium	AES-128
ZigBee	2.4 Ghz	20–250 kb/s	10–100 m	Medium	Medium	AES
RFID	120 KHz–10 GHZ	1 kbps	10 cm–200 m	Very low	Very low	RC4

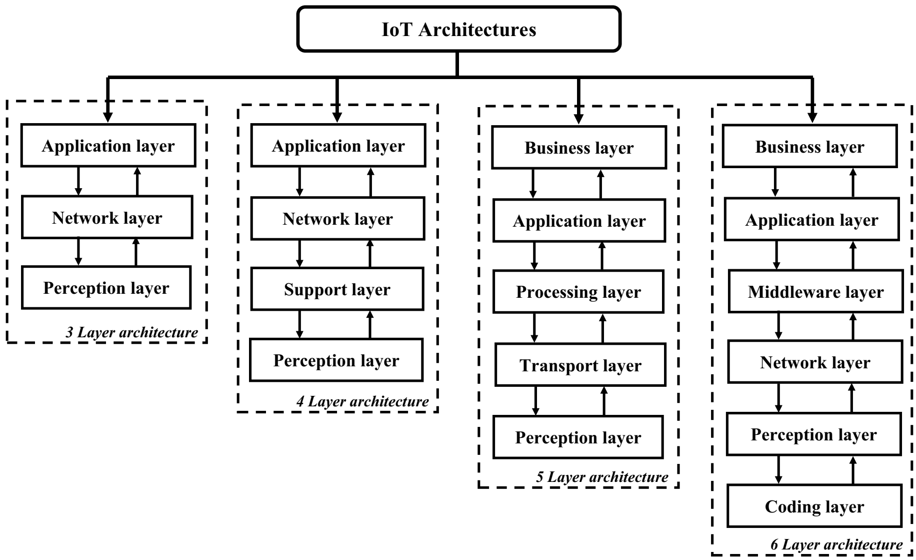

Fig. 2 Different IoT architectures

Because of the huge data generated by IoT devices, handling and managing this data is a challenge and requires a database which is highly reliable, scalable, diverse and heterogenous [42]. The existing traditional relational database management system such as Oracle, MySQL, etc. are generally not suitable for this job because of the following reasons [43, 44]:

- Traditional database systems obtain a vast volume of data from finite and predefined sources, which is then stored in scalar form according to strict relationship normalization laws. Whereas, in case of IoT, there are a vast and increasing number of data sources which include sensors, RFIDs', and embedded devices, etc.
- In case of IoT database management system, use of strict relational database scheme and a practice of relational normalization can be replaced by unstructured and more flexible forms of structures as it helps in adapting with different types of data and to different complex queries.
- Traditional database management systems are capable in handling the storage, retrieval and update of the basic data items, records and file. Whereas, in case of IoT, these systems should have the capability to handle online data along with support of storage, logging and abilities for online analysis.
- The queries and updates which are occasional in the traditional DBMS, are more frequent and with more requirements in case of IoT.

Apart from the above mentioned drawback of the traditional database management system, these systems have many properties which has helped to create a reliable database management system for IoT application. These properties include the use of remote storage at the object layer, support for unstructured data, relaxation of ACID (atomicity, consistency, isolation, durability)properties to ensure consistency, availability, and integration of data.

As a solution to the relational database scheme, new technologies such as NoSQL, NewSQL, etc. have been introduced [45]. Among these new technologies, NoSQL database management system which emerged in late 2000s, are being commonly used to handle unstructured data [40]. NoSQL systems are referred as the non-relational database management system which have the capability to handle this huge amount of data generated by IoT devices in team of storage, search and analysis. A wide range of NoSQL systems are available in the market which are also open to all. Some of these popularly used database systems are MongoDB, HBase, CouchDB, Cassandra and Redis [46]. As different database management system are available, proper choice of the database is also necessary. Therefore, [46, 47], presented a comparative study on features such as process time, scalability, etc. which can help researches in making a choice of a proper database system for IoT application. A summary of this work is presented in Fig. 3 Further, a comparative study on the features of top five time series NoSQL databases used for IoT application is presented in [40]. In [48], to see the superiority non-rational database system over rational database system, a comparison between MySQL and MongoDB is presented. The comparison presented in [48] shows that non-rational database systems are better compared to rational database system in some accepts while requires improvements in some other .

3 IoT in Smart Agriculture

IoT-connected devices have the ability to constantly monitor the agricultural field parameters and the environment surrounding this field. All the data collected by these devices are stored on a database through the internet. These stored data can be further used by the user for continuously monitoring the field from a remote field location or used for further analysis purposes. This real-time monitoring environment helps to take a proper and precise decision which would help to increase the productivity of the field and at the same time save money, time and converse resources. The graphical representation of smart farming architecture is presented in Fig. 4

3.1 Benefits of IoT in Agriculture

IoT based smart farming can play vital role in the improvement of field productivity when compared to the traditional methods of farming. The benefits and advantages of IoT based smart farming are listed below.

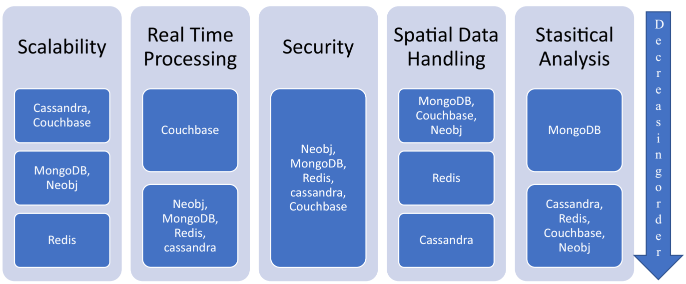

Fig. 3 Comparison analysis of commonly used Database Systems

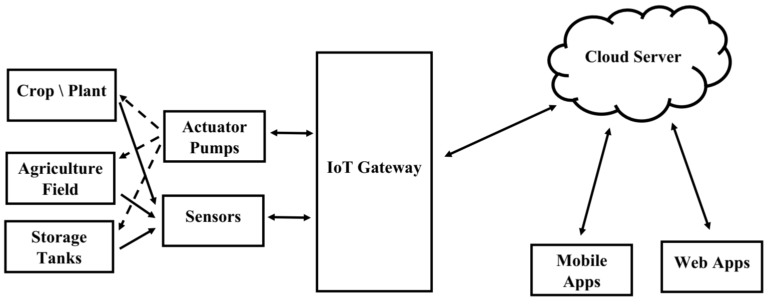

Fig. 4 Smart farming architecture

- With proper monitoring of the soil, farm and environmental parameters, the resources such as water, fertilizers, pesticides, etc. can be effectively used. Further, intelligence tools such as neural networks, deep learning, etc. can help in the optimal use of these resources.
- With proper utilization of the resources, the cost of production can be reduced.
- With IoT, the field area can be effectively monitored. This could help in the prevention of the intrusion of the intruders such as wild animals in the field. This helps in preventing crop damage.
- With proper monitoring of the field parameters, the productivity of the field can be increased which in return increases the profitability of the farmers.
- IoT in agriculture is useful in sustainable farming and also plays an important role in environmental protection.

3.2 Application of IoT in Agriculture

IoT finds a variety of applications in the field of agriculture. Based on the literature review, IoT application in the field of agriculture can be broadly characterized into six categories which are presented in Fig. 5. These six categories are briefly discussed in the following section.

3.2.1 Irrigation Management System

Sustainable use of resources is an important challenge nowadays. In the field of farming, water plays an important role in the production of crops. An IoT-based smart irrigation system is being developed which helps in improving the irrigation management system. These system help in optimizing the use of water in the fields. Smart irrigation systems mainly focus on real-time monitoring, controlling, and weather forecasting.

3.2.2 Pest and Disease Control

Pesticides and fertilizers used in a controlled way help to increase crop quality and quantity. They also help in minimizing the farming costs. To achieve this, constant monitoring of the crops and disease identification is required which is a tough job in the traditionally farming methods. IoT can provide a solution to this problem. By proper monitoring,

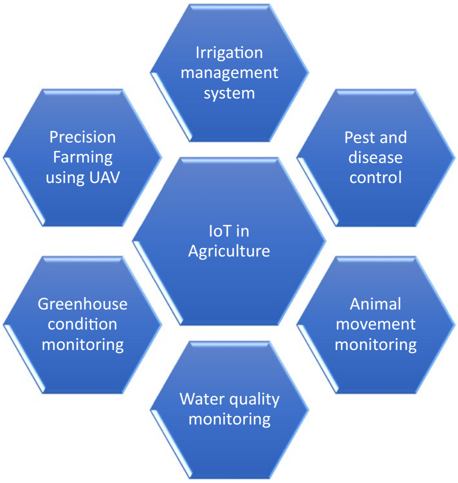

Fig. 5 Application of IoT in agriculture

data processing, etc. one can constantly monitor the plant's health and if required can take appropriate decisions to stop the disease.

3.2.3 Animal Movement Monitoring

Many research articles show that agriculture fields are constantly being destroyed by the movement of animals in the field [15–17, 49, 50]. To avoid this traditionally puppets were used in the agriculture fields to mimic the presence of humans in the fields. But, this method does not guarantee success. IoT-based smart monitoring can be an efficient way to solve this problem. Using IoT the movement of animals into the field can be monitored and controlled.

3.2.4 Water Quality Monitoring

Water quality is another issue that can affect crop health and reduce their harvest. The factors which affect the quality of water are temperature, pH, conductivity, dissolved oxygen, etc. IoT-based water quality monitoring system is slowly coming up as a solution to tackle this problem. These systems can be used to remotely monitor the physical and chemical parameters of the water and control them if necessary.

3.2.5 Greenhouse Condition Monitoring

Other than water and pests, crop health is also related to temperature, humidity, pH, etc. Greenhouse gases have an adverse effect on the climatic condition and thus, directly impact the crops' heath. Therefore, it is important that greenhouse gases are constantly monitored. Different works have presented ideas to remotely monitor greenhouse gases.

3.2.6 Precision Farming Using UAV

In this modern area, unmanned aerial vehicles (UAV) and drones are also finding a place in farming. UAVs and drones can help in precision farming which contributes to enhancing the production of crops [28, 51]. UAVs and drones provide support for advanced monitoring of weather conditions, fields, real-time data analysis, etc.

4 Review on IoT-Based Smart Farming Literatures

Some literature shows that IoT and blockchain technology together has emerged as new technology which can ameliorate the state of the food chain. In [52], a rigorous literature review on the new state of the art development in information security using blockchain technology is presented. Further as per the smart agriculture requirement, a generalized blockchain security architecture with a detailed cost analysis is presented.

In [53], a GSM-based smart irrigation system is presented. This system could help in conserving water and power together. The system senses the parameter such as soil moisture, temperature, and humidity. Depending upon these parameter values, motors outputs, used for controlling purposes, are determined using the fuzzy logic controller. This helps in optimally using the power and water requirement for the equipment and crops.

In [54], a low-cost intelligent smart irrigation system is presented. This system is capable to be used in the greenhouse, garden, farms, etc. This system has the capability which includes admin mode which allows user interaction, and a one-time setup for automatic irrigation management. For the automatic mode, a neural-based smart decision-making system, and real-time remote monitoring. MQTT and HTTP are used for updating users with the field parameters. Neural networks help to estimate the scheduling depending upon the input parameters. This system is tested with crop testbeds such as spinach, beans, carrots, etc.

In [55], an innovative precision farming model named, AgriPrediction is presented. This model aims to help farmers increase productivity with the help of WSN technology, mobile computing, and forecasting strategies. Agriprediction not only helps in real-time monitoring of field parameters but also can predict data. AgriPrediction comprises an Agrimeasure for field data collection, low power wide area network (LoRaLPWAN) gateway for data transmission, and AgriPrediction server for processing and storing data. For data prediction, an autoregressive integrated moving average (ARIMA) model is used which helps in calibrating the data as per the need of the crops. This model is tested on arugula cultivation. It helped to increase the size of leaves by 17.94 and total weight by 14.29 in comparison to the traditional cultivation method.

The conventional judgemental analysis for the remedial option for countering plant diseases and nutrient deficiency to enhance the field production. Therefore, in [56], a multilevel parameter optimized feature selection algorithm incorporated with IoT and Extreme Learning Machine (ELM) is presented. The system presented in [56] is capable to remotely monitor plant disease, nutrients deficiency, humidity, and temperature. The complete process takes place in three phases. In the first stage images of leaves are captured, whereas humidity and temperature are monitored which are stored in a database using wi-fi and Bluetooth. The data are normalized using multilevel parameter optimization techniques i.e. genetic algorithms. In the last phase, plant diseases and nutrient deficiency are classified using the ELM classifier. As per the classification, the quantity of fertilizer to be supplied to a specific field is finalized. This system is tested on a standard high dimension biomedical dataset and real-time leaf disease dataset. The system showed an accuracy of 9.52 and 5.71 in classification and minimized 58.50 and 72.73 features respectively for the two datasets.

In [57], the authors presented a smart agriculture system based on deep reinforcement learning. The proposed model is built in four layers, namely an agriculture data collection layer, an edge computing layer, agriculture data transmission layer, and a cloud computing layer. The intelligent information computing technique helps in determining the amount of water needed for the crop so that crop health is good. This system improves crop growth and increases food production.

In [58], an automated low-cost IoT-based fertilizer intimation system is presented. This work also presents a design of a new novel nitrogen potassium and phosphorus (NPK) sensor which is used to monitor nutrients present in the soil. All the sensor data are sent to the google cloud server for further processing. To detect the deficiency of the nutrients in the soil, the fuzzy logic concept is used. To compute the quantity of fertilizer required for the soil to maintain its nutrients level, Mandani Fuzzy inference system (FIS) is used. The concluded amount of fertilizer required is sent to the user via message alerts. This designed system is tested on three types of soil which are mountain, desert, and red soil.

In [59], the authors proposed a cloud-enable CLAY-MIST measurement index based on temperature and relative humidity which could assess the comfort level of a crop. The presented method extracts the comfort level by subtracting the relative humidity with the constant optimal temperature which is determining based on the amount of water vapour and pressure in the air which appraises the plant growth. This method is tested in real-time. The results were found to be 94% accurate with comparative less execution time when compared with thermal comfort technique.

A Wireless sensor network and IoT-based system for precision agriculture are discussed in [60]. WSN is used to monitor ambient parameters like humidity, temperature, soil moisture with a prior ten days weather report. This system stores all the information to a server that can be accessed by a user via the website and mobile application. For the design part, this system comprises KIANI sensor nodes which are developed by SIXAB and IZU-WSN research lab, a Texas Instruments $CC1101$ processing unit, transceiver processing unit, and Rpi3. For powering the unit, a rechargeable battery is used.

To optimally utilize the water, an IoT-based smart irrigation management system is presented in [61]. This presented system can predict the irrigation requirement of an agriculture field. depending upon ground parameters like soil moisture, soil temperature, environmental condition, and weather forecasting. The data are collected over the cloud and it can be monitored via web services. The system is equipped with a smart algorithm that works as closed-loop control and makes the system a fully autonomous irrigation system.

To detect Gramineae weeds in a rice field, a new method to fuse low resolution multispectral and high-resolution RGB image is presented in [62]. The images are taken using a fixed-wing UAV at an altitude of 60 to 70 m. Further, a neural network detection system is used for weed detection. To evaluate the performance of the method, the percentage of detected weed area M/MGT index and precision of weed detection i.e. MP index are used. These indices showed that the best weed detected had a M/MGT index of 80-108% and MP of 70-85%

Energy cost is an important issue that affects the profitability of agriculture holding. In [63], a real-time model called smart photovoltaic irrigation manager (SPIM) is presented to address this issue. SPIM is developed to synchronize the photovoltaic power availability with the energy required to pump the irrigation requirements of different sectors of the irrigation networks. To calculate the key management variable of this system, daily irrigation requirements, hydraulic behavior of irrigation network, instantaneous photovoltaic power production, and daily water balance are observed. During the deficiency of the photovoltaic power, the system maintains the balance by either water stored in soil or extending the duration on the following day. The system is tested in real olives orchards in southern Spain. The system provided enough water and avoided the emission of 1.2 tons of CO_2.

In [64], an IoT-based smart irrigation and fertilization system is presented. This developed system aims on improving the field yield by properly scheduling the irrigation and fertilization of the agricultural field depending on the current crop requirements, environmental conditions, and weather forecasting. To efficiently use fertilizer, the system spreads the fertilizer near the roots of the crops. The field parameters can be monitored using a mobile-based application. This system is tested on chili cultivation.

In [65], an IoT-based smart monitoring system for smart farming is presented. This system is equipped with different features like temperature sensing, moisture sensing, irrigation facilities, intruders scanning, and GPS-based remote monitoring and controlling. For the process of data and controlling the parameters, this system uses a PIC16F877A microcontroller. This system is capable in sending alerts to the user when some control action is required. Further, a detailed description of the field data is provided to the user which can be accessed using a mobile application.

In [66], IoT-based system named agro logger has been presented. Agro logger is a water management, crop monitoring, and pesticide control system. Agro logger consists of an Arduino mini pro microcontroller, sensors like temperature sensor, moisture sensor, pressure sensor, humidity sensor, and light sensor and actuators. All the equipment is connected with Xively via wi-fi communication modules. This system provides automatic and manual control support. For manual control, android application support is provided. All the data from the sensors are stored on the cloud server.

To prevent crop damage caused by wild animals, an IoT-based wireless sensor network system is presented in [14]. The system is equipped with a PIR sensor, sound generators, flash generators, and RF modules. Once the intrusion detectors detects movement of wild animals, the data are sent to a central control node which generates sounds and flashes to divert wild animals away from the field. The live status of the field can be viewed using a graphic user interface display. This system is tested in a laboratory and in a small village near Sasward, Pune India.

Krishna et al. [67] investigated a robot-based smart farming system. This robot is equipped with various sensors, speakers, solar panels, cameras, Zigbee, etc. which helps it to monitor and control soil parameters, plant health, and scan for intruders such as birds and animals. The robot can be controlled and programmed from a remote location using a personal computer.

In [68], a smart greenhouse system is presented. This system aims at the real-time monitoring of key parameters which include temperature, humidity, moisture, CO_2, and light intensity. This system can automatically control these parameters based on the reference value and also support manual control options for the users. All the information acquired from the sensors is stored on the cloud which can be accessed by the user from a remote location.

In [69], monitoring of farmland using UAVs has been presented. The authors have developed a lightweight UAV with an installed camera which can perform actions such as detection of vegetable, extract features of plant and classify them. This system could help to estimate the distribution of the crops and weeds in the field. The overall system could increase the productivity of the field and reduce the use of herbicides and pesticides. This developed system is tested in two locations, one in Germany and one in Switzerland. The system could efficiently analyze the field and classify individual plants in the field.

A study to increase agricultural productivity and minimize water consumption using modern technology is presented in [70]. This system consists of a variety of sensors, pumps, ZigBee, room heaters, cooling fans, micro-controllers, cameras, etc. which are used to monitor all rounds of parameters within the field and crop storage facilities such as a warehouse. The proposed system also comprises robots that help to monitor crop's health. These robots also help in monitoring the intruders' movement such as birds and animals. The system is equipped with automatic and manual control options which helps to maintain the parameters of the field and the warehouse.

Some of the other works presented in various literature presented in reputed conferences are presented in Table 3. Further, a comparison of the hardware platform used to design IoT based smart farming prototypes is presented in Table 4.

5 Review on IoT-Based Smart Farming Commercial Products

Apart from the literature which discusses innovative ideas on how IoT can be used for smart farming, many commercial IoT-based smart farming products have come up and are being used worldwide. In this section, some of the existing IoT-based smart farming systems briefly discussed. Further, a comparison of these systems based on some of the key features is presented in Table 5.

5.1 Botanicalls

Botanicalls (https://www.botanicalls.com/) is a smart farming system that helps users remotely monitor their farms. It uses sensors and an ATmega 368 microcontroller. Based on the measured data, this system request assistance by sending alerts via calling or messaging to a user. This system also updates the status of the plant on social networking sites like Twitter which can be viewed by the user.

5.2 Edyn

Eden [71] is a fully automated smart grading system. This system includes sensors like soil moisture sensor, humidity sensor, temperature sensor, and acidity sensor. This system is powered using solar energy to provide an uninterrupted power supply. It can provide recommendations to the user on the type of fertilizers, amount of water, etc. to be provided to plants so that the health of the crop can be maintained. For controlling the moisture content of the soil, automatic valves connected with the sprinkler system are provided to the system. All the data received from the sensor are collected and stored in a database provided by Edyn cloud services. Users can access all the data using the cloud server on a mobile application. This enables real-time monitoring of the plant and soil health.

5.3 Parrot: Flower Power

Parrot [35] is equipped with integrated sensors that can monitor parameters such as sunlight, ambient temperature, fertilizer, and soil moisture level. To establish a communication network, bluetooth communication protocol is used. A parrot can measure parameters in a precise manner and comes in the form of plastic stalks. The sensed information is sent to the user's phone.

Table 3 Description of the work reported on IoT application in Smart Agriculture

Sr. no.	Article	Focused application	Brief description
1	[72]	Animal Movement Monitoring	This system can help in detecting the intrusion of wild animals in the field
			This system uses of four pillar placed at the corners of the field
			Each pillar is equipped with electronic sensors, buzzers, laser detectors, RF transmitter and a microcontroller
			An alert signal is send to the user from the transmitter node using Energeia IDE once animal movements are detected
			Buzzers also gets activated to divert the animal away from the field
			This system could reduce crop damage by less than 5%
2	[73]	Irrigation management system	This device uses different sensor to measure soil parameters
			The system uses can automatically control soil moisture
			All the field information are store to a open source cloud server provided by Thinkspeak
			User can remotely monitor the store parameters for a remote location
3	[74]	Irrigation management system	The system uses an ardunio microcontroller which makes it cheaper
			Parameters like soil moisture, pH and temperature can be detected
			Sensor data are stored to cloud server for which ESP8266 WiFi module is used
			An open source IoT platform Thinger is used as a cloud server
			Automatic control actions are performed based on the threshold value
4	[75]	Irrigation management system	Another Ardunio microcontroller based smart irrigation system is presented
			This system is capable in detecting soil moisture and water level of the tank
			This system can automatically control moisture level of the soil only
			The sensor data are stored to an open source cloud server provided by Thinkspeak
			The data can be monitored via Thinkspeak smartphones application or website

Table 3 (continued)

Sr. no.	Article	Focused application	Brief description
5	[76]	Irrigation management system	This system comprises of different sensor nodes and a master node
			Sensor node are equipped with different sensors, Atmega328 microcontroller and a relay
			Sensor nodes communicates with master node using ZigBees
			At the master node all the data are send to a cloud server where the data received are processed and control signals are generated which are send back to master node
			For remote monitoring, a mobile application is provided
			Apart from automatic control option, user can choose for manual control
			In manual control, user gets the updates of the field parameters which the controlling actions are to be performed by the user manually
6	[77]	Greenhouse conditioning motoring	The system aims to monitor two important environmental parameters, temperature and humidity
			The methodology used to monitor the parameters includes a temperature sensor (TMP007) for measuring temperature and humidity sensor (HDC1010) for measuring the humidity
			For IoT development, a CC3200 programmable Wi-Fi MCU chips is used
			The setup also uses camera for taking the pictures
			If the sensor notices any abnormal reading, alerts are sent to the user so that user can take appropriate actions
7	[78]	Irrigation control system	This prototype includes a LM35 temperature sensor and a soil moisture sensor to monitor the temperature and moisture level of soil respectively , a RPi 3 model B, IC 3208 converter, relay and buzzer
			The prototype is equipped with automatic control features which help to control the soil moisture by controlling the motors
			For remote motoring, data are stored at cloud can be accessed via mobile and PC
			User gets an alert message when motors are turned ON/OFF

Table 3 (continued)

Sr. no.	Article	Focused application	Brief description
8	[79]	Irrigation control system	This system can help in decreasing the water loss, labour efforts and improve the productivity of crops This system includes a digital soil moisture sensor, Ardunio microcontroller, wi-fi module and pump All the sensor information are stored to a cloud server using on board wi-fi modules As per the crop requirement, a threshold moisture value is set which helps in automatic control actions This system is quite useful in the conservation of water
9	[80]	Irrigation control and animal movement monitoring	This smart agriculture system can monitor soil parameters and detect movement of animal's This system is equipped with various sensors, relays, motors microcontroller for motoring purpose An ESP8266 wi-fi module and a GSM module for 2G, 3G and 4G services are provided for communication and data storage on a cloud server An android mobile application is interfaced with the system which helps the user in real time monitoring and controlling of the parameters Users also gets alert if any animal movement is detected
10	[81]	Irrigation management system	This system aims to optimize the use of water consumption and maintain ambient parameters This system includes WSAN components, ZigBee for communication, cloud support and user application The information obtained are transmitted to cloud server using on board GPRS All the data saved on the cloud server can be remotely monitored using the user applications
11	[82]	Irrigation management and pest disease control	This remote monitoring system is capable in monitoring soil chemical properties along with moisture and temperature This system can optimize the use of fertiliser and reduce the risk of crop failure The soil is characterised on the basis of pH value where it is alkaline or acidic Sensor information are transfer to the user mobile phones via Bluetooth and based on the data received user can act on the fertilization of the soil A STM32 Board is used for designing this system

Table 3 (continued)

Sr. no.	Article	Focused application	Brief description
12	[83]	Irrigation management and precision farming	This real time monitoring system helps in monitoring soil parameter like pH, temperature and humidity
			This system based on the soil and environmental properties can suggest the crop which is suitable for cultivation
			Sensors are interfaced with MCP3008 and ARM11 microcontrollers and all the information collected are sent to cloud server using Wi-Fi
			Base value are set which help the system to automatically control the parameters
13	[84]	Greenhouse condition monitoring	This proposed system is capable in monitoring the changes in factors like temperature, humidity, soil moisture using different senors
			All the sensors are integrated to Raspberry pi
			All sensor data are stored to a MySQL database which later can be used for further analysis
			User can remotely monitor the field parameters through mobile application
			Mobile application also updates the user (basically farmers) with latest agricultural updates of schemes and news, market crop rates, weather information, Government Market crop prices, etc
14	[85]	Precision Farming using UAV	In this work, authors investigated the use of multiple UAVs in smart farming using a swarm control algorithm
			To evaluate the performance, four experimental cases are investigated using seven performance indices which are total time, flight time, setup time, battery consumption, inaccuracy of landing, haptic control and converge ratio
			Upon the investigation, the authors showed the multi-UAV system is quite superior to a single UAV system

Table 3 (continued)

Sr. no.	Article	Focused application	Brief description
15	[86]	Precision Farming	In this work, authors suggested a planned agriculture system which can use resources in a reasonable manner They considered precision farming system as a multi-agent system with multiple mission plans such as expected benefits, energy consumption, etc These missions are treated a multi-objective optimization problem and a hybrid genetic algorithm and particle swarm optimization is present to solve the objectives The simulation results presented show an efficient resource optimization Further, the approach is to be tested in real scenario

Table 4 Different hardware platform used to develop IoT devices for smart farming [35] (https://www.arduino.cc/, https://www.raspberrypi.org/)

Parameter	Ardunio Mega 2560 REV3	Ardunio Uno	Ardunio Nano	Intel Galileo	Intel Edison	Beagle Bone Black0	Raspberry pi 4	Raspberry pi B+	Raspberry pi zero	ARM Mbed NXP LPC1768
Processor	ATMega2560	ATMega328P	ATMega328P	Intel Quark SoC X1000	Intel Quark SoC X1000	ARM Cortex-A8	Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz	Broadcom BCM2835 SoC based ARM11 76JZF	Broadcom BCM2835 ARM11 Core	ARM Cortex M3
GPU	NA	NA	NA	NA	NA	Power VR SGX530@520 MHz	VideoCore IV Multimedia @ 500 MHz	VideoCore IV Multimedia @ 250 MHz	NA	NA
Operating Voltage	5V	5 V	5V	5V	3.3V	3.3V	5V	5V	5V	5V
Flash Memory	256 KB	32 KB	16 KB, 32 KB	8 MB	4 GB	4 GB	NA	NA	NA	512 KB
EEPROM	4 KB	1 KB	512 B, 1 KB	8 KB	NA	NA	NA	NA	NA	NA
Clock Speed	16 MHz	16	16	400	100	1 GhZ	1.5GHz	700	1GHz	96
Bus Width	8	8	8	32	32	32	64	32	32	32
System Memory	8 KB	2 KB	1KB, 2 KB	256 MB	1 GB	512 MB	1, 2 GB, 4GB	512MB	512MB	32KB
Communication Supported	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	802.11ac Wi-Fi / Bluetooth 5.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial

Table 4 (continued)

Parameter	Ardunio Mega 2560 REV3	Ardunio Uno	Ardunio Nano	Intel Galileo	Intel Edison	Beagle Bone Black0	Raspberry pi 4	Raspberry pi B+	Raspberry pi zero	ARM Mbed NXP LPC1768
Development Enviornment	Ardunio IDE	Ardunio IDE	Ardunio IDE	Ardunio IDE	Ardunio IDE, Eclipse, Intel, XDK	Debian, Android, Ubuntu, Cloud9 IDE	NOOBS	NOOBS	NOOBS	C/C++ SDK, Online Compiler
Programming Language	Wiring	Wiring	Wiring	Wiring, Wyliodrin	Wiring, C, C++, NodeJS, HTML5	C, C++, Python, Perl, Ruby, Java, NodeJS	Python, C, C++, Java, Scratch, Ruby	Python, C, C++, Java, Scratch, Ruby	Python, C, C++, Java, Scratch, Ruby	C, C++
I/O Connectivity	SPI, I2C, UART, GPIO	SPI, I2C, UART, GPIO	SPI, I2C, UART, GPIO	SPI, I2C, UART, GPIO	SPI, I2C, UART, I2S, GPIO	SPI, UART, I2C, McASP, GPIO	SPI, DSI, UART, SDIO, CSI, GPIO	SPI, DSI, UART, SDIO, CSI, GPIO	UART, SDIO, CSI, GPIO	SPI, I2C, CAN, GPIO
Cost ($)	40.30	23.00	20.70	75.86	71	43.75	35, 45, 55	35	10	51.95

Table 5 Comparison of commercial IoT devices

Sr. No.	Product Name	IoT Capability	Cloud support	App support	Cost of product (approx in $)	Purpose
1.	Botanicalls	Yes	No	No	100	Garden
2.	Edyn	Yes	Yes	Yes	99.99	Irrigation
3.	Parrot	No	No	Yes	60	Garden
4.	Planklink	Yes	Yes	Yes	79	Irrigation
5.	HarvestGeek	Yes	Yes	Yes	–	Irrigation
6.	Iro	Yes	No	Yes	149.99	Irrigation
7.	Spruce	Yes	No	Yes	230 (controller and sensor) 200 (controller)	Irrigation
8.	Open Garden	Yes	Yes	Yes	–	Garden, irrigation and aquaponics
9.	Koubachi	Yes	Yes	Yes	129.99	Irrigation
10.	Niwa	Yes	Yes	Yes	349	Irrigation
11.	Growlink	Yes	Yes	Yes	–	Irrigation
12.	GreenIQ	Yes	Yes	Yes	–	Garden
13.	Smart elements	Yes	Yes	Yes	–	Irrigation
14.	Pycno	Yes	Yes	Yes	-	Irrigation
15.	Sensefly	Yes	Yes	No	-	Precision farming

5.4 Plantlink

PlantLink [35] is a smart farming system that includes wireless sensor links that helps to measure the moisture content of the soil. All the measured data at these links are sent to a base station router. Zigbees are used to establish a communication network. All the information received by the router is stored in the Planklink cloud server. The cloud server provides support features such as plant condition monitoring, schedule automatic watering times, and alert when plants need to water. The alerts are provided to the user via email and SMS. Moisture reading is taken every 5–10 min. The system is equipped with automatic watering valves for watering the plant. The system schedules the watering time based on the local weather pattern to optimize the use of resources.

5.5 HarvestGeek

HarvestGeek [35] is equipped with sensors like air, temperature, soil moisture, ambient light, CO_2 level, etc. which helps to monitor various important parameters of the soil, plant, and the environment surrounding the plant. HarvertGeek is also equipped with a cloud server that helps to store the information received by the sensors and provides real-time monitoring support. Based on the analysis of the data, HarvestGeek can automatically control the parameters. All the information is also shared with the user using message alerts, push notifications, and emails.

5.6 Iro

Iro (https://rachio.com//) also known as Rachio is a smart irrigation control system that is basically designed to control sprinklers automatically. Iro is supported with a WiFi controller. Users can set the information of the expected weather condition from a remote location based on which Iro can control the operation of the sprinklers.

5.7 Spruce

Similar to Iro, spruce (https://spruceirrigation.com//) is a smart irrigation control device. Unlike Iro, spruce is equipped with a soil moisture and temperature sensor. These sensors sense the soil moisture and temperature and save the data on a cloud server. Users get real-time status of the plant condition in smartphones.

5.8 Open garden

Open garden [35] is a versatile device that can be used in three case scenarios, i.e. indoor in house or greenhouse, outdoor in garden or fields, and hydroponics. The open garden also features multiple communication options which include wifi, GPRS, and 3G. An open garden provides cloud support to upload and save data. Sensor nodes are used to collect information and each node can communicate with each other using 433 MHz wireless radio signals. Sensor nodes are equipped with a sensor that collects data such as air, temperature, light intensity, soil moisture (under indoor and outdoor operation), pH, and conductivity of growing medium (under hydroponic operation). The system also supports real-time data visualization which helps users to monitor data. For the controlling part, this system is equipped with actuators that control water pumps, sprinkles, and oxygen pumps. An additional feature of an Open garden is that it supports the user to schedule the automatic settings of the system.

5.9 Koubachi

Koubachi [35] is an application-oriented smart farming system. This system controls the water sprinklers such that the watering of plants can be optimized. Sensor such as soil moisture, temperature, and ambient light are used to measure some of the vital soil parameters. A low-power communication channel and cloud supports are provided with the system. As per the need of a user, the number of sensors and controllers can be connected in a mesh topology which helps each device to act as a transceiver. The valves and sprinklers are automatically controlled and the data can be monitored in real-time using smartphones and tablets from anywhere.

5.10 Niwa

Niwa (https://getniwa.com/) is a smart hydroponic system that can be installed at home. It does not require a yard or garden and can be used indoors. Niwa comes with wi-fi connectivity and cloud server support. The sensor installed in Niwa gives information to the user about the plant needs which can be monitored using a mobile application. Light, ventilation, water level, and humidity are automatically controlled after the analysis of the data received from the sensor. These parameters can also be controlled remotely by users with mobile applications.

5.11 Growlink

Growlink (https://www.growlink.com) is equipped with various sensors like temperature humidity, CO_2, VPD, light level, and soil moisture which helps in monitoring vital parameters of soil and the environment surrounding the field. An IoT controller included in Growlink helps to control these vital parameters. Users can remotely monitor these parameters via the website and mobile application.

5.12 GreenIQ

GreenIQ is a product by Eastern peak (https://www.easternpeak-com) which provides smart irrigation system support. GreenIQ monitors the soil parameter and as per need, it controls the watering. GreenIQ provides mobile application support for the user to remotely monitor the parameters of the garden on a real-time basis.

5.13 Smart Elements

Smart Elements (https://www.Smartelements.io) is a smart device that can be used in smart Agriculture. The sensors used in the smart element helps to monitor soil moisture level, the water level in the reservoir, accurate weather conditions, and temperature. All the data being monitored can be remotely accessed via the website.

5.14 Pycno

Pycno (https://www.pycno.co) is an IoT device that helps to monitor, analyze, and control vital parameters of the soil. Pycno helps in detecting the moisture content, real-time weather conditions, predict disease and health of crops. Pycho comes with website support which helps to remotely monitor and analyze data from anywhere.

5.15 Sensefly

eBeeSQ is an agriculture drone developed by Sense-fly (https://www.senesfly.com) which can be used for precise framing. eBeeSQ helps to monitor the agriculture field and analyze important data such as plant health, weather conditions, etc. eBeeSQ is supported by a compatible flight controller.

Apart from these devices some of the other devices which helps to practice smart farming are Bitponics [71], arable (https://www.arable.com), semios (https://www.semios-com), mothive (https://www.Mothive.com), agrihot (https://www.agrihot.ee), Farmapp (https://www.Farmappweb.com), CropIn (https://www.cropin.com/), Aibono (http://www.aibono.com/), DeHaat (https://agrevolution.in/), etc.

6 Future Challenges

Upon the literature review and going through the commercial products developed to practice smart farming, some future concerns and challenges were found. In this section, these challenges are briefly discussed.

- Cost of the equipment used in the development of smart farming products is a major concern. New state of the art methods are being developed to reduce the cost of the hardware and software used for IoT development. Still, the present works do lack in the domain of cost-effectiveness which can be observed for Table 5.
- Power is another important accept which has to take care of. Power is an essential tool without which the concept of IoT vanishes. All the devices used for monitoring, communication, and storage purposes require energy. Therefore, new state of the art methods should be developed which should be efficient in energy management. Moreover, focus on the use of renewable energy sources should be given.
- Connectivity is another issue in rural areas. Many rural areas don't have reliable and fast internet connectivity. Connectivity issues also increase in dense forests. Therefore, network performance and bandwidth limits should be improved to fix this problem.
- Data security and privacy is also an important issue in the domain of IoT. The system should be secure enough to avoid data breaches, loss, and hacks to provide data security and privacy.
- The IoT systems should be robust enough that they could work appropriately under some faulty conditions. The fault is a major issue that can affect the performance of the overall system. The most common fault which can be faced is the failure of the hardware modules. The system design should be robust enough so that faults can be detected while the system should work accurately with the faults.

- The users of the smart farming devices are generally the farmers who have less knowledge of the technicalities of the complete system. Therefore, the IoT systems should be designed in a user-friendly manner in which the user can easily adapt and work.
- Smart farming IoT devices are generally installed in remote locations. Therefore, the stability and reliability of the communication channels should be ensured.
- All the equipment used for smart farming should be robust enough so that they could withstand the harsh environment such as dust, moisture animal attracts, etc. in the field location of rural areas.
- Data analytic would a further useful tool which can be used to study the behavior of corps, environment, climate, etc. in a particular area. This could help the farmer to predict the type of crops they could grow which may lead to profitability.
- Agriculture support people by providing them with job opportunities. Smart farming reduces manpower which will lead to a reduction of job opportunities. Therefore, alternative employment opportunities must be generated for the people.
- Another issue which should be taken care is the portability of the devices developed to practice smart farming. The final product should be small in size so that it can be easy ported from one place to other. For this reason, system on chip (SoC), System in Package (SiP), etc. should be preferred.
- As discussed in Sect. 2.1, data plays an important role in IoT and a huge amount of data is generated by the IoT equipment. Therefore, the database system should be highly efficient in handling, processing and storing of the data generated by the devices.
- With reference to the above mentioned point, the database system should be able to process the massive amount data generated by the IoT device. For this purpose, efforts should be made to optimize the cost of communication and treatment while maintaining a check on the requirement of storage, application, latency and bandwidth.

7 Conclusion

Internet of Thing based smart farming techniques are become popular in the field of agriculture because of the superiority it plays over the traditional agricultural methods. This article presents a comprehensive literature review on the recent advancement in the in the field of IoT based smart farming. An extensive review on recent literature and commercial IoT based smart farming product is carried out and there contributions and features are discussed in this study. This study thus helped to bring out the advancement in the technologies which has helped to improve the quality of agriculture products and increased there productively. Further, based on the study some key points and challenges which are still lagging in the present works are highlighted in the future challenges section of the article.

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