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IoT-Smart Agriculture: Comparative Study on Farming Applications and Disease Prediction of Apple Crop using Machine Learning

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Abstract

Recently, the Internet of Things has emerged as an encouraging technology that is scaling up new heights towards the modernization of real word physical objects into smarter devices in several domains. Internet of Things (IoT) based solutions in agriculture drives farming into a smart way through the proliferation of smart devices to enhanced production with minimal human involvement. This paper presents a comprehensive study of the role of IoT in prominent applications of farming, wireless communication protocols, and the role of sensors in precision farming. In this research article, the existing frameworks in IoT-based agriculture systems with relevant technologies are presented. Furthermore, the comparative analysis of the apple disease prediction system concerning different types of disease found in the apple crop are discussed. In addition, this paper presents the contributions made by numerous researchers over the past few years in the apple disease prediction system. The aim of this research is to support the development of smart agriculture applications that would be helpful in precision farming for the optimization of resources with the help of IoT in agriculture and early disease prediction in apple crops.

Keywords: IoT, Precision agriculture, Crop diseases, Apple, Machine learning.

1. Introduction

With the explosive progress of digital innovations, the number of Internet of Things (IoT) devices has increased dramatically in recent years. Millions of new devices, sensors, and applications are going to be online in the next decade fuelled by digital innovative technologies. Sensors/Devices are interconnected and generate, transmit an enormous range of data through network infrastructure[1][2][3].

Agriculture is considered as one of the key strengths of the global economy and contributes significantly to the development of the country's economy. The role of the Internet of things (IoT) in attaining sustainable growth has provided a competent and structured approach for the observation of crops in the field with the assistance of sensors. IoT-enabled technologies signify the future of computing and communication in agriculture. The wireless sensor network is the dynamic strength technology that can transform the agriculture domain area from being fixed and labour-intensive to dynamic and smart and leads to boost the agriculture production with the least human efforts[4][5][6].

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India is an agrarian nation and ranks second in the list of fruit and vegetable-producing nations in the world. In India, different varieties of fruits are produced that are deciduous fruits consisting of pome fruits and stone fruits, which are mostly cultivated in hilly regions. Considering the apple crop, millions of people are associated with it, and is considered one of the major industrial fruits among deciduous fruit. Indian stands in sixth place for the largest production of apples in the world [7].

Apple is attacked by several diseases such as Scab, Marsonina Coronaria, Alternaria Powdery Mildew, etc. that affect the production in terms of quality and quantity, which directly impact the economic status of the region. Other various diseases affect the crop during different stages of the growing phase with time. Crop diseases outbreak is a threat to productive production. Traditional methods of disease handling, awareness lacking and insufficient technology usage among the farmers lead to an average loss of crops every year.
Numerous diseases spoil crop production to a large extent. So early disease prediction is much needed for the timely prevention of crop infection in the initial stages of disease spread. Traditionally farming methods are not technically systematic and are tedious processes. As the world is advancing towards using modern technologies, it is necessary to use that technology in agriculture. The IoT-enabled technologies are a ground-breaking development that signifies the future of computing and communication in the agriculture sector [8][9]. The adaptation of IoT and machine learning technologies in the agriculture sector lies in the possibilities offered for minimum inputs in farming and return the maximum productivity and profitability of farming [10][11].

This survey focuses on the work related to the IoT-Agriculture system, IoT applications, and solutions in the farming system, the role of agriculture sensors, wireless communication protocols, and existing apple disease prediction systems.
The structure of the paper is as follows: Section 2 discusses the agriculture applications through IoT, while section 3 provides information about the different types of sensors and their role in agriculture. Section 4 discusses the communication protocols in precision agriculture and provides comparison tables of existing wireless communication protocols. The existing agriculture framework is discussed in section 5. The Apple disease prediction system is discussed briefly with a comparison table in section 6. Finally, section 7 concludes the paper and presents the possible future directions in this field.

2. IoT-Based Smart Farming Applications

The speedily growing population in the world is increasing the demand for food for survival on earth. Various technologies are being incorporated to increase the production of crops to face the challenges. Modern farming replaces the traditional concept of farming as the traditional way of farming could be one of the causes for minimal crop production in agricultural fields even though ample arable land is available. The concept of precision farming is to escalate crop production and make a smart cropping system. Precision farming is the utilization of agricultural resources and information about farming intelligently through sensing and communication technology with maximization in production and finance return[12][13][14].

Numerous techniques like calculated fertilization, perfect time for spraying pesticides, controlled and automated irrigation systems, etc. are taken into consideration in smart farming for helping the farmer improve agricultural productivity. Precision farming with the use of wireless sensor networks changes the agriculture sector into a technology track for enriching agriculture production with minimum human efforts. The usage of wireless sensor networks in precision agriculture will deliver an enormous amount of information for the farmers including the taxonomy of energy efficiency, energy harvesting techniques, and wireless communication technologies[15]. Developing a system on the basics of wireless sensor nodes for monitoring the crop through three components such as hardware, web application, and mobile application for data collection, data analysis for prediction, and control through web application such as watering the crop[16].

Precision agriculture includes retrieving information about the soil condition, weather, and crop with the use of sensors installed in the field. The specific sensors and software, ensure that the crop receives what it needs for optimizing productive sustainability[17][18]. The system of agriculture will get many benefits and turn intelligent while adopting and applying machine learning to data collected from sensors. The precision farming concept for field monitoring describes the leverages of the IoT and machine learning together can increase production and automate crop monitoring while producing an affordable smart farming module[19][20]. The implementation of IoT, wireless communication, and machine learning in sensitive areas like crop disease, pesticide control, weed management, water management, irrigation system, etc., can solve issues through these technologies more accurately[21].

Farming based on IoT consists of various applications, such as crop monitoring, disease prediction, irrigation, climate monitoring, soil monitoring, harvesting, etc. The IoT-based structure in agriculture applications is illustrated in Figure 1. In IoT-based agriculture, farming has become more industrialized and technology-driven by the use of various types of sensors such as soil moisture, temperature, humidity, leaf wetness, etc. as shown in the below figure for better control over the process of raising fruitful production. The concept of Precision farming makes the farming practice more controlled and accurate and is one of the most famous applications of IoT in the agriculture sectors in different domains such as crop disease monitoring, irrigation management, yield monitoring, optimal fertilization system, etc. for enhancing the highly transparent farming.

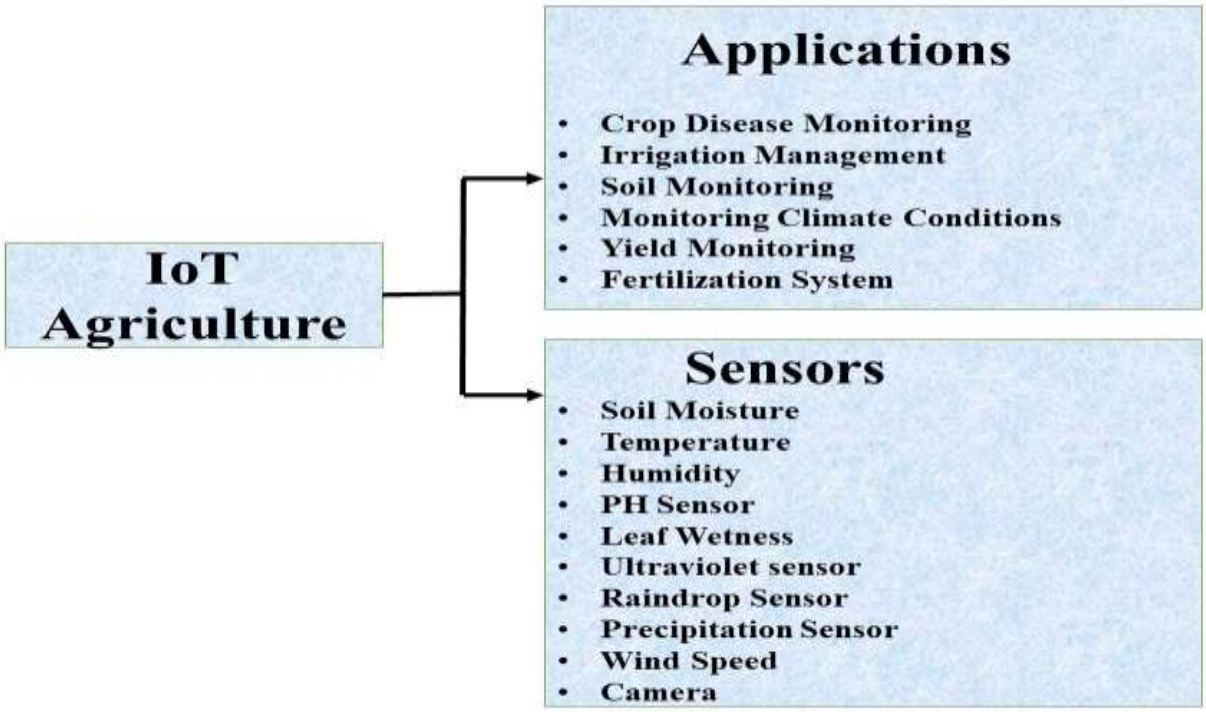

Figure 1: IoT in Agriculture

2.1 Crop Disease Monitoring

Numerous diseases spoil crop production to a large extent. Crop diseases outbreak is the main causes of production and financial loss for farmers. Through IoT technology, the farmer can benefit by avoiding crop losses through early prediction of disease. Early disease prediction will play an important role in halting the spread of disease that affects crop cultivation. There are IoT and machine learning-based systems proposed to forecast the disease attack on mango crops. The past weather data were taken into consideration with the live weather data for the prediction of the disease with machine learning techniques[22].

The Heterogeneous IoT method for the detection of leaf disease is based on the identification of gestures of the leaf image and to find out the leaf and fruit that are suffering most from the disease and pointed out the disease in the leaf [23]. Detecting the stem diseases of jute plants using an Android application, by taking the pictures of stems of a jute plant affected by the disease and sending them to the cloud server for analysis through machine learning technique[24].

A method based on the Mask-RCNN was proposed by [25]to identify the various types of leaf disease in apple crop during early stages and alert the farmer and nearby institute to take appropriate action in due course of time. In their work, 1821 images dataset of apple leaves, which includes both normal and infected leaves, were taken into consideration. 90% accuracy was achieved in classifying the disease.

A Convolution neural network model was also developed for identifying disease in apple crop and with the help of proper image augmentation. The model was made better by making the dataset more suitable for CNN training and achieved around 99% accuracy [26]. In addition, a deep convolutional neural network method was introduced for detecting apple leaf disease. In that work, the dataset contained 2970 images of five common diseases and normal apple leaves and the DCNN method yielded an accuracy of 98.82% [27].

2.2 Irrigation Management

One of the main difficulties faced in this field is the lack of knowledge regarding the soil type and content, irrigation patterns, and quantity dependent on the soil porosity and its soil capacity of water retention. Crop quality and quantity production are significantly affected when facing a deficiency of water, as irregular irrigation can provoke different microbial infections and reduce soil nutrients.

It is not an easy task to have a precise assessment of the water requirement of crops, in which various factors are taken into consideration like soil type, crop type, precipitation, soil moisture retention, etc. Thus, smart irrigation is a key component of precision agriculture with enormous benefits for farmers. For optimization of water usage in the agriculture domain, the monitoring and decision-supported system based on a combination of sensor network technology and fuzzy logic were proposed to provide an optimal irrigation schedule [28].

The intelligent irrigation system based on drip irrigation techniques and a wireless sensor network enhances the quality of agriculture production, crop efficiency, and conservation of water and energy resources [29]. Measuring the soil parameters such as moisture of soil and soil temperature to determine the real-time requirements of irrigation through the sensory array integration with sensor networks[30]. Estimating the quantities of water required for plants and controlling the water stress of plants through the Internet of Things devices[31].

2.3 Soil monitoring

The monitoring of soil is an important parameter in the production of crop development. The improper management of soil leads to both crop loss and degradation of soil quality. An IoT-based system can monitor and test the soil through different sensors such as soil moisture sensor, soil temperature sensor, soil pH sensor, and humidity sensor for assessing the nature of soil and soil properties. Based on information from sensors, the results of the test will give the appropriate suggestion for the farmer to cultivate the crop that suits the soil[32]. The IoT and machine learning together can increase production and automate crop monitoring while producing affordable smart farming[19].

2.4 Monitoring Climate Conditions

The monitoring of the weather conditions is an important factor for the future course of farming action. The weather parameters, such as temperature, humidity, air pressure, precipitation, wind direction, etc. are also important for crop production. The data of these parameters are useful for the action required for the crop and will improve crop production. Acquiring information about the environment through the use of different sensors will be helpful for the farmer in their yield production[33][34].

2.5 Yield Prediction

The crop yield prediction is highly beneficial from the cost and marketing perspective. The IoT and techniques of machine learning can predict the crop-based data collected from sensors. Based on the current environment the most suitable plants can be predicted and the farmer is given suggestions for the kinds of the crop to plant[35]. Thus, the techniques of machine learning and other new technologies when applied to the farming sector can maximize the yield of crops[36].

2.6 Fertilization System

For enhancing production and growth, fertilizer plays an important role in the crop development life cycle. Fertilizers are natural or artificial materials that can be added to the soil in the appropriate quantity when the soil lacks the required nutrition level. Improper use of fertilizer can also have negative effects on the crop as well as the plant. It’s important to locate the location of the soil where fertilizer is required and provide the fertilizer in a precise amount.

Various fertilization techniques have been presented using a wireless sensor network. The IoT-based fertilization system is used to monitor and analyse the presence of nutrients in the soil and detect nutrient deficiency from the sensed data[37]. The checking of the quantity of the major macronutrients such as nitrogen, phosphorus, and potassium present in the soil with help of IoT technology will minimize human involvement[38]. Monitoring the soil will increase crop production and through test report analysis appropriate fertilization is recommended to the farmer[39].

3. Role of Sensors in Agriculture

The role of the sensors in agriculture is to collect and generate information about environmental and physical parameters. The role of the IoT in achieving sustainable growth has provided a competent and structured approach for the observation of crops in the field with the assistance of sensors. The farming domain possesses different requirements such as:

- Monitoring of the farming field for crop growth.
- Sensing, collecting, and communication of data parameters such as soil temperature, soil moisture, leaf wetness, etc.
- Study the requirement of fertilizer and water content at different areas of the cultivation land.
- Study the requirements of crops based on different types of soil and weather conditions.

3.1 IoT Devices / Sensors in Agriculture

Agriculture through the technology of IoT tracks the information/data of the field through various sensors. The sensors are physical objects that sense and measure the physical environment parameters and perform tasks without human involvement. Various sensors are used in agriculture applications and some commonly used sensors are listed in Table 1[40][41][42].

Table 1: Role of IoT Sensors in Agriculture

Sensor	Task	Role
Soil Moisture	Soil health	Measure the water quantity and moisture content of the soil.
Temperature Sensor	Soil Temperature	Measure the temperature of the soil.
PH Sensor	Soil Nutrients	Monitor the accurate amount of nutrients in the soil (acidity and alkalinity)
Leaf Wetness	Wetness of leaf	Information about the wetness of the leaf / small amounts of water present on the leaf
Humidity Sensor	Moisture ratio in air	Measures the comparative humidity level in the air
Ultraviolet Sensor	Detects light rays	Monitor the ultraviolet rays
Raindrop Sensor	Sensing rain	Measuring the rainfall intensity/rate.
Precipitation	Weather forecasting	Measures the rain quantity and intensity
Wind speed	Weather forecasting	Measure wind direction
Camera	Pictures collection	Provides pictures of the crop (leaf, fruit, plan**t)**

4. Wireless Communication Protocols in Agriculture

Various wireless communication protocols are being introduced due to the rapid rise of IoT technology[43][44][43]. Each protocol has its specifications and depends upon various factors. IoT-based agriculture equipped with a communication system can contribute to agricultural automation by increasing crop production and quality. The most common wireless communication protocols are discussed in Table 2.

Table 2: Comparison of existing wireless communication protocols

Protocol	Standard	Data rate	Frequency	Range	Power Consumption
Bluetooth	IEEE 802.15.1	1–2 Mb/s	2.4GHz	30 m	Low
RFID	ISO 18000-6C	40 to 160 kbit/s	860-960MHz	1-5 m	Low
ZigBee	IEEE 802.15.4	250 Kb/s	2.4 GHz	10–100 m	Low
LR-WPAN	IEEE 802.15.4	40–250 Kb/s	868/915 MHz	10–20 m	Low
Wi-Fi	IEEE 802.11	1–54 Mb/s	2.4 GHz	50 m	High

5. Existing Framework in Precision Agriculture

Agriculture contributes a significant figure to the country's economy and nation development. Traditionally agriculture methods are not technically systematic and are tedious processes as the world is advancing towards using new technologies, it is necessary to use these technologies in agriculture. Numerous diseases spoil crop production to a large extent so the process of early disease prediction is much needed.
In the last few years, many frameworks were used in the agriculture domain. IoT devices, wireless sensor networks, and internet connectivity can reduce human efforts through automation, resource usage can be optimized and farmland can be monitored much better by the farmer without being there[45].

[46] proposed a framework based on an Android application that helps farmers with advanced technology to perform various agriculture tasks such as buying and selling products and getting information about various stages of fruit ripeness through a computerized approach.
Environmental conditions and farming methods are the main factors on which the production of crops is dependent. Irrigation is also one of the important parameters and sometimes scarcity of water also leads to crop loss during peak time. Thus, a fuzzy-based approach was proposed by [47] for the monitoring and effective utilization of water supply in the field[48].
The world population is increasing speedily and to solve the human food requirement problem the production of food must increase continuously to feed the people. A framework using IoT Gateway for agriculture was proposed by [49] for increasing food production so that it will help the farms and application of IoT in making farming systems intelligent.

[50] proposed an IoT-based semantic framework namely Agri-IoT, for smart agriculture applications based on IoT that supports the real-time data streams from heterogeneous sensors, which support data analytics in large volume and event detection. Semantically Enriched Computational Intelligence possesses the huge capability to be implemented in different applications of smart farming such as smart Sensing and Monitoring, Planning/Analysis, Smart Control, etc.
The disease classification system based on the SECI can include various types of diseases and their features[51]. An IoT-based farming system that connects the agriculture farms with end-users where internet connectivity is provided to sensors and controllers in the farm so that the end-user will be allowed to monitor and control the connected farm through a smartphone application[52].

[53] proposed a framework that identifies the disease in the plant while utilizing the sensor's information of the plant leaves such as temperature, moistness, and shading. The technology of wireless sensor network plays an important role in agriculture. In smart farming, the sensor deployed in the field collects the physical and environmental conditions regarding the crop, but the sensors have limited power resources and battery capacity, which has a negative impact.

A wireless sensor network framework based on a multi-criteria decision function for decreasing the bottleneck chance among the sensors while making the smart decision regarding data routing and reducing the ratio of energy consumption[54]. Sensing the characteristics of the farming field and giving suggestions to the farmer for proper growth and treatment of crop is required. Data collected from the sensors and then based on sensing and optimal values the appropriate suggestions will guide the farmer through Android applications about groundnut farming[55].

6. Apple and Disease Prediction

6.1 Apple

The diverse climatic condition of India ensures a large variety of fruits in the subcontinent. Apple (Malus Domestica) is one of the most important fruits of India in terms of production, livelihood, consumption, and economic level, and apple trees are cultivated worldwide. People million in number are associated with it directly or indirectly and is considered one of the major industrial fruits among deciduous fruit. The major problem for fruit growers is the rise of disease that affects crop yield. Moreover, the various diseases that occur commonly in apple production on a large scale cause ample economic losses.

Detection and diagnosis of disease during the initial stages are crucial for the development of the apple industry and has become one of the important topics for researchers. Various diseases affect the apple crop and need to be closely monitored and predicted early. Apple is affected by many pathogens such as fungi, bacteria, viruses, mycoplasmas, and nematodes and most of these diseases are caused by pathogenic fungi. Numerous kinds of diseases are also found in apple crop are, apple scab, Marssonina leaf blotch, Black rot canker, Alternaria leaf spot, Powdery mildew, Apple mosaic, Rust, Bitter Rot, etc. and most of these diseases are triggered by pathogenic fungi and bacterial disease and are dangerous for crop production [7][56][57][58].

6.2 Apple Disease Prediction

Bhargava et al. [59] designed a wireless sensor network for the building of a decision support system for apple crop disease prediction in the hilly region. In their study, the sensors were deployed in the field for the collection of data. Temperature, humidity, and leaf temperature sensors were used. The NS-2 simulator was considered for the simulation of the wireless sensor network.

Dubey et al. [60] introduced a classification approach for the prediction of fruit disease in apple crops based on image classification. Color, texture, and shape are the features that were studied in this approach for disease classification. The detection of infected fruit was done through the method of K-means clustering. Three types of diseases and normal fruit were taken into consideration for the experimental study. Finally, the method of multi-class support vector machine was used for the classification of healthy or infected apples categories.

Chuanlei et al [61] proposed a method for apple leaf disease identification based on image processing and pattern recognition techniques. The apple diseased leaf images were collected for data by image collection system, and 90 images of three kinds of disease with light blue background were considered. The combination of genetic algorithm and correlation-based feature selection was used for the feature selection and improving the identification accuracy of apple leaf disease. Finally, the disease was recognized through the SVM classifier. .

Singh et al. [62] suggested an image processing technique for the detection of apple leaf disease on a leaf image dataset. An image set consisting of one thousand images was used, where 400 images of Marsonina Coronaria and 400 from Scab diseases images were considered. The remaining 200 images of healthy leaves. The segmentation algorithm in combination with the k-means clustering technique used to provide better results as compared to k-means clustering alone.

Wrzesień et al. [63] proposed a prediction model for the apple scab based on machine learning and meteorological variables with the help of sensors. The data was collected from the two types of wetness sensors planted in the tree canopy in four locations on the tree with four-sensor for leaf wetness. Machine learning-based models have been developed for wetting sensors that can be also used as virtual sensors. Finally, the results were compared with the virtual sensor and real sensor through the apple scab model.

Jiang et al. [64] developed a method for the detection of the most common diseases that affect the apple crop are such as Rust, Alternaria leaf spot, Brown spot, Mosaic, and Grey spot. The deep learning approach was proposed for disease detection. The method of deep learning detects the disease in apple crop of five types while extracting the features of the image of a diseased apple. Furthermore, 26,377 image dataset was used in their work. The INAR-SSD model was found to have high accuracy and provide an optimal solution for apple leaf disease in real-time detection.

Baranwal et al. [65] introduced a model for monitoring and detecting the disease in the crop from the initial stages. The manual process of disease identification is time-consuming and requires technical and expert skills in crop diseases. Machine learning-based approaches could identify diseases at an initial stage, which could save the farmers from loss. The leaf image dataset of healthy 1000 samples and 1526 diseased apple leaf images were considered for the study of the model. The approach of deep learning was used for disease detection in apple trees through a convolutional neural network. The trained model showed high accuracy scores.

Liu et al. [27] presented an approach for the early detection and identification of diseases on crops that can ensure healthy crop production by identifying diseases through the deep convolutional neural network for leaf disease identification in apple crops. Using a dataset that consisted of 13,689 images of diseased apple leaves to identify the common apple leaf disease of four types was generated with the help of image processing techniques. The proposed model based on convolutional neural network recognition has an accuracy of 97.62% and has reduced the number of parameters to some level.

Yan et al. [66] offered a model based on a deep convolutional neural network for identifying apple leaf diseases. In their work, the dataset consisted of 2446 pictures, and the original dataset was divided into two subsets one for the training of the model and the remaining for testing. The work was carried on healthy, Scab, frogeye spot, and cedar rust leaves, and the results illustrated that the general accuracy of apple leaf classification can reach up to 99.01% using the proposed model.

Zhong et al. proposed a method for the recognition of apple leaf diseases. In their study, the data set contained 2462 images, and the dataset was separated into the ratio of 8:2 for training and test the data. The data consisted of six apple leaf diseases: Healthy Apple, General Scab and Serious Scab of apple, Gray Spot, General Cedar Rust, and Serious Cedar Rust of apple (labeled from 0-5). The proposed method achieved accuracy on test dataset was 93.51%, 93.31%, and 93.71% respectively[67].

Table 3: Apple Disease Prediction systems of the above-defined systems

Paper	Year	Area	Aim	Data set		Predicted Disease	Method/ Algorithm used
				Sensors	**Images**		
[59]	2014	Disease Prediction	Building of decision support system for apple disease prediction	✓		Scab	Mills table
[60]	2015	fruit disease	Approach for the prediction of fruit disease based on image classification.		✓	Blotch, Rot, scab	K-means clustering, Multi-class support vector Machine
[61]	2017	Leaf Disease identification	Disease identification method based on the techniques of image processing and pattern recognition techniques.		✓	Powdery mildew, mosaic, Rust	RGA, GA-CFS, and SVM.
[27]	2017	Leaf Disease Identification	Approach for identifying disease based on the deep convolutional neural network for the leaf disease identification		✓	Mosaic, Rust, Brown spot, Alternaria leaf spot	SVM, CNN, SGD, NAG
[62]	2018	Leaf Disease Detection	Detection of apple leaf disease based on a leaf image dataset		✓	Marsonina Coronaria, Scab	K-means clustering.
[63]	2018	Apple scab	Predictions of apple scab based on sensor data (4 leaf wetness senor	✓		scab	Random Forest
[64]	2019	detection of apple leaf diseases	Detect the disease of five types in the crop while extracting the features of the image of the diseased apple.		✓	Rust, Alternaria leaf spot, Brown spot, Mosaic and Grey spot	INAR-SSD, Faster R-CNN, SSD.
[65]	2019	Disease Detection	The deep learning-based approach was for disease detection in apple trees through the convolutional neural network.		✓	Black Rot, Cedar, Rust, Scab	Convolutional Neural Networks
[67]	2020	Leaf disease recognition	Proposed a method for identifying apple leaf diseases while considering six types of apple leaves		✓	Gray Spot, scab, Rust	Deep learning
[66]	2020	Leaf Diseases Recognition	proposed a method for identifying apple Leaf Diseases		✓	Scab, frogeye spot, cedar	deep convolutional neural network

7. Conclusion and future work

Precision agriculture is a modern concept that enhances the production of crops and optimizes the handling of available resources with the use of the latest technologies. In this paper, a comprehensive survey was presented on the state of the art of IoT solutions in the field of precision agriculture, which facilitates the farmers to enrich crop productivity.

Furthermore, the study discussed the role of sensors, sensor types, and communication protocols in agriculture. In addition, the comparative study on apple disease prediction was present as numerous diseases spoil crop production to a large extent. So early disease prediction is required as it affects crop cultivation for timely prevention and to find out the heavily affected fruits and leaf diseases so that the economic situation for farmers will improve. The study revealed that there is a need to explore a more intelligent and computational crop disease diagnosis framework for early prediction.

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