Chapter 21
Internet of Things (IoT) and Sensors Technologies in Smart Agriculture: Applications, Opportunities, and Current Trends

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Abstract For sustainable agricultural production and timely preparations to mitigate the climate change impacts, innovative modern technologies can be used. These technologies have great potential for monitoring agricultural systems and valuable solutions to combat climate change in order to offset the adverse impacts on agricultural production. Farmers need continuous information throughout the crop life cycle for implementing profitable farming decisions. Internet of things (IoT) is one of the advanced technologies in smart agriculture. IoT is the network of Internet connected devices to obtain and transfer real-time data. Now, the manual and conventional procedures are being replaced with automated technologies globally. IoT is becoming popular in agriculture sector as compared to conventional agriculture due to its distinguishing features such as less energy requirement, good global connectivity, and real-time data collection. On the other hand, device compatibility is the major limitation in IoT but now the solutions are being developed with technological advancements. This chapter focuses on the role of information communication technology (ICT) and IoT in agriculture domain and proposes the benefits of these wireless technologies. Use of IoT technology in smart farming can serve as a solution for several management and decision-making for building climate resilience in agriculture.

Keywords Climate change · Smart agriculture · Internet of things · Sensors · Precision agriculture · E-Agriculture

21.1 Introduction

Nowadays, climate change is becoming one of the most important barriers for agriculture production and sustainability globally. Climate variability has an impact on the number of natural events involved in agriculture such as increased erratic rainfall, temperature rise, more invasive pathogens, heat waves, and floods. (Puranik et al. 2019; Amin et al. 2018; Ashraf et al. 2017; van Ogtrop et al. 2014). Hence, the changing patterns in the trends of environment are compromising the overall success of agriculture along with its sustainability. This global climatic change is predicted to affect global food security by disrupting food production, availability, and quality. For instance, temperature extremes and more erratic rainfalls are dominantly minimizing agricultural production (Malavade and Akulwar 2016; Ali et al. 2019; Ahmed et al. 2014). Increase in the severity and frequency of these climatic events is predicted in the upcoming future. Hence, it indicates more vulnerability to sustainable agriculture (Fig. 21.1). These scenarios lead to the evolution of climate smart agriculture based on smart climate monitoring methods and technologies to increase preparation and sustainability in agriculture (Lipper et al. 2014; Rahman

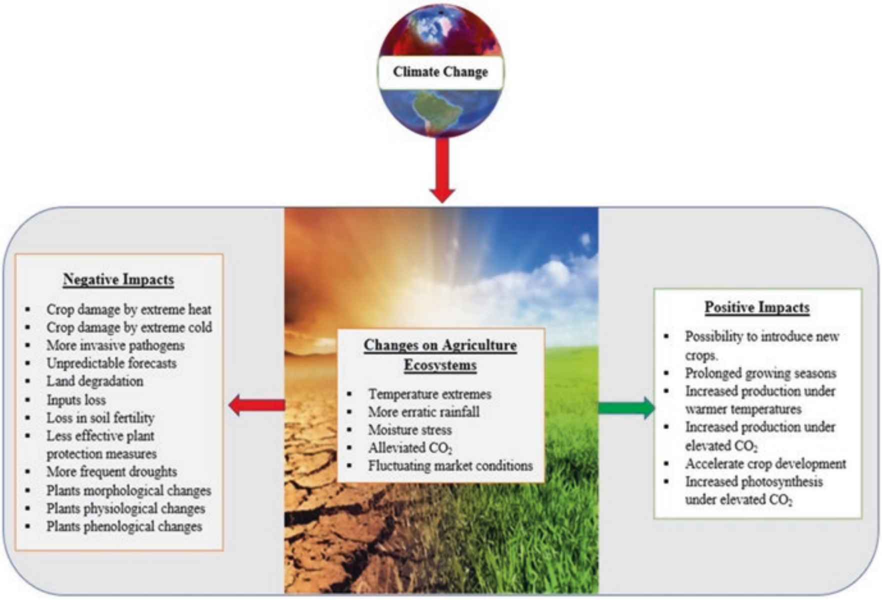

Fig. 21.1 Impacts of climate change on agriculture

et al. 2020; Jabeen et al. 2017; Ijaz et al. 2017). Therefore, to boost agricultural productivity and sustainability, more innovative techniques and technologies are needed to be utilized in agriculture (Ahmed, 2012, 2020a, b, Ahmed and Ahmad, 2019, 2020; Ahmad and Hasanuzzaman, 2020; Ahmed et al. 2013, 2018, 2020a, b, c, d, e; Ahmed and Stockle, 2016; Ahmed and Hassan, 2011). One of these innovative technologies, the Internet of things (IoT) is rapidly developing as an applied technology in wireless environments. Internet of things technologies have great application potential in the climate, food, and agriculture domain especially in the context of climatic challenges faced in these sectors (Patil and Kale 2016). The IoT technologies can transform the agriculture sector by contributing to food security, monitoring farm environments, increasing preparation, and optimizing the agricultural inputs to reduce wastes. However, the success of these technologies is linked with the remarkable change in the culture (Brewster et al. 2017).

Agriculture informatics is referred to as the use of innovative techniques, ideas, and scientific knowledge to expand the use of computer science in agriculture. Information communication technology (ICT) and IoT are used for management, land use, and analysis of agricultural data. Use of IoT and ICT in agriculture is also known as E-agriculture (Gakuru et al. 2009). E-agriculture focuses on enhancing agricultural development by using advanced information and communication technology. It involves development, application, and evaluation of innovative means to use ICT in agriculture (Dlodlo and Kalezhi 2015; Aslam et al. 2017b). IoT is the framework for connecting physical things (like sensor, devices, etc.) to the Internet that enables the monitoring and controlling of the physical world from remote locations (Kopetz 2011). IoT provides an ICT infrastructure to facilitate exchange of things and the main function is to minimize the gap among things in physical world and their representation in information system technology (Weber and Weber 2010).

IoT consists of software, networks, devices, and different types of sensors. There are many reasons that IoT is an efficient technology including (i) Global connectivity (ii) Less human involvement (iii) Communication (iv) Quick access, and (v) Less time consumption.

In developed countries, representation of real-world in ICT systems has been in practice for the last two decades, but the last decade has shown an unprecedented growth of ICT usage in developing countries. In 2015, there were 13.4 billion devices that were connected to the Internet, and there is an expected increase of up to 38.5 billion by 2020 (Research 2015). Now, public services and information are readily available in remote areas. Use of wireless technology has eradicated the waiting periods to undertake vital decisions. Recent advances in technologies have resulted in easy access to networks and more sophisticated, smaller, and economical sensors. Smart agriculture can serve as a solution for agricultural sector problems; farmers can monitor their agriculture sector individually with the help of IoT devices and networks (Abbasi et al. 2014).

The ICT and IoT drivers in agriculture have the advantage of (i) Connectivity and low cost, (ii) Adaptability and affordability of tools, (iii) Data exchange and storage advances, (iv) Innovative models for business, and (v) Demand of information services in agriculture (Nlerum and Onowu 2014). However, in rural areas, there are some barriers that should be addressed by ICTs broadband. These barriers include (i) Distance barriers, (ii) Economic barriers, and (iii) Social barriers (Stratigea 2011).

IoT in agriculture can be used in various scenarios and can enhance agricultural processes. Cloud enabled systems can be used for agriculture data and its uses in simulated systems. By using IoT technology, farmers can get timely knowledge about the recent trends in agriculture. IoT devices can monitor the soil properties, weather variables, plant characteristics, etc. Therefore, it can play a vital role in timely management of agricultural systems under swiftly occurring climate changing scenarios and boosting agriculture production.

21.2 IoT System

This section delineates several components of the IoT system, classification, and development trends (Fig. 21.2).

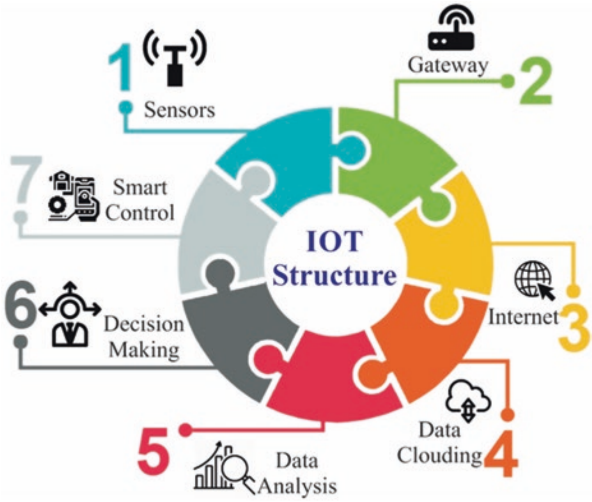

Fig. 21.2 IoT structure

21.2.1 IoT Platforms, Standards, and Protocols

IoT has the potential to grow in the future and many companies (The Yield, Agrosmart, Fieldin, Cowlar, HerdDogg, etc.) are focusing on this technology that is leading to the emergence of solutions and new platforms. Device compatibility is the main challenge that needs to develop solutions for general use. Single board computer device is the main concept for most IoT devices that have sufficient computing power, use open source solution, and have low energy needs. Advanced Reduced instruction set computing Machine (ARM) processor is commonly used in IoT devices. These devices have operating system for both MS Windows and Linux platforms (Dusadeerungsikul et al. 2020; Bacenetti et al. 2020).

21.2.2 IoT Networks

For proper operation of IoT devices, Internet connection is a basic need; mostly this connection is wireless. These connection technologies have different standards and parameters. The common characteristics of wireless connections depend on (i) Energy consumption, (ii) Downlink and uplink data rate, (iii) Size of package, (iv) Range, and (v) Frequency. IoT comprises of many technologies and networks primarily designed for IoT (such as SigFox and LoRaWAN), while on the other hand, it also uses technologies that are developed for other purposes (such as Wi-Fi, GSM, and LTE). Lower energy use is the main feature of IoT designed networks. It is assumed that with the advancement in technology, IoT devices will be enabled to operate for years or decades with only a simple battery (Dusadeerungsikul et al. 2020; Bacenetti et al. 2020).

21.2.3 Classification of IoT Devices

Any Internet connected device falls in the IoT device category. However, there are some other features that are used for further classification of devices, such as (i) Usage purpose, (ii) Internet connection type, (iii) Device or sensor type, and (iv) Energy use (Dusadeerungsikul et al. 2020; Bacenetti et al. 2020).

21.2.4 Trends in IoT Development

IoT has the potential to be used in each area of human activity. Current trends in IoT development are (i) Specific IoT network development, (ii) Reliable security, (iii) Minimal energy use, (iv) Miniature devices, and (v) User-friendly controls, solutions, and settings (Dusadeerungsikul et al. 2020; Bacenetti et al. 2020).

21.3 Wireless Technologies in Smart Agriculture

In smart agriculture, several kinds of IoT devices are used (such as wireless sensors) for the purpose of data collection of environmental and physical attributes (Fig. 21.3). In the agriculture domain, sensors are used for the following reasons:

(i) Weather, crop, and soil monitoring and data collection.
(ii) Fertilizer and irrigation management.
(iii) Increased preparedness to respond to abrupt climatic changes.

However, these sensors or IoT devices utilize some network protocols to transmit the data remotely. In this section, common wireless technologies used for data acquisition and transmission in smart agriculture are presented and compared for distinctive features. Weather monitoring and prediction is becoming more challenging under the current climate changing scenarios. Moreover, these extreme climatic events are severely impacting the agricultural environments and making farming practices harder and vulnerable. Therefore, there is a need to put in place the more effective strategies to combat the increasing food demands and climate variability (Ahmed et al. 2017). Several cellular and wireless technologies have been developed to play a vital role in smart agriculture (Andreev et al. 2015). A new IoT system has been developed on the basis of Long-Term Evolution (LTE) features and is known as Narrowband IoT (NB-IoT). The main functions of this system are to

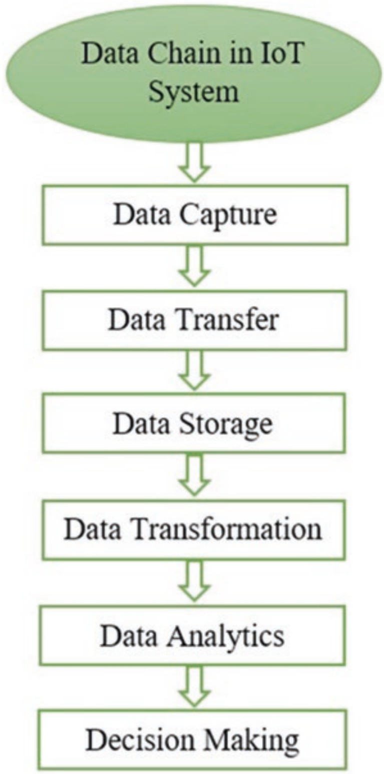

Fig. 21.3 Data chain in IoT

Table 21.1 Comparison of all the wireless technologies

	Range	Cost	Power Consumption
LoRa	5 km	Low	Low
SigFox	10 km	Low	Low
ZigBee	100 m	Low	Low
4G/3G/GPRS	10 km	Medium	Medium
Wi-Fi	100 m	High	High
GPS and BT	10 m	Low	Medium

increase the coverage area and reduce power consumption (Ratasuk et al. 2016). In the future, NB-IoT technologies like Long Range Radio (LoRa) will be used in agriculture on a larger scale due to its lower energy use and enhanced coverage (Table 21.1).

21.3.1 Long Range Radio (LoRa)

This protocol was introduced by the LoRa Alliance. It is a system with wide area coverage and less power consumption as compared to other wireless technologies (Pitì et al. 2017). It consists of LoRa end device, gateway device, and a network server. This protocol is used for moisture, humidity, temperature, and light monitoring in greenhouses and fields as well (Ilie-Ablachim et al. 2016).

21.3.2 SigFox Protocol

SigFox is a narrow band cellular network (Pitì et al. 2017). This protocol was used in a system that was developed for locating animals in pastures and grazing lands. This system is also used for animal tracking in mountains and pastures.

21.3.3 ZigBee Protocol

ZigBee is a wireless, low-cost IoT network technology (Sarode and Chaudhari 2018). Low cost of this technology allows it to be widely adopted in wireless monitoring applications. As an advanced technology, it has gradually become popular and considered as the best choice for agriculture. This technology identifies and obtains real-time data for crops pests, moisture and drought, and transfers data to remote monitoring centers. With real-time information of field data, automated devices can be used for controlling irrigation, fertilization, and pesticide (Cancela et al. 2015). ZigBee can be used up to 100 m effectively (Jawad et al. 2017).

21.3.4 4G/3G/GPRS

These are packet data services used for cellular phones. These modules can be coupled with sensors to control the irrigation to crops depending on weather and soil monitoring (Gutiérrez et al. 2014). It is a cost-effective method for monitoring agricultural information.

21.3.5 Wi-Fi

It is one of the most commonly used wireless technologies in portable devices. Mobile phone applications are connected and used by utilizing Wi-Fi and 3G technologies to monitor and regulate agricultural operations (Chung et al. 2015). However, it requires high cost and power (Mohapatra and Lenka 2016). It can be used up to 20–100 m. This technology can be used in agriculture for weather and soil monitoring in fields and greenhouses.

21.3.6 GPS and Bluetooth (BT)

BT is used for connection and communication between devices like mobiles, laptops, etc. It is used to satisfy various agricultural operations (Ojha et al. 2015). A system was developed to monitor weather, moisture, and temperature by utilizing Global Positioning System (GPS) and BT technologies. The purpose of this system is to conserve water and increase productivity by controlling irrigation (Kim and Evans 2009; Mubeen et al. 2013). BT can be used up to 10 m only. It has been used in agriculture for its lower energy requirements and ease of use (Vellidis et al. 2016). Using this technology, fertilizer and pesticide use and weather and soil conditions can be monitored while irrigation can be controlled.

21.3.7 Crop Simulation Modeling

Modeling is the representation of real systems using equations or sets of equations. Crop simulation models mimic the plant growth and development (Oteng-Darko et al. 2013; Mahmood et al. 2017; Aslam et al. 2017a; Mehmood et al. 2017, 2020). These models simulate plants and environment relationship for yield prediction, decision-making, crop management, and studying the climate change impacts on global food security (Kasampalis et al. 2018; Asseng et al. 2019; Liu et al. 2019). The basic purpose of agricultural model development is to increase the scientific understanding of underlying process in crop production and to improve the decision-making based on scientific understanding (Ahmed, 2012, 2020a, b; Ahmed et al. 2013, 2018, 2020a, b, c, d; Ahmed and Stockle, 2016; Ahmed and Ahmad, 2019, 2020). Crop simulation models predict on the basis of weather, soil, fertilizer, genetic, and environment information as well as their interactions (Wallach et al. 2018). Recent advances in crop simulation models have enabled the insects, pests, and diseases prediction as well. Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom et al. 2019; Jones et al. 2003), Agricultural Production Systems Simulator (APSIM) (Keating et al. 2003) and Environmental

Policy Integrated Climate (EPIC) are very well-known crop simulation models worldwide.

21.3.8 Remote Sensing

It is an art as well as a science to acquire knowledge and information about the object from distance. Information is remotely sensed by sensors through several platforms like satellites, UAVs (Un-manned Aerial Vehicles), airplane, and hand-held devices (Bregaglio et al. 2015). Remotely sensed satellite images have very useful application over the last few years (Kasampalis et al. 2018). Remotely sensed data is used to monitor the crops, vegetation type, vegetation indices, vegetation vigor (Silleos et al. 2006), canopy, leaf area index, absorbed photosynthetically active radiations, evapotranspiration, biomass, and yield (Franch et al. 2019; Leroux et al. 2019; Campoy et al. 2020). This data is used to develop primary productivity models and simulation of productivity (Han et al. 2020; Zhang et al. 2020; Chen and Tao 2020). Remote sensing in combination with crop simulation models can help in yield assessment. Remote sensing can provide the enhanced spatial information and actual field condition that can improve the growth and yield assessment under the anticipated climate change (Kasampalis et al. 2018; Nasim et al. 2011).

21.3.9 UAVs (Un-manned Aerial Vehicles) and Drones

UAVs and drones are aerial vehicles equipped with multispectral cameras, sensors, and microcontrollers to facilitate the daily work in the fields. In recent years precision agriculture is the main focus of community research (Hassan-Esfahani et al. 2014; Pederi and Cheporniuk 2015). Monitoring the health of crop is essential for yield increase in agriculture (Carbone et al. 2018). For agricultural monitoring use of drones and UAVs are now becoming very common. These are used to monitor the growth and development of crops as well as plant height, soil moisture, pest population, and variations occurring in the field (Potrino et al. 2018). These drones and UAVs help in remote sensing of agricultural crops by taking images of crops and fields. These images are used for analysis by using different kinds of software to improve the understanding. Drones and UAVs have the advantage of providing high-resolution images than satellite images (Carbone et al. 2018). These drones and UAVs are also used for spraying of chemicals like insecticides, pesticides, etc. (Pederi and Cheporniuk 2015).

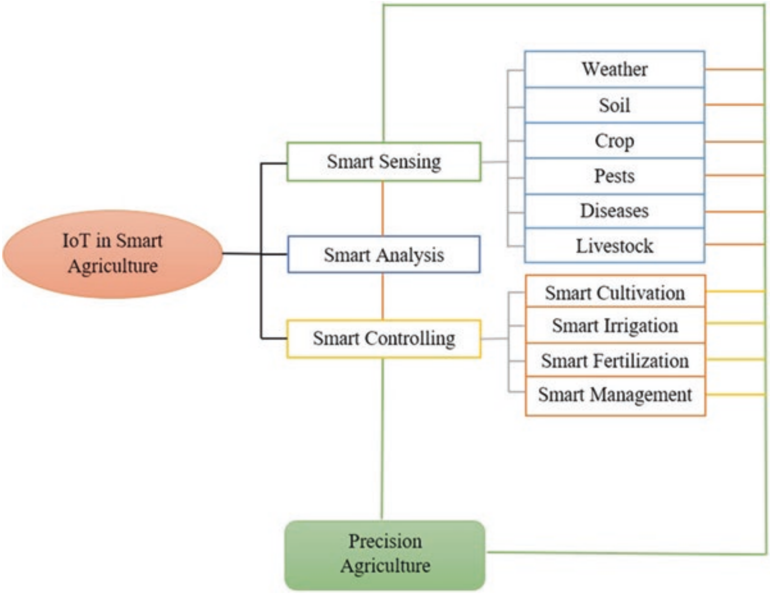

Fig. 21.4 IoT in smart agriculture

21.4 Potential Applications, Opportunities, and Current Usage Trends of IoT System in Agriculture

IoT system has numerous applications in the agriculture sector. It is used for monitoring and management of several processes with the help of modern technology (Fig. 21.4).

For decision support, raw sensor data is processed. Then, information is used for decision-making and performing different farm operations. A variety of sensors used for monitoring and data acquisition in agriculture are described in Table 21.2.

21.4.1 Weather Forecasting

To reduce agricultural risks associated with climate change, previous weather data can be used for weather forecasting through big data analysis. Environmental conditions can be monitored with the help of different environmental sensors. Depending on the collected data, timely decision-making, and farm management can be done.

Table 21.2 Sensors used in smart agriculture

Weather sensors	
Met station one (MSO)	Detection of wind speed and direction, temperature, humidity, and barometric pressure
Compact weather (CM-100)	Detection of wind speed and direction, temperature, humidity, and barometric pressure
T and R.H sensor (HMP45C)	Measurement of air relative humidity (0–100%) and temperature (−40 to +60 °C)
T and R.H sensor (SHT71)	Measurement of the relative humidity and temperature
Temperature sensor (107-L)	Measurement of air, water, and soil temperature
Soil sensors	
Moisture sensor (ECH_2O)	Detection of soil water content
Soil moisture sensor (MP406)	Monitoring of volumetric moisture content of soils
EC sensor (EC250)	Measurement of the electrical conductivity of soil
Hydra probe II soil sensor	Detection of moisture, conductivity, salinity, and temperature
Pogo portable soil sensor	Detection of soil temperature, conductivity, moisture, etc.
Plants/leaves sensors	
Photosynthesis (TPS-2)	Monitoring of leaf photosynthesis
Leaf wetness sensor (LW100)	Detection of leaf surface wetness and rainfall
Chlorophyll sensor (YSI6025)	Estimation of phytoplankton concentrations by detecting the fluorescence from chlorophyll
Temperature sensor (LT-2M)	Monitoring of absolute leaves temperature

21.4.2 *Pest Control*

Along with the weather and climate data, pest life cycle can also be monitored. It can play an important role in predicting pest outbreaks. For pest management, data of environmental variables (like humidity, precipitation, leaf wetness, etc.) are collected using different kinds of sensors. A disease known as Phytophthora was monitored and reduced with the help of sensor (TNOdes) in potato production (Baggio 2005).

21.4.3 *On-farm Water Management*

Irrigation and water management play a key role in agriculture (Zia et al. 2017). Climate change has resulted in erratic rainfall, water shortage, and health problems (Rasool et al. 2018). Remotely controlled irrigation systems such as drip irrigation and sprinkler irrigation can be opted in water-stressed areas. Linking the data of various variables (like radiation, humidity, temperature, etc.) from different types of sensors can control the amount and placement of water depending on the needs. Website real-time presentation of a river basin can be done. Sensors are used that feed the information into the websites. It enables users to monitor the river basin and react to changing patterns. As flooding is the main problem in river basins, it can be used as risk management strategy in agricultural communities.

21.4.4 Greenhouse Management

Monitoring the environment in the greenhouse is very critical (Ahmed 2017). Sensors are used in greenhouses for controlling and monitoring the moisture, temperature, humidity, etc. These sensors can be linked to a system, and Internet and can lead to smart agriculture that would help in effective management (Fig. 21.5).

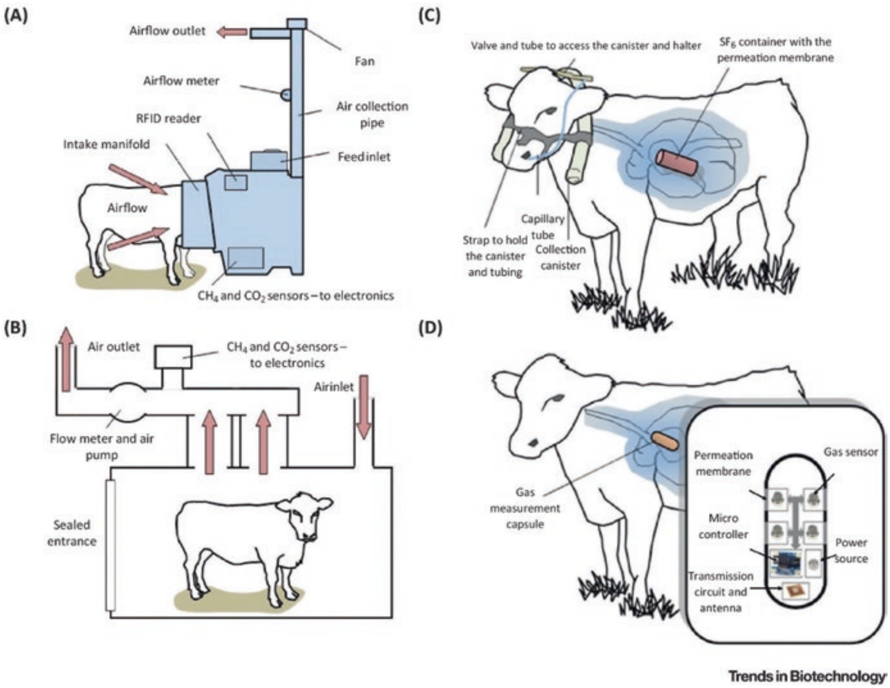

Fig. 21.5 Different sensors-based gas measurements techniques (Source: Hill et al. 2016 with permission from Elsevier)

21.4.5 Forest Management

Forest management can also be done effectively using IoT technology. Forest fires and illegal cuttings are the major issues in forest management. Fire can be detected by satellite technology using photos and heat sensors. Scannable plastic barcodes can be inserted in trees, to prevent illegal cutting. In this way, trees can be tracked from forests to the consumers.

21.4.6 Pollution Detection

IoT can play a vital role in pollution detection. In massive water bodies, satellite light radiations are used to detect water pollution. This technique would become convenient in aquaculture. By using the radiation wavelength, the type of pollutants can also be identified (Mubarak et al. 2016).

21.4.7 Livestock Monitoring

Radio frequency identifiers (RFIDs) are attached to animals for tracking animals and preventing theft. The position of animals can be seen in control or data centers where RFID readers are placed. It is helpful in communal grazing systems where animals get lost. GPS is used for location tracking. Similarly, measurements of enteric methane (CH_4) emissions from ruminants could be easily monitored by different sensors-based devices (Hammond et al. 2016; Huhtanen et al. 2015; Hill et al. 2016). This could help to design strategies to minimize emission of enteric CH_4 which is a significant source of greenhouse gas (Figs. 21.5 and 21.6).

21.4.8 Marketing

For market prices, data from national markets are filtered out and disseminated through small information centers having Internet access. In more remote areas, radio broadcast can be used. IoT can be used for branchless banking services. Especially in rural communities where farmers have no access to banks within reasonable distance, they can make money transactions and bill payments at retail outlets.

Precision agriculture and smart agriculture are aimed to maximize the net returns on investment. IoT technology can play a vital role in precision agriculture. Decision support systems running on smart devices can assist in better farming management. Mobile applications can help farmers in decision-making in farming operations

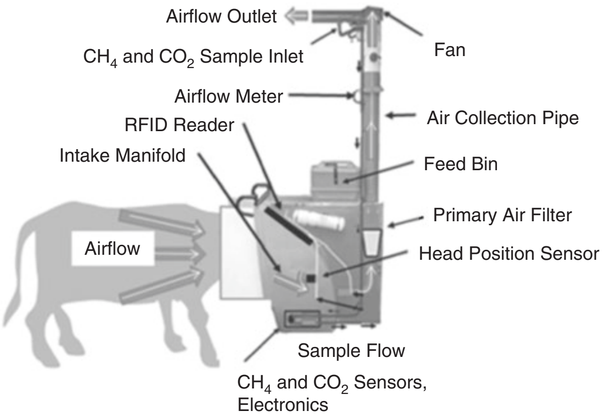

Fig. 21.6 Layout of GreenFeed system (Source: Huhtanen et al. 2015 with permission from Elsevier)

(irrigation, disease and pest management, etc.) and diagnosing the diseases. IoT technology systems track and monitor animals. Similarly, farm product delivery can also be facilitated by IoT technology. Sensors and mobile Internet cut out the role of middleman and enable farmers to directly contact with consumers. Near Field Communication (NFC) systems can facilitate the purchasing and buying of farm inputs and farm products without using cash. Electronic transactions are replaced with cash and enable branchless banking in remote areas far from banks (Dlodlo and Kalezhi 2015).

Precision agriculture has become a prime focus worldwide (Jiang 2014) and use of modern IoT technologies in smart agriculture has gained importance in recent years (Table 21.3).

21.5 Scope and Future of IoT

By using smart agriculture technologies, more area can be brought under cultivation to meet the increased demands. Livestock management can be done more effectively with the help of IoT and other modern technologies to improve the quality and cleanliness. However, on the other hand, affordability, sustainability, and scalability are the major obstacles for adoption of these technologies. Farmer literacy and technical education are vital to use modern advanced technologies.

Developing countries are lagging behind the developed countries in the agriculture sector. Therefore, it is a prime necessity to take serious initiatives to promote modern technology to make agriculture more efficient and profitable. Hence, smart agriculture will result in optimizing resources, improving product quality, reducing production losses as well as improving the farmers' and country's economic conditions.

Table 21.3 Applications of IoT and ICT in smart agriculture

Region	Crop	Purpose	Findings	Reference
USA	Floriculture crops	Plant tissue nitrogen detection	Development of low-cost image analysis technique for determination of tissue nitrogen content	Adhikari et al. (2020)
USA	Soybean	Monitoring of nitrogen fertilization responses	OptRx™ sensor has the potential to detect nitrogen responses under varied nitrogen application rates in soybean	Sivarajan et al. (2020)
Malaysia	Rice	Monitoring soil Electrical Conductivity (EC).	Designing and development of IoT-based system to assess the nutrients availability by measuring soil EC in rice	Othaman et al. (2020)
India	Banana	Temperature responses detection	Development of SQLite local web database to monitor and track the banana growth and generate alerts on the basis of weather detection	Geethanjali and Muralidhara (2020)
China	Grasses	Monitoring of grasslands	Implementation of dynamic threshold method to construct a time series of Satellite Pour l'Observation de la Terre Vegetation (SPOT Vegetation) and Normalized Difference Vegetation Index (NDVI) data from 1999 to 2012 to monitor the green-up date	Guo et al. (2019)
USA	Cotton	Plants phenotyping	Development of terrestrial LiDAR-based high throughput phenotyping system for cotton	Sun et al. (2018)
Japan	Tomato	Leaf area detection	3D depth sensor (Microsoft Kinect) can be used to measure the light interception characteristics and leaf area nondestructively	Umeda et al. (2017)
Malaysia	Multiple crops	Plants nutrients stress	Spectral reflection pattern measurements in visible and infrared ranges can be used to detect plant stresses	Me et al. (2017)
UK	Wheat	Plants phenotyping and growth detection	Results indicate that multi-temporal, very high spatial resolution, 3D digital surface models via Structure from Motion (SfM) photogrammetry can be used successfully to monitor crop height and growth rate	Holman et al. (2016)
China	Potato	Shape and size detection	Ellipse axis method can be used to detect the shape of potato, with 98.8% accuracy level	Liao et al. (2015)
Israel	Apple	Mature apple detection	Apple detection can be done with shape analysis of using by implying the convexity test	Kelman and Linker (2014)

(continued)

Table 21.3 (continued)

Region	Crop	Purpose	Findings	Reference
China	Cotton	Foreign fiber detection	Image analysis segmentation method can be used with great accuracy and speed than the other methods to remove the foreign fibers	Wu et al. (2014)
Spain	Maize	Crop stand detection	Development and verification of automatic expert image system to assess the maize cropping geometry and aid in different treatment applications in field	Guerrero et al. (2013)
Germany	Multiple crops	Leaf detection	Ellipse approximation method in combination with active shape models can be used for individual plant identification under overlapping conditions	Pastrana and Rath (2013)
USA	Apple	Apple grading	Automatic adjustable algorithm method for segmentation of color images, using linear support vector machine (SVM) and Otsu's thresholding method can be robustly used for apple sorting and grading	Mizushima and Lu (2013)
Portugal	Grape	Grapes color detection	The proposed image analysis method can be used for the detection and location of crops in fields	Reis et al. (2012)

21.6 Benefits of IoT Technology in Agriculture

IoT technology can improve living standards and alleviate the poverty of farmers. For example, a wide range of crops can be grown in organic greenhouses that results in extra income and contribute to country's gross domestic product (GDP) (Akram et al. 2018). The role of the middleman is lessened with mobile Internet because farmers can directly contact consumers.

Agriculture surveillance programs can be run with IoT that enable farmers to take preventive measures before the economic threshold level is reached. Therefore, even in droughts, bumper harvests can be obtained through precision agriculture. Smart health cards for crops and livestock can facilitate effective and efficient diagnosis and treatment with historic information of affected crops and livestock (Alonso et al. 2020).

IoT facilitates farm product tracking. Buyer can know where the product is and when it will be delivered. It can also empower transporters by providing information about farmers who require transport. Near Field Communication (NFC) system use facilitates the seller and buyer in paperless transactions and minimizes theft and fraud. It is also beneficial for rural area people who do not have bank access. Satellite transmissions can serve as means to obtain information in remote areas about markets, prices, government services, facilities, etc. The major advantages of IoT in agriculture are (i) Efficient water management without water wastage (Kumari and

Iqbal 2020), (ii) Continuous monitoring and timely management (Shafi et al. 2020), (iii) Minimal labor and time requirements (Panda and Bhatnagar 2020), (iv) Soil and plant management (Othaman et al. 2020), (v) Disease diagnosis in plants and animals (Nayak et al. 2020), and (vi) Global marketing access (Panda and Bhatnagar 2020).

21.7 Challenges in Wireless Technologies

There are a number of challenges in observing different agricultural climates. Challenges and recommendations are listed below:

21.7.1 Communication Range

Communication range is a major challenge in wireless technologies. This range is short in agricultural applications. In ZigBee technology, it can be extended up to 100 m. In a farm field, this range can be extended using UAVs and drones.

21.7.2 Cost

Cost of sensors and monitoring equipment is important. The equipment should have low cost and robust performance. Cost reduction can make these technologies available to be adopted in poor countries.

21.7.3 Power Consumption

Power consumption of these systems should be minimal. On the other hand, this challenge can be overcome by introducing alternative energy harvesting ways like solar, wind, etc.

21.7.4 Reliability

Information collected from sensors are directed to farmers and organizations therefore information reliability is essential to deal immediately with dangerous information.

21.7.5 Real-Time Data

In precision agriculture real-time data is critical. Crops are vulnerable to changing climatic conditions. Therefore, real-time data is required to avoid crop failures and disasters.

21.7.6 Fault Tolerance

Sensors and systems should be fault tolerant. Communication or sensor fault can lead to serious crop damage. For example, if the sensor controlling irrigation is not working correctly or communicating, it can cause water stress damage to plants.

21.8 Conclusion

This chapter has reviewed the IoT applications in agriculture for sustainable developments and management of agricultural systems. IoT can benefit agriculture in several domains under the changing climate like weather forecasting, drought, crop, livestock, water and disease management, etc. Agricultural and rural development policies influence IoT technology adoption. Regions and sites specific IoT technologies should be developed to target poverty alleviation and economic uplift of farmers. Large number of IoT devices can be classified on the basis of type, usage, connection, place, etc. Instead of developing greater amount and variety of IoT structures, focus must be directed towards the development of reliable, more secure, minimal energy using, and more user-friendly devices. Agriculture is a more suitable area for IoT implementation, and there is room for development. IoT standards, platforms, and protocols should be open source software and evolving solutions for device compatibility issues. These solutions can decrease implementation costs and broaden the implementation of IoT as well.

Markets grow and collapse, disruptive business ideas emerge and die, but the people on the planet always need food for living. Therefore, developments and advancements in food and agriculture will always be a top priority, particularly under the current observed and predicted dynamics of climate extremes on the earth. Hence, application of IoT in agriculture has a promising future in terms of enhanced sustainability, efficiency, and scalability of agricultural systems.

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