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Review Article

Recent advancements and challenges of Internet of Things in smart agriculture: A survey

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ABSTRACT

The Internet of Things (IoT) is an evolving paradigm that seeks to connect different smart physical components for multi-domain modernization. To automatically manage and track agricultural lands with minimal human intervention, numerous IoT-based frameworks have been introduced. This paper presents a rigorous discussion on the major components, new technologies, security issues, challenges and future trends involved in the agriculture domain. An in-depth report on recent advancements has been covered in this paper. The goal of this survey is to help potential researchers detect relevant IoT problems and, based on the application requirements, adopt suitable technologies. Furthermore, the significance of IoT and Data Analytics for smart agriculture has been highlighted.

Contents

1. Introduction

The increasing demand for food, both in order to ensure quality and quantities, has accelerated the need of industrial growth and intensive methods of production in agriculture. At the forefront of the new agricultural era, there is an emerging Internet of Things (IoT) market that is suggesting several creative solutions. Research organizations and scientific associations are seeking to increase their own scope and speed by connecting with IoT, contributing technologies and goods to a range of different agriculture markets. The IoT idea gained prominence in the year 2000, with the development of the Auto-ID at MIT and the subsequent market research reports. In IoT, these systems communicate, perceive, and connect with internal & external state embedded technologies [1]. IoT is widely seen as the next-generation technologies with widespread applicability across almost every facet of the market, with the ability to increase the degree of integration of end products, systems, and services. IoT technologies are ideal for a number of applications, including healthcare services, smart communities, traffic management, agricultural systems, and security facilities.

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ICT(Information and Communication Technologies) being integrated into conventional agricultural activities is helping to spark a fourth farming revolution. An important facet of technologies such as machine learning, UAVs (Unmanned Aerial Vehicles), Remote Sensing, Big Data Analytics, etc. is having the capability to boost farming activities to new heights. A broad variety of agricultural parameters, such as environmental factors, production status, soil condition, irrigation water, herbicides and pesticides, weed control, and greenhouse output climate, may be tracked in smart agriculture to increase crop yields, minimize costs, and maintain process inputs. Smart agriculture and the use of reduced pesticides and fertilizers in crops will help to mitigate leaching issues and pollution, as well as the effects of climate change, in precision agriculture [2].

Burgeoning IoT technology offers many new solutions and further growth opportunities, particularly for novel ideas in the agricultural sector. We also benefited greatly from recent developments in communication systems and protocols [3], primarily on the lower layers, which is the physical, network, and link layer. Besides that, the protocols in the topmost layers of the network are critical for effective data exchange and gathering. There are many applications, procedures, and designs that can be used in the agricultural sector as a whole. There are several ongoing developments in IoT agriculture research that involve network engineering and applications, device design, security challenges. Furthermore, in several nations and institutions around the world, various IoT guidelines and policies have been adopted in agriculture. However, an impressive amount of research has been done on IoT and there is still a great need for further research on the topic in the agricultural field. This survey paper examines numerous challenges and trends related to smart agriculture.

2. IoT-based smart agriculture

The IoT is reshaping the agriculture sector by providing farmers with a diverse set of tools to address several challenges faced by them on the field. Farmers can connect to their farm from almost anywhere and at any time using IoT-enabled technologies. Sensors and actuators are used to regulate farming processes, while wireless sensor networks are being used to monitor the farm. Wireless cameras and sensors were used to remotely monitor the farm and collect data in the form of videos and pictures. Farmers can also use IoT to keep up with the current conditions of their agricultural land using a smart phone from anywhere in the world. IoT-enabled technologies have the potential to deplete the crop production cost and increase productivity of the land. Some of the key role played by IoT in smart agriculture is illustrated via Fig. 1.

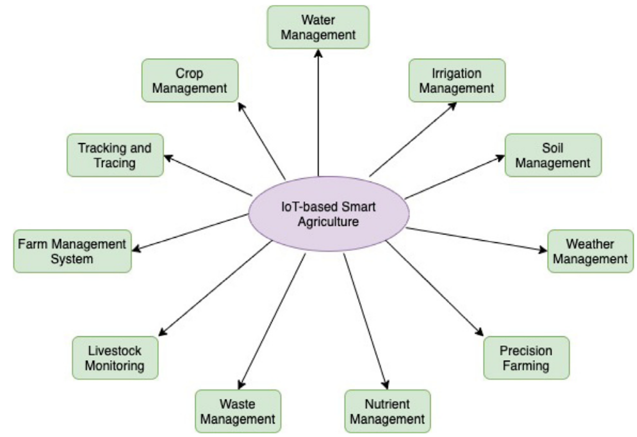

Fig. 1. Role of IoT in smart agriculture.

i. *Water management:* A major challenge in greenhouses is determining the exact amount of water required [4]. To prevent unnecessary water use, smart sensors are installed and operated using a variety of IoT techniques. Water storage in greenhouses is achieved by the use of automated drip irrigation, which is regulated by a soil moisture threshold. Water management may be handled effectively via IoT technology by avoiding water waste through the use of various kinds of sensors. The sensors are used to monitor the amount of water in the tank, and data is saved on the cloud through a mobile application. Farmers may monitor the water level using their cell phones. The motor will operate automatically as a result of this technology. If the water level drops, the motor automatically turns on, and if the water level is high, the motor will shut down. Up to 50% of this water is lost in conventional irrigation systems owing to over-watering due to inadequacies in traditional irrigation techniques and systems [3]. To address this issue, smart irrigation systems powered by IoT assist farmers in avoiding water waste and improving crop quality via timely watering. Temperature and soil sensors are installed on fields in smart irrigation systems; these sensors communicate field information to farmers via a knowledge gateway. Weather-based precision agriculture controllers monitor and modify irrigation schedules depending on local weather information.

ii. *Irrigation management:* It is in charge of anticipating the design, improvement, operation and management of irrigation systems. Tracking water requirements of crops based on gathered data and actuating the water flow in accordance with the anticipated needs without the participation of human operators is one of the objective of irrigation systems. It uses dispersed sensors to monitor different soil, water body, plant, and micro-climate factors. The irrigation technique (e.g., spray, drip, flooding and nebulizer) has an influence on how to properly monitor the water body as well as the actuation mechanism. Weather is one of the most significant variables in calculating agricultural water needs. The IoT will help to upgrade the new irrigation infrastructure in a more fascinating way. By tracking weather and soil conditions, a farmer can refine his irrigation system in a variety of ways [5]. Weather prediction data, manage and track the whole farm from almost anywhere, Ethernet, and WIFI are all exemplars of how IoT technology tracks irrigation systems.
Smart irrigation systems driven by the IoT make use of field-deployed sensors to monitor soil properties, weather and climatic conditions, and agricultural terms for irrigation.

iii. *Soil management:* Soil management entails determining various soil parameters such as pH, moisture content, and so on. These parameters can be conveniently calculated using IoT sensors. Farmers will then take measures such as fertilization, drainage, irrigation, and so on. Soil management assists in the discovery of the right plant breed. It also assists in the identification of fertilizer needs in the soil. It necessitates a low-latency network for urgent intervention. For both enterprises and farmers, soil monitoring has been among the most challenging activities in agriculture. There are several environmental concerns in soil testing that have an impacts on crop productivity. If these types of problems are correctly defined, farming patterns and procedures can be readily understood. Soil Humidity, Precipitation, Fertilization, and Temperature are among the factors being monitored. The moisture content of soil is monitored using moisture and humidity sensors. The findings of a soil testing research survey improve crop production and propose fertilization options to farmers [6]. Furthermore, using IoT technology to identify polluted soil protects the field from over-fertilization and crop degradation.

Soil management protects and improves the productivity of the soil. Additionally, it lowers input costs, avoids pollution, and increases agricultural yields and quality. Prior to planting, the topsoil should be in the optimal fitness level for the crop in order to promote fast and effective root development. While each farm and crop has unique soil needs, there are a few measures that may help promote good soil biology such as: organic fertilization, soil analysis, proper tillage, measure for chemical soil protection, etc.

iv. *Weather management:* Many relevant factors are combined to preserve and establish an optimal ambience for plants while staying under strict limits, such as airflow, temperature, CO_2, and O_2 levels. This can be achieved by deploying an IoT-enabled ecosystem, in which smart sensors and devices exchange data for improved decision-making [7]. Weather have the greatest impact on crop production. Farmers can decide the best time for planting, irrigation, and harvesting using an IoT-enabled weather forecasting system. Probabilistic weather analyses were done using sensors in IoT applications. Farmers can learn about environmental conditions such as soil moisture, humidity, and air temperature by embedding remote sensors in the fields. Farmers should prepare accordingly and adjust the harvesting and irrigation period to boost the crop based on historical results. Farmers should take proactive measures to ensure a safe crop harvest by arranging and reviewing collected data.

v. *Precision farming:* It is an IoT-based farming technique which primarily entails the analysis of data collected in the field in order to determine the most productive crop. Farmers gather data using sensors and analyze it for forecasting in precision farming. Farmers may use the information collected to schedule their farming operations, including what seeds to sow, how much fertilizer to use, when to harvest, and also what crop yields to expect. Farmers may also track the farm through sensors that detect moisture levels, crop output, and livestock levels with the deployment of IoT. The sensors can effectively monitor irrigation machinery from afar. The data collected on the land is analyzed by IoT linked devices, making data-driven decisions on resource allocation and crop harvesting. The conventional method of farming to maximize yield and preserve crops was focused on physical inspection, and if there was a problem, it was typically resolved after a severe event involving the farm, and it was performed on a trial and error basis. However, in precision farming using IoT applications, anything can be pinpoint sooner and behave in compliance with the collected data. IoT innovations are assisting farmers in increasing agricultural output quantity while maintaining efficiency, productivity, and cost effectiveness. Farmers will face a variety of problems, including water shortages and floods, a lack of suitable land for crop plantations, and cost control. Farmers can reduce possible missteps and increase returns by implementing the IoT infrastructure and associated technology. IoT-enabled farming allows farmers to make fast decisions depending on the circumstances. The use of IoT in farming would greatly improve operational productivity.

For example: A precision agricultural practice is one that involves assessing a field's inherent soil variability. When the soil in a particular region retains more water, crops may be sown more thickly and irrigation can be used sparingly. Alternatively, if the plot is utilized for grazing, it may accommodate a greater number of cattle than a comparable area with lower soil quality.

vi. *Nutrient management:* Nutrient management entails making the most effective use of crop nutrients while also preserving the environment. Nutrient management is based on the concept of matching soil nutrient supplies with crop needs. Nutrients help in producing optimal crop yields when supplied in the appropriate amounts and at the right times; providing too little will restrict output, while applying too much will not make practical sense and may damage the environment. Nutrients that are not properly used by crops may leak into surface and groundwater waters nearby. For example, too much ammonia, phosphorus, or nitrogen may degrade water quality. Measuring the concentration of nutrients in the soil allows for selection of the best crop for multiple cropping cycles on the same land. Nutrients and technologies are critical for achieving sustainable agriculture while minimizing environmental and economic costs [8].

vii. *Waste management:* The Internet of Things (IoT) proposes a waste disposal solution. IoT sensors may be used to create intelligent trash cans. This could be used to read, store, and transfer waste-related data through a network. Governance of waste can be accomplished with the aid of certain intelligent and streamlined algorithms [9].

viii. *Livestock monitoring:* The growth of agricultural production to provide adequate food for the world's population is becoming a growing worldwide issue. As a result, the significance of livestock management in farmland is essential for the survival. Farmers, on the other hand, are trying to maintain their cattle in the context of rising worry over land and water supplies. Apart from that, farmers continue to focus on reducing waste and lowering total expenses. New technological advances are critical in helping to enhance the quality and quantity of agricultural output. The Internet of Things (IoT) enters the scene at this point. It allows farmers to improve the health of their livestock via remote access and data-driven decisions. Cattle Watch is a system for monitoring livestock. This cloud-based technology is often used to remotely track the well-being of livestock and aids in the identification of livestock locations using communication and energy sensors [10]. This method obviates the use of an alert system. If any state goes outside of a predetermined parameter, the users are told by call, text, or email. As a result, people can view real-time information from the comfort of their own homes or workplaces using their smartphones. The IoT livestock tracking scheme entails implanting sensors in animals that collect specific details about their body and their well-being. Farmers may monitor the position, counting, and other similar details of livestock using wireless IoT applications. The real-time data provided by the livestock tracking system allows sick animals to be identified and removed from the herd, preventing disease spread.

For example: Farmers can monitor their livestock's cardiac output, blood pressure, respiration rate, digestion, and perhaps other vital signs around the clock using connected sensors.

ix. *Farm Management System (FMS):* Farm management systems centralizes, administers, and optimizes a farm's output and operations. IoT based farm management system automates the collection and storage of farm data, manages business expenditure, agricultural budgets, monitors and analyses farm operations and consumption. Smart farming raises production while lowering environmental effects, but this smart farming approach is only feasible with the help of FMS. For smart farming, FMS is an important component for production, planning, and decision-making [11]. Farmers can track the entire farm with an interconnected FMS that uses Wireless Sensor Networks (WSN), Global System for Mobile Communications (GSM) modules [12], and a micro-controller to capture all of the data. On all sensors and devices throughout the field, an identifier is used to provide proper awareness of fertilization, weather details, automated buffer zone width tracking, and automatic information record generation based on daily farm activities. This data is saved in a regular format on the server and can be accessed for even further processing through a mobile phone or the internet. An automatic irrigation and control system [13] is used to maximize the usage of water supplies. In addition to the irrigation scheme, the farm is secured from pests and animals [14].

x. *Tracking and tracing:* IoT provides agricultural firms with helpful data to help them make better choices, such as organizing, handling, and communicating with business associates intelligently while saving resources and time. RFID and GPS are used to map the conditions of soil, air, water, herbicides and pesticides in a growing environment. Using wireless network connectivity, a GPS device is used to pinpoint the precise location of an agricultural areas and track different agricultural parameters. In [15], an architecture was developed to remotely track soil condition and soil structure in accordance with crop culture requirements. Through using WSN, ZigBee is linked to other devices such as CMS, GSM, and GPRS to track and acknowledge real-time data processing. When unexpected changes arise, GPS provides an interface to communicate with ARM (an intelligent control device to accomplish tasks such as SMS/MMS) and sends an alert to the farm manager, enabling the farmers to take appropriate action. Despite its high operating and maintenance costs, it is commonly used in agriculture because of its accurate positioning identification and control capabilities.

xi. *Crop management:* Crop management involves assessing and recording the well being of a crop. Plant and crop diseases can be detected using IoT sensors and RFID chips. These details can be gleaned from RFID tags and shared across the internet by the reader. This data are processed remotely by the farmer, and necessary steps are taken. This will keep pests away from the crops. In agricultural sector, production tracking and prediction have played an important role in delivering benefits to users in order to produce valuable output while minimizing losses. [16] suggested using SVM to forecast rice production with the aid of a Chinese monitoring station for specific knowledge of geography. [17] has demonstrated an efficient automatic counting strategy for coffee fruit, which helps farmers schedule their agricultural processes and efficiently prevent risk. Neural Networks has been used to forecast crop production and analyze pest management in the context of environmental conditions. Analogously, the research scientist used an Artificial Neural Network to predict the current agricultural yield [18]. Due to the extreme changeover in spatio temporal and also its crop yielding task, the K-means approach has been proposed for evaluating the extreme computational measure. Crop production is fully estimated under various edaphoclimatic types of environmental conditions. The effect of numerous agricultural parameters within the spectrum of obtained loss by applying decision tree algorithm on grain loss analysis and prediction has been explored [19]. Furthermore, CNN [20] was used to recognize and categorize the generated drop based on an illustration of a vein leaf containing red, white, and soya bean.

xii. *Blockchain with IoT for agriculture:* The blockchain is a decentralized ledger of transactions that all parties contribute and maintain. It offers a trustworthy source of information about the condition of farms, inventory, and agreements in agriculture, where such data gathering is often extremely expensive. Blockchain technology enables the tracking of food's origin, thus facilitating the establishment of trustworthy food supply chains and the development of trust amongst suppliers and consumers. As a secure data storage medium, it enables the employment of data-driven technology to improve agriculture's intelligence. Additionally, when used in conjunction with smart contracts, it enables payments on time to stakeholders that may be prompted by blockchain data alterations [21].

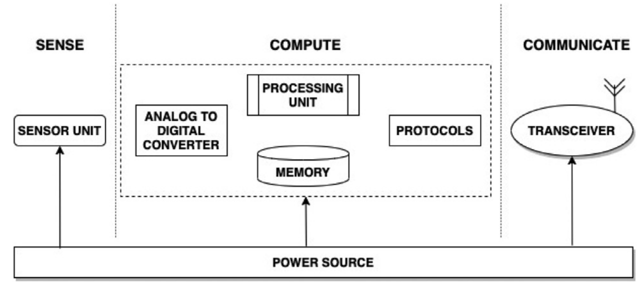

Fig. 2. Components of sensor node.

Table 1 highlights few recent findings and shortcomings of different IoT based frameworks for performing smart agriculture.

3. IoT sensors for smart agriculture

This section of the paper gives an overview of different IoT sensors and sensor networks being used for making the agriculture sector smart. A sensor is indeed a device that monitors several parameters, such as pressure, light, moisture level, and so on. Most of the time, the sensor output is an electrical signal, which is sent to a micro-controller for the further analysis on a network. The development of simple to advanced sensors represents a transformation in the way we gather information, conduct analysis, and connect diverse structures in order to attain new ideas we may never before have conceived of. Fig. 2 illustrates the components and basic structure of a sensor node used for performing smart agriculture.

An intelligent sensor node comprise of three components namely: Sense, Compute, and Communicate. The sensing component is responsible for capturing the real-world parameters such as moisture, temperature, etc. The computational component preprocesses the captured parameter value and the communication component makes sure that the gateway sensor nodes are able to communicate with gateway nodes and can share the information among them. A variety of sensors are available for measuring and calculating the specifications of a farming field. The underlying concepts of different sensors, as well as their corresponding requirements, are summarized below:

Table 1
Research findings and shortcomings of IoT-based smart agriculture.

Ref.	Research finding	Shortcoming
[22]	Use of Unmanned Aerial Vehicle for weed detection	Data collection details and issues are missing
[23]	Robotic harvesting, spotting pest using IoT	Missing details regarding crop monitoring, Real-time monitoring issues are not discussed
[24]	Review on collaborative research and context reasoning	Missing details of communication technologies
[25]	Discussed about IoT communication technologies	IoT sensor details are missing
[26]	Presents framework for monitoring plant health	Deployment challenges are not discussed
[27]	Precision agriculture using different communication protocol is discussed	Real time data collection details are missing
[28]	Data forwarding algorithm for monitoring nutrient deficiency	Less secure

- *PH sensors* are being used to track the precise quantity of nutrition in soil, which is important for the stable germination of seeds and crops. The absorption of chemicals or biomolecules, as well as the speed or rate of chemical processes, are both affected by pH [29]. Soil pH is very important because it affects biological & chemical processes. For instance, when pH is low, nutrition, growth, and productivity of most crops suffer, and when pH is high/optimal, productivity enhances. Many crops thrive in soils with a pH of 6 to 7.5, whereas others favor acidic or alkaline soils. For example: In soil management, soil pH acts as an important indicator for crop production, therefore its geographical variation must be handled to enhance precision management choices.
- *PIR sensor:* A motion detector is integrated into the PIR (Passive Infrared) sensor, which tracks the direction of an individual's movements in the field. Additionally, the sensor has a light detector feature: when monitoring an object, it converts rise in temperature to voltage for the purpose of examining crop production [30]. Everyone produces some IR radiation, with some emitting modest levels and others emitting high levels depending on just how hot they are. Two slots of IR sensitive material are included in a PIR sensor. Both slots detect the same amounts of IR if there is no motion in front of them. When anything hot pass in front of the slots, such as an animal, the very first slot detects a variation in IR level and produces a positive differential between the two slots. As the animal moves from the second slot to the first, the impact is reversed, resulting in a negative difference between the two positions. The PIR detects these fluctuating amounts of IR.
- *UV sensor* monitors the intensity of ultraviolet radiation for optimal crop production [31]. For instance, while using Iot components for weather management, it is evident to notice that plants respond to a variety of environmental factors, including soil nutrients, airborne chemicals, watering frequency, and the amount and type of light they receive. UV radiation has also been shown to affect the flavor, fragrance, and appearances of food cultivars, as well as increase the terpene concentration of cannabis crops.
- *Weed seeker* is a self-confined unit that is usually fitted with opto-electronic components for the purpose of weed identification and spraying. The unit is composed of an activated source of light and a specific spray sensor that detects chlorophyll. By the use of an optical system, the device is capable of detecting and spraying mainly weeds throughout the field. The service's systemic application will greatly minimize herbicide use. As a consequence, only a small amount of chemical is needed, lowering the implementation cost [22]. While performing crop management, weed control using IoT in agriculture is a time-consuming and costly process. Precision weed management (PWM) is defined as the administration of the appropriate quantity of inputs to the correct target (weeds) at the appropriate time. PWM is centered on using information technology to make site-specific weed management decisions. The spectroscopic reflectance of the leaves may be used to distinguish between various plant species [32].
- *Wind speed* indicates the speed of the wind at the surface. It is often important to observe occurrences in a field, such as changes in wind direction. These sensors must be installed at an appropriate height based on the location of the crop [33]. The input on wind direction is utilized for weather forecasting, crop harvesting, insecticide spraying, and other agricultural operations. Wind speed is monitored using a cup-type sensor, with the speed related to the number of revolutions. A potentiometer is used to detect the direction of the wind.
- *Water content/Soil moisture* sensors for measuring water content are used in a broad variety of research fields. The proportion of the quantity of water available in the test soil to the overall amount of the test soil denotes the soil water content. It is quantified by the variation in capacitance value, that is dependent on the soil's dielectric constant [34]. It can vary from completely dry to the saturation porosity of the material. Since the measurements vary according to the soil condition, the sensor should be tuned at each location. This sensor tests soil water suction, which seems to be a substitute for the effort exerted by the plant root in absorbing moisture from the ground. It may be used to determine the amount of water contained in the soil or the amount of irrigation necessary to achieve a desired level of soil water. The sensor determines the amount of water and the degree of moisture present in the field. [35] describes the usage of a wireless moisture sensor to track the greenhouse irrigation method. Dielectric Soil Moisture Sensors [36] measure an electrical characteristic that varies based on the quantity of moisture present in the soil to determine moisture levels.
- *Temperature sensor* monitors the temperature changes in the soil that have an impact on the absorption of nutrients and moisture. A novel sensing technique was developed to precisely map the volume of nutrients in the soil and on the surface of the water. A 3-dimensional crop sensing element equipped with photosynthetically active radiation technology can be deployed in any field area to measure temperature [37]. Ambient condition & asset monitoring are two significant aspects of smart agriculture that need temperature sensors. Ice wine cultivation, for example, is known to take place within a limited temperature window between −10 °C to −12 °C throughout a harvesting period. The ice wine business requires very precise temperature and humidity for efficient output. Temperature sensors are crucial in almost all smart agricultural asset monitoring applications.
- *Gas sensor* determines the precise concentration of poisonous gases in farmland, livestock and hydroponics by monitoring infrared radiations [38] There are a variety of strategies for reducing agriculture's carbon output, but all

of them require the ability to calculate and consider existing pollution levels, as well as track improvements. This is typically accomplished by the usage of gas sensors equipped with various analytical capabilities which could be used to monitor and log the quantities of CH_4, CO_2, or hydrocarbon gases. For example: CO_2 monitoring is essential for the long preservation of grains and cereals. Variations in temperature and relative humidity levels in grain storage may be detected using gas sensors, which is significant for freshness and edibility.

- *Humidity sensor* captures humidity that has a detrimental effect on plant leaf growth, and photosynthesis. As a result, this sensor involves measuring the moisture and temperature content of the air to indicate the degree of humidity [39]. Grofit offers a variety of climate control instruments that measure air temperature, relative humidity, and solar radiation. The device's data transfer range is up to 200 m, and it records measurements for a period of 30 days.
- *Motion detector sensor* is often used to locate the position of animals and fields; however, it detects the motion of an unexpected entity in the farm and sends warnings to the farmer, allowing for prompt intervention and crop loss prevention [40].
- *GPS (Global positioning system)* provides the precise positioning of farm, or livestock with respect to latitude, longitude and altitude. With respect to farm management systems, drones may be used, that can operate in tandem with sensor and GPS. It may be commanded remotely or fly autonomously using software-controlled scheduled flights in their embedded devices. Crop condition, irrigation, fertilization, sowing, plant enumeration, yield prediction, etc. may all be learned from drone data. Drones may be purchased and kept near farmland where they will be charged and serviced, or they can be scheduled for agricultural surveys (drone as a service). Following the surveys, the drones must be transported to neighboring laboratories where the gathered data can be analyzed.
- *Photodiode* helps in identifying the soil properties such as organic matter and moisture content using light. It can be used by γ ray attenuation for measuring the soil-water content [41].
- *Tensiometer* detects the force used by roots for water absorption. It measures soil compaction using probes. Irrigation scheduling uses tensiometers to assist farm owners and other irrigation operators in determining when to irrigate. Tensiometers may be used in combination with a water retention curve to calculate how much they should water.

The subtype of IoT sensors being used in agriculture domain is illustrated via Fig. 3.

4. Data analytics in smart agriculture

Precise data analysis is important in agriculture towards growing operational reliability and productivity. Based on IoT applications requirement, data analytics can be categorized into following types:

i. Memory-level [42]
ii. Massive analytics [43]
iii. Business Intelligent data analytics [44]
iv. Offline analytics [45]
v. Real-time analytics [43]

Memory-level data analytics deals with analyzing the data stored in some storage memory statically. Memory analytics contributes to the overall performance of a business intelligence system and offers BI users with quicker responses than conventional disk-based BI, particularly for requests that take a very long time to execute in a massive database. Massive analytics is also referred as big-data analytics. It is the delicate procedure of analyzing large amounts of data in order to extract information – such as correlations, market trends, and consumer preferences – that may assist companies in making sound business choices. While both business intelligence and data analytics include the use of data to uncover insights that help the company, there is one significant distinction to make. Simply stated, business intelligence is concerned with present, whereas data analytics is concerned with the future. Real-time analytics is a strategy that involves reasoning and statistics on data in order to provide insights that may be used to make faster, and more rational decisions. For certain scenarios, real-time analytics simply implies that the analyses are performed immediately on the arrival of fresh data.

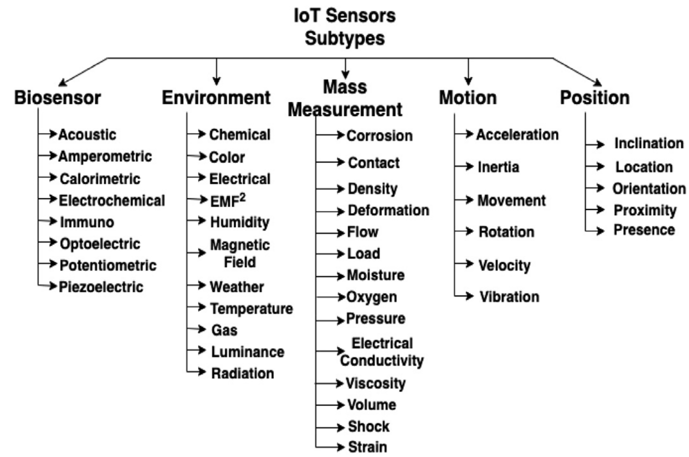

Fig. 3. Subtypes of IoT sensors.

Image analysis has been widely used in agriculture for a variety of applications, including disease identification in leaves, stems, & fruits, fruit quality assessment, weed identification and irrigation. Lately, image processing and IoT have been used in agriculture to boost the efficiency of crop production. This entails the need for drones to acquire aerial photographs on a regular basis, as well as environmental surveillance using IoT devices. Numerous data analytics techniques have been explored in depth in [46]. Fig. 4 illustrates the involvement of data analytics in performing smart agriculture. This survey paper would not address these techniques in detail. We address the significance of data analytics in agriculture and how it can be used to assist in protection, estimation, storage management, precise application, and decision-making.

Estimation: The IoT generates massive amounts of data that can be analyzed over time to determine current environmental conditions. Data analytics may be used to analyze data obtained from various forms of network sensors, and use intelligent algorithm to forecast environmental trends and have data-driven solutions. Even though IoT data could also be used to monitor different facets of a field, including irrigation systems, it also can be used to forecast and alert farmers about disease and adverse weather events, such as flooding or drought [47]. For example, in forestry, sensors may be used to detect fire outbreaks and forecast the area within a forest that is at risk of igniting. This knowledge will assist firefighters in implementing preventative steps at the precise spot. Another field of forecasting is early alert systems for natural hazards in order to enhance emergency response.

Protection: Landowners are often subjected to harsh climatic conditions, which may result in a substandard yield. Fortunately,

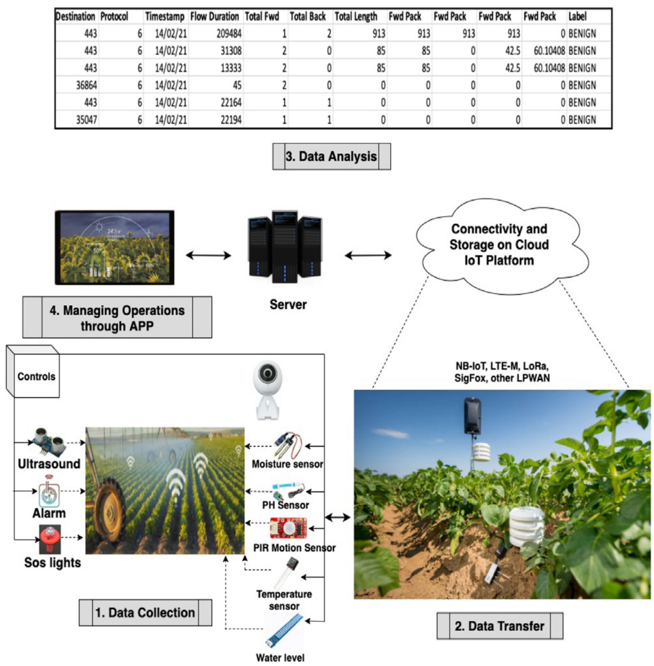

Fig. 4. Data analytics in smart agriculture.

farmers can insure their crops and livestock with the usage of IoT technologies. A sensor network can be configured, and remotely unmanned stations can perform surveillance. The data may then be analyzed in the cloud. The insurance scheme will have a notification device, in which adverse weather events are forecast and insured farmers are notified by text message. This encourages farmers to take preventative steps to safeguard their activities. An additional value of data analytics in insurance is that insurance providers have access to information from distant farms and may trigger an automatic payout through IoT digital payment services in the context of adverse weather conditions. This will obviate the need for a prolonged claim procedure in which the insurance provider visits the farms to determine the degree of the harm.

Storage management: Agricultural commodities are often destroyed as a result of insufficient warehouse control. Although climate, humidity, and some other external conditions significantly influence food product, bugs, microorganisms, etc may affect the production of food products [48]. The incorporation of IoT and data analytics into storage monitoring systems has the potential to significantly increase agricultural commodity storage. Sensors may be used to keep an eye on storage warehouses and the surrounding environment. The data is stored and processed in the cloud. To change the environmental circumstances, a self-automated decision framework based on analyzed data can be used. Additionally, when severe circumstances are encountered or a pest is found in the warehouse, an alarm signal may be sent to farmers. In India, approximately 35% to 40% of fresh produce is lost following harvest due to a variety of reasons, like rancidity or pest. Although the IoT has the ability to enhance agricultural storage facilities, protection should be incorporated into those networks to deter commodity theft during rolling blackouts.

Precise application: By using sensor data, it is possible to apply pesticides and fertilizers precisely to particular areas of the field, increasing production thus decreasing farming costs. Although developed countries have already implemented precision agricultural practices on farms, developing countries are starting to adopt the tech, particularly on research farmlands [49]. Consequently, the implementation expense, technology, and knowledge of IoT-based smart agriculture programs in different countries continue to confine their adoption. Additionally, since the majority of farms in developed countries are small-scale, most farm workers do not see the value in implementing such technologies. Developing suitable precision farming systems for smallholder farmers remains a testing and design challenge for researchers and designers. Another benefit of data analytics in smart agriculture is its use of directing machinery to specific positions inside the farm utilizing GPS and position details, thus growing farming productivity as opposed to human-driven equipment. This will result in time and fuel savings, as well as cost savings on operations.

Decision-making: Making decisions involves accurate knowledge, which can be gleaned from sensor data. The vast volume of data gathered by sensors creates resources for learning to enhance decision making in continuously evolving environmental scenarios. These choices may be taken in the immediate, intermediate, or long term. When those requirements are fulfilled, the IoT device may make automatic decisions, requiring little to no human interference. These automatic decisions may vary from temperature regulation to irrigation system management. For example, in solar farms, machine learning may assist in determining the optimum condition for growing a specific crop by analyzing data from sensors measuring nutrients, yield, development, transpiration, brightness, smell, and re-transplantation. The amount of knowledge gathered from data analytics will also help administration and all stakeholders make better policy decisions; thus, it is critical that the data is reliable, succinct, full, and timely. Numerous strategic decision-making frameworks have been created to assist farmers in making rational agricultural and livestock management decisions [50]. The data analytics makes professional recommendations to landowners, manages pests and diseases, and makes recommendations derived from remote expertise control systems.

Machine Learning technological farms: Machine learning (ML) may be seen as a breakthrough mechanism for machines to mimic human active learning, acquire new information, continuously boost efficiency, and attain unique development. On other side humans (in case of agriculture: Farmers), are masters at multi-modal processing and can almost immediately integrate incoming inputs into an hypothetical knowledge based on their experience [51]. In recent years, machine learning models, concepts, and implementations have been very effective when coupled with other agricultural methods to reduce crop expenses and increase output. On agricultural fields, machine learning technologies may be used in a variety of ways, including disease diagnosis, crop identification, irrigation management, soil quality, weed tracking, crop quality assessment, and weather prediction. After harvest, machine learning may be used to analyze the freshness of products (fruits, vegetables, etc.), lifespan, quality of products, and market analysis. The application of machine learning in IoT-enabled agriculture could be based on a variety of different machine learning algorithms, including Gaussian mixture models, Neural networks, support vector machines (SVM), fuzzy clustering, etc. [52] present an Iot system with a ML algorithm that anticipates climatic conditions for fungal detection and mitigation based on temperature, comparative air humidity, speed of wind, and rainfall; furthermore, [53] developed a mechanism for disease prevention and monitoring on cotton leaves in conjunction with soil quality tracking. In certain scenarios, where the machine learning based IoT model faces shortage of streamline flow of data, interactive machine learning proves to be fruitful. The interactive machine learning algorithms regulates the learning factor of the algorithm by involving humans as agents [54]. The farmers can play the role of agents in case of agriculture domain. It has also been presented that the intelligence of machines can be improvised by involving human(farmers)-in-the-loop [55].

5. Smart agriculture applications, software and hardware

In this section, we have highlighted few apps, software and hardware which are playing a crucial role in making the agriculture system behave smartly. The apps are responsible for collecting the data for further analysis.

5.1. Smart agriculture apps

Following are some of the most widely used IoT apps in smart agriculture:

i. *Nutrient ROI calculator:* eKonimics has launched a revised edition of its highly esteemed ROI (return on investment) calculator [56] which aims to assist farmers in optimizing yields and earnings. The most recent iteration of the calculator integrates spatial uncertainty, providing farmers with a more precise representation of predicted nutrient response in production-scale agriculture. Farmers are able to create more precise fertilizer application strategies as a result, optimizing the gains of farm inputs and therefore can enhance their profitability.

ii. *Sirrus:* It enables collaboration between agronomists and farmers by rendering field data available and simple to obtain [57]. By linking to the agX framework, users and applications can access structured field data offline and exchange it with some other users and devices. The advanced advice editor in Sirrus Premium enables service providers to offer changes in the field or when consulting with a grower. Users may modify fertilizer application rates, costs, and overall product prices. Sirrus credits prices dynamically depending on recent or flat rate applications. After selecting a product, labeling and safety data sheets (SDS) are widely sufficient to ensure proper product safety and usage.

iii. *FieldAgent:* It collects data to create stunning agricultural crop health charts, count seeds, plants and identify weeds, among other things. It is compatible with the majority of modern DJI (Da-Jiang Innovations) drones and takes care of all the flying specifics, allowing you to concentrate solely on the targeted map. It displays the comprehensive orthomosaics, plant species, weed positions, and precise Normalized Difference Vegetation Index (NDVI) crop-health items directly on your computer, along with position data to facilitate in-field scouting [58]. Task forecasts are given at the start of each trip and are revised as the task changes. Prior to takeoff, you can view and change almost any part of your flight route. Without regard for size, way-point, or acreage restrictions, you may fly vast fields simultaneously. When the drone's batteries run out, FieldAgent would drive it home and drop it off where it departed off.

iv. *OpenIoT:* It assists plant breeders in determining the state of various varieties of wheat by calculating humidity, temperature of air and soil. This enables farmers to forecast harvest dates, irrigation schedules, and nutrient requirements for plant development [59].

v. *Farmbot:* It makes use of open-source hardware and software for IoT in farming. It is based on developing an open source autonomous smart agriculture machine for the sake of mankind [59]. FarmBot assists customers in producing and growing their own food, developer Rory Aronson (CEO of Farmbot Inc.) said [60]. "It is something more than just understanding the origins of your food. Anyone who wishes to participate and assist us in building the future of agriculture has the potential to do so through their open-source technology".

vi. *SmartFarmNet:* It responds in near real-time to requests raised on time-series streaming data via sensors. It integrates non-SQL (NoSQL) and conceptual storage arrays. This arrangement manages (user, sensor, aggregated) data, and data caching. SmartFarmNet gathers, extracts, and aggregates data streams [61] from nearly all Internet-of-Things (IoT) system. For data ingestion, the SmartFarmNet gateway makes use of the OpenIoT X-GSN feature [62]. Wrappers are used to interact with sensors. A wrapper is a platform which enables the gateway to retrieve and transmit data from and to an underlying IoT system. At the moment, the SmartFarmNet network supports data ingestion from over thirty IoT interface platforms.

vii. *iSOYLscout:* iSOYLscout is an intuitive field scouting application which s imply labels areas manually or using the built-in GPS when on foot or in a vehicle. The application can be used to monitor crop production, weed infestations, and any other function you want to track around the field. Each logged function instantly estimates the area. Interest points are denoted by a text tag such as 'Broad weed'. Additionally, notes and/or a photograph may be included with the point. ISOYLscout files are automatically imported to mySOYL, allowing for wireless and quick data sharing among field and office [63].
Using iSOYLscout app, the farmer/user initially defines the region of interest, which may be scaled to include a single field, a portion of the farm, or the entire farm. For instance, the user may choose this based on the kind of data they want to collect, which may range from weed infestations to water-logging. Using GPS signal, the app will correctly record the position of these locations. Furthermore, the software has a manual sketching feature that could be used to distantly add a tag to a known place of interest even when the user is not in the vicinity. In any scenario, the app will inform the user of the estimated area and allow them to modify it. This is particularly advantageous for planning purposes. For instance, if a farmer has to establish a 1.0 hectare area of wild bird seed, the application will capture this and assist the farmer in properly establishing and recording the exact area. Along with regions of interest, any additional information deemed helpful by the farmer may be recorded at a particular location on the property. Users may create and modify a list of farm-related points. GPS data may be recorded automatically or manually. Free text changes of any length are also available, as well as the addition of pictures.

viii. *AgVault 2.0:* It enables users to navigate whole fields with ease using an inspire drone [64]. The software enables the user to configure the UAV's height, sensor settings, overlapping, steering angle, and survey region. The UAV is launched from the inside of the app, autonomously completes the preset path, and returns automatically. AgVault app helps in inspecting different areas of the field for analyzing the growth rate of crops, insect infestation, etc.

ix. *AgriSync:* It helps farmers and consultants to communicate and collaborate on farm service concerns. Farmers may communicate with several advisors from different organizations in near real-time via video to send and request assistance. Advisors can monitor several customer requests with a console and remote video, which enables them to see exactly whatever the farmer experiences in real time. The advisor's company will view open cases, settlement status, and farmer reviews in real time from a Web-based customer support dashboard [65].

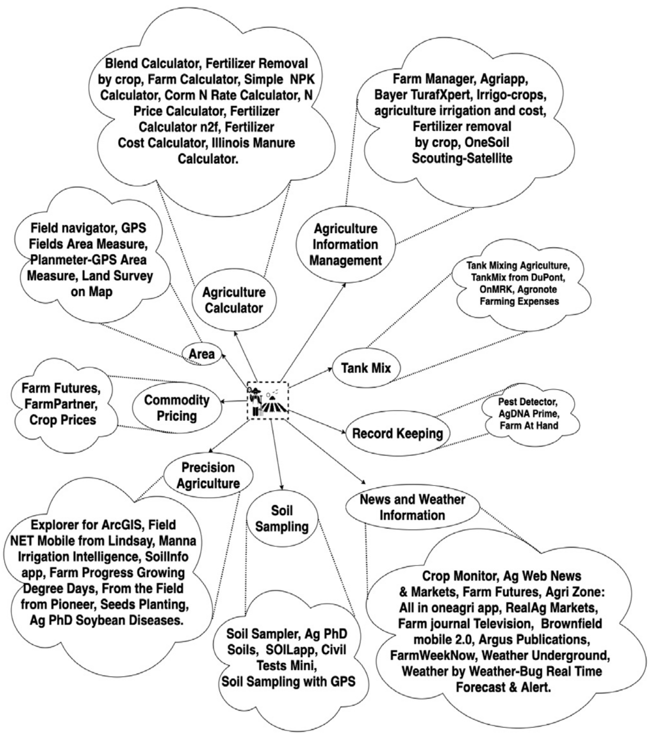

Fig. 5. Taxonomy of agricultural application.

x. *FARMapper:* It is a web-based application of the next generation that enables users to rapidly and easily create farm maps [66]. Your map is safely stored in the cloud and it can be accessed through mobile, tablets and desktop devices. You can view the farm project from nearly every platform that supports a Web browser. The app parses public land statistical data for the Municipality, Range, Segment, and quarter segment upon clicking on any point. It adds information to every clicked point and highlights the parcel. Using the app's drawing tools, you can create custom polygons in no time. Additionally, the app assists farmers in maintaining information on water resources, easements, and cultivation. In FARMapper app., the different fields are clubbed in the form of maps which can be accessed anytime. Custom Polygons are in the app represents different field locations owned by any individual farmer. All the maps are stored in cloud and can be accessed anytime with a single click using the app, thus helping the farmer to monitor several plots easily.

Fig. 5 demonstrates the taxonomy of different agricultural applications.

5.2. Smart agriculture software

In agriculture, the IoT combines robotics, drones, remote sensors, and computer vision with constantly improving machine learning and computational software to track crops, survey and analyze fields, and provide evidence to farmers for appropriate farm management strategies that save time and money. Table 2 discusses some of the well known IoT software being used in agriculture domain.

5.3. Smart agriculture hardware

In this section, we highlighted some of the well known IoT hardware being used in agriculture domain. The most significant hardware component of IoT could be its sensors. Power modules, radio frequency modules, and sensor modules are used in these units. Table 3 discusses some of the widely used IoT hardware.

6. Principal advantages of IoT in smart agriculture

Through remote sensing, smart agricultural systems minimize wastage, increase production, and allow management of a wider variety of resources. In conventional farming techniques, the farmer was continuously out there in the field, checking the farmland condition. However, as farms have become bigger, it has become increasingly difficult for farmers to manage everything everywhere. This is particularly true in micro-farming, where many distant pieces of land could be cultivated for a variety of crops, each of which requires a unique set of circumstances and precise control over soil and water. Control systems handle sensor input, providing remote monitoring for supplies and decision support, as well as automating machinery and equipment to respond to developing problems and to assist production. This is not dissimilar to the success criteria for any other "smart" marketing strategy; a standardized methodology establishes the better utilization of resources enabling production process on the supplier side and for satisfying strict demand-side limitations. Thus, in a smart agriculture system, it is about controlling agricultural production and, depending on its state, establishing the appropriate growth factors – such as moisture, fertilizer, or material content – to ensure production of the desired crop.

During production, it is all about resource management in order to optimize the growth process. Smart and precision farming methods, for example, focus on precise sowing using unmanned tractors to minimize seed waste and optimize plant spacing to provide the greatest potential output per acre. Another example is water usage, which may be improved by using precision water delivery techniques such as dripping or subsurface irrigation to decrease evaporation and increase soil moisture content by providing water only if it is required through sensors and automation. Overall, the whole procedure from farm to fork is monitored by sensors and managed by software which reduces overall costs, increases overall yield and supply quality, and ultimately improves the farmer experience. Following are some of the key benefits of using IoT for performing smart agriculture:

i. *Agility:* The improved agility of operations is one of the advantages of utilizing IoT in agriculture. Farmers can rapidly react to any major change in climate, humidity, quality of air, or the condition of soil or crops, thanks to real-time surveillance and forecast systems. Emerging IoT technologies aid agricultural experts in saving crops in the face of severe weather fluctuations.
ii. *Clean Process:* Precision farming using IoT-based technologies not only saves water and energy, making farming more environmental friendly, but it also reduces pesticide and fertilizer usage considerably. In comparison to conventional farming techniques, this technology provides for a better and more organic end result.
iii. Automating sowing, irrigation, and harvesting operations may help save resources, minimize human error, and lower total costs.
iv. Accurately monitoring production rates per field over time enables accurate forecasting of a farm's future crop output and value.
v. The Internet of Things will aid in the advancement of community farming, particularly in remote areas. The IoT can be used to encourage services that enable communities to exchange data, knowledge and increase contact between landowners and farming expertise [80].

Table 2
IoT software used in agriculture.

Software	Description
Android things	It is a Google-developed embedded operating system for Internet of Things applications built on Android. It optimizes resource use and simplifies the operating system for the company's gadgets as well as other Google certified hardware kits [67]. The OS includes an automated upgrade framework to address the challenges inherent in different vendors being liable for upgrading their own handset operating systems.
Cooja	It includes a cross-layer WSN emulator based on Java. It enables simulation at several stages, from physical layer to application layer, as well as hardware emulation for a set of sensor nodes.
AVR-IoT	It is a compact board yet conveniently expandable presentation and system architecture for Internet of Things (IoT) solutions. It is built on the AVR micro-controller design and utilizes Wi-Fi technology.
Apache Mynewt	It is a real-time OS with a diverse library set that simplifies prototyping, installing, and handling 32-bit micro-controller-based Internet of Things applications [68]. It is highly composable, allowing for the development of embedded machine applications (e.g., medical equipment, and industrial IoT) using a variety of different micro-controller forms. Mynewt is a pun on the English word minute, which means "extremely small".
Contiki	It is a free and open source OS designed for interconnected, memory-constrained applications, with an emphasis on low-power IoT gadgets. It is used in a variety of applications, including streetlights, sound control for smart communities, environmental monitoring, and warning systems.
Raspbian OS	It is a Debian based OS. It is used on Raspberry Pi and comprise of more than 35 000 packages. The robust CPU, along with the Bluetooth 4.1 and wireless LAN, enables it to be a perfect candidate for IoT ventures, since it can link to several sensors concurrently. Additionally, the Raspberry Pi comes equipped with a 40-pin GPIO connector for connecting external sensors [69].
Zephyr	Zephyr's goal is to include all components necessary for the development of resource-constrained micro-controller or embedded systems. It is a small RTOS for connected, resource-constrained, and embedded devices (with a focus on micro-controllers) that supports various architectures and is available under the Apache 2.0. Apart from the kernel, Zephyr contains all the modules and libraries necessary for developing a complete program, including device drivers, firmware updates, etc [70].
Google Fuchsia	It is a cross-platform operating system that works smoothly on every computer, including smartphones, tablets, desktops, laptops, and wearable [71]. Since logging in along with the Google account, the program can remember your position through different platforms. Google refers to it as Ledger, which it describes as "a distributed file structure for Fuchsia".
Dip Trace	It is an electronic design automation (EDA)/computer-aided design (CAD) software platform for constructing schematics and printed integrated circuit boards. It features a multilingual GUI. It is comprised of four modules: a circuit design editor, a PCB layout editor with an integrated shape-based auto-router, feature editor, and a design editor [72].
Proteus 8 Simulator	The Proteus Design Suite is a closed-source software application suite mainly used for electronic systems engineering. Electronic system engineers mostly use the program to produce blueprints and digital sketches for the purpose of making integrated circuits. It is a Windows based technology used to create schematics, simulate them, and design PCB layouts. It is available in a variety of configurations, based on the scale of the prototypes being developed and the simulation specifications for micro-controllers [72]. Both PCB Design items contain an auto-router and the ability to perform simple mixed mode SPICE simulations.
FarmBeats	It is a complete IoT framework for agriculture that allows the gathering of data from a variety of sensors, devices, and drones in real time [73]. It is a device architecture, which takes weather-related power and Internet outages into account directly, allowed six-month implementations in two US farms.
Snappy	It puts bulletproof encryption, dependable notifications, and the vast Ubuntu community at your fingertips, taking the developer community's preferred cloud framework to a broad variety of internet-connected objects, connected computers, and automated machines [74].

Table 3
IoT hardware used in agriculture.

Hardware	Description
ESP8266	The ESp8266 [75] is a wifi module that helps in establishing wireless connection between different components of IoT-based smart agriculture.
RTC module	This module helps in setting up a real time clock. It enables the module to keep track of precise timings of any operation to be performed by the designed IoT system [76]
DHT11	The DHT11 is a widely used sensor for measuring humidity and temperature. The DHT11 temperature and humidity sensor is a widely used component. The sensor is equipped with a specialized NTC for temperature measurement and an 8-bit micro-controller for serial data output [77]. Additionally, the sensor is factory tuned, making communication with other chipsets easy. The sensor has a precision of ± 1 °C and $\pm 1\%$ when measuring temperature between 0 °C and 50 °C & humidity between 20% and 90%. Therefore, if you need measurements within this range, this hardware might be the best choice
GSM module	It can allow SIM from any GSM network provider and can operate as a smartphone with its own specific contact number. The RS-232 protocol can be used to link the controller quickly [69].
PIC Micro-controller	It is used in defense, monitoring devices and domestic appliances. Often included is an EEPROM that is being used to permanently store the content [78]. This can be used to store the data collected by drones while analyzing the farmland.
LM35	The LM35 temperature sensor generates an analog O/P voltage equal to the measured temperature. It indicates the output voltage in Celsius (C). It is self-calibrating and does not involve external tuning circuitry. The LM35 [79] has a sensitivity of 10 mV/degree C. If the temperature rises, the output voltage rises as well.

vi. Smart agriculture makes extensive use of drones and robotics, which help in a variety of ways. This enhancements strengthen the data collection mechanism and facilitate wireless surveillance and control.

vii. The agricultural sector faces a number of challenges, not the least of which is ensuring adequate productivity while still ensuring a healthy and nutritious food supply. Numerous allegations of food theft have been produced, including adulteration, counterfeiting, and artificial manipulation [81]. This kind of fraud is hazardous to one's health and may have a detrimental economic effect [82]. Several of the components of food theft discussed in [83] can be resolved by the use of IoT technologies, including product validity, procedure integrity, individual truthfulness, and data integrity. The Internet of Things can be used to include logistical and analytical regulatory compliance for food [84].

viii. One of the alleged benefits of IoT is the opportunity to control equipment remotely [85]. The implementation of IoT in agriculture would enable significant time and cost savings in inspecting vast fields as contrasted to staff personally checking the field by vehicle or foot. Through using IoT to determine when and how to apply fertilizers or pesticides, expense and wastage may be reduced.

ix. The adoption of IoT would enable new business opportunities through which independent farmers will escape the manipulation of "middle men" and establish direct relationships with customers [86], resulting in increased benefit.

x. IoT can allow real-time surveillance of farm properties and equipment to prevent fraud, expedite component replacement, and ensure routine maintenance is performed on time.

7. Key challenges & open research issues

We have encountered significant technological advancements over the last few decades, and these advancements have impacted our daily lives. It is credited with making our lives more convenient by putting resources at our fingertips. Among the many innovations in progress, IoT, also recognized as M2M, has effectively drawn a large community (in which smart sensors gather real-time data and communicate with one another or with the internet in order to take appropriate action). IoT as a technology presents both prospects and challenges. M2M can be divided into four distinct layers. The first component is a sensor that collects real-time data, followed by a communication device that handles data transmission. The third computational unit is in charge of data analysis, while the service layer is in charge of performing any required actions. These four elements are largely carried forward to the Internet of Things. The following are the imminent critical issues confronting IoT:

i. *IoT standardization:* It is a crucial aspect in developing credibility and establishing a market for a novel idea. The introduction of physical objects into the internet creates a number of problems in terms of the adaptability of existing internet protocols and applications to these objects [87]. In recent years, detailed study has been conducted to match current procedures and solutions to these artifacts. The IoT includes a diverse variety of heterogeneous devices; if these devices utilize disparate standards and protocols, achieving high degree of interoperability is challenging. As a result, IoT regulatory agencies such as the IEEE, ETSI could prioritize implementing a technical standard to address standardization concerns. There are continuing efforts to develop the protocols and specifications necessary for millions and millions of IoT devices to communicate with one another. This entails interoperability on technological, semantic, conceptual, and organizational levels [88]. Interoperability of syntax is synonymous with code formats such as XML, JSON, EDI, comma separated variables, etc. as common syntax for data exchange [89]. Significant research is expected to be done to promote open standards in order to increase interoperability across billions of IoT apps and platforms.

ii. *IoT data:* Some of the major issues with data usage in smart agriculture includes data reliability, data uniformity, and data volume. *(a.) Data uniformity:* Agricultural data may be lost due to equipment failure or network node breakdown, post-processing errors, or pest/disease infestation. Due to the loss of a large number of recorded incidents, missing data results in erroneous calculations and degrades the success of IoT applications in agriculture. Several researchers have suggested numerous imputation approaches over time, including multiple mean matching, kernel smoothing, regression technique, and uniform kriging. *(b.) Data Reliability:* In agriculture, the primary cause of missing data is mechanical failure, electricity, weather conditions, mislabeled data, and computation error. Numerous implementations of data mining techniques [90] exist in smart agriculture, including crop safety assistance, irrigation prediction [91], and pesticide reduction [92]. In the other side, noisy and abnormal data pose significant impediments to the successful use of data mining techniques in smart agriculture. As a result, it is critical to manage noisy data using proven techniques [93], *(c.) Data Volume:* Heterogeneous data is another issue with data that arises as a consequence of big data's existence. Agricultural data may be collected using a variety of different technologies, including monitors, drones, cameras, and RFID tags. Indeed, since big data is heterogeneous, we can employ frameworks that reduce memory requirements and processing time correlated with data analysis.

iii. *Regulatory issues:* It is necessary to sort out the regulatory and legal structures governing the management and possession of farm data between farm workers and data firms [94]. Regulations can vary by country in terms of service provision [95] (for example, frequency for wireless IoT), technological difficulties, competitiveness, data protection, and security [96]. Different laws in different regions of the world can have an effect on how IoT is applied in specific applications, such as monitoring and agro-food supply.

iv. *Market issues:* Agriculture sector has a very low profit margin, and as such, there is a need to coordinate the introduction of IoT-enabling technologies against the future benefits. As a result, we address market challenges associated with IoT implementation in terms of expense and industry awareness.

- *Cost:* There are certain costs associated with IoT implementation in agriculture, which can be classified as setup and operating costs [97]. The setup cost covers the expense of IoT hardware required for framing a smart environment for agriculture. The operating cost is based on a consistent subscription to centralized networks or IoT systems that facilitate data processing, maintenance of IoT devices, and knowledge exchange, among other aspects. Additional operating costs include those associated with data sharing among IoT devices, gateways, and cloud servers, as well as energy and maintenance. While certain IoT providers offer free subscription packages with restricted features, the amount of linked IoT devices, and the volume of information that can be stored is limited. Increased features and facilities result in increased payment rates.
- *Lack of awareness:* A significant factor impeding IoT adoption in agriculture is a lack of sufficient awareness about IoT and its applications, notably among farmers in rural areas. This is a frequent occurrence in developed nations, where the bulk of farmers reside in remote areas and are often illiterate. If human interference is unavailable, the farmer's failure to use knowledge can be a significant obstacle.

Table 4
Different security concerns and attacks on smart agriculture.

Mode	Attack
Perception	Random Sensor incidents, Autonomous System Hijacking, Autonomous System Disruption, Irregular measurement, Sensor Weakening, Node Capture, Optical Deformation, Fake Node, Sleep deprivation
Data attack	Insider data leakage, Cloud data leakage, False data injection attack, Misinformation attack
Network	DoS/DDoS, Data Transit Attacks, Routing attacks, Signal disruptions, Radio Frequency (FR) jamming attack, Malware injection attack, Botnet attack, Side Channel attack
Edge	Forged control for actuators, Gateway-cloud request forgery, Forged measure injection, Booting, Unauthorized access, Man-in-the-middle, Signature wrapping, Flooding
Supply chain attack	Third-party attack, Supply chain software update attack, data fabrication attack, Interdiction attack
Application	Phishing, Malicious Scripts, DoS/DDoS
Other	Compliance and Regulation violation, Cyber Terrorism, Cloud computing attack

v. *Security:* In smart agriculture domain, IoT devices are susceptible to physical tampering, including burglary or attacks by rodents and livestock, as well as changes in physical address or connection [98]. [99] addressed different security breach cases such as Data Theft, SQL Injection attack, etc. at different layers of IoT. Physical components, such as sensors and actuators, are the prime focus of the perception layer. Accidental or deliberate human activity, malware, or crooks may lead physical equipment to malfunction. Consequently, complex and complicated algorithms are challenging to incorporate in IoT devices due to their restricted memory, connectivity capacities, and low energy usage. Congestion threats, DOS attacks, and routing attacks are all possible on the gateway. The protection and positioning of location data and IoT-enabled services used in smart agriculture are vulnerable to attacks such as system capture [100]. An intruder traps an IoT device and removes cryptographic signatures, allowing the attacker unlimited access to the details contained on the device's memory. Such higher-level networking layers may be susceptible to denial-of-service (DOS) threats, jamming and man-in-the-middle attacks [101]. Cloud repositories are susceptible to data tampering and unauthorized resources that may disrupt smart farming process [102].
The fast development and widespread use of smart mobile technology, and also the combination of IoT with corporate digitalization and automation, create new risks and hazards for Information and Communication Technologies security on the worldwide market. Potential cyberattacks on a variety of different smart agricultural systems may create significant security concerns in a dynamic and dispersed cyber–physical context [103]. These risks and cyberattacks have the potential to cause significant disruptions to linked companies. Additionally, in agriculture's highly automated environment, smart technology and remote administration employed in precision agriculture and smart farming are novel to its stakeholders, with the majority of new risks in this sector being closely related to comparable concerns in other industries. These risks are mostly concerned with cybersecurity, data security, and loss of data [104]. Additionally, since the precision agriculture industry makes extensive use of heavy equipment that is linked to the internet, there are many new vulnerabilities that may have catastrophic effects. Table 4 lists out the different potential cyber attacks on smart agriculture.
It is important to note that the majority of today's smart agriculture applications are built on IoT technology, which means they may directly inherit their security issues. Security features are disabled by default in protocols like MQTT (Message Queuing Telemetry Transport) and CoAP (Constrained Application Protocol), and the operator must enable it as per the project's objectives. [105] demonstrates a system for predicting irrigation needs based on climatic and environmental data. The technology predicts soil moisture using sensor data and makes irrigation recommendations. A web page is used by the end-user to communicate with the system. In the gathering, transmitting, and storing stages, the article presents no security measures, authentication checks or failure diagnostics. Because of the absence of security, systems are susceptible to different types of the attack, indicating that the system is extremely insecure. Data corruption or inaccuracy causes predictions to be incorrect and decisions to be made incorrectly. Incorrect actions can undermine the growth and diminish the system's acceptance.
Likewise, [106] developed a system that uses soil moisture, light levels, humidity and temperature sensor to monitor farms. Irrigation can be controlled manually or automatically using web or mobile apps. The system description is devoid of any security mechanisms, leaving the system vulnerable to the entire array of attacks described in Table 4. Controlling actuators with instructions from a web application that lacks strong security safeguards provides an ideal chance for malevolent adversaries to manipulate the system via malicious scripts and illegal access. Similarly, for data sharing between the host, the gateway, as well as the nodes, [107] offer a smart agriculture architecture. The article presents the system's architecture but makes no mention of interactivity or remote control, and it exhibits no security issues. The most damaging attacks, such as DoS, signal interruption, data transit, and routing, are those that target the network layer, since it is a data exchange platform. Some of the open issues [108] available for researchers include: (Malicious Scripts, Phishing attack, Deny of services) at Application layer, (Signature wrapping, Booting Vulnerabilities, Forged control of actuators) at Edge layer, (Signal disruptions, Data transit attack, DoS, Routing attack) at Network layer, (Autonomous system disruption & Hijacking, Fake node, Sleep deprivation, Node capture) at Perception layer.

vi. *Reliability:* The Internet of Things devices are intended to be installed outdoors. This exposes the devices to extreme environmental factors, which may result in sensor deterioration over time and connectivity failures. Physical security of installed IoT devices and networks [109] must be maintained to safeguard expensive equipment against adverse weather events such as floods and hurricanes.

vii. *Scalability:* In smart agriculture, a significant number of connected devices and sensors are installed, necessitating the use of an intelligent IoT management framework for the detection and control of every node [110]. Gateways and protocols in use today would have to accommodate a massive range of IoT devices/nodes, e.g., Sigfox supports 10^6 nodes.

viii. *Localization:* Numerous considerations must be weighed when deploying IoT systems. These considerations include the IoT device's capacity to accept position and play capability, i.e., to be installed anywhere and linked to the remainder of the globe without requiring any (or minimal) modification or the deployment of external hardware, such as gateways. Other considerations include the optimal location for the IoT system to have sufficient knowledge and reliability without creating disturbance [111].

ix. *Networking issue:* Smart agriculture presents a difficult communication challenge between various sensor nodes [112]. Sensors conduct large computations that consume energy, but sensor batteries have a limited capacity. As a result, networks need effective energy storage. These problems do not occur just at the hardware implementation stage, yet even at its network layer. Wireless connectivity [113] is critical for the implementation of smart agriculture owing to the uptick expense of wiring. Physical implementation demonstrates that the efficiency of approved transceivers is exaggerated by the proximity of humans, temperature, moisture, and a variety of other obstacles inside the region in which a wireless system or node wishes to interact. As a result, the most effective and stable technology can be used to transmit data in view of environmental problems and rural environments [114]. A thorough review of the problems and issues associated with IoT-based smart agriculture connectivity is offered in [115].

x. *Resource optimization:* Farm owners require a resource optimization process to decide the optimal number of gateways, IoT devices, communicated data and cloud storage required to achieve an advancement in profitability. This is made more difficult by the fact that various farms have varying sizes and need varying types of sensors to detect farm variables for certain crops or livestock [116]. This will necessitate the implementation of sophisticated algorithms and statistical models capable of determining the optimum resource distribution while mitigating costs and optimizing agricultural production and income.

After setting different prospects for prolonged research efforts, most IoT applications in themselves enable to identify difficulties for research and development to get a dependable as well as viable solution. The roadmap was drawn up by correctly identifying the research goals and objectives based on an assessment of the following criteria: *(i)* Thorough apprehension of the Smart-IoT architecture, *(ii)* Appropriate establishment of constraint free communication interface in the network minimizing the cost and maximizing the heterogeneity, *(iii)* Correct recognition and subsequent signal processing of incoming data when items are synced via the Internet via communication devices, there is a tremendous data generation. Therefore, correct management of collaborative data sharing is one of the top-priority, *(iv)* Standards should be developed to enable a broad variety of applications and meet common criteria for all potential IoT Smart-agriculture applications.

As IoT primarily develops via synchronization of internet devices, steady progress in all domains, from time to time, attracts critical concerns, along with updates, that cannot be neglected or disregarded. Over the last several years, the Internet of Things (IoT) has made great strides. The resources accessible beneath the hood of IoT have run out, and current situations have prompted a slew of questions that must be addressed in some manner before expanding to newer dimensions. In light of the ever-expanding scope of the IoT, several future-related questions have been raised that must be answered before we enter a new horizon of performing smart-agriculture.

– Would there be any next major step in properly identifying and managing the vast array of sensors being introduced to setup smart environment for agriculture?
– How will the future generation of smart-agriculture systems operate in tandem with IoT, especially when technological advances is not incessant?
– Safeguarding of electrical circuits in IoT system against specific environmental conditions such as fire, heavy rain, winds, excessive humidity, etc.

Different IoT systems for performing smart-agriculture has been proposed by several researchers, but crop residue remains a major environmental concern. To address this issue [117], we could indeed develop an IoT system infused with biotechnology that can assist in gathering data (which would include climate factors for growing bacteria and fungi for various sites and croplands) to solve the crop residue problem as well as provide a remedy to biodegrade the residue.

8. Conclusion and future trends

IoT has expanded steadily in last few years and a variety of IoT-based frameworks have been formulated in a variety of domains, most notably in agriculture. This review article discussed the prevailing state of the IoT in agriculture by reviewing key works of literature, analyzing current IoT research trends, and investigating common IoT sensors, devices, agriculture APPs, benefits & challenges, and analytics in IoT-based agricultural production. Despite of many challenges, IoT is an innovative breakthrough with a predicted exponential rate of growth of 27.1 billion connected components by 2021. Via its ubiquitous internet networking, it links diverse gadgets, devices, and individuals. The upcoming studies, inventions, and initiatives mostly in field of IoT-based smart agriculture would improve the quality of living for farmers and result in significant improvements in the agricultural sector. However, a variety of questions remain unresolved in order to make things sustainable for small and medium-scale growers. Security and expense are critical considerations. As competitiveness in agriculture intensifies and beneficial policies are adopted, it is projected that the increasing adoption of IoT for framing a smart agricultural environment will increase proportionately.

Some of the future trends of smart agriculture includes: construction of generic platform for all sort of crops and livestock, QoS (Quality of Service), usage of explainable artificial intelligence to monitor crop growth and disease control, Policies standardization, other technological and deployment advancements. Explainable AI [51] is one of the major necessity in most of the domains for understanding the reasons behind any specific decision. It fades away the traditional black box concept of machine learning and enables the farmers/users in understanding the factors behind the obtained solution.

CRediT authorship contribution statement

Bam Bahadur Sinha: Conceptualization, Methodology, Investigation, Writing – original draft, Visualization, Writing – review & editing. **R. Dhanalakshmi:** Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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