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Systematic review of Internet of Things in smart farming

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ABSTRACT

Agriculture unquestionably is one of the traditional occupations, which feeds all mankind in the world. Continuous changes are happening in the agricultural field to increase production. Researchers are applying various techniques to improve farming methods. To monitor plants even from remote places and to improve the yield of plants, Internet of Things (IoT), which is a boon in today's world, is applied in farming, in general, known as smart farming. Smart farming is a way where the farmers can monitor their field and manage farming activities from remote places. This reduces man power and increases resource utilization in farming. In this article, we have studied the architecture of smart farming and studied different smart farming techniques, also we have classified smart farming techniques into three categories, namely, IoT-based agricultural monitoring and controlling system, automatic irrigation system, and plant disease monitoring system. The review for the article is selected based on the systematic literature review method, and articles published from 2011 to 2019 are considered for review. Different IoT technologies such as sensors, gateway, communication system, user interface and experiment nature, plant type, disease type, advantages, and limitations are also reviewed. Future research direction and challenges in smart farming techniques are also discussed.

1 | INTRODUCTION

The world population is estimated to be about 9.7 billion in 2050, as such there will be great demand for food.[1] To increase the production and reduce man power efforts in agriculture, researchers started applying various techniques in farming. Technologies such as sensor network,[2-4] Global Positioning System (GPS),[5,6] and remote sensing[7,8] are used in agriculture to automate farming technique. The major issues with these technologies are farmers/end users cannot access or operate necessary functions from remote places, interoperability, complex structure, difficulties in adding new devices, cost, high energy conservation, and so on. To overcome these issues, Internet of Things (IoT) was introduced in agriculture, which helps to interconnect heterogeneous devices. IoT techniques also act as a platform to access and control devices from remote places at any time.[9] Because of ease of use, low cost, compatibility, quality of service, IoT techniques are applied in different application such as home automation, health care monitoring, smart city application, industrial automation, environment monitoring, cattle management, and agriculture.[10-12] Through improved operational efficiencies as well as new revenue creating products and services, by the year 2025, the potential economic impact of the IOT is estimated to be \$2.7 to \$6.2 trillion per year.[13] This shows that evolution of IoT in different fields. In agricultural Internet of Things (AIoT), various sensors and actuators are used to monitor different environmental parameters in agricultural field, and these data are updated to the end user and it can be used in variety of farming activities so that man power required for agriculture can be reduced, also farmers can have the privilege to control various agricultural activities from remote places and provide pleasant environment to crops in order to increase the production. To achieve the above requirements, researchers are developing a range of plant monitoring systems using IoT technologies. Recently researchers applied IoT techniques to automate different farm activities such as plant monitoring, controlling environment parameters, insert/pest monitoring, automatic irrigation system, food storage and supply system, and so on. In this article, we have studied an assortment of agricultural IoT techniques that have real-time implementation. Already some review articles are presented by researchers on IoT-based smart farming but systematic and analytical analyses of IoT components are missing in these studies.[14,15] To overcome these issues, we applied systematic literature review (SLR) mechanism in our review procedure and also various critical IoT components of smart farming systems are studied. We have classified agricultural IoT applications into three categories, namely, IoT-based agricultural monitoring and controlling system, IoT-based automatic irrigation system, and IoT-based plant disease detection system. In this review, we mainly focus on IoT technologies that are used such as sensor, actuators, gateway, communication module, storage component, user interface, implementation nature (ie, indoor (or) outdoor), plant type. The rest of the article is organized as follows. Related work is discussed in Section 2. Review selection techniques are described in Section 3. Section 4 describes IoT techniques in agricultural environment monitoring. Section 5 deals about IoT-based agricultural monitoring systems and controlling systems. IoT-based automatic irrigation systems are discussed in Section 6. Section 7 provides details about IoT-based plant disease detection system. Further improvement required for agricultural IoT techniques is given in Section 8. Conclusion is given in Section 9.

2 | RELATED WORK

Atzori et al[16] presented a survey on IoT techniques. In this article, the architecture, applications, and challenges of IoT technologies were discussed. Various environmental and agricultural monitoring applications were discussed. Zhang et al[17] projected various agricultural data transmission methods in his review article, namely, voice information transmission, short message service (SMS) information transmission, online information transmission, video conference information transmission, and multichannel-based information transmission techniques. Case studies, features, applications, examples, and limitations of various information transmission techniques were discussed. Kamilaris et al[18] projected survey on big data analysis in agriculture. In this article, 34 agriculture works were considered for the study and different features such as tools applied, big data algorithm used, problem and proposed solution implemented, and data used were discussed. The type of plants and experimental duration and advantages and limitation of algorithms were missing. Talavera et al[14] reviewed IoT applications in environment and agroindustrial system. The authors discussed about various IoT techniques involved in monitoring, communication, logistics, energy and resource management in environment monitoring, and agroindustrial system. In this study, the authors approached all the IoT techniques with following two questions: what is the primary technical solution of IoT in environmental monitoring and agroindustrial system and which methodology and IoT components such as sensors, actuators, and communication technique used in environmental monitoring and agroindustrial system. Various technical details such as power source, visualization, deployment scenario, and architecture model of the IoT systems were discussed. The limitation of this article such as implementation results, scalability, and reliability of the systems is not discussed. Tzounis et al[15] projected a study on trends and challenges in IoT-based agriculture. Different IoT components such as sensors, platforms, communication and its features like memory, microcontroller, transceiver, wireless standard, network type, maximum range, and operating frequency were discussed. IoT-based agriculture systems were classified into farm monitoring and control, agriculture stock management system, food safety, and supply management system, and these systems are discussed briefly. Different IoT challenges such as network coverage challenges, security issues, and IoT hardware and software issues in agriculture systems were discussed. The main defects of this study are advantages, disadvantages, and reliability and scalability of the IoT systems were not discussed in this article. Khanna and Kaur[19] discussed overview progress of IoT techniques and precision agriculture. Various communication techniques such as IEEE 802.15.4, LongRang (LoRa), 6LoWPAN, and so on and its features were discussed. IoT-based smart farming techniques were also discussed. However, the main features like sensor, actuators, gateway, plant type, and communication techniques of smart farming techniques were not discussed. Asghari et al[20] reviewed various IoT applications such as smart city, health care, environmental monitoring, industrial application, and so on. The following features such as objective, approaches, sensors, communication technique used for IoT-based agriculture system were analyzed. The limitation of this article is that only nine smart farming techniques were discussed in this article. The weakness of existing review techniques are given below and these limitations are conquered in present review.

- The full details of IoT techniques such as sensor, actuators, gateway, communication technique, storage details, and user interface are missing in many existing review.
- Scalability, reliability, energy conservation, and other important features of IoT system are not included in many existing review articles.
- Some existing studies do not included article selection methodologies.
- Advantages and disadvantages of IoT systems are not discussed.

To overcome the above mentioned disadvantages, we have applied SLR mechanism to select optimal article in smart farming technique. After article selection, we have analyzed various technologies such as sensors, actuators, gateway, communication technique, storage system, user interface technologies in smart farming, and also implementation factors such as reliability, scalability, energy consumption, cost, solar energy utilization, and security of smart farming techniques. These various details help to provide a clear understanding of existing smart farming technique. The further research direction of IoT-based smart farming techniques is also described.

3 | REVIEW SELECTION METHOD

The article selection methodology for SLR mechanism[21-23] is discussed in the below section. By considering identical and other possible spelling of the essential elements, following keywords are defined:

- ("Agriculture" OR "Smart Farming" OR "Precision Agriculture" OR "Plant Monitoring" OR "Crop Monitoring" OR "Automatic Irrigation" OR "Smart Irrigation" OR "Hydroponic System" OR "Disease Detection" OR "Disease Analysis") AND ("Internet of Things" OR "IoT").

The following scientific questions are considered regarding the objective of the research[14,20]:

Question 1: Which particular agriculture function is automated by IoT application?
Question 2: Whether IoT application is implemented in real time?
Question 3: What are the IoT components used?
Question 4: How system performance is evaluated?
Question 5: What is the future scope of the IoT system?

To find the research articles, we utilized the following scientific publisher: IEEE Explorer, Elsevier, Springer, SAGE, John Wiley, Inderscience, Taylor & Francis, Sensors, Scopus, Google Scholar. We have found 242 articles by using SLR method. We selected articles by using the following criteria:

- Articles published from 2011 to 2019.
- Articles applied IoT techniques to solve agricultural-related issues.
- Articles contain real-time implementation data.

We also excluded articles for review by applying the following criteria:

- Review and study articles.
- Articles not published in English.
- Articles not peer-reviewed.

Figure 1 shows the diagrammatic representation of review selection method. After applying various selection criteria, 64 articles from 242 articles were selected for review. All these articles were analyzed, discussed, and classified into respective farming application.

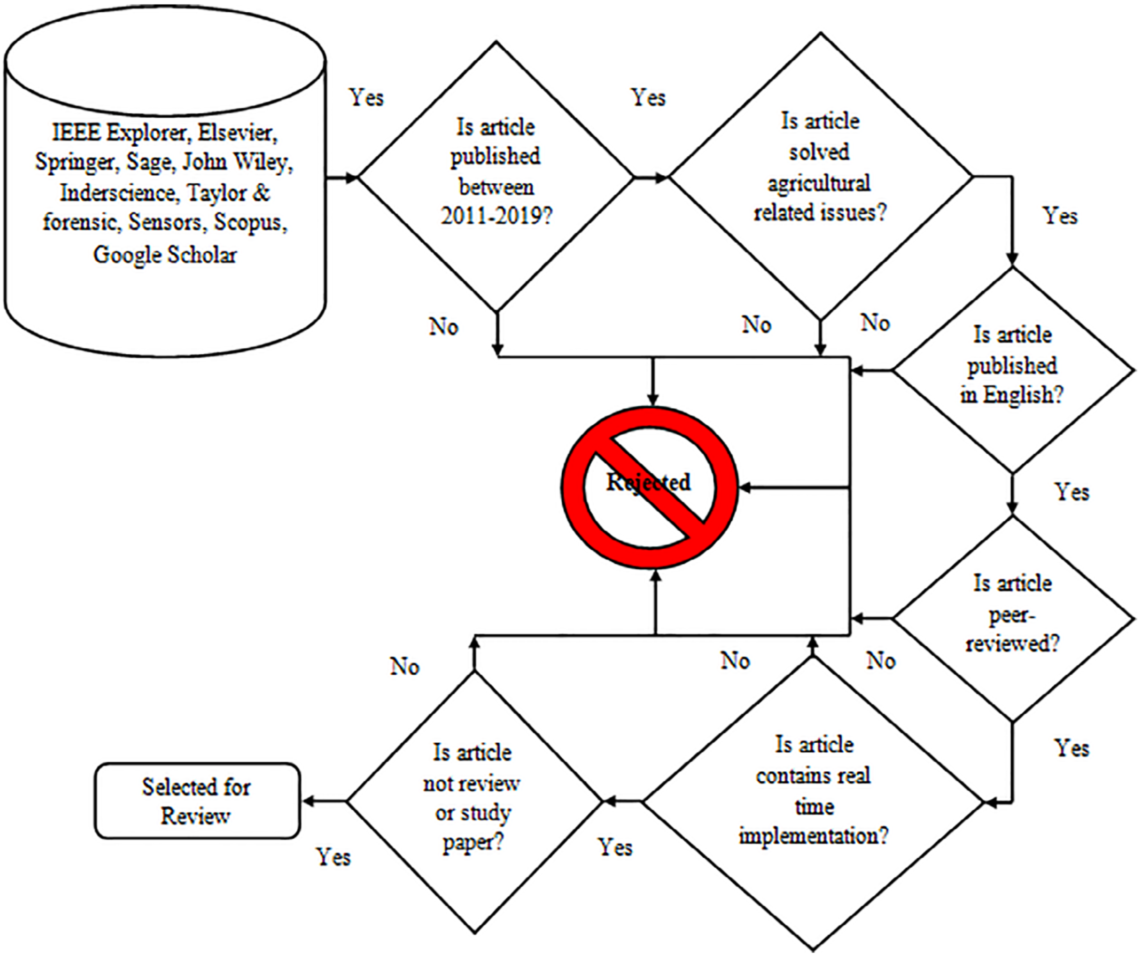

FIGURE 1 Review selection method

4 | IOT IN FARMING

In this section, the role of IoT techniques in agricultural areas is discussed. The yield of agriculture depends on many parameters such as plant type, water quantity, environment temperature, the soil type, soil temperature, nutrients in soil, sun light, and so on. To measure these parameters from different environment medium low-cost sensors are used. These sensors are lightweighted; they observe environment conditions but many of such sensors are unable to connect to the Internet and send data to store in database or cloud. In order to receive data from sensors and do initial processing of received raw data, small powered computer called gateways are used. Gateway is a device that collects data from a variety of devices and transfers data to the Internet, which is then stored in the server or cloud platform. To build communication between sensors and gateway, a variety of protocols can be used such as ZiggBee, message queuing telemetry transport (MQTT) protocol, and so on. These protocols were mainly developed for low-cost devices. Gateway uses Wi-Fi modules (or) general packet radio service (GPRS) to connect to the Internet. The collected data are stored in any database (MYSQL, NoSQL, etc) or cloud platform. The stored data are processed using machine learning or big data analytics for decision-making purposes. The conceptual view of farming using IoT is shown in Figure 2. Systems are designed in such a way that the end user can control the devices (actuators) such as water pump, fog pump, and so on from the remote places. Also, IoT systems provide automatic controls such as when soil moisture is less, water pump is triggered automatically and when sunlight is less, lights are operated automatically for optimal growth of plant, and so on. These kinds of automation are made through deep learning or big data analytics and this kind of automation reduce human physical work and also increase agricultural production. IoT techniques are not only applicable to traditional farming but are also applied to hydroponic plants. Hydroponic plants are plants that do not use soil instead use nutrient solutions as medium. IoT provides efficient way to monitor and control different nutrients in the hydroponic techniques to provide proper growth to the plants.

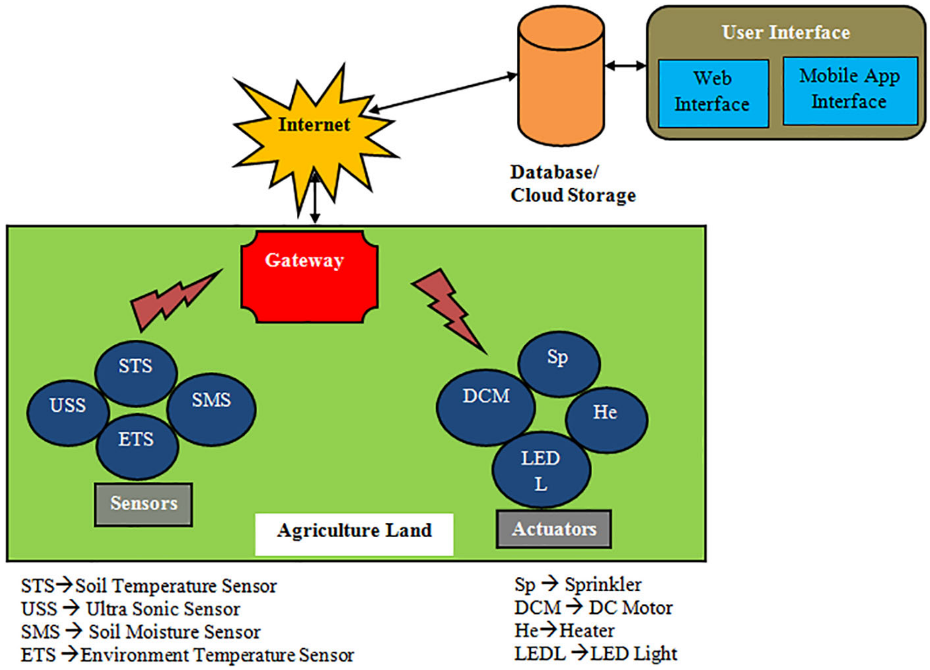

FIGURE 2 Conceptual view of smart farming using IoT

5 | IOT-BASED AGRICULTURAL MONITORING AND CONTROLLING SYSTEM

In farm monitoring, different devices were used to monitor various environment conditions and the observed details were accessed even from remote places. Farmers can monitor, analyze. and control devices from remote places.

Ma et al[24] project IoT-based water quality monitoring system in farm ponds situated in Jiangsu province, China. Water sensor was customized and used for measuring various water qualities such as pH level, dissolved oxygen (DO), NH3-N, electrical conductivity, temperature, and water level in farm pound. Various actuators such as water pumps, thermostat, and enhanced DO equipment's were used to control the concentration of the water parameters. The environment parameters includes air, temperature, humidity, wind speed, rain gauge, solar radiation were measured with weather sensors. The observed data were sent to gateway node using IEE802.15.4. The gateway was equipped with RS485 communication standard and it sends collected data to lock server using GPRS communication. Whenever DO level is low, alarm message is sent to the farmer. The farmer triggers the enhanced DO equipment by an SMS service. The environmental and pond water details were accessed by web portal. Solar energy with battery power was used as energy source for sensor and actuators. The system was used to maintain water quality of farm ponds in order to improve agriculture production.

Liu[25] proposed IoT-based farm land monitoring system. Sensors such as CO_2 sensor, temperature and humidity sensor, soil moisture sensor, light intensity sensor, and pH value sensor collect the environment data and forward to the gateway node. In additions to these sensors, cameras were used to record photos and video of the monitoring field. C8051F350 microcontroller was used as a gateway device. Gateway collects data from sensors and forwards it to the web portal. The users can view, add, and delete the environmental data in the web portal, and the data were stored in the SQL database. ZigBee technology was used as communication technology and Window socket methodology was used for communication between camera and gateway. The devices were powered by solar and battery power. The disadvantage of this system is the performance evaluation that is missing in this article.

Lamprinos and Charalambides[26] analyzed the performance of ZigBee communication technology in greenhouse environment. Greenhouse environment is monitored by PT-1000 soil temperature sensor, SHT75 humidity sensor, SQ 110 solar radiation sensor, MCP9700A temperature sensor, TGS4161 CO_2 sensor, and gas sensor. All the devices were equipped with XBee PRO S2 ZigBee module. These sensors measure the environmental data and forward them to PC through router. Experiments were conducted in tomato plant greenhouse and empty greenhouse. The test was conducted for 40 days and the result showed that to achieve better result, sensor and router should be placed with proper distance and density.

Palande et al[27] projected automated hydroponic system for indoor plant. In this system, different sensors were used to measure pH level of water, temperature of water, and carbon dioxide (CO_2). The system automatically adjusts the pH level from 5.6 pH to 6 pH, the water was heated or cooled between 24°C and 25°C and CO_2 was provided by CO_2 releasing pad, and oxygen was fused in water for healthy plant growth. Light emitting diode (LED) light was provided to act as artificial sun light, and it was switched on for 14 hours to imitate day. A camera was also present in this system. Light and camera can be remotely accessed by web interface or Domoticz mobile app to monitor the state of the plants. This system uses Arduino gateway, which collects data from the sensors. The sensors were communicated with Arduino using NRF24L01+ radio. The system also notifies the user with a message whenever the measured value goes out of bounds. The data were made available to the mobile application and web interface by connecting the gateway with a Raspberry Pi running a local server. Experiments were conducted in indoor environment and it had shown that the plant monitored using IoT obtained better growth than the plant that was kept outside of the system. Advantage of this system is that any type of plant can be used, and the limitations are security and consumption of power, which are not considered.

Yung et al[28] proposed IoT-based greenhouse system, which utilized cloud services for data storage and Hadoo for data analysis. Different sensors were applied to collect a mixture of environmental data such as humidity, temperature, amount of light, amount of different gases like CO_2, O_2, O_3, and NO_2. These sensors transfer data to STM32—ARM processing chip, which collects data and sends the collected data to MYSQL using Wi-Fi module (ATK-ESP8266), which uses TCP socket protocol for data transmission. Periodically, data were stored in MYSQL database and transfer to cloud platform. Big data analysis such as HADOOP HDFS was used to analyze plant details, which provides useful data to end user through web and android interface. Video monitoring systems were also used to store videos of the farm. The advantage of this work is that it achieves best result in terms of accuracy, memory consumption, and time consumption. The limitation of this article is power consumption and security aspects, which are not considered.

Ryu et al[29] deployed IoT-based farm, which uses &Cube (installed in Raspberry Pi) as IoT gateway to connect different sensor and devices into IoT platform called Mobius. Sensors and controllers such as temperature sensor, humidity sensor, heater, sprinkler, and LED lights were connected to IoT gateway &Cube using ZigBee communication. &Cube forwards the collected data to Mobius IoT platform. The end user can access the data using representation state transfer (REST) application programming interface (API). The end user can access controllers in virtual representation of their smart phones. Advantage of this technique is that the user can connect farms with the system, and the disadvantage is that the system results are not discussed.

Chieochan et al[30] projected IoT based on Lingzhi mushroom farm. DTH22/AM2302 sensors were used to measure the humidity of the mushroom farm. To maintain humidity level to 90% to 95% in Lingzhi mushroom farm, automatic fog pumps and water sprinkler were controlled through IoT application. Sensors send the measured humidity to NodeMCU, which act as gateway. The NodeMCU sends data to NETPIE by using Wi-Fi. NETPIE was cloud-based platform that helps to interconnect IoT devices. Different NETPIE subservices such as NETPIE Freeboard, NETPIE FREED, and NETPIE REST API were used for data storage and data accessing purpose. The measured data can be accessed in mobile and computers with the help of NET Freeboard. Result shows that the implemented IoT technique reduces manpower in maintaining mushrooms. This system provides an accurate result, but security and power consumptions are not considered.

Kodali et al[31] used Arduino as microcontroller to monitor and control a range of parameters in the greenhouse. Ultrasonic sensors were used to monitor the level of water in water tanks and whenever the level of water falls below threshold, an SMS was sent to the user and the user sends back an SMS to switch on the pump. Inside greenhouse, temperature and humidity sensor were placed, whenever the temperature or humidity crosses the threshold, a microcontroller will trigger a relay attached to the fogger that release microdroplets of water, which remains suspended in air and drops the temperature and maintains the relative humidity. LED lights were also present inside the greenhouse, whenever the light sensor measures light less than the required amount (from the sun), the lights were turned on, which boosts the growth of the plants. The bee hive boxes were fitted with ultrasonic sensor, which measures the amount of honey and sends an email when it crosses the threshold value. Finally, the product was stored in a storage house in containers that have ultrasonic sensor, which sends these data to Google spreadsheet and a mail to e-commerce website.

Ferrández-Pastor et al[32] proposed precision agricultural based on IoT. In this work, edge nodes such as sensors and actuators were used to observe different environment parameters such as soil moisture, soil PH, soil EC, water pH, water EC, inside/outside temperature, and so on. The observed data were transferred to fog node, that is, device with processor, GPU, operating system using MQTT protocol. Edge nodes were mainly used for data capturing, filtering, and data connectivity process. Fog nodes were used for monitoring, analyzing, supervising, and storage purpose. In fog node, machine learning techniques were applied and decision tree was used for water consumption and plant growth control. Analyzed details were stored in cloud platform such as Ubidots and Mobile-Alerts Cloud. Finally, the farmers were able to access the data from cloud through mobile devices. The advantages are the proposed system designed in such a way that it can be integrated with existing automated systems, and disadvantage is the lack of contribution toward security constraints and power consumption.

Maia et al[33] developed IoT smart device, which was built of humidity sensors, temperature sensors, and luminosity sensor to measures various environment variables. This device was powered by solar energy and battery, ZigBee was used for communication and it was also equipped with GPS for positioning purpose. This device was enabled with Raspberry Pi 3 with software written by NodeJS (open source). The device (called as monitoring node) observes environment and sends data to the node called central node. Central node collects data and stores the data in NoSQL database. Stored data were transmitted into cloud platform for storage purpose. The device was tested in Sao Paulo, Brazil, and the results are encourageable. The advantage of the system is highly portable, and the farmers can carry the system to all places easily to test the soil nature and environmental conditions. The systems elapsed time was 38 hours without solar power, which could be increased by efficient energy utilization.

In Reference,[34] the authors measure soil parameters such as moisture, temperature, and pH value. The system was developed based on STM32 Nucleo platform. To measure the soil temperature, DS18B20 sensor was used, which contains Dalla's one wire protocol. Antimony electrodes were used to measure the pH level of soil and moisture sensors were used to measure moisture level of soil. Bluetooth technique was used to transfer data between sensor and mobile phone. DC power supply or battery power supply was used to supply power to microcontroller. To make sensors smart, any IoT communication protocols need to be used instead of Bluetooth for communication purpose.

Tervonen[35] proposed smart vegetable storage using IoT. The system was developed to monitor environment atmosphere of potato seed warehouse. Temperature sensor and humidity sensors with 868 MHz radios (from Atmel) were used for measuring environmental data, which were then forwarded to the access point (sensor) that was connected to the laptop by USB cable. Data were sent from laptop to database through Wi-Fi Internet connection. Sensors were assigned with unique identifier, and radio signals (modified Bitcloud radio stack) were used for communication between sensors. The observed data were accessed from mobile and Internet. Through this experiment, environment condition of warehouse can be monitored even from remote places and it also helps in quality control of potatoes seed. The limitation of this article is that the results were not accurate, to increase the accuracy multiple measuring point were required.

Pérez-Expósito et al[36] projected IoT-based vineyard monitoring system. Environment sensors such as DS18B20 measures temperature and DHT22 measures humidity. To observe soil parameters SHT11 sensor was used. The collected data were forwarded to the gateway using REST API. Raspberry Pi acts as gateway. Wi-Fi modules (IEEE 802.11b/g/n) were used for communication purpose. To measure weather details such as wind direction, speed, and rain details, anemometer, weather vane, pluviometer, and Arduino board were used. Solar system was used to provide energy to the gateway system. The collected data were stored in MYSQL, where the end users can get details using web application, which was developed by hypertext markup language (HTML), hypertext preprocessor (PHP), and so on. The strength of the system was solar power used for IoT devices and system used low-cost devices. The weakness is security constraint, which was used to prevent security attacks.

Pooja et al[37] proposed MQTT protocol based farm-monitoring system. Different environment parameters were measured by different sensors such as soil dampness sensor, moistness and temperature sensor (DHT11), light intensity sensor. These sensors send collected data to the gateway called Raspberry Pi and controllers forward the data to the database using MQTT protocol. Farmers can send ON or OFF message to relay, to control the motor operation. This system reads various environmental data with less response time, but energy utilization and security issues are not considered.

Zhang et al[38] put forth the concept of IoT-based monitoring system to monitor temperature, nutrient, and soil moisture in citrus orchard of Three Georges Reservoir in China. Soil moisture sensor HA2001 (Handan Dingrui Electronics Co., Ltd, Handan, China), soil temperature sensor HA2002 (Handan Dingrui Electronics Co., Ltd, Handan, China), and humidity sensor FM-KWS (Hebei fly dream Electronic Technology Co., Ltd, Handan, China) were used to observe the environmental parameters. These sensors send observed data to the gateway called JN5139 using ZigBee communication module. To improve the efficiency of the system, decision-making system was used with IoT techniques, which helps to obtain accurate result and data, which then analyzed using Web GIS. The accurate results help the farmers in Three Georges Reservoir Area to fertilize and irrigate citrus plants. The cost of the system is high.

Bachuwar et al[39] developed IoT-based plant monitoring framework that uses ADS 1115 (analog to digital converter [ADC]), which utilizes I2C protocol. Different sensors such as temperature (DS18B20), soil moisture, and humidity sensor (SY-HS220) forward observed data to ADS analog to digital converter and digital converter forwards data to ESP826612E Wi-Fi chipset. Furthermore, the collected data were sent and stored in ThingSpeak server. The advantage of this system is that it consumes less power than other IoT frameworks.

Jayaraman et al[40] gave the idea of SmartFarmNet platform. In SmartFarmNet platform, user can integrate smart devices such as sensors, camera, and so on. These smart devices communicate with SmartFarmNet gateway. OpenIoT X-GSN was used in gateway for data collection. The gateway annotated received data are then encoded by predefined ontology. The annotated data represented using resource description framework (RDF) are then stored in No SQL graph database then in cloud platform (linked sensor middleware-light [LSM-Light]). To discover sensors, scheduler and service delivery and utility manager of OpenIoT was used, which was used to discover the data sources. This model allows the users to register smart devices with SmartFarmNet platform. Then users can access statistical data of smart device details from the web page. The advantage of this platform is that user can access IoT services without having knowledge of programming.

Pitakphongmetha et al[41] monitor and control greenhouse using hydroponics farming. Temperature and humidity were measured by DHT11 sensor, soil moisture is measured by KG003 sensor, ultrasonic sensor (HC-SR04) was used for measuring water level in water tank, and these sensors forward observed data to the gateway called NodeMCU. These details are stored in cloud platform called ThingSpeak. To reduce heat produced by greenhouse, ultraviolet (UV) lights were used and were controlled by NodeMCU. User interface was developed by Blynk platform. Cantonese, petioles plants were used in this project, and the result shows that the system increases plant survival by 45.83%. This system reduces water consumption and energy consumption. The weakness of this system is security constraints, which are missing.

Crisnapati et al[42] employed IoT technique to monitor nutrient film technique (NFT) farm, which utilizes hydroponic technique. Ultrasonic sensor (HC-SR04) was used to measure the level of nutrient solution, pH sensor was used to measure acidity (pH) level in nutrient, temperature sensor (DS18B20) was used to measure temperature, EC sensor was used to observe EC/PPM (concentration of the nutrient), and these observed data were forwarded to Arduino microcontroller. Raspberry Pi 2 was used to store and provide interface to web framework. The system was powered by solar energy. The user can access data from web interface or through an SMS alert. The whole system helps farmers to monitor the farm from remote place.

Mekala and Viswanathan[43] used IoT technique to measure temperature and humidity of the crop. To find the comfort level of the crop, thermal comfort level was calculated from the environment data. To measure temperature, DHT11 sensors were used and to measure environment condition thermistor was used. Arduino Uno was used as gateway and CloudMQTT protocol was used for communication between devices. Observed data were stored in public cloud called ThingSpeak. The system was also able to measure the crop comfort level, and the result shows that sensor processing time was reduced to 37% and the error rate was reduced to 6% compared with other existing techniques.

Lee et al[44] implemented IoT with big data mechanism to monitor and manage greenhouse. Temperature/humidity sensor, solar radiation, and CO_2 sensors were used to measure environment parameters and forward the collected data to gateway. ATmega128 acts as gateway and it sends the received data to the database. The system was implemented and tested in greenhouse for 9 months to monitor tomato plants growth. The system utilizes ZigBee module for communication between sensor and gateway and 6LBR was used as border router in the gateway. Big data analysis was used for the prediction and optimized management. Result shows that the system reduces energy conversion due to less usage of wireless devices.

Cambra et al[45] utilized IoT techniques to maintain pH level (bicarbonates, salts, and nitric acid) in nutrient solutions of hydroponic agriculture system. pH sensor and pH electrode measure the pH level and hydrogen concentration in nutrient solution and forward the collected data to the gateway NRF24L01. The gateway forwards data to MYSQL database and cloud storage was used to save data. Whenever pH level was low, micropumps adds the required amount of acid in the nutrient solution. Decision-making system decides the amount of acid to be added in the nutrient solution and was built by Java Drools, PHP, and HTML5. The system was implemented in greenhouse for maintaining lettuce and tomato plants. The advantages of this article were system consumes less energy and could be adaptable for large area.

Estrada-López et al[46] used different sensors with IoT and cloud techniques to measure the soil parameters such as phosphorus and other nutrients. In this work, the authors used different sensors and devices to measure all types of soil conditions in two levels, namely, soil parameters measurement at 7 and 20 cm level (this level may vary according to root of the plant). To measure soil temperature and humidity, sensor SHT10 and Ti10 Fluke infrared were used. To measure soil conductivity, SEN0114 soil conductivity sensors were used. These sensors measure soil parameters and forward the data to gateway MSP430FR5969. For communication between sensors, XBee PRO S2C radio modem was used, which provides ZigBee communication. To transfer data between server and gateway, MQTT and REST protocols were used. To measure soil phosphorus, artificial neural network technique called normalized difference vegetation index (NDVI) was used. In this system, soil parameters were measured in two levels that helped to increase phosphorus detection accuracy. The system also provides significant energy conservation with help of dynamic power management system.

Aliev et al[47] monitored various agricultural parameters by using IoT device, and it also predicts weather details using neural network technique. To measure temperature and humidity, DHT11 sensor was used. To get soil moisture, six Groovec sensors were used. To control these sensors, STM32L476RG was used as microcontroller and ESP-12E Wi-Fi module was used for communication. The NodeMCU Wi-Fi board was used for establishing Wi-Fi connection. The collected data were stored in ThingSpeak cloud platform. The user can access the sensor details using Android mobile application. The advantage of this technique was it achieves high accuracy with help of neural network and the disadvantage was high product cost.

Singh and Chandra[48] implemented the system to monitor greenhouse parameters such as temperature, humidity, and different gasses using IoT technology. To measure temperature and humidity, DHT11 sensor were used and MQ5 gas sensor was used to indicate hydrogen (H_2) and methane (CH_4) gas leaks in greenhouse. Gas sensor MQ7 was used to measure carbon monoxide (CO) gas in greenhouse. These sensors send the collected data to Raspberry Pi gateway. MQTT protocol was used for data communication. The weakness of the article was that the detailed implementation details were missing.

Yan et al[49] provided remote monitoring system using different sensors. The system was implemented in desert and costal area of China (Kubuqi Desert, Ulanbuh Desert, Taklimakan Desert, etc.) and data were collected for 1-year period. To read different environment parameters, the following sensors were used; air humidity and temperature sensor, wind direction and wind speed sensor, soil humidity and temperature sensor, water level, pH sensor, and luminance sensor. The system used MSP430F5438 as microprocessor and ZigBee communication protocol were used for data transmission between sensors and microcontroller. For remote data transmission, GPRS module (H7210-GPRS-RS485) was used. Sensors and other devices were powered by wind energy, solar energy, and battery. The collected data were stored in MYSQL database. Big data analytics were also used with IoT techniques to build early warning system based on the received data. The results show that, the system was capable of providing early warning for agriculture. The system needs to utilize machine learning system to make optimal decision making.

Geng and Dong[50] used IoT techniques with deep learning methodology for plant monitoring. To monitor environmental parameters, soil temperature and moisture sensor, humidity sensor, light intensity sensor, and temperature sensor were used. To communicate between sensor and central node, ZigBee technology were used. To position various chips, CC2530 (Texas Instrument) were used. Deep learning technique called restricted Boltzmann machine was used to make decision based on received environmental values. The detailed description about implementation is missing in this article.

Yim et al[51] used LoRA technology to monitor environmental parameters in tree farm. Low-power wide area network (LPWAN) is represented by LORA. To test the communication range of LORA, the experiments were conducted among maple, pine, and oak tree in Indiana rural tree plantation, United States. Different sensors such as temperature and humidity sensor (DHT11), flame sensor, photosensitive sensor, and soil humidity sensor were used to measure the environmental parameters. All these sensors were interfaced with Arduino Uno board and LoRA Gateway—LG01 was used for communication portal. In this experiment, they tested communication range of LoRA among trees by placing sensor in different distance. The result shows that LoRA does not provide expected communication range among trees.

Jian et al[52] monitored tomato plants in Anhui Agricultural University, China. Soil temperature and humidity, air temperature and humidity, and photosynthetic radiation were measured by respective sensors and measured values were displayed in liquid-crystal display (LCD) screen. To collect and process the measured data, MC9S12XS128 microprocessors were used. Sensor node used ZigBee communication module for data transmission, and microprocessor which is used GPRS module to send data to remote server. GPS was used with IoT technique for getting geographical information. The detailed descriptions of statistics data were missing in the article.

Kalathas et al[53] used IoT techniques to monitor tomatoes seeds. The tomatoes seeds were kept in IoT monitored seedbed and ordinary seedbed. Environmental conditions of the seedbed were monitored by different sensors such as soil temperature and humidity sensor (SHT10), air humidity and temperature sensor (DHT22 and Tmp 100). These sensors periodically forward the data to Arduino Uno. The measured values were used to activate heating circuit whenever seedbed environment conditions were not favorable to tomato seeds. Obtained result show that IoT monitored seedbed reduces the time of seed growing and it increases seed breeding. The system is lacked in energy conservation and security constraints.

Halim et al[54] used IoT techniques to monitor mango plants, which were cultivated in UniMAP Agrotech greenhouse, Malaysia. To measure environment parameter following sensors were used: temperature sensor, humidity sensor, light sensor, soil moisture sensor, and carbon dioxide sensor. MIB520CB were used to collect data from sensor using Wi-Fi module. Data were stored in MYSQL database and Lab view was used for interfacing and programming purpose. The detailed description about the system outcome is missing in this article. Additional features like solar system, automatic alerts, and security constraints are to be added.

Ferrández-Pastor et al[55] monitored and controlled environmental parameters of hydroponic crops in greenhouse environment using different sensors/actuators such as temperature, moisture, PH, EC sensors and luminosity, electro-valves, pumps, lamps, and so on. Raspberry Pi and Photon IoT devices were used to collect data from the sensors using MQTT protocol and REST API. Collected data were processed and stored in Ubidots cloud-platform using Internet. Various devices such as electric pumps, lights, electrovalves were triggered manually (from remote place) and automatically (by IoT system) used whenever required.

Moon et al[56] used lossy compression technique to compress the data from smart farm. In this article, various environmental data such as temperature, humidity, wind direction, solar radiation, and wind speed were collected from orchard in South Korea. The collected data are compressed by four compression algorithms, namely, boosted tree (BT), decision tree (DT), logistic regression (LR), random forest (RF), and the following three transformation technique, namely, discrete wavelet transform (DWT), discrete cosine transform (DCT), and fast Walsh-Hadamard transform (FWHT) were used for lossy compression. The result shows that compression schemes help to reduce the size of IoT data with a minor loss of data quality. The compression techniques can be applied when we collect large amount of data farm using IoT technique.

Akkas and Sokullu[57] used MicaZ motes to monitor various environmental parameters in greenhouses. The environment data are observed by MicaZ motes and it transfers collected data to gateway device such as MIB 250 platform. The gateway is connected to PC through wired medium. Mote View were used in PC to visualize the data. The experiment was conducted in Nazilli, Turkey for 2 days. To reduce the cost of the system, low-cost sensor can be used to read the environmental data. Table 1 shows the important components of IoT-based environment monitoring and controlling system and Table 2 describes various features such as gateway, sensors, actuators, communication system, storage, user interface, experiment nature, plant name/type, advantages, and disadvantages of IoT-based environment monitoring and controlling system. Gateway is overall coordinator, which receives data from sensing devices (sensor), manipulates data, and then forwards data to storage device. Sensors and gateway are connected by standard communication channel. The gate devices send data to the storage devices using Internet. Different storage devices such as SQL, local server, or cloud storage such as Mobius, ThinkSpeak are used to store data from gateway devices. From the storage devices, data are sent to farmers and it was accessed by web portal, mobile application, or SMS. The farmers can operate devices even (actuators) from remote places. The experiments nature such as indoor/outdoor, advantages, disadvantages of the IoT systems are described in the table.

6 | IOT-BASED AUTOMATIC IRRIGATION SYSTEM

In automatic irrigation system based on the environmental condition, the system automatically irrigates the field, which saves farmers time and efforts and also saves water usage. The detailed descriptions of a variety of irrigation systems are given below.

Subashini et al[58] proposed IoT-based smart farming system to monitor light intensity, humidity, soil moisture and temperature and automatic irrigation is provided to the plant. To measure various environmental parameters, following sensors were used: soil temperature was measured by thermistor, soil moisture was measured by coplanner capacitor, light intensity was measured by photo-resistor, humidity and air temperature were measured by DHT11. The sensed data were forwarded to 8-bit AVR microcontroller (gateway), which transmits the data into Wi-Fi module by using universal asynchronous receiver-transmitter (UART). Wi-Fi system ESP8266 ESP-12, transmit data to the web server using HTTP GET request. Weather updates were obtained by Weather Underground (San Francisco based company). ThingSpeak platform were used to store and retrieve IoT data using HTTP protocol. Irrigation pump were connected to the microcontroller and was operated automatically based on air, temperature, and soil moisture level. The prototype was tested outdoor for 3 days and obtained results were slightly deviated from actual result. To determine the reliability of prototype, it should be tested for more number of days and metrics of prototype should be discussed in terms of water consumption, energy consumption, plant growth, and so on.

Mohanraj et al[59] proposed IoT-based agricultural land monitoring system, where Arduino Uno board and TI CC 3200 Launch pad were used as gateway. This system was able to remind the farmers regarding the time to reap, spray fertilizer or pesticide, irrigation timing, based on the stored data through SMS. Based on the estimated water needed to the crop, the field was irrigated by the irrigation planner equipped with 5 V channel relay and L293D H Bridge motor driver; it irrigates the field and also displays the information whether the field was dry or irrigated. To collect soil moisture, KG003

TABLE 1 Various components of IoT-based Agricultural Monitoring and Controlling System

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/ type	Advantages	Weakness
Ma et al,[24] 2014, China	—	Customized sensor	IEE802.15.4 and GPRS communication	—	Web portal and SMS	Outdoor	—	—	—
Jun,[25] 2016, China	C8051F350 microcon-troller	CO2 sensor, temperature and humidity sensor, soil moisture sensor, light intensity sensor, pH value sensor, camera sensor	ZigBee communication	SQL	Web portal	Outdoor	—	—	Performance evaluation is missing in the article
Lamprinos and Charalambides,[26] 2015, Greece	—	Soil temperature sensor, SHT75 humidity sensor, SQ 110 solar radiation sensor, MCP9700A temperature sensor, TGS4161 CO_2 sensor, and gas sensor	ZigBee communication	PC	Web portal	Indoor	Tomato plants	—	High energy consumption
Palande et al [27] 2018, USA	Arduino and Raspberry Pi	An electrical con-ductivity probe, a pH sensor, a water tempera-ture sensor, and an air tempera-ture/humidity sensor	NRF24L01+ radio	Local server	Web and mobile applica-tion by Domoticz	Indoor and hydroponic	Hydroponics plants	System can be customized for any kind of plant	System is applicable to indoor plants only
Yung et al[28] 2017, China	STM32 – ARM processing chip	Temperature sensor, humidity sensor, illumination sensor, video camera, and so on	Wi-Fi, TCP socket protocol	MYSQL, Cloud storage and Hadoo for data analysis	Web page/ mobile applica-tion	Indoor (Greenhouse)	—	High accuracy	Not considering power consumption, system security

(Continues)

TABLE 1 (Continued)

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/type	Advantages	Weakness
Ryu et al[29] 2015, South Korea	Raspberry Pi with &Cube	Temperature, humidity, heater, sprinkler, LED lights	ZigBee communication	Mobius IoT platform	Mobile application	Indoor	—	High scalability	Statistical data are missing
Chieochan et al[30] 2017, Thailand	NodeMCU	Humidity sensor, fog pumps, and water sprinkler	Wi-Fi	Cloud platform (NETPIE)	Web page/mobile application	Indoor	Lingzhi mushroom	High accuracy	Not considering power consumption, system security
Kodali et al[31] 2016, India	NRF24LO1 Transmitter	Ultrasonic sensor, temperature sensor, humidity sensor, fog pump, grow LED, and so on	Wi-Fi	Google drive	Web/mobile application	Indoor	—	Low cost	Statistical data are missing
Ferrández-Pastor et al[32] 2018, Spain	—	Temperature sensor, humidity sensor, soil sensor, and so on	MQTT protocol and Wi-Fi	Cloud platform (Ubidots and Mobile-Alerts cloud)	Mobile application	Indoor	—	High scalability	Not considering power consumption, system security
Maia et al[33] 2017, Brazil	Raspberry Pi 3	Humidity sensors, temperature sensors, luminosity sensor	ZigBee	NoSQL database and cloud platform	Web application	Outdoor	—	High portability	High energy utilization
Na et al[34] 2016, India	STM32 Nucleo platform	Soil moisture, temperature, and pH level	Blue tooth	—	Mobile application	Outdoor	—	Low cost	Low accessibility
Tervonen [35] 2018, Finland	Sensor node	Temperature sensor and humidity sensors	Radio signals (modified Bitcloud radio stack)	Database	Mobile and web application	Indoor	Potato seeds	—	Low accuracy

TABLE 1 (Continued)

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/ type	Advantages	Weakness
Pérez-Expósito et al[36] 2016	Rasberry Pi with Arduino, weather station	Environment temperature, humility, soil temperature, and moisture	Wi-Fi [REST API]	MYSQL	Web Application	Outdoor	Vineyard (0.34 acres)	Low cost	Not considering power consumption, security
Pooja et al[37] 2017, India	Raspberry Pi	Soil moisture sensor, temperature and moistness sensor, light intensity sensor, and water motor	MQTT protocol	MYSQL	Web and mobile application	—	—	Less response time	Not considering power consumption, system security
Zhang et al[38] 2017 China	JN5139	Soil moisture sensor, soil temperature sensor, humidity sensor	ZigBee communication	—	Web interface	Outdoor	Citrus orchard	High accuracy	High cost
Bachuwar et al[39] 2017, India	ADS 1115 and ESP826612E Wi-Fi chipset	Temperature, soil moisture, and humidity sensor	I2C protocol	ThingSpeak platform	Web application	Indoor	—	Low power consumption	Framework implemented and tested in small scenario
Pitakphongmetha et al[41] 2016, Thailand	NodeMCU	Temperature and humidity sensor, soil moisture sensor, ultrasonic sensor, UV lights	—	ThingSpeak platform	Mobile application using Blynk platform	Indoor	Cantonese (hydroponics plants)	Less water and energy consumption; plant survival rate is high	Security constraints should be added
Crisnapati et al[42] 2018, Indonesia	Arduino and Raspberry Pi 2	Ultrasonic sensor, pH sensor, temperature sensor, and EC sensor	Wi-Fi	—	Web application	Outdoor and hydroponic	Pakcoy plants, lettuce plants	High accuracy	Security constraints should be added
Mekala and Viswanathan[43] 2019, India	Arduino Uno	Temperature sensor and thermistor	CloudMQTT protocol	ThingSpeak	—	—	—	Less error rate	Detailed implementation is not given

TABLE 1 (Continued)

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/type	Advantages	Weakness
Lee et al[44] 2019, Republic of Korea	ATmega128	Temperature/humidity sensor, solar radiation meter, CO_2 sensors	ZigBee	—	GUI based application	Indoor (Greenhouse)	Tomato plants	Low power consumption	High cost
Cambra et al[45] 2018, Spain	NRF24L01	pH sensor, pH electrode, micropumps	—	MYSQL database, and cloud storage	—	Indoor (Greenhouse)	Tomato and lettuce plants (hydroponic)	Low power consumption and high scalability	Security constraints should be added
Estrada-López et al[46] 2018, USA	MSP430FR5969	Temperature and humidity sensor, infrared light, soil conductivity	ZeeBee	Cloud storage	—	—	—	High accuracy and low power consumption	—
Aliev et al[47] 2018, Italy	NodeMCU	Temperature and humidity sensor, soil moisture sensor	Wi-Fi	ThinkSpeak	Mobile application	Indoor	—	Accurate results	High cost
Singh and Chandra[48] 2018, India	Raspberry Pi	Temperature, humidity sensor, gas sensors	MQTT protocol	—	—	Indoor (Greenhouse)	—	—	Implementation details are missing
Yan et al[49] 2018, China	—	Air humidity and temperature sensor, wind direction and wind speed sensor, soil humidity and temperature sensor, water level, pH sensor, and luminance sensor	ZeeBee and GPRS	MYSQL	Web application	Outdoor	—	High durability	Optimal decision making system can be used

TABLE 1 (Continued)

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/type	Advantages	Weakness
Geng and Dong[50] 2017, China	CC2530 (Texas Instrument	Soil temperature and moisture sensor, humidity sensor, light intensity sensor, and temperature sensor	ZeeBee	—	—	—	—	—	Implementation details are missing
Yim et al[51] 2018, USA	Arduino	Temperature and humidity sensor (DHT11), flame sensor, photosensitive sensor, soil humidity sensor	LoRA	—	—	Outdoor	Oak, pine, and midlife maple tree	High accuracy	—
Jian et al[52] 2014 China	MC9S12XS128 microproces-sors	Soil temperature and humidity, air temperature and humidity, and photosynthetic radiation	ZeeBee and GPRS	—	LCD	Outdoor	Tomato plant	Security constraints are added	Statistics data are missing
Kalathas et al[53] 2016, Greece	Arduino Uno	Soil temperature and humidity sensor (SHT10), air humidity, and temperature sensor (DHT22 and Tmp 100)	Wired	—	—	Indoor	Tomato seeds	High productivity	Not considering power consumption, system security
Halim et al[54] 2016, Malaysia	MIB520CB	Temperature sensor, humidity sensor, light sensor, soil moisture sensor, carbon dioxide sensor	ZeeBee and Wi-Fi	MYSQL	Mobile App	Indoor (Greenhouse)	Mango	—	Not considering power consumption, system security
Akkas and Sokullu[57]	MIB 250 platform	MicaZ motes	MicaZ wireless module	—	Web portal	Outdoor	—	—	High cost

TABLE 2 Different features of IoT-based environment monitoring and controlling system

Author	Scalability	Energy consumption	Security	Remarks	Cost	Fully automated	Solar energy usability
Ma et al[24]	✓	✓	✗	Water quality is increased	High	✓	✓
Jun[25]	✓	✗	✗	Plant growth	Low	✓	✓
Lamprinos and Charalambides[26]	✓	✗	✗	Environmental monitoring	Low	✓	✗
Palande et al[27]	✓	✗	✗	Plant growth enhanced	Low	✓	✗
Yung et al[28]	✓	✗	✗	Memory consumption, time consumption	Low	✓	✗
Ryu et al[29]	✓	✗	✗	IoT platform	Low	✓	✗
Chieochan et al[30]	✓	✗	✗	Man power reduced	Low	✓	✗
Kodali et al[31]	✓	✗	✗	Water consumption	Low	✓	✗
Ferrández-Pastor et al[32]	✓	✗	✗	Water consumption	Low	✓	✗
Maia et al[33]	✓	✗	✗	Highly portable	Low	✓	✓
Abdullah et al[34]	✓	✗	✗	Remote monitoring	Low	✓	✗
Tervonen [35]	✓	✓	✗	Remote monitoring	Low	✓	✗
Pérez-Expósito et al[36]	✓	✗	✗	Improving environmental and agricultural parameters	Low	✓	✓
Pooja et al[37]	✓	✗	✗	Improving environmental and agricultural parameters	Low	✓	✗
Zhang et al[38]	✓	✗	✗	Remote monitoring and decision support system	High	✓	✗
Bachuwar et al[39]	✓	✗	✗	Remote monitoring	Low	✓	✗
Jayaraman et al[40]	✓	✗	✗	Remote monitoring and environmental recommendation	Low	✓	✗
Pitakphongmetha et al[41]	✓	✓	✗	Plant growth	Low	✓	✗
Crisnapati et al[42]	✓	✓	✗	Monitoring and controlling hydroponic plants	Low	✓	✓
Mekala and Viswanathan[43]	✓	✗	✗	Monitoring comfort level of plant	Low	✓	✗
Lee et al[44]	✓	✓	✗	Remote monitoring and control	Low	✓	✗

(Continues)

TABLE 2 (Continued)

Author	Scalability	Energy consumption	Security	Remarks	Cost	Fully automated	Solar energy usability
Cambra et al[45]	✓	✓	✗	Remote monitoring of hydroponic plants	Low	✓	✗
Estrada-López et al[46]	✓	✓	✗	Soil parameter estimation	Low	✓	✓
Aliev et al[47]	✓	✗	✗	Remote monitoring	Low	✓	✗
Singh and Chandra[48]	✓	✗	✗	Remote monitoring	Low	✓	✗
Yan et al[49]	✓	✗	✗	Early warning system	Low	✓	✓
Geng and Dong[50]	✓	✓	✗	Remote monitoring	Yes	✓	✗
Yim et al[51]	✓	✗	✗	Remote monitoring	Low	✓	✗
Jian et al[52]	✓	✗	✗	Remote environmental monitoring	Low	✓	✗
Kalathas et al[53]	✓	✗	✗	Seed bread monitoring	Low	✓	✗
Halim et al[54]	✓	✗	✗	Remote monitoring	Low	✓	✗
Ferrández-Pastor et al[55]	✓	✓	✗	Remote monitoring and irrigation	Low	✓	✗
Akkas and Sokullu[57]	✓	✗	✗	Remote monitoring	Low	✓	✗

soil moisture sensors were used. A calamity checker was present which changes the irrigation plan according to the weather forecast from yahoo weather API. To provide sufficient sunlight in winter, artificial lights (grow light) were used, which helps the plants grow better, the amount of sunlight was monitored by Light Intensity Sensor (BH1750 module). Statistical data were missing in this article.

Sureephong et al[60] proposed smart wetting front detector using IoT. In this article, the authors investigate the performance of two soil sensors such as resistor based (RB) sensor, frequency domain reflectrometry (FDR) sensor. Along with the soil sensor, temperature sensors were used for detecting soil moisture and temperature. The observed soil parameters were sent to the web server using Wi-Fi. From the collected data, it is identified that FDR sensor achieves better performance in terms of precision detection. The advantage of this article is developed prototype were highly portable and can be handled easily. The experiment conducted for 30 days can also be conducted for more number of days for reliability of the data.

Goap et al[61] developed IoT-based irrigation system, which utilizes machine learning techniques to analyze online weather details to predict possibility of rain in that region. Sensors such as soil temperature sensor, soil moisture sensor VH-400, temperature sensor DHT22 and GUVA-S12SD ultraviolet light radiation sensor and Op Amp SGM8521 were used to collect details about the field and the collected data were send to the gateway device Raspberry Pi with Arduino Uno using ZigBee protocol. The gateway device transfers data for further processing using Wi-Fi module. The collected data and online weather information were used to predict the water requirement. If plants need water, the system automatically starts irrigation. This method helps to avoid wastage of water during rainy season and also system provides accurate result. The disadvantage is that the system cost is high and experiments were conducted only for 3 weeks, which can be extended.

Keswani et al[62] projected smart IOT-based irrigation system. To observe field details, soil moisture and temperature sensor, environment temperature, humidity and CO_2 sensor and sunlight sensor were used. The sensors were powered by solar energy and the collected data were sent to Raspberry Pi board (gateway) by ZigBee communication system. Wi-Fi communication was used to obtain data from Raspberry Pi and data stored was extracted using MATLAB. Fuzzy logic system was applied for weather prediction. To locate water deficiency places structural similarity (SSIM) technique was used. The analyzed data help to trigger the sprinkler unit in only dry places. This helps the system to save water.

Agale et al[63] designed tiny prototype using sensor nodes and Raspberry Pi. Soil moisture, humidity, temperature, water level details were collected and the observed details were used to automate the irrigation system. The collected data can be analyzed in web interface. The limitation of this method was that, the prototype used was very small range plants, experiment duration was not given and many statistical data were missing in this article.

Salvi et al[64] proposed IoT-based irrigation system for indoor different types of plants. Moisture sensor, DHT11 (humidity and temperature) sensor, light intensity sensor collects data from environment and forwards the data to Arduino Uno using Bluetooth module (HC-05). The collected data were stored in cloud using ThingSpeak. The system was designed in such a way that it automatically triggers motor whenever required. However, in this article many statistical data are missing, so we cannot realize the efficiency of the system.

Shekhar et al[65] used machine learning technique for smart irrigation system. The machine learning algorithm, K nearest neighbor (KNN) was used to decide irrigation in field. Moisture and temperature sensor collects data from the environment and sends the data to Raspberry Pi through Arduino microcontroller. KNN algorithm was used in Raspberry Pi to decide water requirement. Based on water requirement, it was supplied to plant. The collected data were then stored to Google drive. Ethernet (wired-connection) was used as communication module. In this article, the authors developed a prototype that was tested in small scale, experimental and statistical details were explained properly.

Imteaj et al[66] proposed GSM about automatic irrigation system. Environmental data such as soil moisture (FC-28), water level (funduino sensor), light intensity (cell) were measured and these analog details were converted to digital details using Arduino and these details were forwarded to Raspberry Pi using Wi-Fi module. The observed values were sent to the end user using an SMS. The system triggers water motor when moisture was low and sunlight was high and it also gives an option to operate the motor from remote places. The limitation of this article was that the prototype was tested in small-scale area, instead it could have been tested in large agricultural area. Detailed experimental details are missing and instead of SMS technique, mobile application could have been used as user interface, which would have helped in reducing the communication cost.

Monica et al[67] projected smart irrigation system. Moisture sensor (LM393 comparator), LM395 temperature sensor, LDR luminosity sensor collects data and forwards the collected data to Arduino Uno board. To transfer data, Wi-Fi module and GSM module were used. Periodically the collected data was transferred to the end user using an SMS service. These data were also stored in cloud storage using Sparkfun. The user can also control motor pumps by integrating Bluetooth.

The experiment was conducted in groundnut plant and the result showed that water consumption was reduced. However, also it was observed that the system should be improved in following terms such as energy conservation, security constraints and consideration of weather details before irrigation.

Rajalakshmi and Mahalakshmi[68] used different sensors such as soil moisture sensor, temperature sensor, humidity sensor, light intensity sensor (light dependent resistor), ultrasonic sensor (HSC-04) to automate irrigation system. Soil moisture and temperature sensor sends the details about environment condition and ultrasonic sensor sends the details about the water level of tank. These details can be accessed by the end user through mobile app and web application so that the end user can operate (ON/OFF) the motor from remote places too. Arduino was used as gateway; ZigBee was used as communication protocol between sensor and gateway. Arduino forwards data to web server using Wi-Fi module and the forwarded data were stored in MYSQL database for further processing. The experiment was conducted for 2 months and it was found that the water consumption was reduced. Some potential experimental details such as name of the plant, size of the experimental area and statistical data are missing in this article.

Vaishali et al[69] automated irrigation system using mobile application. Here temperature and humility sensor measures environment parameters and sends the details to a gateway called as Raspberry Pi. If moisture was less than threshold value, the gateway triggers motor for water supply to plants. The end user can obtain moisture and temperature details from remote place using mobile application. The Bluetooth module called Blue Term was used for communication. The disadvantage of this article is that the experimental details and statistical data were missing and IoT communication technologies could have been used instead of Bluetooth communications.

Kumar et al[70] used IoT devices to automate irrigation process. Different sensors such as soil moisture sensor, rain sensor, water flow sensor, temperature sensor were used to decide the moisture level of the land and the observed values were sent to Raspberry Pi through Wi-Fi connection. The algorithm that executed in Raspberry Pi decides the water flow based on the observed values. The DC motor was automatically triggered through relay. The water level in the water tank was monitored by rain drop sensor. The gateway also sends data to cloud storage and user can access data through mobile application. The advantage of this system is scalability, system was capable to irrigating water only to the required place and speed of the water was controlled with help of water flow sensor. The disadvantage of this system was statistical data were missing.

Saraf and Gawali[71] gave automatic irrigation system using different sensor such as temperature and humidity sensor (DHT11), water level sensor (M116), soil moisture sensor (LM 393). The sensors observe environmental parameters and transfer the data to the gateway called AtMega328 microcontroller through ZigBee communication module. The microcontroller sends data to computer. Received data were transferred and stored in cloud storage through Internet. The algorithm runs in cloud platform and decides the need of irrigation. The user can get details about it through mobile application. The major drawback of this article was, experimental and statistical data were missing.

Mat et al[72] proposed irrigation system for greenhouse using precision agriculture. Moisture sensor, humidity sensor, temperature sensor were used to observe heat and moisture level in greenhouse. The measured soil moisture data was sent to gateway using xBee wireless system. This system reads three types of liquid, namely, silicon oil, glycol, and acetone from the soil. The gateway transfers the received data to computer using Wi-Fi module or GSM for further analysis. The experiment was conducted with 100 chilli tree (capsicum annum). Result showed that automatic irrigation system saves 1500 mL water per day per tree. The disadvantage of this system was that experimental results were discussed only for 2 days, which could be projected for more number of days.

Cambra et al[73] projected multimedia-based smart irrigation system. Environmental parameters such as vegetation index (measured by AR Drones with HD camera), flow level, and wind speed were used to automate irrigation system. To measure and forward the observed field parameters 868 MHz wireless mesh network were used. LoRa Alliance was used for mobility and communication purpose. The obtained data were stored in MYSQL database. The rule set was used to determine the irrigation system. This system also detects fungus attack in the field, which helps farmers to protect crops from fungus attack.

Mehra et al[74] proposed IoT controlled hydroponics system based on deep neural network. The system was developed to monitor tomato plant, which was grown by hydroponic technique. Sensors such as pH sensor, temperature and humidity sensor (DHT11), light intensity sensor, temperature sensor, water level sensor were used to observe the environmental parameters and the observation was sent to Arduino board. Raspberry Pi programmed with deep neural network technique to get data from Arduino and it takes decision based on the received values. This decision was sent to Arduino to activate light, pumping water, and so on. The system data were periodically saved in cloud storage. To communicate between devices, UART communication module was used. The advantage of this system was it achieves higher plant growth. The disadvantages were system is not suitable for large scale, also agriculture and machine learning techniques could have be applied to increase the system accuracy.

Jaichandran et al[75] used IoT technique to irrigate multiple agriculture lands with well water. The authors created IoT-based prototype to test the efficiency of the system. Floating sensors were used to detect water level in well (water tank), when the water level was adequate, the system gets ready to trigger DC motor for irrigation. Before the DC motor gets activated, the soil humidity sensor in the field measures soil humidity and sends the data to microcontroller. Based on the soil humidity, microcontroller (ARM LPC 2148) sets the flow of water and triggers DC motor for irrigation. The system was tested with a simple prototype, instead real-time application could been used. To irrigate the land only soil moisture was used, which alone was not enough to take decision for irrigation instead other environmental details such as temperature, weather details were also needed. System used wired communication which is not feasible for real world scenario.

Izquierdo et al[76] developed IoT platform based on edge and cloud computing for smart farming technique. The system was designed to monitor the greenhouse environment, which was responsible for water and nutrition irrigation. IoT platform contained three layers, namely, cyber physical system (CPS), edge plane, cloud platform. Environment monitoring devices such as temperature sensor, humidity sensor, pH sensor, electrical conductivity sensor, solar radiation, pressure sensor, and actuators such as liquid counter, valves, water pumps were connected to CPS using wired channel. CPS collected data from sensors and was involved in atomic operation such as water irrigation, sending alert SMS when water consumption was high, water supply was low, power cut was detected, and so on. CPS also sent the collected details to edge plane using MQTT protocol. Edge plane was responsible for nutritive solution preparation and supply, pH adjustment in acid tank, cleaning nutritive solution tank. Edge plane forwarded farm details to cloud plane for data storage and further data analysis. CPS was designed with IPex16 controller, 32 bit CP, 4 GB memory card, USB, CAN, Ethernet, I/O ports, and so on. Edge plane was virtualized in a local server installed in farm premises. Cloud plane was high end server place in University of Murcia, Spain. The advantage of this system was it reduces water and nutrient consumption. The disadvantage was the cost of the system.

Bajer et al[77] developed Arduino-based garden (greenhouse) monitoring system. In this system, FC-28-B soil moisture and humidity sensor were used. The garden environment data were measured and forwarded to Arduino gateway. The gateway operates the actuators such as relay to automate the irrigation. The collected data were stored in memory card and user was able to check the environmental values in LCD screen.

Various important components of IoT-based irrigation systems are listed in Table 3 and important features of IoT-based irrigation system are displayed in Table 4.

7 | IOT-BASED PLANT DISEASE DETECTION SYSTEM

Potamitis et al[78] proposed smart traps, which help farmers to monitor agricultural land from remote places against insects. The basic mechanism in smart trap was that traps have a light emitter and a light receiver sensor facing each other, and whenever an insect crosses this set up it disturbs light and voltage. In this way, the numbers of insect entering were counted. Different traps were designed to detect different insects and the system can count insects, which were larger than 6 mm. The insect count was transferred to the server using GPRS mode, which utilizes transmission control protocol/Internet protocol (TCP/IP) and HTTP protocol. The data were stored in MYSQL server and was accessed by PHP scripting language. The system provided high accuracy in insect detection and its scalability was high. The issue with this technique was, external factors such as raindrop had a chance of affecting the result and this issue should have been solved.

Rustia and Lin[79] proposed insect monitoring system in greenhouses. The system had three main components- Raspberry Pi, which acts as gateway, Raspberry Pi camera, which was a light camera with image sensor used to capture the image of the insect and multi-environmental sensors which include temperature, humidity, atmosphere pressure, light intensity sensors. In every greenhouse, the sensor node was connected to the Internet using a star WSN topology, either by Wi-Fi or 4G router. A sticky article was present facing the camera (insect will come and get stuck), the camera captures the image of the article every 10 minutes from 7 AM to 6 PM also the sensor sends the environmental conditions every 5 minutes to the server. All the data was stored in a SQL database and the processing was done using server side scripting language PHP. The server can process the image and find the insect pest count. Even though system achieved high accuracy, test was conducted for less number of days and less number of plants.

TABLE 3 Various components of IoT-based automatic irrigation system

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/type	Advantages	Weakness
Subashini et al[58] 2018, India	8-bit AVR microcon-troller	Soil moisture sensor, soil temperature, light intensity, humidity, air temperature, irrigation pump	Wi-Fi	ThingSpeak platform	Web application	Outdoor	—	—	Not Reliable
Mohanraj et al[59] 2016, India	TI CC 3200 Launchpad and Arduino Uno board	Irrigation system, soil moisture, light intensity	—	Cloud platform	Mobile application	—	—	—	Results are not sufficient
Sureephong et al[60] 2017, Thailand	Microcontroller	RB sensor, FDR sensor, temperature sensor	Wi-Fi	—	Web application	Outdoor	—	Prototype is highly portable	—
Goap et al[61] 2018, India	Raspberry Pi with Arduino Uno	Soil moisture and temperature, air temperature and relative humidity, radiation, relay switch, motor	Wi-Fi and ZigBee Communication	SQLite and Apache	Web application	Outdoor	—	High accuracy	High cost
Keswani et al[62] 2018, India	Raspberry Pi	Soil moisture and temperature sensor, CO_2 sensor, environment temperature and humidity sensor, sunlight sensor, sprinkler unit	ZigBee Communication	MYSQL database	Web application	Outdoor	—	—	—
Agale et al[63] 2017, India	Raspberry Pi	Motor, temperature, moisture and humidity sensor, float sensor, passive infrared sensor	—	MYSQL	Web application		—	—	Prototype is tested in small environment

(Continues)

TABLE 3 (Continued)

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/type	Advantages	Weakness
Salvi et al[64] 2017, India	Arduino Uno	Moisture, temperature and humidity, light intensity sensor, UV LED, motor relay	Bluetooth module with serial port protocol and Wi-Fi	Cloud storage using ThingSpeak	ThinkSpeak web application	Indoor	—	—	Statistical data are not sufficient
Shekhar et al[65] 2017, India	Arduino and Raspberry Pi 3	Temperature and moisture sensor	Ethernet	Cloud (Google drive)	Web application	Indoor	—	—	Prototype is tested in small environment
Imteaj et al[66] 2016, Bangladesh	Arduino and Raspberry Pi 3	Soil moisture, water level sensor, photo cell, water pump	Wi-Fi and GSM module	—	Mobile (using SMS)	Indoor	—	—	Not scalable
Monica et al[67] 2017, India	Arduino Uno	Soil moisture, temperature, luminosity sensor	Wi-Fi, Bluetooth, and GSM module	Cloud (Sparkfun)	Mobile application	—	Groundnut plant	Water conservation is low	Not considering weather updates
Rajalakshmi and Mahalakshmi[68] 2015, India	Arduino	Soil moisture, temperature, humidity sensor, light intensity sensor (light dependent resistor), ultrasonic sensor (HSC-04)	ZigBee, Ethernet	MYSQL	Web application and mobile application	Outdoor	—	Water conservation is low	Experimental and statistical data are missing
Vaishali et al[69] 2017, India	Raspberry Pi	Temperature and moisture sensor	Bluetooth	—	Mobile application	—	—	—	Experimental and statistical data are missing
Kumar et al[70] 2017, India	Raspberry Pi	Soil moisture, temperature, rain drop and water flow sensor, relay, DC pump	Wi-Fi module	Cloud	Mobile application	—	Beans, ladies finger, radish, curry leaves	Scalability and less water conservation	Statistical data are missing

TABLE 3 (Continued)

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/ type	Advantages	Weakness
Saraf and Gawali[71] 2017, India	AtMega328 microcontroller	Temperature and humidity sensor (DHT11), water level sensor (M116), soil moisture sensor, relay, motor pump	ZigBee Communication	Cloud	Web and Mobile application	—	—	—	Experimental and statistical data are missing
Mat et al[72] 2016, Malaysia	—	Moisture sensor, humidity sensor, temperature sensor used	XBee communication module	—	Web application	Indoor (Greenhouse)	Chili tree	Less water conservation	Experimental duration is very less
Cambra et al[73] 2017, Spain	868 MHz mesh network	Drones with HD camera	LoRa Alliance	MySQL database, and cloud	Mobile application	Outdoor	—		
Mehra et al[74] 2018, India	Raspberry Pi and Arduino Uno	Temperature and humidity sensor (DHT11), water level sensor, photo resistor, DC motor, DC pump,	UART Communication	Cloud (Google Firebase cloud)	Web application	Indoor (hydroponic)	Tomato plant	Higher plant growth	Lot suitable for large scale agriculture
Jaichandran et al[75] 2017, India	ARM LPC 2148 microprocessor	Floating sensor, soil moisture sensor, DC motor, GPS	Wired connection	—	LCD	Indoor	—	—	Simple prototype
Izquierdo et al[76] 2018, Spain	Customised system	Temperature sensor, humidity sensor, pH sensor, electrical conductivity sensor, solar radiation, pressure sensor, liquid counter, valves, water pumps	MQTT protocol	Cloud	Web application and SMS	Indoor	Tomato plant	Low Water and nutrient consumption	High cost
Bajer et al[77] 2015, Czech Republic	Arduino MEGA 2560	FC-28-B, relay, pump	Ethernet	Memory card	LCD	Indoor	—	—	Limited functionalities

TABLE 4 Different features of IoT-based automatic irrigation system

Author	Scalability	Energy consumption	Security	Remarks	Cost	Fully automated	Solar energy usability
Subashini et al[58]	✗	✗	✗	Water consumption	Low	✓	✗
Mohanraj et al[59]	✓	✗	✗	Water consumption	Low	✓	✗
Sureephong et al[60]	✓	✗	✗	Not applicable	Low	✓	✗
Goap et al[61]	✓	✗	✗	Water consumption	High	✓	✗
Keswani et al[62]	✓	✗	✗	Water consumption	High	✓	✓
Agale et al[63]	✓	✗	✗	Water consumption	Low	✓	✗
Salvi et al[64]	✓	✗	✗	Water consumption	Low	✓	✗
Shekhar et al[65]	✓	✗	✗	Water consumption	Low	✓	✗
Imteaj et al[66]	✓	✗	✗	Water consumption	Moderate	✓	✗
Monica et al[67]	✓	✗	✗	Water consumption	Low	✓	✗
Rajalakshmi and Mahalakshmi[68]	✓	✗	✗	Water consumption	Low	✓	✗
Vaishali et al[69]	✓	✗	✗	Water consumption	Low	✓	✗
Kumar et al[70]	✓	✗	✗	Water consumption	Low	✓	✓
Saraf and Gawali[71]	✓	✗	✗	Water consumption	Low	✓	✗
Mat et al[72]	✓	✗	✗	Water consumption	Low	✓	✗
Cambra et al[73]	✓	✗	✗	Water consumption and fungus detection	Low	✓	✗
Mehra et al[74]	✗	✗	✗	Plant growth	Low	✓	✗
Jaichandran et al[75]	✗	✗	✗	Water management	Low	✓	✗
Izquierdo et al[76]	✓	✓	✗	Water and nutrient consumption	Low	✓	✓
Bajer et al[77]	✓	✗	✗	Water management	Low	✓	✗

Thorat et al[80] projected IoT-based system, which was equipped with soil moisture sensor, temperature sensor, humidity sensor (DHT11 sensor), and camera. These entities collect data and transfer it to Raspberry Pi (Raspbian OS) via wired and wireless medium. In the server (Apache server), the received data were compared with the threshold value and if any difference then a notification was sent to the farmers' mobile or website. The disease in the plant was detected using a camera and the image of the plant was captured and sent to the server. The image was processed using Open CV. The system was able to detect a range of lead diseases such as black spot, botrytis blight, leaf spot, and powdery mildew and rust diseases. The disadvantage of the system was that it was not scalable. For large environmental area it was found to be difficult to place camera and capture the image of all the plant leafs. Even though experimental results were encourageable, system should have be modified in such a way that, it suits for large area.

Kapoor et al[81] integrated image processing with IoT technologies to detect factuators which hinder the growth of the plant. Devices such as temperature sensor (DHT11), soil moisture sensor, and serial JPEG camera module were used to detect environmental changes. The observed data was sent to Arduino Uno, which acts as a gateway. The received data was then stored in SD card. The camera captures leaf of plant and MATLAB was used for processing the captured images. Plant was kept in different environments such as indoor, outdoor, semioutdoor and results were analyzed. The correlation between plant growth and different environment scenarios were studied using the observed details. The advantage of the system was that the environmental factors such as temperature, soil moisture also were considered to detect the plant diseases. The disadvantages were, the system was not fully automated and not scalable to large agriculture area.

Rau et al[82] detected nutrients deficiency in rice plants and designed smart irrigation system. Temperature and humidity sensor were used to detect plants state and water motor was used to pass the required water to the plants. Raspberry bi was used as gateway. The image of rice leafs were captured and these leafs were analyzed by MATLAB. The captured leaf's green color intensity was obtained from MATLAB and it was compared with IRCC (International Rice Color Chart). This comparison helped to find the Nitrogen content variation, brown leaf spot and bacterial blight diseases successfully. The disadvantage of this system was that minimum 13 MP camera was needed to take leaf picture, and system was not fully automatable.

Pérez-Expósito et al[83] developed system called VineSens, which helps farmers to monitor vineyard and detect disease called downy mildew. Two kinds of sensors were used to collect data from the environment. To measure humidity and temperature of atmosphere, DS18B20 sensors were used and to measure moisture and temperature of soil, SHT11 sensors were used. Sensor nodes were directed by ESP8266 microcontroller. It collects and sends data to the sensor through REST API. Raspberry Pi 2 acts as gateway and it uses Wi-Fi (IEEE 802.11b/g/n) for data transmission. TP-LINK router was used to connect the whole system to the Internet. To get details on weather information, weather station was launched that consists of Arduino, data acquisition board and sensors. The entire system was powered by solar energy. The collected data were stored in MYSQL database and the user can access the data through web portal. The system helped to prevent and detect the downy mildew disease using Rule 3-10 model. Rule 3-10 model predicted the downy mildew disease by environmental conditions. After detecting downy mildew, the system suggested phytosanitary treatment. According to weather and environment parameters, the system decided the range of treatment. In this article, experiment was conducted in Galicia, Spain for 0.34 acres and results were encourageable. The advantage of the system was scalability and result accuracy. System did not use any other article techniques such as usage of camera to capture leaf picture for disease analysis, since using camera to take photo of plant leaf for large agricultural area was impossible for implementation.

Kim et al[84] proposed disease predication system for strawberry plant. The IoT systems were based on oneM2M platform and consist of LoRa Class C devices and gateway. Sensors measures CO_2 concentration, humidity, and temperature of greenhouse and saves the measured value in the form of data. The collected data were then forwarded to gateway using LoRa based wireless module. Gateway were connected to wired communication using RS-485, CAN. Experiments were conducted on Seolhyang strawberry variety. The objective of this article was to predict the strawberry disease called *Botrytis cinerea*. *B. cinerea* disease occurred due to temperature and leaf surface wetting duration and it was successfully detected based on weather condition by the system and it suggests that the required nutrient solution supply limit.

Foughali et al[85] used decision-making system to prevent potato late blight disease with help of IoT. The system was implemented and tested in Ras Jebel region in Tunisia. Waspmote sensor (combination of temperature and humidity sensor) was used to measure environmental status and the data was transferred to gateway using ZigBee interface. Meshlium (gateway) collects the data and sends the data to Ubidots cloud platform. Ubidots were also used to send warning message to farmers whenever the environmental status reaches below threshold value. SIMCAST model were used as decision making system. This article used environmental data to predict the late blight disease. The system could have been extended to large environmental area.

Sarangi et al[86] implemented IoT in advanced call center called Wisekar in India, which helped farmers to understand more about plant disease. Farmers capture image of the affected plant and forward the picture to call center through web interface. From call center, the picture would be sent to crop-disease detection center. Crop-disease detection center use Java and MATLAB to recognize the crop-disease. Once the disease was identified the details of the disease were forwarded to the farmers. In this way Wisekar helps farmers to identify and learn more about plant diseases. The system was helpful to the user but India has 29 states, most of the states have their own language. So call center and website should support regional languages so that Wisekar would be able to help the user.

Hsu et al[87] designed IoT platform for cloud fog computing to monitor and detect pest in farm land. In this article, temperature sensor, humidity sensor, and Raspberry Pi camera were used to observe the environment data and pest in plants.

These devices send the observed data to fog mediation system. The mediation device (Raspberry Pi) forwards the data to gateway and gateway forwards the data to cloud storage. The main objective of mediation device is to manage and handle the sensor and camera data. This mediation helps to analyze plant pictures and sensor data. Then the analyzed data are uploaded to cloud storage from mediation device. The result also showed that the fog calculation reduces network cost time and analysis time. The observation of the system was decentralized data analyze helped in reducing the data analyze time and network time.

The above discussed disease/pest detection systems help farmers to protect their plants from diseases, insect, and pet. These articles have its own advantages and disadvantages. Various important components and features of these techniques are displayed in Tables 5 and 6 respectively. Many of the authors did not discuss about accuracy of the system. To prove the reliability of the system, system performance should be compared with real-time scenario. Also, many techniques fail to minimize the energy usage of the devices and also the system should utilize the solar energy for IoT devices. Some authors use camera to capture the image of the plant leaf to detect the plant disease; however, for the large agriculture area, this kind of the technique may fail. Instead flying drone with camera can be used to capture the image of the plants. However, this also may increase the system cost. So, plant disease should be predicted by environmental condition and informed earlier to former for proactive actions.

8 | DISCUSSION

The evolution of IoT in agriculture helps farmers in many aspects, but following shortcomings should be addressed in the future IoT-based smart agricultural systems.

Security: The most important issue in the above-mentioned technique is lack of security. Because most of the studied techniques mainly communication protocols are prone to various security attacks.[88,89] For an example ZigBee is vulnerable to packet decoding, data manipulation, and traffic sniffing issues and IEEE 802.11 is vulnerable to jamming, scrambling, and passive attack.[90] The required significance work should be carried out to guard the data communication, trust management techniques in IoT.[91,92]

Usage of renewable energy: Only a few existing IoT systems utilized renewable energy in smart forming. Instead of using electrical energy (or) battery energy for IoT components, all the IoT-based smart forming systems need to utilize renewable energy. Energy harvesters can be used to obtain different form of energies such as solar energy, electromagnetic energy, thermoelectric energy, and radio frequency energy from the environment.

Scalability: In real-time scenario, agricultural activities are carried out in large-scale area. Even though most of the IoT systems are highly scalable, it creates varieties of issues in large-scale deployment such as cost, data storage, data reliability, data synchronization, data aggregation, and so on.[93]

Cost: Even though a few sensors and actuators are cheap, some high-quality IoT devices are still costly. For the large-scale implementation, it makes big burden to farmers. The low-cost devices (with high accuracy) need to be introduced in order to reduce the burden of farmers.

Connectivity: The IoT technology should enable formers to connect with customers or distributors. So that farmers can understand the requirements and demands. This helps farmers produce right crops in right time. Some works are carried out in food supply[94-97]; however, these work lack real-time implementation and solving real-time issues. Thankfully, some researchers shown possibility of IoT contribution in food supply,[98,99] but further more contribution required in this area.

TABLE 5 Various components of IoT-based plant disease detection system

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/ type	Advantages	Weakness
Potamitis et al[78] 2017, Greece	—	IED lights	GPRS, TCP/IP, and HTTP protocol	MYSQL database	Web page (HTML5, PHP, Angularjs, Javascript, Jquery)	—	*Rhynchophorus ferrugineus*	High accuracy	Not suitable for outdoor plants
Rustia and Lin[79] 2017, Taiwan	Raspberry Pi	Raspberry Pi camera, temperature, humidity, atmosphere pressure, light intensity sensor	Wi-Fi or 4G router	MYSQL database	Web page (HTML5, PHP)	Cabbage	White flies, fruit flies	High accuracy	Less scalability
Thorat et al[80] 2017, India	Raspberry Pi	Soil moisture sensor, temperature sensor, humidity sensor (DHT11 sensor), and camera	Wi-Fi	Apache sever	Web page/mobile phone	—	Leaf disease (black spot, botrytis blight, leaf spot, etc)	—	Less scalability
Kapoor et al[81] 2016, India	Arduino Uno	Soil moisture sensor, temperature sensor, humidity sensor (DHT11 sensor), and camera	—	SD card	—	Philodendron plant	Leaf lattice	—	Not fully automated and less scalable
Rau et al[82] 2017, India	Raspberry Pi	Temperature and humidity sensor, solenoid valves, rapi camera	—	—	Mobile application	Paddy plant	Bacterial blight, brown leaf spot	—	High cost and not fully automated

(Continues)

TABLE 5 (Continued)

Author, year	Gateway	Sensors and actuators	Communication system	Storage	User interface	Experiment nature	Plant name/ type	Advantages	Weakness
Pérez-Exposito et al[83] 2017, Spain	Raspberry Pi 2	Atmosphere humidity and temperature (DS18B20) sensor, soil moisture and temperature (SHT11) sensor	Wi-Fi	MYSQL	Web application	Vineyard	Downy mildew	Fully automated and high scalability	—
Kim et al[84] 2018, Tunisia	OneM2M platform	CO2, humidity, temperature sensors	LoRa and RS-485, CAN	—	—	Strawberry plant	*Botrytis cinerea*	High accuracy	—
Foughali et al[85] 2018, Tunisia	Meshlium	Waspmote sensor (combination of temperature and humidity sensor)	ZigBee communication	Ubidots	Web application	Potato	Potato late blight	High scalability	
Hsu et al[87] 2018, England	Raspberry Pi	Temperature sensor, humidity sensor, Raspberry Pi camera	MQTT protocol	Cloud storage	—	—	—	Network and data analysis time is less	

TABLE 6 Different features of IoT-based plant disease detection system

Author	Scalability	Energy consumption	Security	Remarks	Cost	Fully automated	Solar energy usability
Potamitis et al[78]	✓	✗	✗	Insect detection	Low	✓	✗
Rustia and Lin[79]	✗	✓	✗	Insect detection	High	✓	✗
Thorat et al[80]	✗	✓	✗	Disease detection	High	✗	✗
Kapoor et al[81]	✗	✓	✗	Disease detection	High	✗	✗
Rau et al[82]	✗	✓	✗	Disease detection	High	✗	✗
Pérez-Expósito et al[83]	✓	✗	✗	Disease detection	Low cost	✓	✓
Kim et al[84]	✓	✗	✗	Disease detection	Low cost	✓	✗
Foughali et al[85]	✓	✗	✗	Disease detection	Low cost	✓	✗
Hsu et al[87]	✓	✗	✗	Disease detection	Low cost	✓	✗

Compatibility: IoT system needs to integrate with other technologies such as big data, machine learning, service composition, resource allocation techniques, and so on, so that IoT systems can deal with huge amount of agricultural data.[100,101] These techniques help in automation process of agriculture.

Early prediction and solution provider: Due to global warming and dramatic changes in climate, agriculture suffers lots. The IoT technologies should help farmers to predict rain, cyclone, and drought. Also, IoT techniques should suggest appropriate plantation according to future climate.

Furthermore, some agricultural IoT pilot projects such as pilot project in China[102] and pilot project in Europe[103] provide the requirements and challenges in large-scale implementation of IoT techniques in agriculture. These studies help to understand different challenges in large-scale implementation issues. IoT techniques that should integrate with satellite remote sensing technique[104,105] helps to analyze and monitor various environment features such as temperature, soil parameters in large scale agriculture land.

9 | CONCLUSION

Agriculture is the backbone of our society. In order to smarten "farming" the practice of agriculture in an effective way, IoT techniques is united with agriculture. IoT techniques are applied in almost all fields of agriculture such as farm monitoring, irrigation, pest monitoring, and so on. Existing smart farming techniques are classified and reviewed; from this study, it is understood that researchers should concentrate more on security aspects, food supply and food distribution. It is also observed that, most of the experiments were conducted in indoor environment. In order to solve more real-time problems researchers should also experiment these techniques in outdoor. On the whole, this work will support researchers to realize the current status assuredly.

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