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Novel Semantic Agro-Intelligent IoT System Using Machine Learning

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8.1 Introduction

Agriculture is the backbone of any country. We are in the digital world. Technology has a bigger role in the field of agriculture and its importance is increasing day by day. Technology has not limited itself only to crop diagnosis but also changing the very old

DOI: 10.1201/9781003185413-8

practices to improve the yield and promote better monitoring ways. Various technologies are now being used in agriculture. The ecosystem in various countries is getting affected due to the dip in the agriculture yield. It is high time that we put agriculture back on track and technology is going to play a bigger role here. A large-scale agricultural system requires a lot of maintenance, knowledge, and supervision.

The volume of devices getting connected to the Internet is growing at an enormous rate. The primary concept of IoT is to connect all the physical devices in the world virtually and sharing the information between them. It is a revolutionary technology that represents how a connected data can be computed and analyzed in a better way: for example, traffic systems, whereby performing the dynamic analysis information can be sent to the nearby police officials on any trouble in the surrounding. Here different systems are connected through Internet and exchange the data for analysis. Recently IoT has been booming up and it has been applied in various fields. IoT aid to build some of the most efficient and cost-effective solutions [1] to humans in the field of agriculture and some of its highlights are as follows,

- IoT involves the connection of any devices over the Internet [2, 3]. For example, Android, IoT sensors, etc.
- Soil nature and soil transformation can be monitored remotely [4, 5].
- Fail Fast technique – to predict issues at an early stage. For example, prediction of infection in the crop by sensing the growth rate and proposing the prevention steps at an early stage.
- With the help of remote monitoring we save a lot of time and human power.
- Connecting different physical devices as well as involving the cloud makes communication and data sharing efficient.
- IoT aids in performing a wide range of analytics.

Smart farming [6, 7] is achieved by involving new technologies like IoT, the cloud, and machine learning (ML). Today's world population is increasing at a tremendous pace and the greatest challenge that is put forth before mankind is feeding all people. This can be achieved in the best possible way by combining the above said latest techniques. There are numerous challenges faced in agriculture today like degradation of soil fertility, insect attacks, and any recent development in various plant diseases. Farmers do not possess the knowledge of the existing trends for specific crop cultivation nor do they have a proper chance to get an alert if there is a change in the nature of the soil. This chapter explains how the farmland can be continuously monitored for any changes in the soil involving a model using ML techniques where the ML system continuously monitors and provides feedback on soil change and what adaptation or proactive action should be taken to attain the expected yield.

ML techniques can be involved for model creation, where the system can be created with the vector space containing the attributes for soil monitoring. With the help of IoT the sensors connected to the soil can send values of different parameters like soil nature, weather changes, and crop growth, and when the system senses any abnormal situation or any deviations from what has been expected, an alert will be sent to the farmer. Also the system can be connected with the cloud [8, 9] system so that recent trends of crop growth can be inferred by referring to the data collected globally. Also a statistical opinion can be provided to the farmer to improve the crop yield. This chapter discusses the same, where Section 8.2 explains the existing techniques of ML in the field of agriculture combined with IoT. Section 8.3 explains our proposed approach, explaining how the ML system connects the data received from IoT devices semantically and its response to the user. Section 8.4 details out the results and discussion. Section 8.5 gives the conclusion.

8.2 Related Works

There are many techniques followed in different countries with respect to the subject "Smart Farming." The important ones are as follows:

Malaysia has developed an IoT system for fruit traceability. It is called as Mi-Trace [10]. This system provides traceability to sellers and buyers for any fruit.

Taiwan has introduced an IoT system to monitor soil conditions. This is utilized especially in turmeric cultivation, where with the help of the IoT system the quality of the turmeric is increased from 40 to 60% as well as 70% of the water is saved.

Thailand has developed an IoT system for water control, where based on different vegetations the system helps in guiding the water irrigation to the farmers.

China has built an IoT system to send the instruction to remote places, thereby saving the labor cost by 60% and reducing fertilizer and pesticide use rate to 60% [10].

8.3 Challenges with the Existing Approaches

To meet the rapidly growing population's needs it is very important to increase the yield. To increase the yield the soil has to be monitored continuously. Upon any change in the nature of the soil, the details should be collected by the sensors and the farmer has to be updated or notified immediately. Even the plant growth rate is the one to watch where an insect attack or any recent developing plant disease might hinder the plant growth rate. Water beds are drying up day by day and the weather is unpredictable. To cope with all these conditions we need a system that can monitor and send feedback continuously to the user to improve the yield. Hence the only way to achieve these is to adapt to smart farming, where the latest technologies like ML with IoT would aid to achieve the target. Recent research works have been focused on Agro-IoT, where an IoT-based framework monitors the data continuously; it performs analysis and reasoning. SmartFarmNet is one such IoT-based platform for collecting environmental, soil, fertilizer, and irrigation data. The availability of open-source smart agriculture software is not high. Some of them are explained below:

Farm At Hand is a multi-user agricultural software that has features such as farm equipment management, inventory, and sales.

FarmRexx is an online agricultural software that can be used any place with Internet access. It features maintaining livestock records, monitoring livestock movements, farm equipment management, weather, and managing farm chemicals.

FarmOS [11] is another web-based farm management application that uses a web application framework called Drupal. The same can be used for planning, recording, and agricultural management activities [12].

Trimble is yet another web-based farm management application where its basic plan is free of cost to farmers. Farmers can use this application from anywhere having Internet access. It features the maintenance of yield records and weather prediction.

Tania is an open-source farm management application that is built on Go, VueJS, and SQLite. It allows us to connect with various sensors and manages them while we are on the go.

8.3.1 Issues and Challenges

8.3.1.1 Hardware

IoT devices are exposed to harsh environmental conditions like rain, high temperature, and humidity, which may destroy the same. These devices are bound to high industrial standards and thus are costlier [13, 14].

8.3.1.2 Infrastructure

Assuring smart agriculture [15] environment is challenging because smart agriculture demands continuous monitoring and feedback. Open-source tools and frameworks should be made available to agriculture application developers to build sustainable and affordable applications.

8.3.1.3 Networking

Wireless technology [16] is preferred more in smart agriculture due to the wiring cost and maintenance. Due to the physical obstacles the signal becomes weak when they reach the transceivers, which leads to the demand for more robust networking technologies.

8.3.1.4 Reliability

In smart agriculture more IoT devices are connected to send the data to the cloud. There are many external impacts where those systems can fail to send the data. A large number of gateways are needed to make sure the data has been sent to the server or cloud systems without any hindrance.

8.3.1.5 Data Security

In smart agriculture a lot of data needs to be sent every day. We need to make sure the data that has been sent over is safe. The data that has been sent has to be encrypted. New security and privacy problems arise such as authentication, integrity, and access control.

8.4 Problem Statement

One factor that is more concerned in agriculture is "high yield." Recently crop yield has faced a great deal of downtime due to incorrect predictions. Inability to understand the nature and demand of the soil leads to incorrect decisions. Incorrect decisions could have been prevented by predicting the change in the soil nature, crop growth, climate, recent plant diseases, appropriate fertilizer, etc. To aid these we need a system that can feedback continuously and act as a fail-fast system to inform the farmer if there is a deviation in the expected behavior in the farmland. The system not only should provide feedback of changes in the nature of soil or plant growth or the plant structure to the farmers but also refer to the global data available on the cloud. The objective is to develop an IoT system involving ML techniques where the system not only exchanges data between the devices but also analyzes the same semantically and reasons on it based on the reference with the cloud data. Hence it not only provides feedback to farmers about the yield prediction but also provides suggestions to the farmers on tackling any new issues.

8.5 Proposed Approach

8.5.1 Improving the Training Data

The data fed into training the model cannot depend only on the data from the cloud; instead the training data received can be multiplied into "N" no. of valid data with the help of multipliers, where each word attribute extracted is cross-multiplied and analyzed to determine if it forms a meaningful sentence that can be fed as a training sentence to the model [17, 18]. If the sentence is a valid sentence then the same will be added as a training sentence to the data set.

8.5.2 Agro-Intelli Algorithm

From Figure 8.1, the complete architecture of Agro-Intelli algorithm is depicted. Individual segment involved in the architecture are discussed as follows.

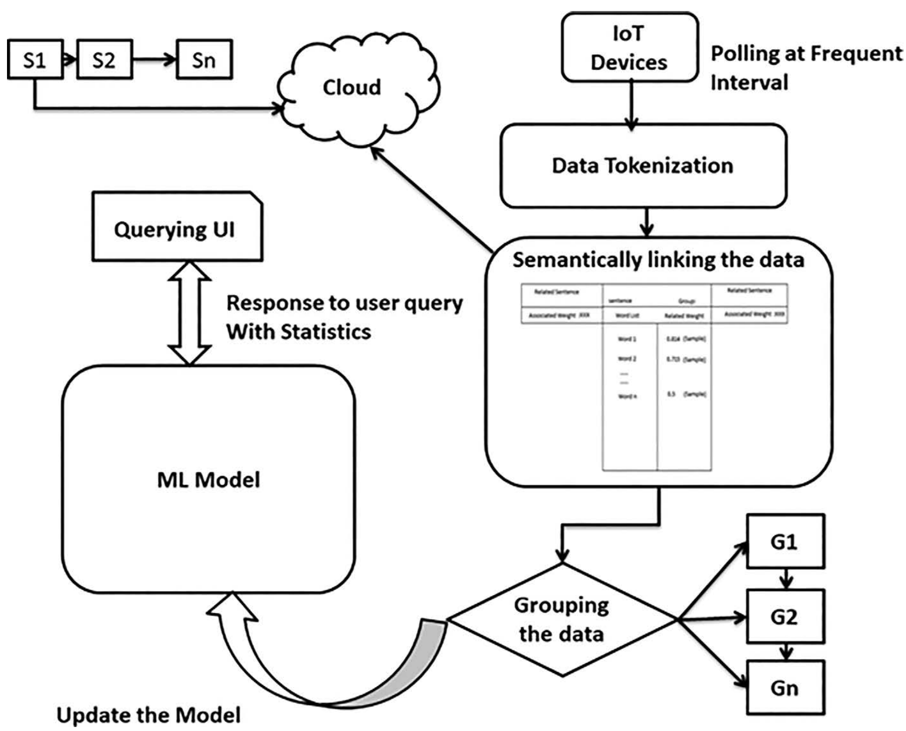


FIGURE 8.1
Architecture of Agro-Intelli Algorithm.

8.5.2.1 Prerequisites

- IoT devices like wireless sensors and actuators placed in the agriculture field to scan and send the field information.
- Sensors are connected to the soil to determine the change in the nature of the soil, in particular the soil behavior when there is an overdose of fertilizer or a change in the soil behavior when the chemical combination in the fertilizer overreacts with the soil nature.
- Sensors to scan the plant thickness and structure. This is to study the plant growth rate and structure to know about insect attacks and other factors.
- In the template user has to fill out the plan details and the target month.

8.5.2.2 Dimensionality Vector

Before we get into the algorithm, we will walk you through the attributes involved in dimensionality vector of the Agro-Intelli Algorithm.

- Humidity Rate – This attribute points to soil humidity. Soil humidity changes based on the weather and other factors.
- PW (plant width), PH (plant height) – These attributes point to the plant width and height, respectively. This attribute is taken to calculate whether the growth of the plant at a particular stage is on track or not.
- Weather – Through this attribute the weather is converted into a numeric value, which is rated against the forecast weather. The current weather conditions will aid the plant growth of not is calculated.
- Market factor – This attribute is calculated based on the influence of other attributes as well as based on the current projected situation regarding how the market factor for a particular crop is going to be when it is out for market after harvest.

From Figure 8.2, the steps involved in the Agro-Intelli Algorithm are as follows:

STEP 1 – Collect the data from the IoT devices connected in the field at periodic intervals.

STEP 2 – Tokenize the data collected such that the feature data is extracted and tagged.

Note: The feature data is passed from the sensors where the information in numeric is appended with the plain texts.

The data from the cloud is also referred to periodic intervals, where the data globally received in the form of text has been tokenized to differentiate and group conditions based on each specific crop cultivation.

STEP 3 – From the tagged data the dimensionality vector is formed, where soil humidity rate is placed as one of the attributes. The other attributes considered in the dimensionality vector are the plant width and height, current weather, plant growth rate, and the market factor.

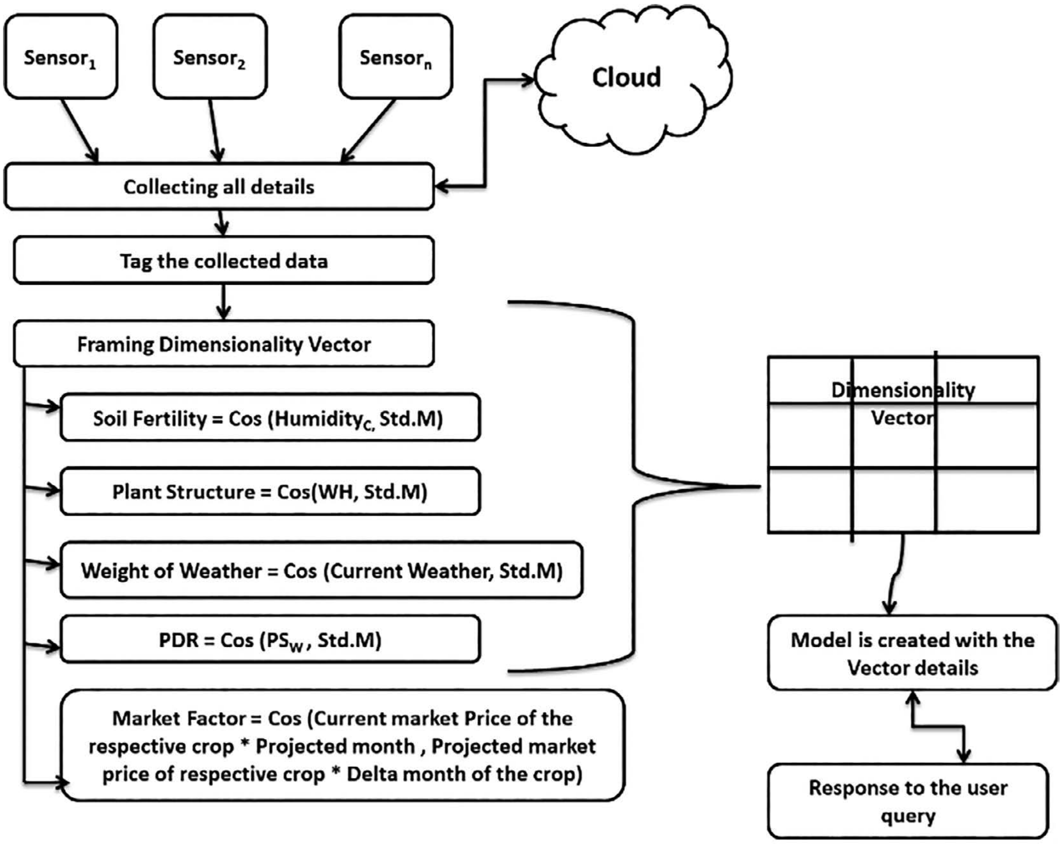


FIGURE 8.2
Agro-Intelli Algorithm.

STEP 4 – The soil fertility rate compared against the weather condition is calculated and the formula is given as

$$\mathbf{S_{FW} = Cos(Humidity_C, Std.M)} \tag{8.1}$$

where S_{FW} (Soil Fertility Weight) = Cosine similarity between current Humidity and Standard Measure.

STEP 5 – Plant structure is calculated by using its width and height and the weight is calculated by comparing it with Standard Measure as follows.

$$\mathbf{PS_W\,(Plant\,Structure\,Weight) = Cos(WH, Std.M)} \tag{8.2}$$

where WH = Width + Height of Current Crop and Std.M = Standard Measure.

STEP 6 – Weather weight is calculated by comparing the current weather with the standards

$$\mathbf{W_W\,(Weather\,Weight) = Cos(Current\,Weather, Std.M)} \tag{8.3}$$

STEP 7 – PDR (Plant Damage Rate) is calculated by comparing the plant growth with the Standard Measure.

$$\mathbf{PDR = Cos\left(PS_W, Std.M\right)} \tag{8.4}$$

STEP 8 – Market Factor Weight (MF_W) is calculated by knowing the current market price of the respective crop multiplied with Projected month with Projected market price of respective crop multiplied with Delta month of the crop.

$$\begin{aligned}\mathbf{MF_W} = \mathbf{Cos}(&\textbf{Current market Price of the respective crop}^{*}\\ &\textbf{Projected month, Projected market price of respective crop}^{*}\\ &\textbf{Delta month of the crop})\end{aligned} \tag{8.5}$$

STEP 9 – With the dimensionality vector updated with the attribute values it is mapped to the output class determined during the grouping of the data.

STEP 10 – Now the model is trained with the dimensionality data available.

STEP 11 – As and when the data gets refreshed in the cloud then the dimensionality vector will be refreshed with the newer values, which in turn leads to the update of the ML Model.

STEP 12 – As soon as the query from the user is input, a response with suggestions, current plant statistics, and forecast details will be sent back to the user by the system.

Note: The system model will get refreshed at periodic intervals with the input from IoT devices and it will have the updated information.

8.5.2.3 Intelli-Group Algorithm

When we have any data from the cloud that data should be grouped based on the crop. It is done using the Intelli-Group Algorithm as shown in Figure 8.3. The steps of the same is as follows:

STEP 1 – From the input data, the data is tokenized based on the attributes. Here the attributes are the filtering conditions of each feature.

STEP 2 – Using the bag-of-words model the tagged data is grouped by referring to the group table. The group table is formed where conditions pointing to a specific cause are collectively represented as one group. When the tokenized data points to a similar grouping condition then it will be tagged as the corresponding group.

STEP 3 – Semantic association is established between the groups. The semantic relationship is established by involving cosine similarity. Cosine similarity is calculated to know the semantic relationship between the feature of a group with the neighbor group.

STEP 4 – The group is linked in order based on the semantic weight between them.

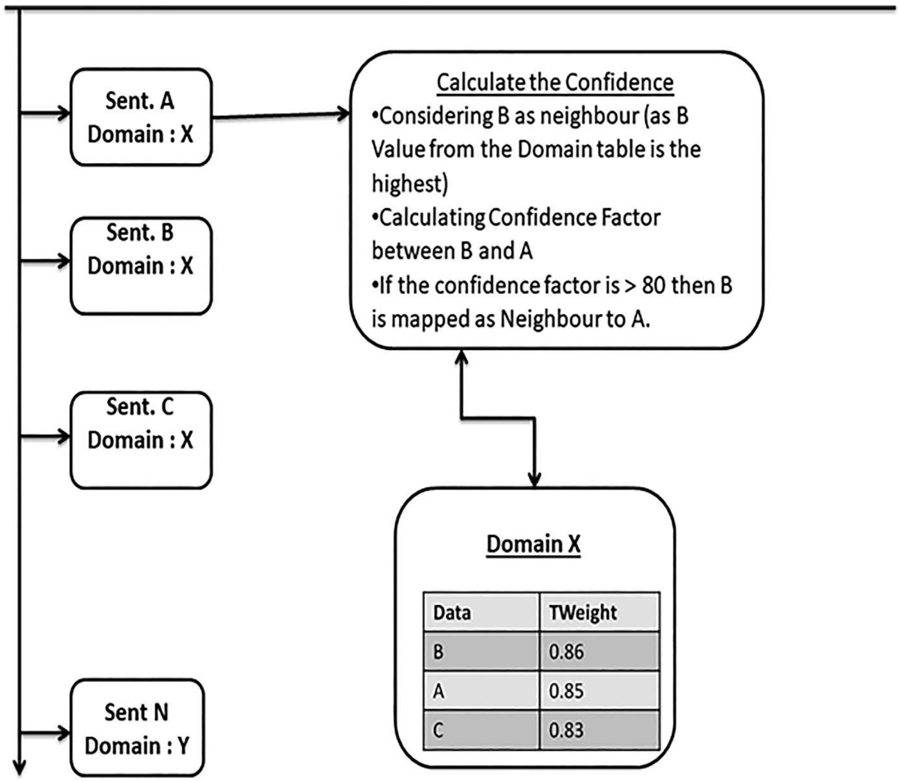


FIGURE 8.3
Intelli-Group Algorithm.

STEP 5 – The chain from a group to another group will not exist if the threshold value weight of 80% is not met.

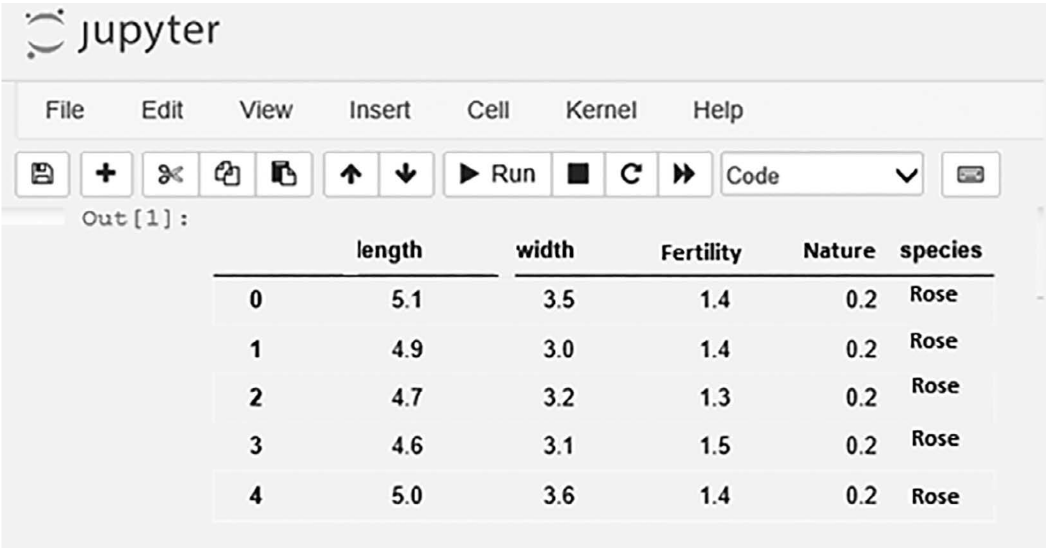
STEP 6 – The link between the groups is refreshed at frequent intervals so that when there is more related association is formed for a group then the linking chain will be re-established.

8.6 Results and Discussion

The datasets are extracted from https://data.gov.in, and for modeling, Weka jar and Pandas (for data processing) are involved. The integrated development environments (IDEs) used to develop the model are Eclipse and Jupyter Notebook as shown in Figure 8.4. For the Agro-Intelli Algorithm using Jupyter Notebook along with ML techniques Python libraries are used to test our theory and the results are as follows.

Figure 8.5 depicts the accuracy difference in group extraction between the SmartAgri framework and the Agro-Intelli algorithm when worked upon data from the cloud.

Figure 8.6 depicts the response of statistics when the user queries about the plant growth and predictions to the model trained with standard data between AgriSys and Agro-Intelli.



	length	width	Fertility	Nature	species
0	5.1	3.5	1.4	0.2	Rose
1	4.9	3.0	1.4	0.2	Rose
2	4.7	3.2	1.3	0.2	Rose
3	4.6	3.1	1.5	0.2	Rose
4	5.0	3.6	1.4	0.2	Rose

FIGURE 8.4
Jupyter Notebook involving plant structure details in the feature vector.

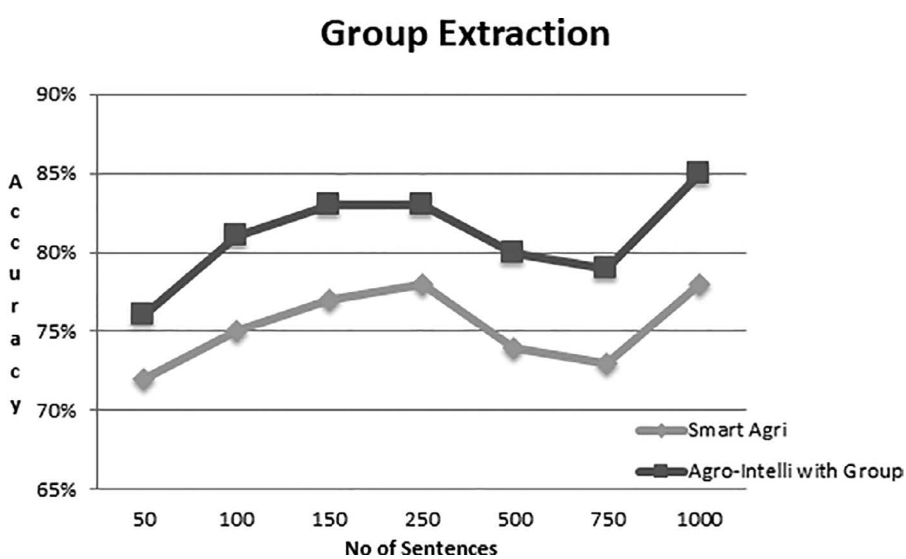


FIGURE 8.5
Accuracy comparison of group extraction between the SmartAgri framework and Agro-Intelli with grouping logic.

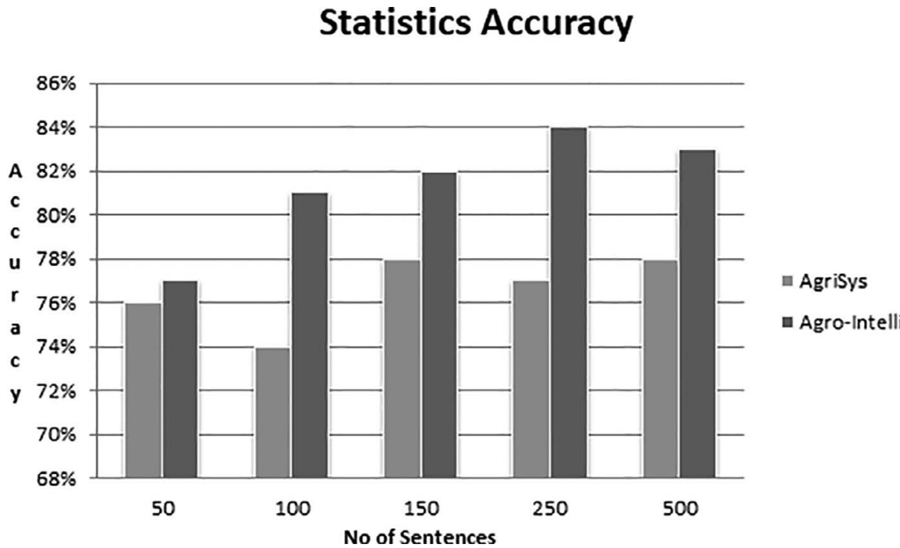


FIGURE 8.6
Comparison of statistics of accuracy between the AgriSys application and the Agro-Intelli algorithm.

8.7 Conclusion and Future Work

As we said in the beginning agriculture is the backbone of any country. To satisfy the population's need the yield has to be improved with good profit, and it is high time that we shift to modern agriculture involving the latest techniques. By making a system intelligent enough to predict the failures early comes as a real savior for the farmer. The system predicts the growth rate of the plant not only with the help of data from IoT devices but also with the knowledge it has received globally with the help of the cloud. The system can provide solutions not only to prevent the recent plant diseases developing for a specific crop but also able to control them, thus making the system a good and efficient feedback system. The work should also be extended to consider additional factors like rainfall and animal movement to make it more efficient and effective.

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9

Yield Prediction Based on Soil Content Analysis through Intelligent IoT System for Precision Agriculture

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9.1 Introduction

Agriculture is the critical juncture in the history of humans. About 11,000 years ago, people changed from hunting life to food producers by agriculture. It changed their lifestyle and had more time to learn and gain knowledge by studying the life that surrounds them. They settled down in life by farming. For decades, people started to cultivate a new type of crop and used animals by experimenting in their own land, which is enough to feed their families. About 1960, high-yield production of wheat and rice were developed by

DOI: 10.1201/9781003185413-9

researchers emerged as the green revolution. Food production plays an important role in population growth and change in politics. Shortage of food arises due to uneven distribution of resources and overpopulation. The challenges in feeding the hungry depend on the type of land and water, which is overcome by agricultural science.

Agriculture is the primary source of food for humans to survive and solve hunger all over the world. Before the industrial revolution, agriculture is the main source for governments in earning profits. Agriculture plays an important role in business including biotechnology, insurance companies, farm equipment, and chemical industries. The agricultural biodiversity aspects are historical resources, ecological community, biotic factors, and social-economical culture.

In agriculture, yield is important, which is a measure of the amount of crop grown in a particular area. Due to technology development in farming methods and tools have improved crop yield. The yield of a crop is usually measured by kilograms per hectare. Today, productivity in agriculture is measured in money produced per land and yields are measured by weights of crop per land. Seed ratio is another paradigm in crop yield. To ensure food security there is a need to forecast the crop yield [1].

Healthy soil is defined by its fertility which depends on physical, chemical, and biological properties. Nowadays, people are not aware of the cultivation of crops at the right time and at the right place. Because of these cultivating techniques the climatic condition also changed against fundamental assets like soil, water, and air leads to food insecurity. By analyzing all these issues and problems like weather, temperature, and several factors, there is no proper solution and technology to overcome [2]. In India, there are several ways to increase the economic growth in the field of agriculture and improve crop yield and quality of crops.

Data mining also helps in predicting the production of crop yield. Generally, data mining is extracting hidden information from database and transform it into an understandable structure for future use. Data mining is the software that allows the user to classify analyze data from more dimensions and provides a summary of the relationship among the class labels [3]. The ultimate goal of data mining is a prediction that has many business applications.

Information from data is obtained from the patterns, associations, or relationships in data mining. It can be converted into knowledge about historical patterns and future trends. For example, review and survey about the production of crops help the farmers to identify the risk factors for poor production and preventive measures to overcome. Crop yield production is a serious agricultural problem. Farmers expect crop yield based on their own experience on a particular crop as they cultivate more crops based on climatic changes. Accurate information about crop yield history helps for making decisions related to agriculture which reduces the risk and cost management [4].

In that point, crop yield prediction based on the soil content analysis is one of the research carried over by many researchers to improve the growth of the crop. In earlier days, crops were chosen by the farmers based on the soil and the monsoon for the particular period [5]. That technique worked well most of the time previously. But, once global warming became a factor and modifies the monsoon periods, which affects the crop yield by changing the mineral quantities and qualities of soil content. In that manner, the earlier prediction model is not suited and the farmers need assistance like an analysis model for predicting the crop yield based on the soil content.

Data mining techniques are used to classify soil and analyze soil for crop production [6, 7]. The fertility of the soil is predicted by the decision tree algorithm. Clustering algorithms help in understanding the current usage of land for agriculture and future prediction of land for crop production. K-means algorithm is used to classify soil and plants before marketing. K-nearest neighbor algorithm is used to predict the weather conditions. Neural networks help in forecasting water resources and identify the ripeness of fruit. Support vector machine (SVM) is used for crop classification and climatic changes. This paper is to predict the category of analyzed soil dataset to indicate the crop yield in particular soil type and suggest suitable crop to be cultivated.

9.2 Related Work

A hybrid decision model is needed to achieve high accuracy and generality in terms of yield prediction capabilities. Analyzing the agricultural data is a challenging task to summarize the report about soil fertility, weather condition, types of crops cultivated, and high yield production. To increase the crop yield with many dimensions the data mining techniques, and multiple linear regression are used [8]. It analyzes the existing soil types and climatic parameters and optimizes the solution to increase production in agriculture.

Crop planning plays an important role in increasing crop production. There are many methods that predict and suggest suitable crops to be cultivated during a particular time period based on soil type and climate. Artificial neural networks (ANNs) and multiple linear regression [5] are used in the prediction of wheat yield based on parameters including rainfall, biomass, evaporation of soil, amount of water soil extracts, and fertilizer usage [9]. Sensors are used in prediction and control irrigation using instruments like electronic sensors, satellite imaging, hyperspectral remote sensing [10]. Many researchers proposed algorithms that increase the production of crop yield by comparing various algorithmic approaches. They analyzed the dataset with algorithms and incremental methods and provided suggestions for further use [6]. The corn and soybean production are based on weekly rainfall [7], which is predicted by ANN and optimized a solution to improve the production. Crop yield can be increased and predicted based on parameters like rainfall, atmosphere, and pH level [11].

Artificial intelligence and satellite imagery [12] are used for crop monitoring with low resolution achieves accuracy compared to CNN algorithm and satellite imagery. ANN analyzes various parameters and achieves the same accuracy as CNN. Fertilizer usage randomly leads to a decrease in the yield, which damages the top layer of soil and causes the soil to be more acidic. To overcome this, a decision tree and SVM algorithm–based system predicts the rainfall and recommends the crop to cultivate [3]. Multilinear regression and decision tree regression form the tree structure to predict yield for the next upcoming years [13]. Prediction is based on k-means clustering and poly regression. Based on the analyzes of crop yield it predicts the soil condition, availability of rainfall for the next 3 years. Lasso and ridge regression [4] were applied to estimate the crop yield. Combining decision tree, linear regression classifies the soil and cross-validates with other methods to outperform.

Prediction is based on analyzing the historical data or mining information from raw data. Harvest is predicted by SVM, RNN, SVR, KNN-R [14] based on parameters like soil, rainfall, humidity, temperature, and water extracts by soil to help management to earn profit. Statistical textural features are considered to predict whether the plant is a crop or weed [15] by using SVM and k-fold cross-validation. SVM and ellipsoid estimation techniques are used to detect the fruit, track and 3D reconstruction [16] to map the crop yield production and estimate the profits.

To detect drought condition, an unsupervised learning method SVM is used [17]. It provides the factor that causes drought conditions and preventive measures to overcome the condition, suitable crop to cultivate in such condition. It also provides a way to increase the yield production of crops based on the threshold. The volume of product to be cultivated per unit area in land is a challenging task [18]. Using the generalized linear model (GLM) and SVM it is able to estimate the amount of crop harvested per unit of land and volume of crop cultivated in a particular area. Stem breakage and root lodging are important in classifying crops to improve production. Using binary patterns, Gabor filters as features of SVM are able to classify the crop lodging with co-occurrence matrix.

The condition of soil is important for agriculture. Soil consists of heavy metals such as nitrogen, potassium, organic and heavy metals that exploits the soil. To detect the heavy metals present in the soil SVM, Random Forest (RF), Extreme Learning Machine (ELM) is used. It detects the metals and suggests the crop that suits that particular soil. Soil properties are predicted by SVM and multilayer perceptron neural networks. Sometimes water logging [19] in land exploits the crop and decreases the crop yield. To overcome this, SVM and ANN help to predict and track the water level by sensors. The moisture of soil during the winter season to cultivate wheat is achieved by machine learning methods of SVM and RF. It predicts the moisture content and suggests whether to cultivate a crop or not. Overall activity in the agricultural field can be recognized by using a smart shirt and classify the various activity using Naive Bayes and KNN.

Location-aware similarity uses spatial social union (SSU) between two users for measuring similarity. It interconnects the users, items, and locations to predict the user preferred location. Rating prediction [20] and item recommendation algorithms are used to experiment on a dataset in real time. The geographic probabilistic factor model (Geo-PFM) framework is an effective user mobility model to recommend location which captures geographical areas [21]. It combines the effects of user mobility and latent factors and influences geographical recommendation systems.

An efficient location recommendation system [22] has challenges such as predicting the user's new location and existing location. To overcome these problems, the probabilistic approach is developed for each user to predict the location based on geographical influence. It computes accurately and suggests the location. Encounter probability [23] is used to measure the similarity in behaviors of two users to identify the similar experience of choosing the location. Based on the rating, the location is recommended and similarity is a measure between random users [24]. It is calculated by applying factorization between users who are dissimilar in locating items. Distance and transitive node similarity [25] proposed algorithms to predict the similarity between the users and the relationship between the different items rated by strangers.

From the above works of literature, the importance of crop yield prediction is identified and the need for machine learning algorithms for prediction was detected. Most of the prediction algorithms use datasets that cannot provide the appropriate decision for the current scenario of crop cultivation. Moreover, the existing systems evaluated the soil nutrients content statically for the specific and the suitable crop for the available soil nutrients are not predicted. Some of the systems provide crops suitable for the soil based on the geographical features and the monsoon period. This is also considered as the static prediction, which suggests the crop cultivation based on the previous years' data collection. The proposed crop yield prediction overcomes all these concerns by providing the continuous soil nutrients level with the current soil moisture level, which is mainly helpful to maintain the required soil content for the efficient predicted crop yield cultivation. The intelligent rules applied here with ensemble classifiers assist in choosing the suitable crop for the soil based on the initial soil nutrients level.

9.3 Proposed Precision Agriculture Algorithm

The proposed IoT system is composed of pH sensors, humidity and temperature sensors, Soil moisture sensors, soil nutrient sensors (NPK) probes, microcontroller/microprocessor equipped with Wi-Fi and Cloud storage. When the sensors are implemented, they measure the corresponding characteristics and transmit time-stamped live data to the cloud server. These sensors work together and provide wholesome data to the analyst. For the Recommending system, we proposed an ensemble classifier model to get the crop suitable for the given soil data and helps to enhance the growth using an optimized farming process.

- The proposed system uses the parameters like soil type, groundwater level, local population, daily, seasonally needs of the local people, labors available of the farmer, the range of the same plantation, and the range of farming land in the locality.
- Classification of soil into low, medium, and high categories is done by adopting data mining techniques to predict the crop yield using the available dataset.

Figure 9.1 shows the overview of the prediction system for crop cultivation at a specific location. The data for prediction was collected from the agricultural field, which includes soil moisture level, nutrient level, and temperature level at a different location. The location plays a major role in crop cultivation because the nutrients level differs based on the location, and also moisture-level changes with respect to the temperature rating at the location. The collected information is transferred to the cloud storage, where the data analysis takes place after the necessary pre-processing stages. The crop yield needs continuous monitoring and, for that, the analysis is viewed through smart devices to improve the moisture level, which implicitly helps to maintain the consistency of soil nutrients.

9.4 Proposed Soil Moisture Evaluation for Location System with Crop Yield Prediction

The soil moisture at a particular depth alone is not a deciding factor for watering the plants, since the water holding capacity of each layer in the field is highly dependent on the adjacent layers. If the bottom soil layer is too dry, then the water supplied at the upper layer will be drained soon. Hence in the real-time environment, the soil moisture content to be maintained in a particular depth is highly dependent on the soil moisture content of the upper and bottom layers. The proposed scientific processing unit accesses the soil

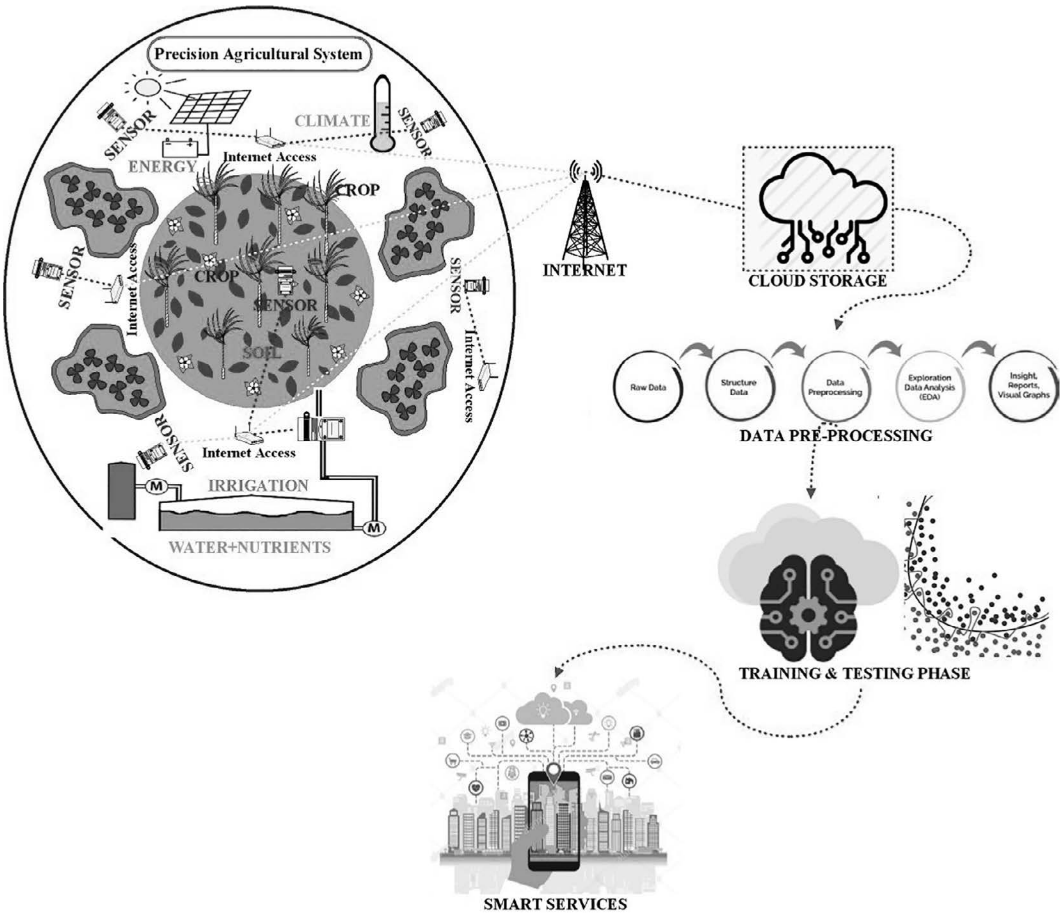

FIGURE 9.1
Prediction of crop cultivation for a specific location.

moisture data from the classified database and analyzes it for calculating the actual quantity of water to be supplied in the plant's root in different periods for cultivation (DC). Table 9.1 shows the procedure to calculate the Soil Moisture Evaluation for the location (SMEL) in different crop periods and the list of symbols used in this algorithm.

TABLE 9.1
List of Symbols Used in SMEL Algorithm

Symbol	Definition
DC	Duration for cultivation
SML_{p1}, SML_{p2}, SML_{p3}, SML_{p4}	Soil moisture values in depth d_1, d_2, d_2, respectively
RSM	Required soil moisture level
SMEL	Soil Moisture Evaluation for Location
l_s	Location at which the soil moisture measures
Temp	Temperature at a specific location

ALGORITHM FOR SMEL CALCULATION

Input: DC, SML_{p1}, SML_{p2}, SML_{p3}, SML_{p4}
Output: SMEL at depth (l_s)

Step 1: Begin
Step 2: if (DC <= 30 days & Temp < 25°C) then
Step 3: if (SML_{p1} <= SML_{p2} && SML_{p2} <= SML_{p3}) then
Step 4: SMEL = RSM
Step 5: else if (SML_{p1} > SML_{p2} && SML_{p2} > SML_{p3}) then
Step 6: SMEL = RSM + SML_{p1}
Step 7: end if
Step 8: end if
Step 9: if (DC> 30 days and DC <= 45 days & Temp > 30°C) then
Step 10: if (SML_{p2} >= SML_{p1}) then
Step 11: SMEL1 = RSM + SML_{p2};
Step 12: else if (SML_{p2} < SML_{p1}) then
Step 13: SMEL1 = RSM;
Step 14: end if
Step 15: if (SML_{p2} > SML_{p3}) then
Step 16: SMEL = SMEL1 + SML_{p3};
Step 17: else (SML_{p2} < SML_{p3}) then
Step 18: SMEL = SMEL1;
Step 19: end if
Step 20: end if
Step 21: if (DC > 45 days and DC <= 60 days & Temp < 25°C) then
Step 22: if (SML_{p3} > SML_{p2} && SML_{p2} > SML_{p1}) then
Step 23: SMEL = RSM + SML_{p2} + SML_{p1};
Step 24: else (SML_{p3} < SML_{p2} && SML_{p2} < SML_{p1}) then
Step 25: SMEL = RSM;
Step 26: end if
Step 27: end if
Step 28: if (DC > 45 days and DC <= 60 days & Temp > 30°C) then
Step 29: if (SML_{p4} > SML_{p3} && SML_{p3} > SML_{p2}) then
Step 30: SMEL = RSM + SML_{p3} + SML_{p2};
Step 31: else (SML_{p4} < SML_{p3} && SML_{p3} < SML_{p2}) then
Step 32: SMEL = RSM;
Step 33: end if
Step 34: end if
Step 35: End

The scientific processing unit calculates the SMEL at a particular location in a particular crop period based on the available soil moisture content at a different location. The conventional static measurement method calculates the quantity of water required based on the soil moisture content at a fixed location, which leads to inaccuracy. The dynamic nature of the proposed algorithm accurately estimates the quantity of water and duration of water supply for the crops. This information is stored as information in the agricultural database and it will be used in intelligent rules while making a decision on crop cultivation. The farmers can log in to the farmer's web portal with a registered username and password to receive the recommendations given by the agriculture scientists. These recommendations help farmers to avoid both overwatering and shortage irrigation of plants and also increase the crop yield. The system provides recommendations to the farmers via short message service (SMS) if any updating information is available.

As a whole, the proposed system helps both the analyst and farmers to frequently examine the dynamic nature of soil moistures in the cultivation fields without frequently visiting the lands with manual interventions. Based on the dynamic nature of the lands, the analyst can guide the farmers about the duration and quantity of water supply to the cultivation land. The proposed approach significantly increases the accuracy of soil moisture measurement with the help of multi-depth sensors and hence conserves the water in dry areas. This water conservation extends the water availability, where water is a scarce resource.

Finally, a set of rules are used in the decision-making process which are listed below based on Actual soil moisture required (ASMR) and Estimated Soil Moisture (ESM),

Rule 1:

```
if (DC <=30 days) then
            if (SM_d1 <= SM_d2 && SM_d2 <= SM_d3) then
                ASMR = ESM
            else if (SM_d1 > SM_d2 && SM_d2 > SM_d3) then
                      ASMR = ESM + SM_d1
            end if
```

Rule 2:

```
if (DC >30 days and DC <=45 days) then
          if (SM_d2 >= SM_d1) then
              ASMR1= ESM + SM_d2;
              else if (SM_d2 < SM_d1) then
                   ASMR1 = ESM;
              end if
if (SM_d2 > SM_d3) then
              ASMR= ASMR1 + SM_d3;
              else (SM_d2 < SM_d3) then
                   ASMR = ASMR1;
          end if
```

Rule 3:

```
if (DC>45 days and DC <=60 days) then
     if (SM_d3 > SM_d2 && SM_d2 > SM_d1) then
            ASMR= ESMR + SM_d2 + SM_d2;
      else (SM_d3 < SM_d2 && SM_d2 < SM_d1) then
            ASMR= ESM;
      end if
      end if
```

9.4.1 SVM-Based Ensemble Classification with Decision Tree

SVM-based ensemble classification with decision tree explains the complete scenario of SVM and the ensemble with decision tree for predicting the crop based on the SMEL algorithm. The SVM classifies the soil type based on the nutrient level and that classified data is considered as the input for the decision tree with SMEL output to take the decision on crop cultivation for the soil. Then the crop that can be grown in that soil is extracted from the database. Then the level of water chosen by the farmer is compared with that of the crops.

Those crops that suit the soil are found. Now the crops are separated as per the user's needs. Now depending upon the need of the users the acre measure of the farmer is found and the land is divided into parts. Based on the value of the crop recommended.

INPUT: Soil nutrient level, ASMR, crop types
OUTPUT: Suitable crop for the soil

Begin
Get the soil attributes from dataset
Get the input vectors N_i, Support vectors N_s
Get the soil types based on features (N_i) with the available N_s
Input the soil types to decision with ASMR
Identify the information gain IG for the features of ASMR and features of SMEL
Segregate the attributes according to IG for each soil
Calculate the IG for child nodes
Labeled the child node with more IG as next level of parent
If IG > bestIG
Then considered as the best soil for crop Else
Check for next child IG
End

In ensemble classification, the decision tree starts by selecting the type of soil. Then the crop that can be grown in that soil is extracted from the database. Then the level of water and the calculated temperature chosen by the farmer are compared with those of the crops. Those crops that suit the soil are found. Now the crops are separated as per the user's needs. Now depending upon the need of the users the acre measure of the farmer is found and the land is divided into parts. The proportional land is given to the farmers for their cultivation. And find the precision and calculate the measures with a decision tree to recommend the crop with accuracy.

9.5 Experimental Setup and Result Analysis

A methodological approach has been followed for measurement of various soil parameters. The cloud system is fed with precise data from the sensors and this can be rendered on a digital screen or as serial input. The system also allows remote monitoring of soil conditions and provides crop surveillance. The experiment was carried out in the field

FIGURE 9.2
Field setup

area 600 × 100 sq. ft. The available field area is categorized into four parts with the area 300 × 500 sq. ft and experiments are conducted with different soil moisture levels and varying temperatures based on exposure to sunlight. The nutrients are added in regular intervals based on the crop planted (lady's finger, tomato) in the field. The area with proper nutrients and soil moisture level maintenance provides high yield than the other field. The yield is not discussed in the result section because the proposed setup concentrates on the prediction of the crop yield based on this experiment conducted on the field. The experiments carried out in the field are considered as the training set and classification algorithms predict the crop yield in the test field as given in Figure 9.2.

The experiment involved the pH sensor observations using a pH meter, which classifies the pH level soil. Different crops require different pH conditions and a well-informed choice can be made. A pH of 7 is neutral, lesser than 7 is acidic and more than 7 is basic/alkaline. A variety of fertilizer mixes can then be used to alter the pH slightly to the demands of the farmer. A moisture sensor is used to measure the soil measure level in addition to temperature sensors to evaluate the humidity level of the region/location.

Another important is NPK sensors. The key/major nutrients in the soil are nitrogen, potassium, and phosphorus (NPK); these nutrient content fluctuations dictate what crop cycles are followed. These readings are especially useful at the start of the season when crop choices are decided and also the farmer can use various fertilizers as per the requirement of the soil. The NPK contents in the soil are measure using a digital soil analyzer. In most of the existing systems for crop yield prediction, the soil nutrients level is not considered, which is very much essential in crop yield. Figure 9.3 shows the initial page for the crop recommendation system, which gets the details of the soil with the location to analyze the soil nutrients level and recommend the crop as per the nutrient level of the specified region as shown in Figure 9.4. Once the user submits the user details, the land details page will ask for information like User name, country, state, District, area hectare, soil type, season, transport cost, Duration days, Market price. Once the user fills and submits the form, the data will be analyzed by applying the SMEL algorithm.

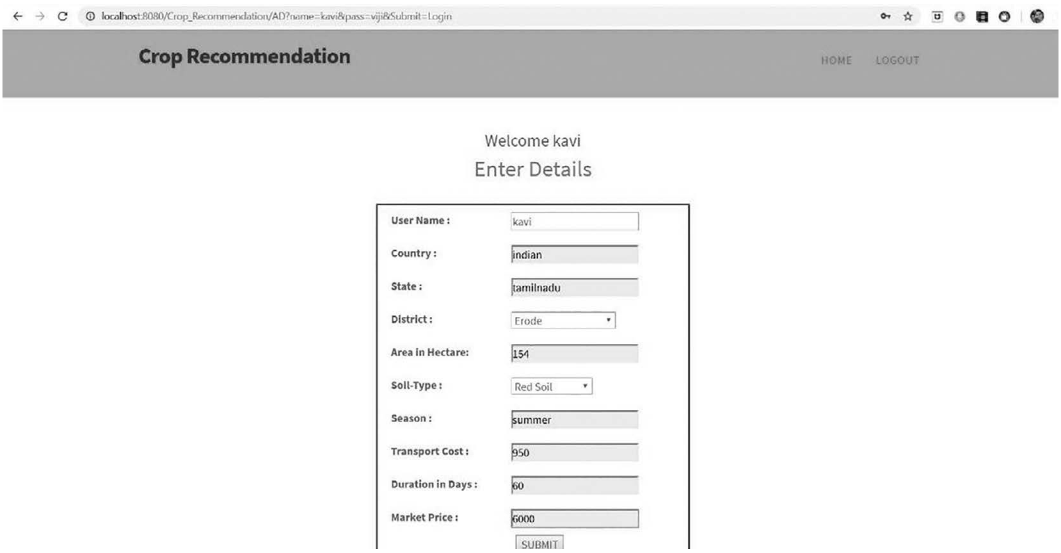

FIGURE 9.3
Crop recommendation system.

9.5.1 Performance of Metrics

9.5.1.1 Accuracy

Accuracy is the most intuitive performance measure and it is simply a ratio of correctly predicted observation to the total observations.

$$\text{Accuracy} = \text{TP} + \text{TN} / \text{TP} + \text{FP} + \text{FN} + \text{TN}$$

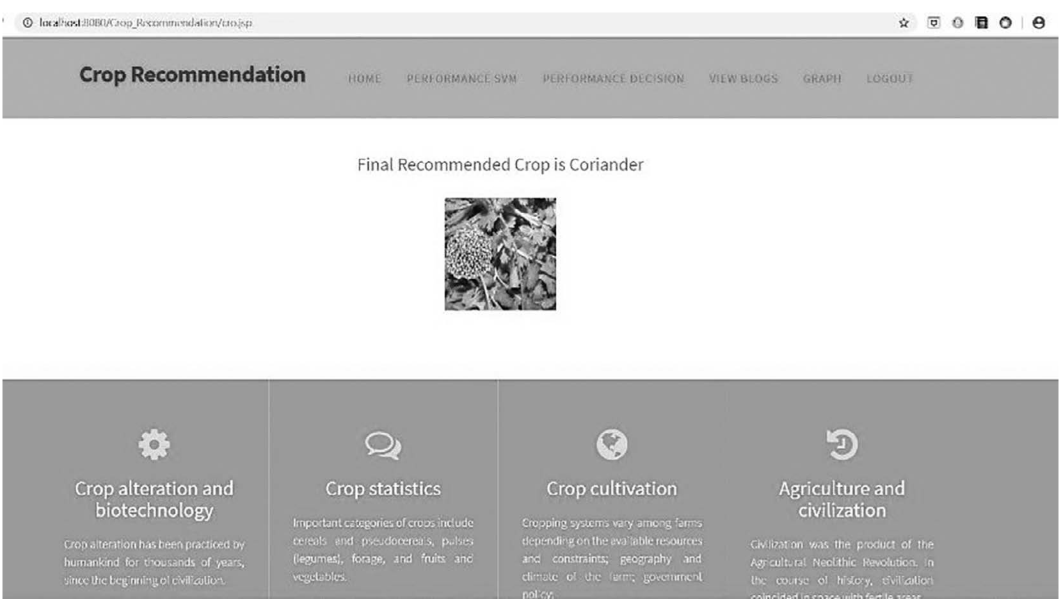

FIGURE 9.4
Crop recommendation based on SMEL-based ensemble classification algorithm.

TABLE 9.2
Performance of Various Classifiers for Crop Yield Prediction

Measures	SVM	KNN	DT	Ensemble Classifier (SVM + DT)
Accuracy	84	88	91	98
Precision	95.5	96.7	97.8	98.9
Recall	97.7	98.8	97.8	99.9
F1 Score	96.6	97.7	97.8	99.4

9.5.1.2 Precision

Precision is the ratio of correctly predicted positive observations to the total predicted positive observations.

$$\text{Precision} = \text{TP} / (\text{TP} + \text{FP})$$

9.5.1.3 Recall (Sensitivity)

Recall is the ratio of correctly predicted positive observations to all observations in actual class.

$$\text{Recall} = \text{TP} / (\text{TP} + \text{FN})$$

9.5.1.4 F1 Score

F1 core is the weighted average of precision and recall. Therefore, this score takes both false positives and false negatives into account and performance of various classifiers is shown in Table 9.2.

$$\text{F1 Score} = 2 * (\text{Recall} * \text{Precision}) / (\text{Recall} + \text{Precision})$$

9.6 Conclusion

The proposed model analyzed the soil nutrients with the temperature and moisture level and predicted the suitable crop for the selected soil location. The proposed SMEL model provides the intelligent rules by including temperature and soil nature to find the suitable crop. The dedicated application will be designed and inputs are processed from the dataset and crop recommendation is going to be done. Also, it will be compared to the existing models such as SVM and decision tree algorithms based on the accuracy level they achieved for crop prediction to the given soil content. Further, this work will be extended by applying fuzzy rough set or swarm intelligence-based techniques to predict the soil for future crop cultivation.

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10

Fuzzy-Based Intelligent Crop Prediction over Climate Fluctuation Using IoT

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CONTENTS

10.1 Introduction

Nowadays, the Internet of Things (IoT) has predominant position in the future generation. Using the IoT, the arena round is getting automatic with the aid of using changing guide procedures when you consider that it's miles strength green and entails minimum guy

DOI: 10.1201/9781003185413-10

power. The Indian authorities have taken initiatives to grow a stable and clever gadget primarily based totally on country's want to use IoT. Smart city is the most important issue targeted through authorities which includes clever parking, women safety, waste management, water management, and agriculture. IoT has a massive effect on smart farming for the reason that agricultural lands are destroyed because of the loss of employees in the field. In sensible farming, in real time, the knowledge required by the farmers is disseminated in numerous destinations. This paper proposes machine-controlled prediction of the crop with the rewards of getting ICT in a global setup. It forecast the route for rural agriculturalists towards exchanging various of the standard methods. This analysis paper overcomes the restrictions of ancient farming methods by exploiting aquatic supply expeditiously and additionally by reducing the labor salary. The agricultural system is additionally machine-controlled frequently to observe the watering (Mohanraj et al. 2016). IoT sensors have the capability to produce data regarding crop yields, downfall to the farmers. In the future, IoT will change the way food grows.

10.2 Background

IoT node combines three fundamental additives including intelligence, sensing, and wireless communications. Some of the real-time applications of IoT are precision agriculture, smart home, waste management, healthcare, and transportation.

A wireless sensor network (WSN) consists of various sensor nodes deployed in huge numbers at different locations to monitor environmental factors. The data sensed by the sensor are analyzed and processed to compare with the knowledgebase. The crop forecast and animal prediction drive up the competence of crop production (Sriharsha et al. 2012; Zhu et al. 2011).

The fact is to know how data are gathered from various heterogenous sources over numerous years. The heterogeneous resources consist of dependent and unstructured records from agricultural researchers, email, net crawling, and farmers' profiles, which lead to big information (Guo et al. 2015). Big data analyzes and examines both the structured and unstructured large data sets of the agriculture field. Semantic extraction from large information the use of ontology is particularly to reduce the searching complexity and improve the accuracy, which in turn would boom the performance of the machine. The crop has been labeled primarily based on weather, soil kind, and life span of the crop. Based on the ontology category of the crop and the use of knowledgebase, the crop which is yielding sufficient quality will be recognized (Nengfu and Wensheng 2007). Chaudhary et al. (2015) proposed a recommended machine using cotton ontology for cotton crops further improves internetworking and cell utility in recommended system.

A monitoring system became proposed by means of Keshtgari and Deljoo (2012), Leona and Jalaob (2013), Othman and Shazali (2012), which makes the farmers be greater worthwhile and sustainable, in the meantime it offers improved water administration. During rainfall circumstances, the land proprietors essential now not irrigate the land due to the fact humidity of the soil receives changed. Water may be stored, which in turn consumes electricity.

A comparative study was done by Mohanraj et al. amid numerous applications accessible with the present established system by considering several features such as knowledgebase, monitoring modules, efficiency, and reliability. The system proposed by them overcomes the restrictions of old-style agricultural measures by exploiting water supply proficiently and also with plummeting labor costs. Table I gives the technology and its objective in the existing system. In the existing method, several authors proposed several methods for automatic crop monitoring but none addressed the issues of big data. In the proposed method, rules framed for the sensed values are compared with the information extracted semantically from various heterogeneous networks to predict high yield crops.

K. Sriharsha et al. focuses particularly on sensing and tracking the Temperature, humidity and water stage of the paddy crop discipline and gives diverse sensing analyzes in the paddy crop field.

Song et al. (2012) classify the attributes of crop usage of agricultural ontology. Jimoh et al. (2013) and Agboola et al. (2013) predict rainfall for the use in fuzzy good judgment. J. C. Kang and J. L. Gao (2013) proposed in the ontology era in farming data recovery to improve accurateness and consistency of the farming records recovery.

Sherine M. Abd El-kader and Basma M. Mohammad El-Basioni (2013) used WSN in cultivating the potato crop in Egypt and additionally stated its software in precision farming and its significance for improving the agriculture in Egypt. N. Sakthipriya (2014) proposed an effective technique for crop monitoring the use of a Wi-Fi sensor network which controls water sprinkling by way of sensing soil moisture.

Hemlata Channe et al. (2015) proposed multiple processing systems for intelligent farming using mobile computing, cloud computing, IoT, and immense data evaluation to enhance agricultural manufacturing and control the cost of agro-merchandise.

10.3 Crop Prediction Framework

The efficient workflow of effective crop prediction using a semantic knowledgebase is depicted in Figure 10.1.

Various sensors such as humidity sensors, temperature sensors, and pH sensors are deployed at farmers' land. The sensed values from various sensors are collected using IoT and sent to the fuzzification function for prediction.

There are two phases of prediction. In Phase 1 based on temperature and humidity and pH values, the list of crops to be grown is predicted using the fuzzy model. Since the temperature keeps changing over time, the fuzzy model best suits crop prediction. In Phase 2, the list of crops predicted by Phase 1 will be tested with the crop knowledgebase and the effective list of crops to be grown will be predicted. The methodology used in this work is discussed in the following section.

10.4 Prediction Using Fuzzy Rules

The overall architecture of the fuzzy-based crop prediction is shown in Figure 10.2.

There are two stages in fuzzy prediction. Stage 1 predicts the climate based on temperature and humidity. Temperature sensors measure the temperature of the atmosphere over time and the data is stored in buffer.

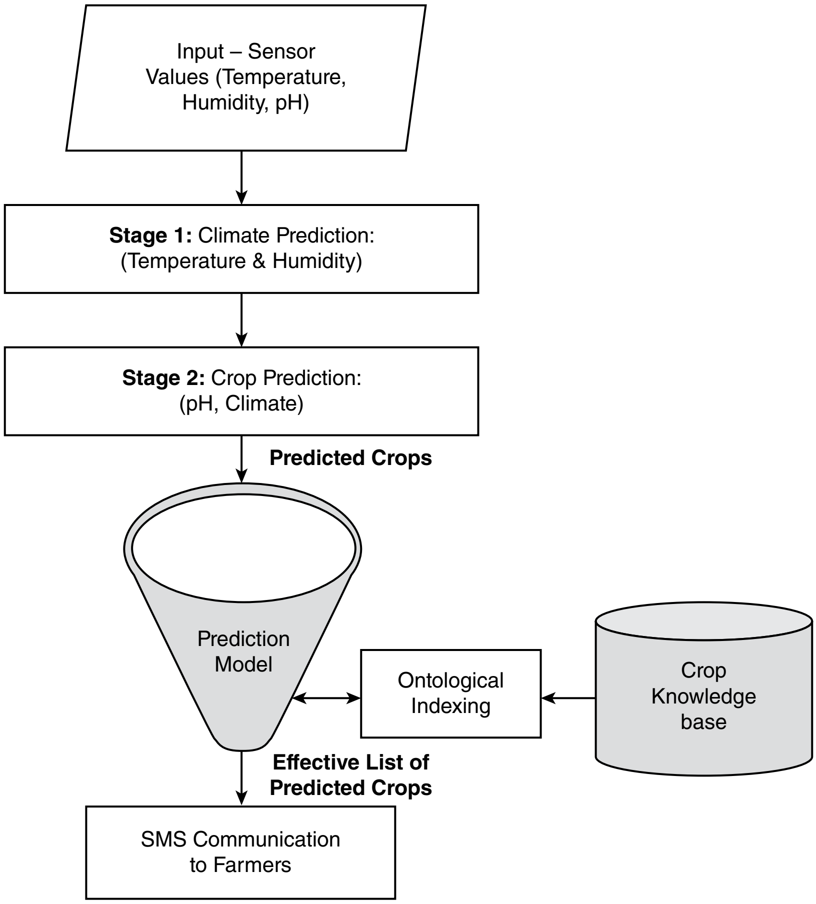

FIGURE 10.1
Effective crop prediction model.

ALGORITHM: CROP PREDICTION USING FUZZY RULES

1. Convert Temperature in Celsius to %.
   - *Split the input temperature into two boundary values as Min & Max values.*
   - *Find average of minimum and maximum values.*
   - *Find temperature in % using the following formula,*

   Temperature = Original value – minimum value/Average value

2. Normalize temperature and humidity values from 0 to 1 using the formula:

   Normalization of (x) = (x–min)/(max–min)

3. Convert it into linguistic variables.
4. Evaluate it using fuzzy rules to find climate.
5. Predict a list of crops to cultivate using weather and soil pH value.

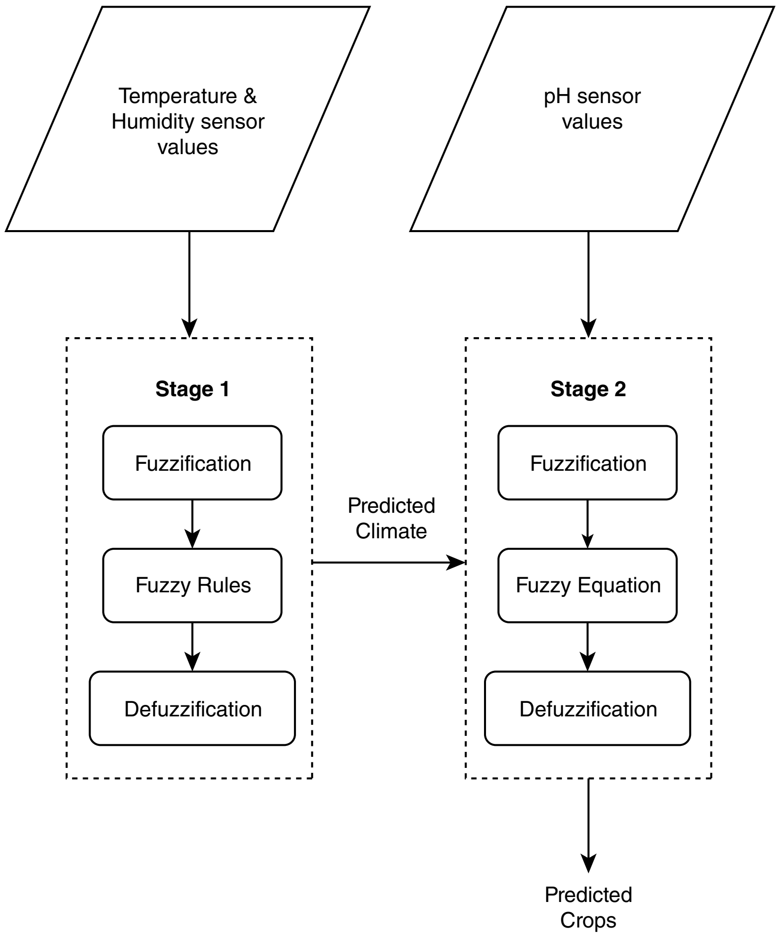

FIGURE 10.2
Crop prediction using fuzzy rules.

Similarly, the humidity sensor measures the humidity of the soil stored in buffer. Temperature and humidity values are given as input for the climate prediction. Since sensors measure different values for a time interval, the measured leads to fuzzy. Climate prediction involves various steps such as fuzzification, fuzzy rule formation using FAM, defuzzification.

Stage 2 predicts the list of crops to cultivate based on predicted weather at Stage 1 and soil pH value. The Crop prediction involves fuzzification, fuzzy equation, and defuzzification. The list of crops predicted by Stage 2 will be tested against the crop knowledgebase and the effective list of crops to be grown will be predicted.

10.4.1 Fuzzy-Based Crop Prediction

Table 10.1 illustrates the FAM (Fuzzy Associate Memory) uses matrix form map fuzzy rules.

TABLE 10.1

Forecasting the Weather through Sample Rule

Rule 1:	If (temp==very high) AND (humidity==high) THEN *(season==summer)*
Rule 2:	If (temp==moderate) AND (humidity==low) THEN *(season==spring)*
Rule 3:	If (temp==very low) AND (humidity==low) THEN *(season==winter)*

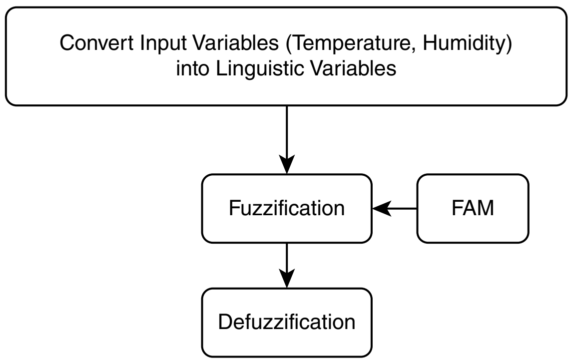

FIGURE 10.3
Flow diagram for climate prediction.

The flow diagram for the prediction of climate using fuzzy rules is shown in Figure 10.3.

Fuzzification converts the measured value from the sensors (temperature and humidity) to linguistic variables of fuzzy sets, which consists of five tuples: Very Low, Low, Medium, High, and Very High. Fuzzy rules are formed and evaluated by Fuzzy Associative Mapping (FAM), which is shown in Table 10.2. Fuzzy Associative Mapping is used to reduce the rate of false negatives (Sherine et al., 2013; Wood et al., 2005).

The output of fuzzification is then evaluated by defuzzification to generate an accurate prediction of climate. Defuzzification uses the mean of maxima defuzzification method to produce the climate (Jiang et al., 2010). The climate-related variables are shown in Table 10.3, which gives the list of crops to be grown in respective climates predicted by the defuzzification process (Sangeetha et al., 2015).

10.4.2 Crop Prediction Using Fuzzy Equation

Crop to cultivate is predicted effectively constructed on weather and soil pH value. pH sensors are used to measure the pH value of the soil.

The type of soil can be identified by analyzing its acidic nature. The list of crops to be grown in respective pH values and soil types is shown in Tables 10.4 and 10.5, respectively.

A fuzzy equation is used for evaluation. It takes climate and pH as two input variables.

TABLE 10.2
Fuzzy Associative Mapping for Climate

Temperature/Humidity	Very High	High	Moderate	Low	Very Low
Very High	Summer	Summer	Summer	Autumn	Autumn
High	Summer	Summer	Autumn	Autumn	Autumn
Moderate	Summer	Autumn	Autumn	Spring	Spring
Low	Spring	Spring	Spring	Autumn	Winter
Very Low	Spring	Spring	Winter	Winter	Winter

TABLE 10.3
Weather-Associated Variables

Characteristic	Forms	Comparative Temperature	Comparative Humidity	Crops to Be Grown
Climate	Summer	Very hot (32°C–40°C)	Very high to moderate	Millets, maize, red chilies, cotton, paddy, soya bean, sugarcane, turmeric, moong, groundnut, barley
	Autumn	Warm days (>30°C) Cool nights (21°C–29°C)	Low	Maize, oats
	Spring	Warm days (>30°C) Cool nights (25°C–29°C)	Low to moderate	Wheat, mustard, barley, peas
	Winter	Cold (10°C–15°C)	High	Oats

TABLE 10.4
pH Value and Suitable Crops

pH Value	Suitable Crops
5.5–6.5	Apple, strawberry
5.5–7.5	Tomato, corn, peas, grapes, carrot
6.0–7.5	Onion, cabbage, beans

Therefore, the list of crops to be grown is predicted based on four tuples (T, H, pH, S), where T – temperature, H – humidity, pH – pH of soil, S – type of soil.

$$S_i = \{A, B, C, D, E, F\}$$

$$X = \{A_i, B_i, C_i, D_i, E_i, F_i\},$$

where A, B, C, D, E, and F – desert soil, black soil, laterite soil, red soil, alluvial soil, and mountain soil, respectively.

X – Set of crops and $A_i, B_i, C_i, D_i, E_i, F_i$ – group of crops to cultivate in procured soil.

Climate is predicted based on fuzzy rules with the attributes such as temperature and humidity using which is represented as,

$$f_1(x) = f(t, h), \tag{10.1}$$

TABLE 10.5

Soil Associated Variables

Attribute	Soil Types	Crops to Be Grown
Soil	Alluvial	Cotton, jute, wheat, rice, sugarcane
2	Black	Oilseeds, sugarcane, millet, rice, wheat, cotton, groundnut
2	Red	Potatoes, cotton, maize, pineapples
2	Laterite	Cashew, tea, coffee, tropical crops, rubber, coconut
2	Mountain	Tea, tropical fruits, coffee, spices
2	Desert	Millet, barley

where t – temperature and h – humidity, x is a crop to cultivate and $x \in X$. Crop is predicted based on soil pH value using fuzzy equation and is represented as,

$$f_2(x) = f\left(f_1(x), pH\right), \tag{10.2}$$

where pH – pH value of soil. $f_2(x)$ is a fuzzy equation that predicts the crops to be grown. The following fuzzy rule gives the effective list of crops to be grown. The sample rule is given as follows.

$$f_2(x) = \text{Summer AND pH} > 7.0 \text{ then } f_1(x) \cap \text{pH}_\text{i}$$

The predicted crops using Equation 10.2 will be used for predicting an accurate list of crops to be grown using crops knowledgebase. The data in the crop knowledgebase are prolonged through domain ontology, further grouped on the basis of ontology and the participation query is scrutinized for semantics. It is then compared with the predicted list of crops from Equation 10.2 to produce an effective list of crops to be grown.

10.4.3 Semantic Extraction in Big Data

The agricultural data from various heterogeneous resources are collected and stored in the database over several years. The heterogeneous resources consist of information from agricultural researchers, Email, Web Crawling, farmers Profile, which leads to Big Data. These data must be preprocessed to remove unwanted data. During preprocessing, it removes HTML and XML labels, and scripting reports from the basic documents.

In big data, the semantic analysis using ontology allows structuring the data from the unstructured data of various resources such as web pages and historical data, which serves as a basis for the implementation of the proposed system for decision support (Zhang, 2011; Mohanraj et al., 2016). The semantic analysis gets initiated with the ontology establishment for the information in the database through keyword comparison by natural language processing. Figure 10.4 shows the semantic extraction from Big Data.

The crop is classified based on ontology, which involves three features: climate, life span, and soil, which is shown in Figure 10.5.

In order to measure the quantity of water droplets in the air the proposed system uses humidity sensors. Further, to determine the temperature level of air from moisture and

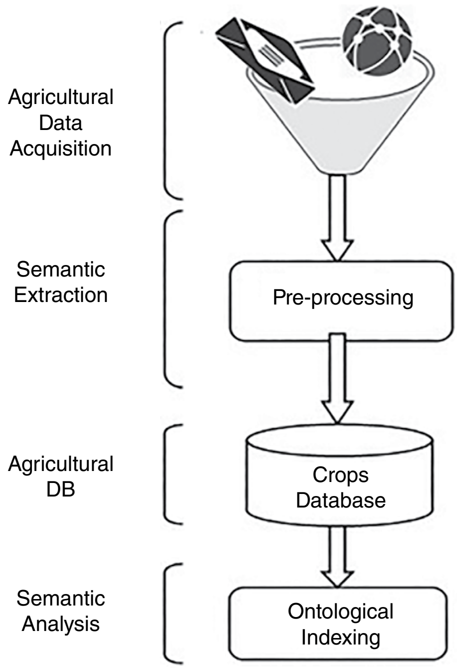

FIGURE 10.4
Semantic extraction from the knowledgebase.

radiation temperature sensors are deployed. Therefore, climate consists of temperature and humidity. The pH sensors analyze the acid level of the soil, and they measure the pH value. Henceforth, through soil pH value the type of soil can be identified. The data in the crop knowledgebase are prolonged through domain ontology, further grouped on the basis of ontology and the participation query is scrutinized for semantics. It is then compared with the semantically extracted data to produce an effective list of crops to be grown.

10.5 Results and Discussion

In order to determine climatic conditions and to predict the season change periodic measurement of humidity and temperature is recorded periodically. The periodic measurement is for a year. The acquired values are analyzed and plotted. The following Figure 10.6 depicts the periodic measurement of humidity and temperature. The values are plotted for the year 2018–2019.

Based on soil pH value the crop to be cultivated is determined. Figure 10.7 shows the pH value of the soil, which varies depending on the type of soil.

The semantic retrieval using ontology has been evaluated based on accuracy and time complexity. This proposed system using Fuzzy logic shows superior performance when compared to the existing system, which is shown in Figure 10.8. The time complexity is

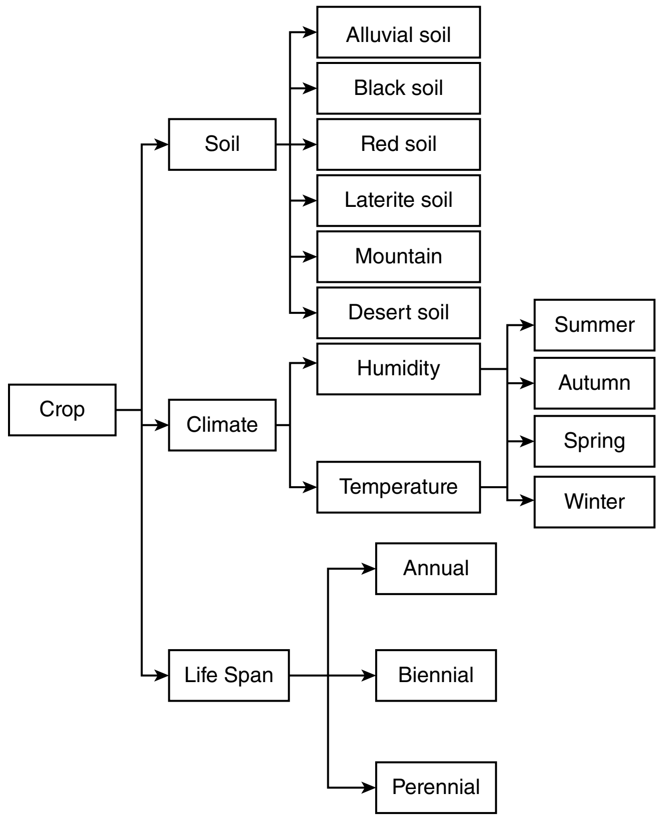

FIGURE 10.5
Ontology classification of crops.

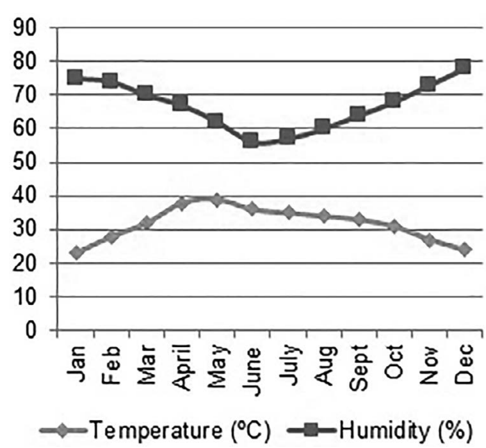

FIGURE 10.6
Humidity and temperature.

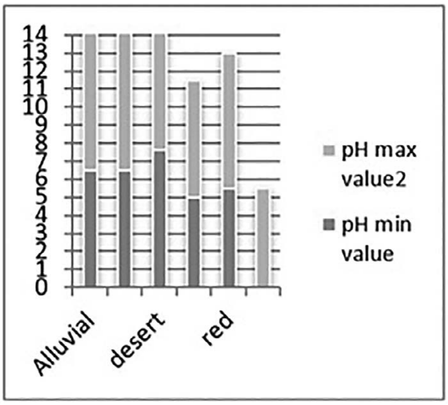

FIGURE 10.7
pH value analysis.

analyzed, which is 45 s for the proposed system and is significantly low compared to existing one (Sherine et al., 2013), which has 82 s; thus proposed system is more efficient.

The performance analysis of the proposed algorithm using the fuzzy rule is estimated based on precision, sensitivity, accuracy, and Matthew Correlation Coefficient (MCC). The accuracy of the system is premeditated by the number of accurate positive (+VE) forecasts by the entire number of positive (+VE) forecasts. Further Figure 10.9 illustrates the overall positive forecasts of the system model. The crop prediction using fuzzy rules sustains the accuracy rate of 80%, correspondingly.

In the following Figure 10.9, performance analysis of the proposed Crop prediction using fuzzy rules-based sensitivity is evaluated. Further, sensitivity is determined by the number of precise positive (+VE) forecasts by overall positive (+VE) forecasts. The proposed system sustains a sensitivity of above 84%. Further, for the Crop prediction using fuzzy rules, accuracy is considered. Figure 10.10 discusses the exactness maintained at above 80% in all measures, namely False Negative (FN), False Positive (FP), True Negative (TN), and True Positive (TP).

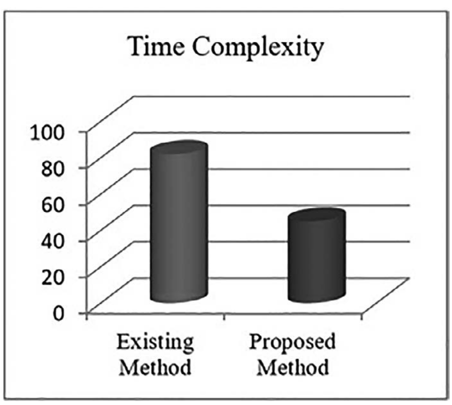

FIGURE 10.8
Time complexity.

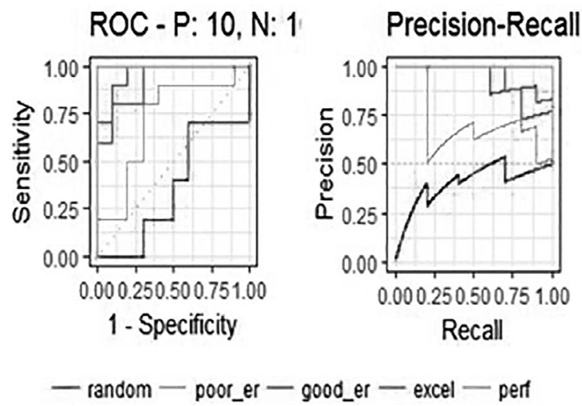

FIGURE 10.9
Sensitivity vs. specificity and precision vs. recall.

Figure 10.10 portrays the manner in which the proposed system model fluctuates for diverse input. Further Figure 10.10 depicts the comparison of numerous attributes through various outputs, namely excel, random, perf, poor_er, and good_er. The number of samples attained is assigned as ten (10), which is positive and the remaining ten are unfavorable. Finally, after analysis the system model ends up in error which is originated through serval process and resulting in consider reduction of the errors in future.

Figure 10.11 depicts the rate of recall and precision after reducing the error. In the proposed model through means of assessment the error gets reduced. In the system model the errors are carefully handled.

Figure 10.12 concentrates the regularized rank as a fixed variable to display the difference between error and precision for diverse values. The rate of accuracy is calculated using the randomized rating. As a result, the accuracy rate is greater than the error rate. This shows that the system model is effective in determining accuracy and error.

In the proposed model, after calculating the precision and error, a comparison is made to determine the specificity, sensitivity, and precision, as depicted in Figure 10.13. The system model uses a similar dataset to determine the performance.

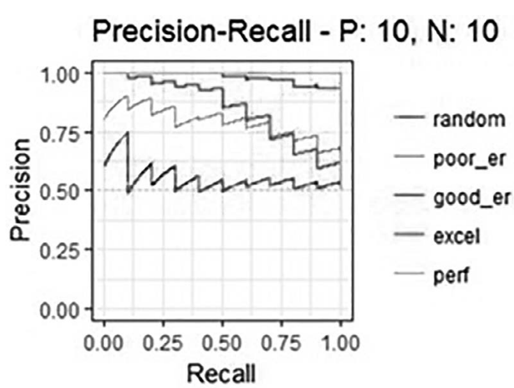

FIGURE 10.10
Recall vs. precision.

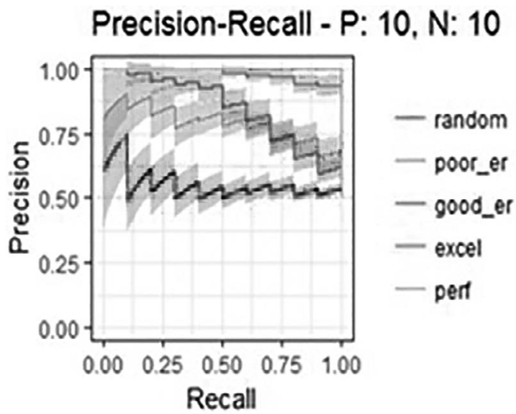

FIGURE 10.11
Subsequently error inference.

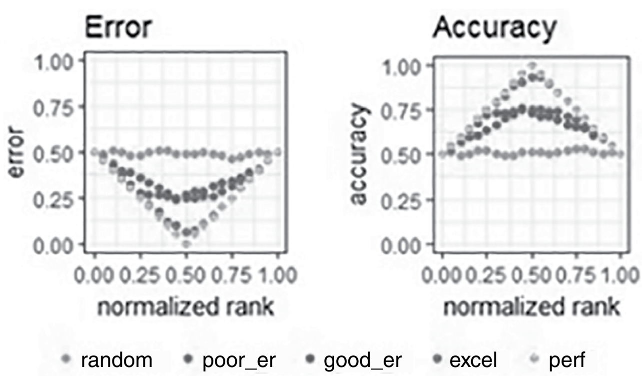

FIGURE 10.12
Error vs. accuracy.

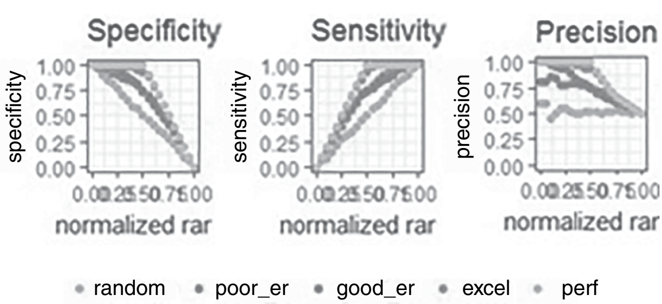

FIGURE 10.13
Comparison of specificity, sensitivity, and precision.

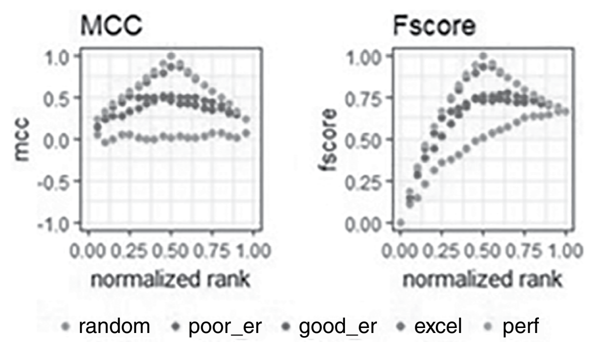

FIGURE 10.14
MCC and F-score.

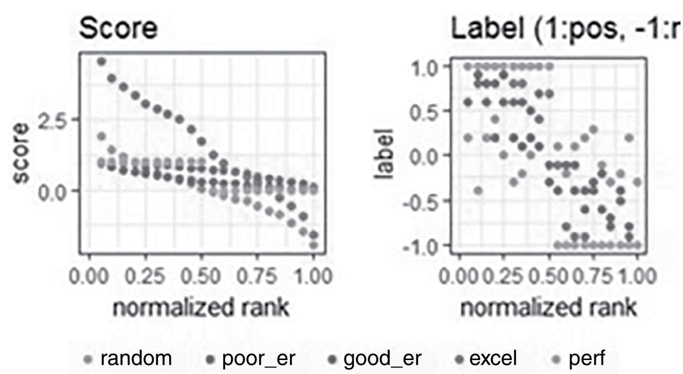

FIGURE 10.15
Normalized and random normalized rank.

The F-score and MCC are calculated, and the performance rate shows high fluctuation comparatively. F-score is the ratio between the recall and precision, as mentioned in Figure 10.14. MCC is used to determine if the error rate is high or low.

Finally, Figure 10.15 shows the comparison between the Normalized and Random normalized for the given dataset. Our proposed model illustrates progressive performance percentages in comparison with the existing system.

In addition to that, MCC is calculated in the proposed methodology. The MCC accuracy is maintained above 80% in all the criteria, namely True Positive (TP). True Negative (TN), False Positive (FP), and False Negative (FN) as mentioned in Figure 10.9.

10.6 Conclusion

This paper uses the IoT era for crop cultivation in large information, which offers low cost and green garage and consumes much less power. The ontology primarily based totally crop farming forecasts the crop to be grown with the excessive harvest. The semantic extraction in large information will increase the overall performance and in flip reduces the looking time and garage capacity. FAM is employed to predict the climate condition, which is principally to cut back the speed of false negatives. Thus, it produces an effective prediction of the crop to be used. Crop monitoring is additionally automated to avoid paucity of water. The performance analysis of the proposed algorithm using the fuzzy rule is assessed based on sensitivity, accuracy, precision, and MCC. Therefore, the proposed method shows better performance and also overcomes the restrictions of traditional agricultural procedures by utilizing water resources efficiently and also by reducing the labor cost.

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11

Application of Drones with Variable Area Nozzles for Effective Smart Farming Activities

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CONTENTS

DOI: 10.1201/9781003185413-11

11.1 Introduction

Drones have several applications in agriculture and they are widely used for extended farming activities in many countries across the globe. Agriculture is the backbone of every country, and the transformation from conventional farming to smart farming is very much essential to cater to the food requirements of the masses. Furthermore, approximately 2 billion people (26.7% of the world population) around the globe depend on agriculture for their livelihood. It also contributes to 4% of global Gross Domestic Product (GDP) and it accounts for more than 25% in developing countries like India [1, 2]. Specifically, the rural population mainly depends on agriculture, where the conventional farming methodologies are still in practice because of the lack of awareness, farm policies, and capital investments. Recently, the use of drones for various agriculture activities has been proved to be very effective in the case of pesticide spraying, Crop monitoring, Crop Damage Assessment (CDA), Surveillance, Irrigation, Planting, replacing labor-intensive and hazardous conventional methods [3].

Among the various applications of drones for smart agriculture activities, the handling of pesticide/fertilizer is a preferred task because of the hazardous nature of the work and it is well-connected with the health of the plants. Hence, Internet of Things (IoT)-enabled systems play a vital role in performing crop health monitoring activities to decide the amount of fertilizer needed at different phases of crop growth [4]. In actual agriculture production, Pests and illnesses of harvests are the central points that influence the yield and nature of yields, and the use of synthetic pesticides is the primary method for their avoidance and control. Additionally, the seriousness of plant illness and insect pests varies with respect to different locations according to the weather and soil conditions. The broad utilization of pesticides straightforwardly jeopardizes the environment and human well-being. Subsequently, disproportionate pesticide usage decreases productivity and it has been acknowledged around the world through various studies. Drones spray the pesticide/fertilizer through a nozzle which is fixed along with the sprayer system. Though agricultural drones have many benefits, the wastage of pesticides or fertilizer is considered to be a major disadvantage because of the absence of sophisticated remotely controlled mechanisms.

In the field of plant security, the variable shower innovation can be applied based on the field of interest and other crop specifications. It has distinct possibilities for improving the usage pace of pesticides and lessening the pesticide deposits. To reduce the wastage of pesticides, it should be applied according to the severity of pests, insects, and weeds with complete field data [5]. To achieve this, variable area nozzles (VANs) are designed and are synchronized with the IoT-enabled sprayer system. Here, the drone camera observes the crop images to determine its health through the image processing software (IPS) deployed in the cloud hub. The IPS computes the degree of infection and the proportionate quantity of pesticide to be sprayed. Subsequently, the required quantity will be communicated to the IoT sensors to trigger the spraying event with appropriate flow rates. Here, the spray system consists of a reservoir, flow lines, throttle valves, and nozzle. Typically, this VAN has three different flow ranges such as 0.16 L/min, 0.32 L/min, and 0.54 L/min, respectively.

As the drone is operated over agricultural land, different areas can be captured according to the field of interest using a multispectral camera. Multispectral camera remote sensing (RS) imaging technology uses green, red, red-edge, and near-infrared wavebands to capture both visible and invisible images of crops and vegetation [6]. With the captured images and subsequent output received from the IPS, the drone operator could plan the flow range required at different locations of the land and use the sprayer system effectively with VANs. It reduces the amount of pesticides being wasted and also reduces the operational cost involved. Hence, this chapter is focused on the design of an IoT-enabled VAN sprayer system (Figure 11.1) and its applications to perform effective smart farming activities.

11.1.1 Roles of Drones in Agriculture

The smart agriculture activities revolve around the IoT systems and drones in terms of several potential applications as listed below:

11.1.1.1 Soil Analysis for Field Planning

Drones can be effectively utilized for the soil and field examination to identify the water system, planting arrangement, and nitrogen (N_2) levels in the soil, as shown in Figure 11.2(a).

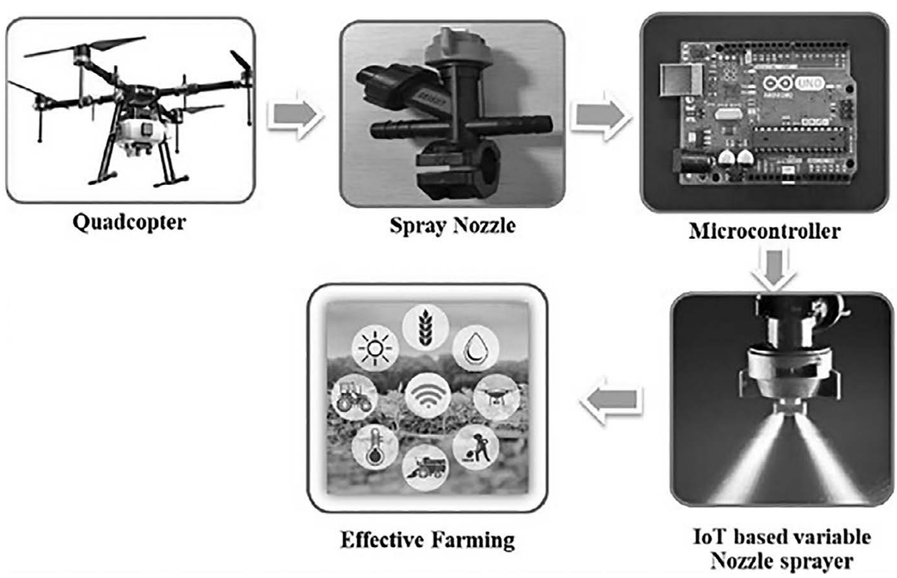

FIGURE 11.1
Schematic diagram for IoT-enabled spraying system.

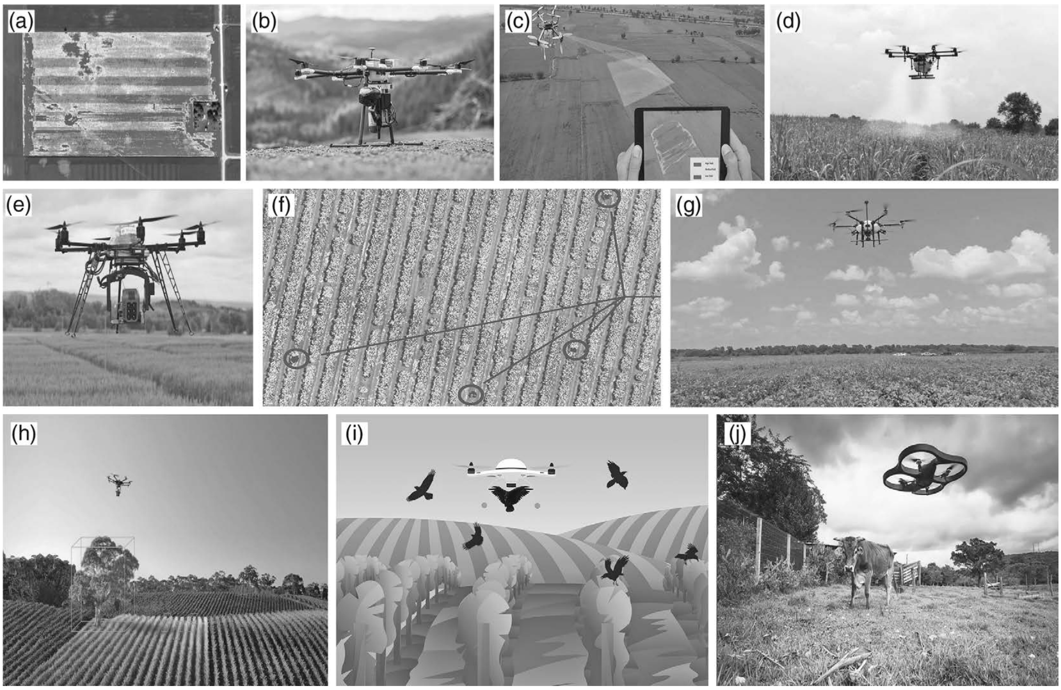

FIGURE 11.2
Roles of drones in agriculture: (a) soil analysis for field planning, (b) seed pod planting, (c) crop monitoring, (d) pesticide spraying, (e) irrigation planning, (f) crop health assessment, (g) controlling weed, insect, pest, and diseases, (h) tree/crop biomass estimation, (i) scaring birds, and (j) man–animal conflict.

In addition, drones are useful to deliver the precise 3D guides that can be employed for direct soil investigation in terms of soil properties, dampness substance, and soil disintegration [7].

11.1.1.2 Seed Pod Planting

In recent times, many kinds of drones have been developed with additional attachments according to various field applications below the flight controller system. As an example, the shoot pod containing seed and plant nutrients is capable of planting seeds into the already-prepared soil with precise spacing at different terrains (Figure 11.2(b)). It helps to reduce the manpower and planting costs with minimum time consumption [7].

11.1.1.3 Crop Monitoring

Crop monitoring is the biggest challenge not only for farmers but also for various stakeholders associated with the agriculture business [8]. This challenge becomes worse in the event of unpredictable weather patterns, which lead to rising crop losses, risks, and maintenance costs. Agronomists and agricultural engineers prefer to use drones with smart crop tracker tools set for large-scale precision farming operations [4]. It monitors the leaves and routes by gathering multispectral geospatial and temporal datasets at predefined scales that are related to crop development and health, as shown in Figure 11.2(c). Drones prepared with special imaging equipment known as the normalized difference vegetation index (NDVI) utilize comprehensive color statistics to show the health of the plants. This advanced information helps to monitor the crop wellbeing much before it is being investigated by manual field observations [7].

11.1.1.4 Pesticide Spraying

The modern drones are optimized to carry the pesticide spray systems of different capacities for proper spraying of pesticides at various phases. Spraying pesticides is a very crucial activity to maintain crop health and these drones are more efficient than any other manual spraying method. (Figure 11.2(d)). Most importantly, the concept of precision agriculture (PA) can be fulfilled only when the time and labor costs are saved significantly. Alternatively, PA also protects the farmers from coming into contact with the various toxic chemicals [9].

11.1.1.5 Irrigation Planning

Drones are equipped with thermal, multispectral, or hyperspectral sensors which can distinguish the pieces of the field with dampness shortages by utilizing multispectral records. The irrigation planning should be aligned with moisture maps and ground reality to overcome the drought and climate change issues. The microwave sensing technology on drones offers perfect images that are better than optical mapping and the picture of the soil will not be affected by vegetation [10]. This system helps to arrange the appropriate water resources to the distinguished regions with exactness on moisture mapping (Figure 11.2(e)).

11.1.1.6 Crop Health Assessment

The GIS plays a vital role in the PA in terms of soil mapping and relevant crop health assessments. Crops reflect visible and clear infrared light, the power level of which changes with wellbeing status and stress concentration experienced by crops. By using the NDVI data, it is much easier to classify the dead leaf, stressed leaf, and healthy leaf of a plant. Drones fitted with health monitoring sensors are suitable for examining the crops by utilizing the infrared light data, and they can also be utilized to follow the wellbeing of the crop throughout a given timeframe (Figure 11.2(f)) [11].

11.1.1.7 Controlling Weed, Insect, Pest, and Diseases

Apart from the evaluation of soil conditions, drones could identify and educate the farmers about field regions perpetrated by weeds, diseases, and insect pests through detailed aerial surveying, as displayed in Figure 11.2(g). With the help of these data, farmers can improve the utilization of synthetics expected to battle against various diseases; henceforth the abrupt losses are reduced by increasing the crops' wellbeing [12].

11.1.1.8 Tree/Crop Biomass Estimation

Crop/tree canopy density and distance from the ground surface can be measured using ultra-compact light detection and ranging (Li-DAR) sensors mounted on the drones. This helps in the estimation of the tree/crop biomass change by studying the variations in height measurements that form a basis for estimating timber production in forest and production estimates in the crops like sugarcanes (Figure 11.2(h)) [1].

11.1.1.9 Scaring Birds

Birds are considered to be a serious issue subsequent to planting seeds on numerous yields. It increases the requirement of manpower to secure the fields, especially in the remote areas, where it takes hours of walking to roam around, for which drones with speakers can be used to produce annoying sounds to frighten the birds off from the fields in alignment with the regulations prescribed by the concerned authorities (Figure 11.2(i)) [13]. Hence, farm management against the scaring birds can now be completed in a few minutes by bird-chasing drones like ProHawk UAV.

11.1.1.10 Man–Animal Conflict

Human–wildlife conflict (HWC) results in crop destruction, loss of human life, and injuries to humans/animals. Recent HWC data shows that the wildlife conflict is continuously soaring over the years across the globe because of the encroachments and negative interactions. Farmers living adjacent to the forests have such major issues during their harvesting times due to monoculture fields. The improved artificial intelligence (AI)-based drones could identify and recognize the increased crop diversity to minimize the HWC. Further, the animals are migrating to society in big numbers in search of drinking water, and food and their migrating path can be well-defined through drone mapping [14]. By drones, one can avoid man–animal conflict by releasing the smoke or making a relevant frequency of sound against the animals through onboard speakers (Figure 11.2(j)).

From the various roles of drones stated above, it is inferred that more than 20 day-to-day applications exist for the agriculture drones in the PA domain. Specifically, pesticide spraying and handling is a key application because of its ill-effects on the farmer's health. Hence, the present chapter is motivated to investigate the challenges associated with the drone spraying mechanisms and the rectification measures as explained in the subsequent sections.

11.2 Existing Spraying Methods

The primary motivation behind any pesticide application method (spraying, dusting, etc.) is to cover the objective with the extreme effectiveness and least activities to monitor the vermin attacks. All the pesticides contain toxic substances which would cause harmful effects to every living organism. Thus, the utilization of pesticides should be extremely prudent with the least pollution to non-targets. Conventional sprayers are available in a variety of sizes and specifications, depending on the requirements of a plant or crop cultivated.

An overview of conventional sprayers is discussed herein to emphasize the comparative advantages of IoT-enabled VAN sprayers in drones. Following are the main types of sprayers used for insecticide or pesticide sprays: (a) low-pressure sprayer (tractor-mounted, high-clearance sprayer, trailer-mounted sprayers, and truck-mounted sprayers), (b) air carrier sprayer, (c) high-pressure sprayer, (d) fogger (mist blowers), and (e) hand-operated sprayer [15].

The widely used method to shower the pesticide in the field by the Tractor mounted low-pressure sprayers are presented in Figures 11.3(a) and (b). It is an expensive method in which the wastage and excessive spraying of pesticides occur very often that eliminates

FIGURE 11.3
Types of sprayers: (a) tractor-mounted low-pressure sprayer, (b) air carrier sprayer, (c) high-pressure sprayer, (d) fogger – mist blowers, (e) hand-operated sprayer.

a great variety of living organisms in agriculture. The high-pressure sprayer splashes the pesticides on the field by revolving around 360°, as highlighted in Figure 11.3(c). For small and medium area land-based agriculture, the farmers carry large shower bottles with them to spray the pesticides that cause numerous medical issues, as displayed in Figures 11.3(d) and (e). A detailed comparison of different kinds of sprayers used for various agricultural activities is summarized in Table 11.1.

As a result of the widespread diffusion of pesticides, a great part of the people involved in agribusiness may get exposed to pesticides due to their occupation [17]. The World Health Organization (WHO) estimates there are more than 1 million occupational exposure pesticide cases reported every year. Among the reported cases, more than one lakh deaths occur every year, especially in the developing countries where pesticides are handled exclusively by human beings [18]. It should be noted that the adverse health effects of pesticides include asthma, allergies, hypersensitivity, cancer, hormone disruption, and problems with reproduction. Hence, the PA and farm management is the need of the hour to create a rapid evolution with smart agriculture activities. The major advantage of drones for crop monitoring and spraying is that it completes the entire process over a large area within a limited time period as compared with other traditional methods.

11.3 Proposed VAN Integrated Quadcopter Sprayer

To overcome the issues related to manual spraying, a novel VAN system integrated Quadcopter sprayer is proposed in this chapter. The component-wise features and functions of the Quadcopter to achieve the objectives of PA are also presented with the schematic

TABLE 11.1

Performance Comparison of Different Spraying Mechanisms [16]

Parameters	Drone Sprayer	Hand-Operated Sprayer	Tractor-Mounted Sprayer	Truck-Mounted Sprayer
Application/day	20–25 hectares/day	0.8–1.3 hectares/day	6.7–20 hectares/day	66.7–80 hectares/day
Pesticide utilization Efficiency	85%–90%	30%–40%	30%–40%	30%–40%
Adaptability	Can be operated at mountains, hilly terrains, and paddy fields.	Few crops, flower, and fruit are easily damaged, trampled or dropped by human-operated sprayer.	Cannot be used in the mountain or hilly terrains and narrow access routes.	Cannot be used in mountains or hilly terrains.
Water consumption per hectare	VAN sprayer ensures uniformity, low dilution rate, and even with the use of highly concentrated liquid pesticide, the water can be saved up to 90%.	Traditional jet spraying, resulting in waste of water, and most of the pesticides lost into the soil along with water.	Traditional jet spraying, resulting in wastage of water, and most of the pesticides lost into the soil along with water.	Traditional jet spraying, resulting in wastage of water, and most of the pesticides lost into the soil along with water.
Safety	Operated away from the field during spraying to avoid pesticide poisoning.	Pesticides enter into the human body by mouth that easily leads to pesticide poisoning.	Applying pesticide from a close range easily leads to pesticide poisoning.	Pesticide is applied from short range and vulnerable to poisoning.

circuits. The nozzle spray nomenclature is illustrated in Figure 11.4(b). Basically, drones are remote-controlled UAVs that use Information and Communications Technology (ICT) to increase agricultural productivity through PA. These UAVs have a huge potential in agriculture in supporting evidence-based planning and in spatial data collection. Despite some inherent limitations, these tools and technologies can provide valuable data that can then be used to influence policies and decisions [8]. The proposed UAV is a combination of a Quadcopter and a spraying system (Figure 11.4(a)) with the following components.

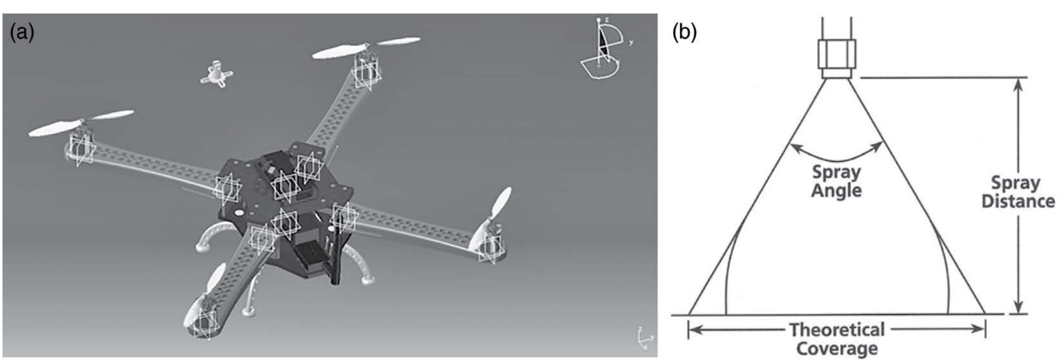

FIGURE 11.4
(a) Quadcopter design prepared using CATIA V5. (b) Nozzle spray nomenclature.

11.3.1 Components

The essential components of the VAN integrated Quadcopter sprayer are as follows: (i) brushless DC motor (BLDC) motors (4 nos.), (ii) propellers (4 nos.), (iii) electronic speed controller (ESC), (iv) Flight control Board (Pix hawk), (v) Li-Po battery, (vi) transmitter with receiver (Fly Sky), (vii) carbon frame, (viii) sprayer (variable nozzle). The actual view of the key components of the Quadcopter sprayer is presented in Figures 11.5(a–h). The size and geometric specifications are not disclosed herein because of the patents involved with each component. The essential functions of basic components of a Quadcopter are discussed briefly herein to offer the key insights about the robustness and reliable working of the system.

FIGURE 11.5
Basic components of a Quadcopter: (a) BLDC motor, (b) propeller, (c) ESC – red brick, (d) frames, (e) battery, (f) transmitter, (g) flight controller, (h) receiver.

11.3.1.1 BLDC Motor

A BLDC is a DC electric motor that uses an electronically controlled commutation system instead of a mechanical commutation system to deliver the required amount of power to the drone components (Figure 11.5(a)). Generally, BLDC motors run at very high RPM and it is available in both clockwise (CW) and counter-clockwise (CCW) configurations. The power to weight ratio of 2:1 to 4:1 is typically fixed based on the payload and auxiliary system requirements of the spraying drones.

11.3.1.2 Propellers

The purpose of Quadcopter propellers is to generate the required thrust and torque to keep the drone flying and maneuvering. The upward thrust force generated by the propellers is usually measured in pounds or grams. To keep the drone flying at a hover, the upward thrust needs to be equal to the weight of the drone (Figure 11.5(b)). Propellers can be made from wood, plastics, composites, and metallic materials.

11.3.1.3 Electronic Speed Controller

An Electronic Speed Controller (ESCs) is a device that allows a drone flight controller to control and adjust the speed of the BLDC motors. A signal from the flight controller causes the ESC to raise or lower the supply voltage to the motor as required, thus changing the speed of the propellers via motor. Different types of speed controllers are required for brushed DC motors and brushless DC motors. The brake setting, low voltage protection, and start-up modes can be programmed in the ESCs that are available in different varieties like Red Brick (Figure 11.5(c)) and Yellow Brick.

11.3.1.4 Frames

The diagonal distance between the motors determines the size of the frames and propellers for a specific Quadcopter configuration. However, there is no thumb rule for the size of the frames, and the most commonly used dimensions vary from 180 mm to 800 mm according to the various types and functions of the drones. The frame is the part that holds all the parts of the drone and mainly it supports the motors and electronic accessories and prevents them from excessive vibrations. Frames can be made of composites (carbon/glass fiber, high-density polyethylene, etc.), and aluminum alloys as well (Figure 11.5(d)). The selection of frame material and size should be made precisely as per the strength-to-weight ratio requirements of agriculture drones [11].

11.3.1.5 Li-Po Battery

A lithium polymer battery or lithium-ion polymer battery is a rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid electrolyte (Figure 11.5(e)). Based on the power-to-weight (P/W) ratio to be produced, range, and endurance of the drones, a specific type of battery with maximum C-rating should be selected for the sprayer drones [19]. The autonomy of the drones increases with the addition of batteries that helps to achieve rapid response during high power demands. Li-Po batteries are competent to deliver the Specific power of 2800 W/kg and the Energy density of 300 Wh/m^2 to accomplish the given agriculture mission of UAVs. A block diagram of Quadcopter arrangement is shown (Figure 11.6) with all necessary components.

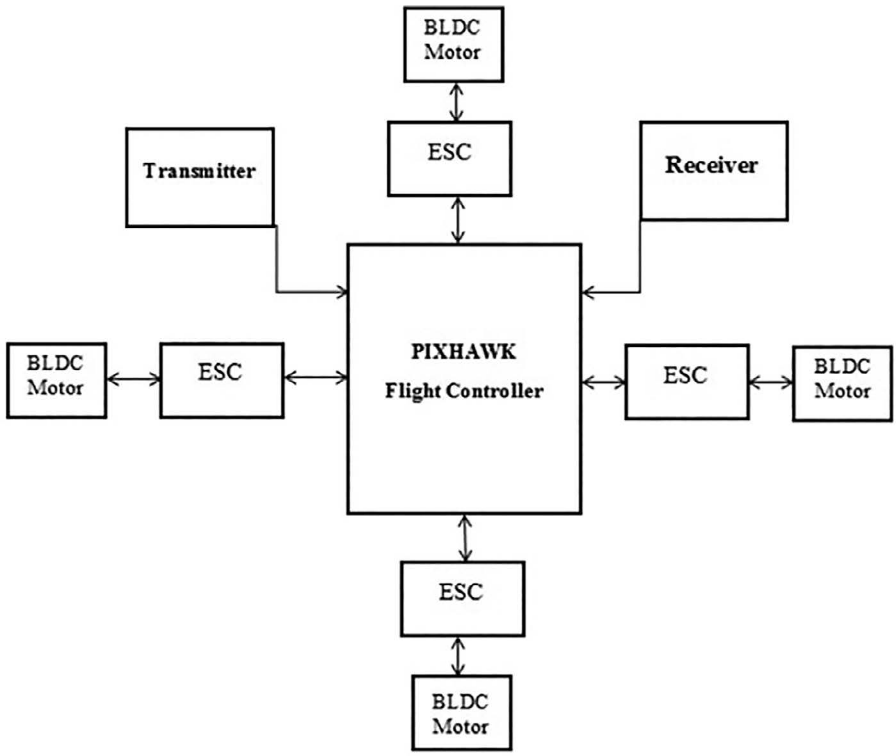

FIGURE 11.6
Block diagram of Quadcopter arrangement.

11.3.1.6 Transmitter and Receiver

The radio control system in the drones is made up of two elements, namely the transmitter and receiver. The transmitter reads the control stick inputs given by the operator or pilot and transmits the commands through a set radio frequency to the radio receiver, which is remotely controlled and fixed inside the drone. Once the receiver obtains the information, it will be passed to the drone's flight controller unit, which controls the stability and performance characteristics of the drone. Generally, a radio control system will have four separate channels for each direction on the sticks along with a few extra ones for any auxiliary switches. Transmitters are of different variants like 6 channel (6CH), 4 channel (4 CH), etc. (Figure 11.5(f)).

11.3.1.7 Flight Controller

A flight controller (FC) is a small circuit board with a range of sensors to perceive the user commands of varying complexity. Further, its function is to optimize and control the RPM of each motor in response to the input commands. A command from the pilot for the multi-rotor system moves forward and is fed into the flight controller that determines how to manipulate the motor's performance for various flight conditions. Simple gyroscopes are used for retaining the orientation and GPS systems are employed for auto-pilot or failsafe purposes. Many modern FCs allow for different flight modes that are selectable

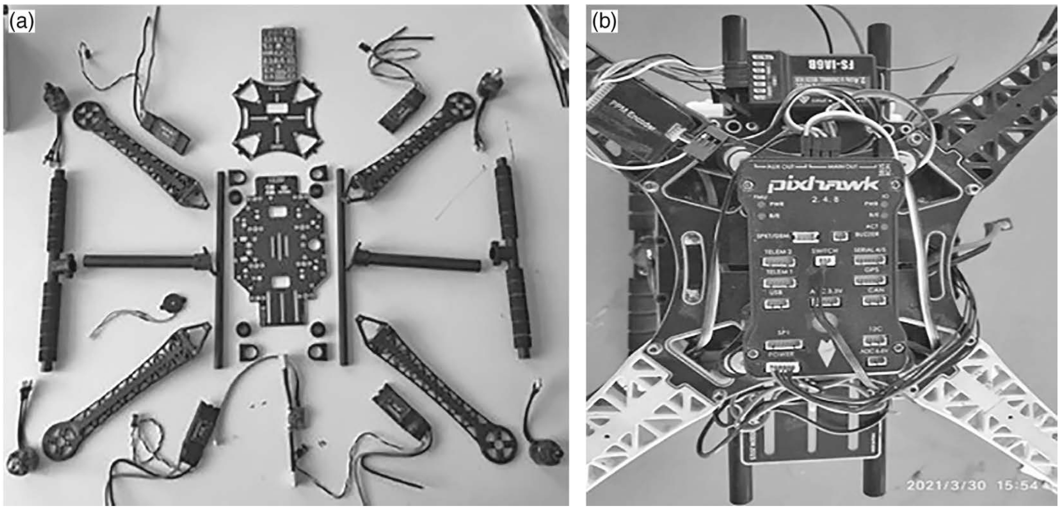

FIGURE 11.7
Quadcopter component views: (a) before assembly, (b) after assembly.

using a transmitter switch. An example of a typical three-position setup is the GPS lock mode, a self-leveling mode, and a manual mode. Different settings can be applied through intelligent electronics and software interface to each profile for achieving required flight characteristics [20]. Quadcopter components view is shown (Figure 11.7) in two phases before assembly and after assembly.

11.3.2 Drone Components with Specification

As discussed in the introduction part of this chapter, there are several types of drones available for agriculture purposes, such as spraying drones, NVDI drones, seeding drones, and surveillance drones. These drones can be made either fully or partially autonomous depending on the field mapping and other requirements in addition to the capital investment constraints to improve productivity. The presented Quadcopter sprayer system is a basic type multirotor model used for agriculture purposes, and high-performance UAVs can be selected for large-scale applications [19]. Table 11.2 provides the specifications of

TABLE 11.2
Quadcopter Components with Specifications

Sl. No.	Component Names	Specifications
1	Four BLDC motors	980 kV
2	Four propellers	10:4.5
3	Electronic speed controller (ESC)	Red brick – 30 A
4	Li-Po battery	4200 mAh
5	Flight control board	Pixhawk 4
6	Transmitter with receiver	Fly Sky 6 CH
7	Frame	Material – carbon fiber
8	Spraying system	Self-developed

different components used in the sprayer drones to offer some basic insights about the proposed design.

11.4 Variable Area Nozzle Sprayer

Agriculture spraying is the primary takeaway regarding the use of drone technology for effective farming and PA. Sprayer and plant-assurance drones are the new devices accessible to farmers which can be utilized to apply pesticides to small land zones and acreages. This sort of drone sprayer could get into the lands that are either excessively wet or, in any case, difficult to reach by the farmers. In addition, the people involved in such activities are removed from the spraying operations, which can greatly help to reduce the toxic effects on humans. The disadvantages involved in the sprayer drones are that they can carry only 8 to 10 liters of liquid with a flight endurance of 20 to 30 minutes. However, these problems have turned into opportunities for small and medium enterprises (SME) in agriculture to deliver sustainable agriculture through sprayer drones. Particularly, if the crops are cultivated adjacent to hilly areas where the complex varying terrains exist, then the shower of pesticides with adequate plant coverage is extremely difficult by manual spraying operations.

The sprayer drones use ultrasonic echoing devices and lasers to adjust their altitude with respect to the changes in topography and geography [21]. Their ability to scan and modulate their distance from the ground enables them to spray the correct amount of the desired liquid evenly in real-time. This results in increased efficiency since the amount of water infiltrating into groundwater is also limited. Drone spraying has also been proved to be a much more effective mechanism by recent studies than any other existing method. The spraying system with a VAN consists of a tank, spray nozzle, actuator, and pump. This auxiliary system can be installed along with the Quadcopter for spraying pesticides or fertilizers on agricultural lands without any additional regulatory requirements.

The raw data composed by the drones would be translated into convenient and coherent information to reduce the cost of spraying by one-third as compared with existing methods. It is well-known that the nozzle is a critical part of any sprayer and it performs the following functions [16]: (i) regulate flow, (ii) atomize the mixture into droplets, and (iii) disperse the spray in a desirable pattern. In any spraying system, Nozzles determine the rate of pesticide distribution at a particular pressure, forward speed, and nozzle spacing [11]. Nozzles are made from different types of materials. The most commonly used materials are brass, plastic, nylon, stainless steel, hardened stainless steel, and ceramics.

11.4.1 Type of Nozzles Used in the Spraying System

Spraying system performance mainly depends on the type of nozzle used [4]. There are four different variations of nozzles used for agriculture applications: (i) flat fan, (ii) hollow cone, (iii) full cone, and (iv) flooding fan. Different nozzles and their droplet size is shown (Figure 11.8)

The performance of the sprayer can be studied or evaluated using various parameters such as spray rate, droplet size, adhesion rate of spray particles, and scattering characteristics. Here, the spray rate helps to determine the area that can be covered per hour and the variation of

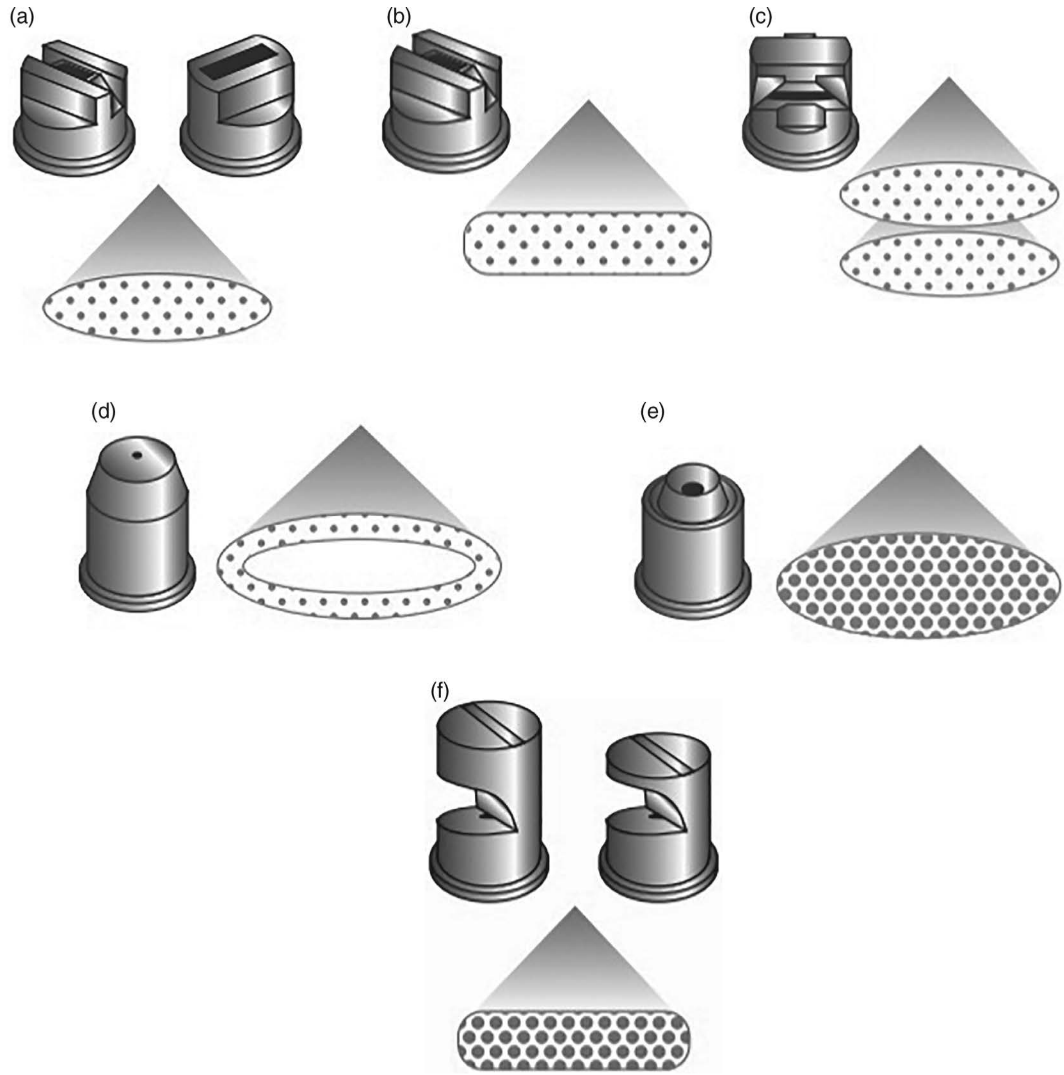

FIGURE 11.8
Different nozzles and their droplet size: (a) flat fan, (b) even flat fan, (c) twin orifice flat fan, (d) hollow cone, (e) full cone, (f) flood fan.

flow pattern as per requirement is fixed according to the droplet size (in microns). Adhesion rate is the strength of the bond between a spraying element and the application surface. Further, the efficiency of the sprayer is measured by the scattering characteristics.

11.4.2 Working Principle of Sprayer System

As the drone is operated over the agricultural lands, it captures the data about the zones of interest in the field, which require additional fertilizers or pesticides using sensors, infrared cameras, multispectral cameras, etc. The data obtained through these systems will be processed by the IPS to enable the IoT sensors to customize the amount of fertilizers or pesticides to be sprayed over the affected areas. The required variation in flow rate can be achieved by a VAN spraying system. It consists of a storage tank, water pump, flow lines, regulator, splitter, BLDC motor, ESC, and nozzles. The water pump is operated by the BLDC motor with ESC instead of DC motors to reduce the weight of the entire system. The VAN has three different flow ranges about 0.16 L/min, 0.32 L/min, and 0.54 L/min, respectively. Then, according to the data obtained from the different sensors, it can be customized by the operator to achieve a balanced distribution of pesticides or fertilizers for different crops based on their growth and requirement. Block diagram with various components of a sprayer system is shown (Figure 11.9).

11.4.3 Performance of VAN System

Spray-drop size is one of the most important factors which affect the drift and it varies from fine to extremely coarse. Spraying with minimal drift and adequate coverage are essential factors that influence herbicide performance. Spray drift is the physical movement of spray particles through the air from the application site to an area where the treatment is not intended, usually resulting in non-target plant injury. Fine-to-medium size droplets are desirable when applying insecticides and fungicides, because they usually provide better coverage. However, the fine droplets are difficult to make deposition on the target, and hence it remains airborne and drifts long distances because of their small, lightweight size. Therefore, coarse to extremely coarse are the preferred droplet size categories, which are idle to be used with VAN [4].

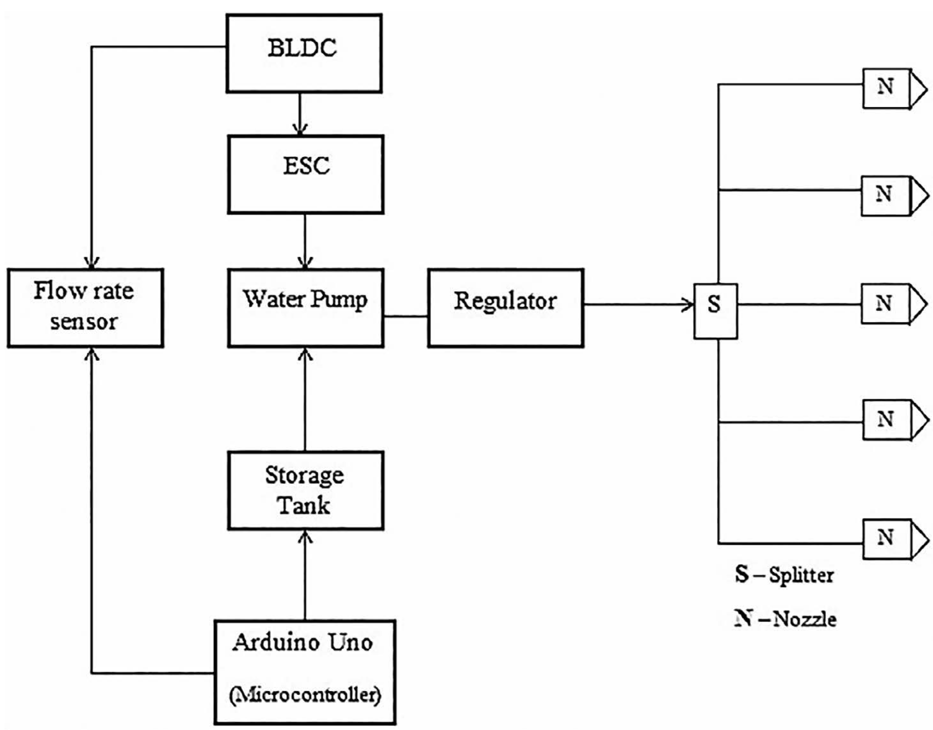

FIGURE 11.9
Block diagram of the sprayer system.

The different factors which would affect the size of a droplet in the nozzle flow are as follows: (i) pressure, (ii) spray pattern type, (iii) spray angle, (iv) nozzle type, (v) specific gravity of the fluid, and (vi) viscosity and surface tension. If the size of the spray droplet is greater than 225 microns, then the drift is less. From the above graph, the droplet size of the full cone and VAN is greater, which will reduce spray particle drift and increase the spraying efficiency (Figure 11.10(a)). Similarly, spray angles have an inverse effect

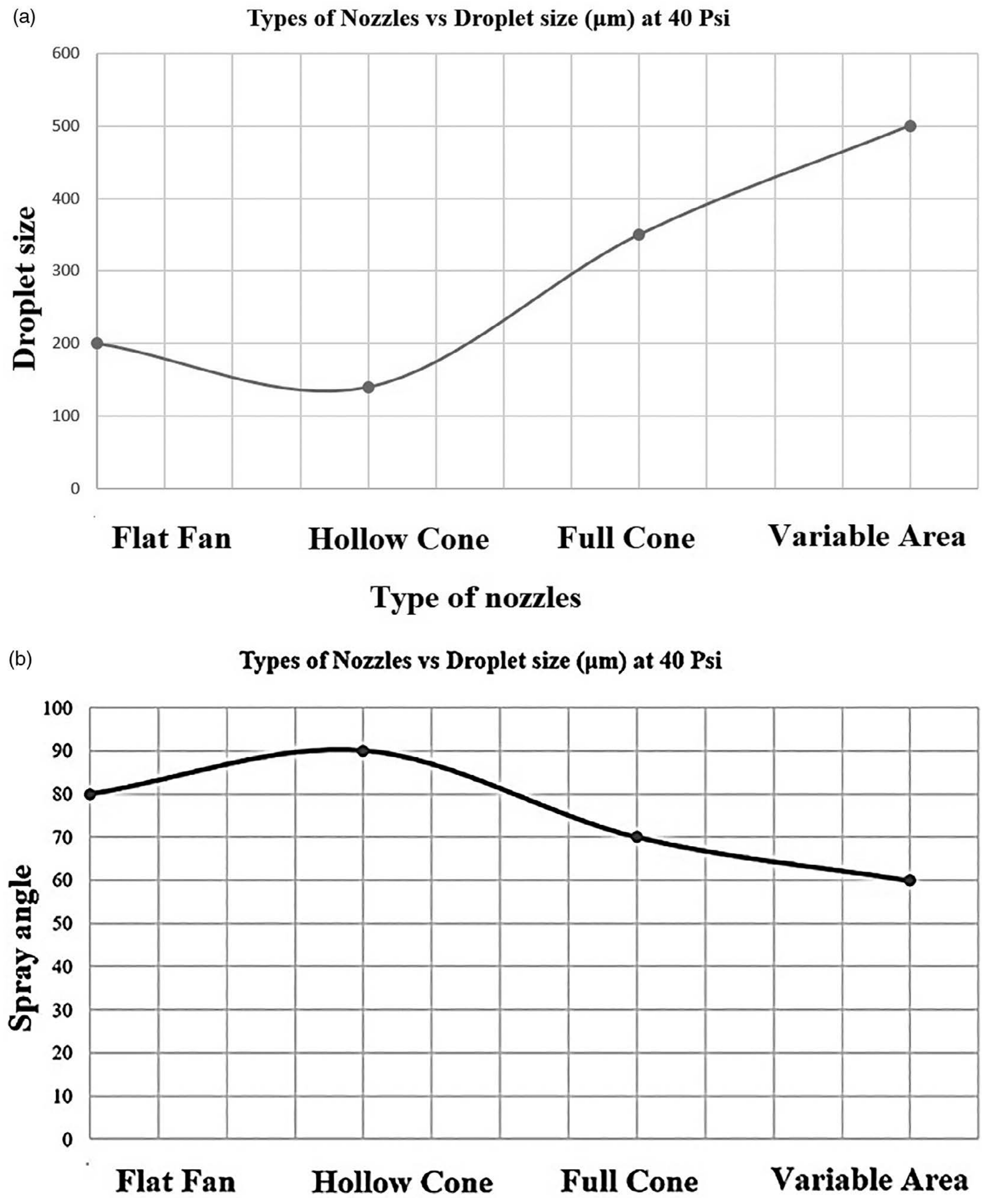

FIGURE 11.10
Performance of VAN Sprayer. (a) Types of nozzles Vs droplet size and (b) spray angle.

on the droplet size. In the spraying drones, an increase in the spray angle reduces the droplet size and vice versa. From the above Figure 11.10(b), when the spray angle for full cone and VAN is minimum, it helps to obtain a large droplet size for better spraying performance.

11.4.4 Challenges for Using VAN in Agriculture

The VAN usage for pesticide spraying to achieve the PA targets has several challenges. Particularly, the height at which the droplets are released, droplet size and the local field wind patterns would affect the process through air dispersion, thus resulting in the wastage of spray chemicals. The crops may appear alike from a specific height but their pesticide requirement could be different and it will affect the efficiency of the system incorporated. Hence, IoT-enabled sensors should be integrated to monitor and communicate the crop health data to the master computer in addition to the live weather statistics. Moreover, to customize the area ratio of the VAN according to the crop requirements, skilled operators are needed. Hence, more autonomous operations are needed with AI-enabled modules to reduce the manpower heads and more profit per operational cycle.

11.5 Smart Farming through Internet of Things

IoT is a promising innovation that provides an efficient and dependable solution toward the modernization of works related to farming. IoT-based solutions are being developed to maintain and monitor agricultural lands with minimal human involvement [15]. IoT sensors are capable of providing information about agriculture fields in alignment with AI, which are essential for farmers to plan their activities to increase production [16]. Five inspirational strategies of IoT that enable PA in various aspects are summarized below.

1. *Data collected by smart agriculture sensors*: The data collected by smart IoT sensors (weather conditions, soil quality, crop growth progress, etc.) can be used to track the state of the Agribusiness in terms of staff performance and equipment efficiency, etc.
2. *Better control over the internal processes*: The ability to forecast the output of production based on the crop health data allows the farmers to plan for better product distribution. If a farmer knows the exact amount of crops going to be harvested, then it is easy to deal with different stakeholders to promote the product with a minimum guaranteed price.
3. *Cost management and waste reduction*: The UAV applications in agriculture have been increasing day by day because of the autonomy delivered by IoT and fifth Generation (5G) technologies [22]. Hence, the IPS could easily identify anomalies in crop growth or livestock health to mitigate the risks of losing their yield.
4. *Increased business efficiency through process automation*: By using smart IoT-enabled devices, farmers can automate multiple PA processes across the production cycle (e.g., irrigation, fertilizing, or pest control and drone pollination) [23].
5. *Enhanced product quality and volumes*: Better control over the production process is possible through PA and higher standards of crop quality, and growth capacity can also be maintained through automation.

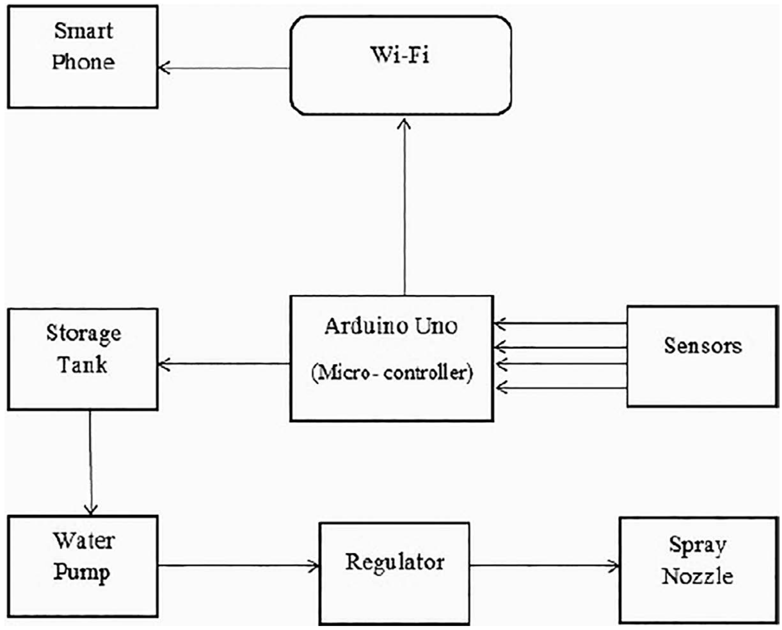

FIGURE 11.11
Block diagram of IoT-based VAN sprayer.

An IoT-based VAN sprayer consists of several varieties of sensors to actuate the microcontrollers based on the field of application. Basically, the medium-weight UAV segment (25 kg $\leq$ W $\leq$ 150 kg) is widely used for agricultural activities that works based on the vigor maps developed by NDVI data. The spatial and temporal characteristics of soil data and the corresponding fertilizer usage are the significant information obtained through the sensor networks. The primary components of IoT-based VAN sprayers are illustrated in the block diagram presented in Figure 11.11.

11.5.1 Arduino Board

Arduino is an open-source programmable circuit board. This board contains a microcontroller that can be programmed to sense and control the objects in the physical world. By responding to sensors and inputs, the Arduino can interact with a large array of outputs such as LEDs, motors, and displays [7]. The inputs for the microcontroller are received from different sensors like temperature, moisture sensors, multispectral camera images, etc.

11.5.2 Sensors

There are a variety of sensors used to provide the necessary information/input to the microcontrollers. They are: (i) location-based Sensors, (ii) electrochemical sensors, (iii) temperature or humidity sensor, (iv) optical sensor, and (v) multispectral sensors. Here, location-based sensors are used for locating the different areas and spots in the agriculture fields [8, 24]. Normally, GPS receivers are used for finding the longitude and latitude of a particular point on the earth's surface with the help of a GPS satellite network. These smart location sensors play an important role in PA by pointing out the location in the fields for monitoring the growing crops toward effective watering, fertilization, and treatment of weeds.

Electrochemical sensors are used to extract a specific composition from a particular biological sample such as plants, soil, etc. [17]. In smart agriculture, these sensors are generally used to detect the pH levels and soil nutrient levels where the sensor electrodes detect specific ions within a soil. Moreover, temperature and humidity are the most important weather factors which directly affect the health and growth of all types of crops. Correct measurement of these environmental factors would be helping the farmers to adjust the quantity of fertilizer and water [21]. Temperature and humidity sensors are available in wireless-enabled and battery-operated types according to the level of autonomy required.

Optical sensors work on the principle of converting light rays into an electrical signal [24]. Several types of optical sensors (such as RGB camera, converted near-infrared camera, six-band multispectral camera, high spectral resolution spectrometer) have been used in UAVs for PA-related applications [25]. Similarly, Multi-spectral sensors are extremely appropriate for UAV-based agricultural analytics. These sensors capture images with exceptional spatial resolution and also possess the capability to determine reflectance in near-infrared [13]. The collection of multispectral data is an absolute necessity for performing analysis of crop health. The multiple bands of light enable the researchers to conduct precision analytic studies and offer precise insights on plant vigor, canopy cover, leaf, and various other parts. The absence of such multispectral data would make the early detection of plant diseases, weeds, pests, and calculation of vegetative biomass almost impossible.

11.5.3 Advantages of IoT-Enabled Spraying System

a. *Easy Control*: Intelligent flight with autopilot according to real-time environmental data [26].
b. *Adaptability*: It can be operated over mountains, hilly terrains, and highly wetted regions.
c. *Foldable*: Foldable frames, easy to transport and versatile to handle by the farmers.
d. *Maintenance*: Modularized design, easy to carry out disassembly and inspection.
e. *Cost Control*: Optimal usage of fertilizers/pesticides and reduced labor costs.
f. *Saves Water*: Less water requirement for spraying activities.
g. *Productivity*: Increase in production/yield through detailed coverage of spraying.

11.6 Agriculture Drone Usage Statistics for Smart Farming

The IoT-based agriculture policies play a crucial role in the growth of smart PA activities across the globe. A substantial revision in the drone usage regulations for the PA activities is the need of the hour in many countries to achieve the goals in food production. Specifically, Internet-of-Ag-Things (IoAT) is an emerging project in countries like the United States of America (USA) with state-of-the-art sensing technologies. However, the investment toward expensive instrumentation is a key deciding factor for the SMEs to move forward with PA with drone applications. Hence, the trade-off studies and advantages of potential applications should be well understood before deploying drones for crop monitoring and control activities. In countries like Brazil, South Africa, and Australia, during 2014 itself several flight trials were conducted with UAVs to ascertain the plant health before and after the application of organic nutrition. As the agriculture business is a labor-intensive industry, the outdated legislative systems present in many countries are the real barrier to deploying spraying and monitoring drones on a large scale. The current usage statistics of agriculture spraying drones in different countries are discussed below, with some key insights to achieve the best results.

11.6.1 Smart Farming in Asian Countries

China's agriculture drone revolution in the Agriculture Ecosystem makes up the largest supply of civilian drones in the world. Globally, it was estimated that approximately 70% of all civilian drones were sold by Chinese manufacturers in the year 2017. Among the commercial drones operated in China, it is estimated that about 13% to 17% of drones are deployed for agricultural purposes [27]. Narrow Band-IoT (NB-IoT) enabled with Low Power Wide Area (LPWA) technology has transformed the PA culture of China through wide coverage and a large number of IoT devices. Meanwhile, in India, 40 drone start-ups are engaged in enhancing the technological standards and reducing the prices of agriculture drones via the "Make in India" initiative to make them affordable and prevalent among educated and uneducated farmers. Farmers of Dahanu-Palghar tribal villages of Maharashtra state have learned to use drones for organic farming, fish farming, crop rotation, bio-control, hydroponics, and biowaste management, on their orchards and farms [9].

Israel has a strong history of high-tech agriculture innovations and it invented the concept of drip irrigation during the 1970s [28]. It is a hot spot for agriculture technology start-ups and PA research and the current trends are summarized as follows:

- Overall, about 30% of farmers use Global Navigation Satellite System (GNSS) auto steer and 75%–85% of large companies use the sprayer drone technology.
- About 10% of existing sprayers and most new sprayers use GNSS boom control.
- About 50% of farmers use satellite images and drone imagery is used at more than 30 farms.
- Variable-rate N_2 fertilizer application is used by 5% of farmers. A few farmers use site-specific weed management and precision-guided cultivation.

Drones now serve to fulfill the objectives of PA in Israel by a variety of methods: monitoring and pesticide use, soil surveys, monitoring irrigation problems, identifying lack of uniformity in the field, as well as fruit picking. But overall adoption of PA technology, except for soil moisture sensors for irrigation management, seems similar to that of Europe [28].

11.6.2 Smart Farming in European Countries

Most of the farmers and SMEs in Germany prefer to use agriculture drones for effective farming if the area of vegetation exceeds 100 hectares. Interestingly, one-tenth of German farmers use drones for their agricultural operations, in which 4% fly their own drones and 6% depend on external drone service providers (DSPs). Similarly, Switzerland operates at the global forefront in the development of drone technologies. It applies in particular to the fields of sensor technology, drone control systems, and data processing, in which the country is setting new standards. Even though the use of drones in Swiss farming is currently still limited, the technology holds significant potential for the country's diverse and highly structured agriculture [29].

11.7 Current Status of Regulations and Provisions for Agriculture Drones

Rules and regulations for the use of drones vary across the countries and four major elements are considered in this regard. They are (i) drone registration, (ii) airspace, (iii) insurance, and (iv) licensed operator (pilot). The requirements of these four elements vary based on the drone mass, altitude, application, and level of pilot license. Considering the variation in these four components of regulations across the countries, six broad approaches to national commercial drone regulations become apparent as follows: [1]

a. *Outright ban:* Countries do not allow drones at all for commercial use without license.
b. *Effective ban:* Countries should have a formal process for commercial drone licensing, but licenses do not appear to have been approved before they comply with all requirements.
c. *Requirement for constant Visual Line of Sight (VLOS):* A drone must be operated within the pilot's VLOS, thus limiting potential range.
d. *Experimental uses of beyond visual line of sight (BVLOS):* With certain restrictions and pilot ratings, certain exceptions to the constant VLOS requirement are possible.
e. *Permissive:* Countries have enacted relatively unrestricted legislation in commercial drone use. These countries have a body of regulations that may give operational guidelines or require licensing, registration, and insurance upon following proper straightforward procedures.
f. *Wait-and-see:* Countries have enacted little, if any, drone-related legislation and monitor the outcomes of other countries' regulations.

Hence, it is perceived that certain unique approaches and provisions are needed from different stakeholders around the globe to accelerate the usage of agriculture drones to ensure smart PA at all levels.

11.8 Conclusions

Quadcopters with IoT-enabled systems would massively transform the farmer's current way of doing agricultural activities in terms of crop health monitoring, soil moisture data, fertilizer usage, crop damage assessment, etc. It is inferred that the payload capacity of Agriculture drones is continually increasing through state-of-the-art propulsive system designs such as with Hexacopter, Octo-rotor designs to expand their usage. Multi-rotor configuration also provides more space for the higher capacity nozzle sprayer systems, which will be very helpful for covering large farmlands in a limited time period as compared with the Quadcopter designs. However, the selection of appropriate dimensions of the drone is determined based on the budget, regulatory provisions, and wireless communication modes available in the region.

Farmers can utilize the VAN spraying system effectively to shower the pesticides for various crops at different stages of their growth. As the splashing can be done from variable heights, ecological contamination is diminished by achieving PA farming with minimum wastage. The objective of such an IoT-enabled spraying system could also reduce the exposure of profoundly harmful pesticides to the people around. One can adapt the hovering mode to customize the droplet size of the pesticides and spraying angle to cover large regions in a short time, according to the crop monitoring data. It is more significant for the farmers as well as consumers to ensure the optimal wellbeing of the yields to gain more ideal opportunities for the promotion of their quality products across the nations.

11.8.1 Future Scope for Drones in Agriculture

Many autonomous drones are still in the testing and development phase that are to be deployed for agriculture activities in the near future. One of the most publicized uses is the pollinating drone technology. Researchers in the Netherlands and Japan are developing small drones that are capable of pollinating plants without causing any damage to them. The next step is to create autonomous pollinating drones that will work and monitor crop health without any constant instructions from the operators [25].

Another remarkable development in drone technology involves machine learning techniques with advanced IPS. Improved AI in drones is important to be able to make them more useful to small farmers in developing nations. Current drone technologies are more effective for monitoring the well-known crops which are planted in the large field patterns in different continents. Drone monitoring programs will have a hard time while recognizing the areas with increased crop diversity, less well-known products, and grains that look similar throughout their growth stages and so are less effective in monitoring the crop growth and health. More intensive research and studies are needed to train AI systems with large datasets to recognize the less common crops and more diverse planting patterns [27].

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12

Standards and Protocols for Agro-IoT

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DOI: 10.1201/9781003185413-12

12.1 Introduction to Standards and Protocols in Agro-IoT

In the agriculture industry the impact of the Internet of Things (IoT) plays a vital role in smartness in all spheres like surveillance, automation, and precision farming even without major human intervention. The realization of sensory architecture is implicitly defined by its inherent nature. The sensor-acquired data has to be transferred to different nodes connected to the network to reach the recipient side irrespective of the distance. This leads to a focus on standardization. Standard is defined as the specifications or rules to be followed to enable the effectiveness of communication systems that are deployed for diverse applications. The method of transmitting information in a huge network and interacting among the devices, even though it depends on different vendors and different communication technology, is possible with the help of a defined term "standard." It leads to enhanced characteristic natures like interoperability, security, accessibility, and scalability [1]. To perform the designed task the set of protocols are essential along with its standards for having control over information and signal level between the sender and receiver.

There are different aspects of technologies looking for minimal human intervention by maintaining appropriate standards. One such field developed for maintaining and monitoring the agriculture sector is called Agro–IoT [2]. It is purely based on different sensors and its configuration applied for smart farming [3]. The structure of protocols and standards leads to a systematic process of Agro-IoT network that ensures the attainment of the desired output. Figure 12.1 depicts the flow of standards and protocols and their necessity. The network setting and its process flow are initialized by the defined standard. The sustainability of the network depends on the subset functionalities like potentially executed tasks and communication flow involved in the network. The specific network message formatting is to be set between the communication devices at each point to validate the transmission flow for measuring the system accuracy.

12.2 Agro-IoT Sensor Network

The revolution of machine-to-machine communication plays a central role for the different kinds of features in application scenarios such as field management, crop monitoring, soil monitoring, wild animals attack monitoring, etc. Figure 12.2 illustrates that the primary objective of the sensor is to collect all the physical information of the desired application from the environment and convert it into digitized signal for further transmission process.

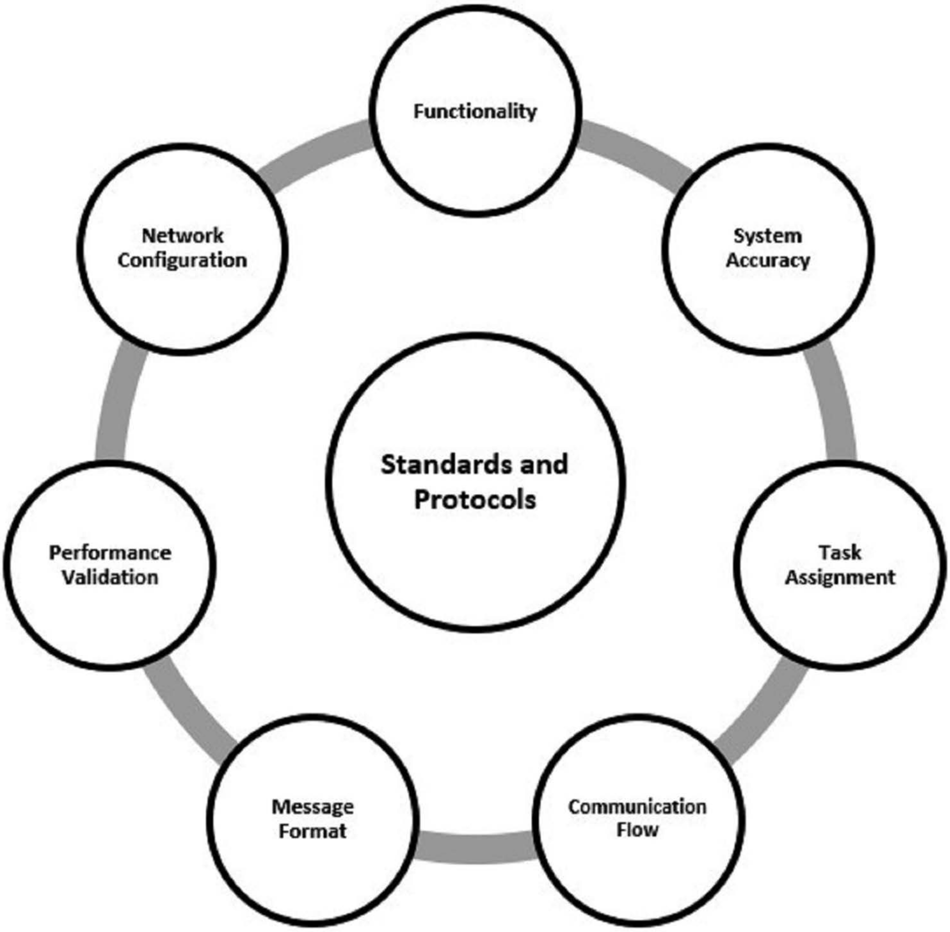

FIGURE 12.1
Importance of standards and protocols.

The digitized output signal will be strengthened with the help of a signal conditioning unit which becomes easier to detect the output. There are different types of sensors used for precision farming such as temperature sensor, humidity sensor, soil sensor, leaf wetness sensor, rainfall sensor, wind direction, and atmospheric pressure sensor.

12.3 International Standards Support for Agro-IoT Communication

The advancement of communication is by many professional societies embodied together to set a standard for communication through various protocol structures in the IoT network, as shown in Figure 12.3 and detailed in Table 12.1. The framework and adoption of various characteristics for carrying out the transmission and sharing the information between any devices is defined by various standards such as IEEE (Institute of Electrical and Electronics Engineers), IETE (Institution of Electronics and Telecommunication Engineers),

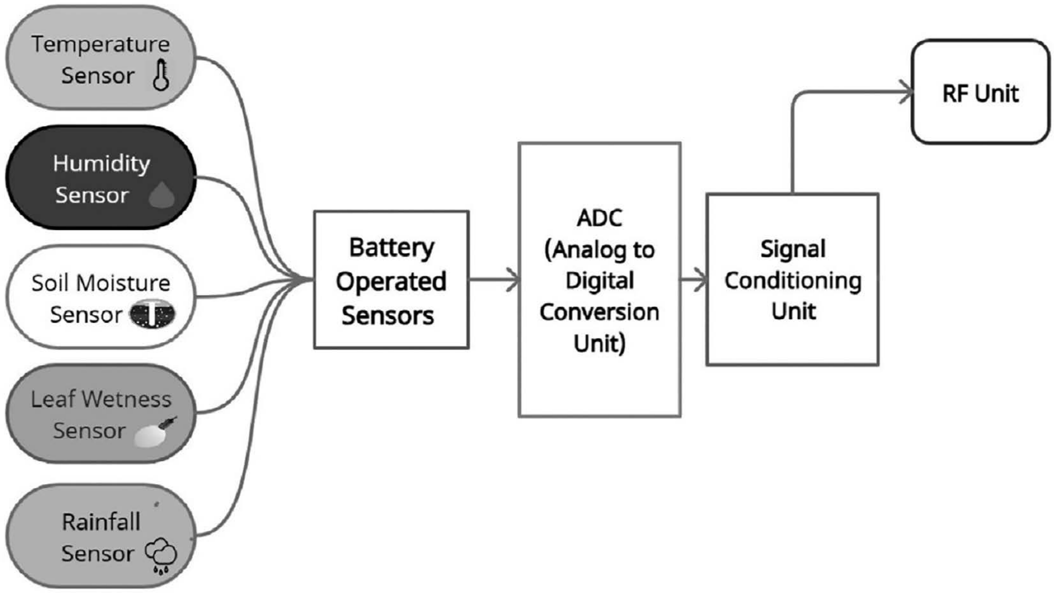

FIGURE 12.2
Block diagram of sensor module working.

IETF (Internet Engineering Task Force) and ISO (International Organization for Standardization). The regulatory parameters which follow the defined standards are Bandwidth allocation, Network range, Affordability, Device power consumption, Network latency, and Security. There are two categories in utilizing the spectrum resources one is licensed and the other is unlicensed. If the radio network is opting for the licensed spectrum, then there is no constraint for security provision and uninterrupted data transmission is possible even though there is a huge amount of data. It is applicable for Wide Area Network communication, whereas the unlicensed one is a bit controversial and useful for the Local Area Networks. The ISM band is free for **I**ndustrial, **S**cientific, and **M**edical applications, so it is useful for IoT-based Agricultural purposes.

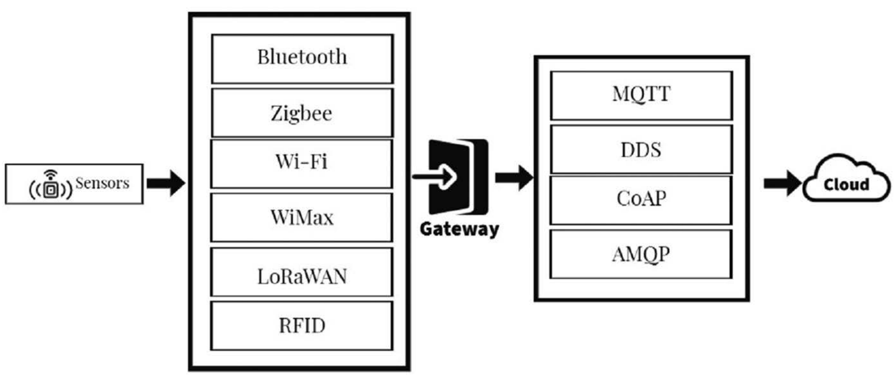

FIGURE 12.3
Overview of standards and protocols in IoT-based communication network.

12.4 Communication Technology for Agro-IoT

12.4.1 Bluetooth

There are many Agro-IoT sensors like Soil moisture sensors and RGB sensors to make the correct decision with the sensed data irrespective of the situation. It is possible with the help of Bluetooth communication module IEEE 802.15.1 for short-distance communication with the unlicensed ISM frequency band of 2.4 GHz [4]. To establish the connection among the nodes the inquiry paging procedure is being done. The communication range is about 10 m. The asymmetric data is being transferred with the data rate of 721 Kbps through the total bandwidth of 1 MB/s [5]. The transmitting method between transmitting end to receiving end followed in Bluetooth is Frequency hopping [6]. It is supportive of eight channels and provides the functional component of interoperability. For the fine-tuning of higher data rate, advanced security and low energy consumption, various standards have been developed such as 1.0,1.0 a, 1.0 b, 1.0 b + ce, 1.1, 1.2, 2.0 + edr, 2.1, 3.0 + hs, 4.0, 5. The autonomous ubiquitous communication using Bluetooth-enabled sensor network deployed for intelligent farming [7] and it is shown in Figure 12.4

12.4.2 Zigbee

For the necessity of low power consumption, the IEEE 802.15.4 protocol named Zigbee comes into the picture that supports the distance of 10 to 20 m in a communication network [8]. The Zigbee operates at three different frequencies such as 868 MHz, 902–928 MHz, and

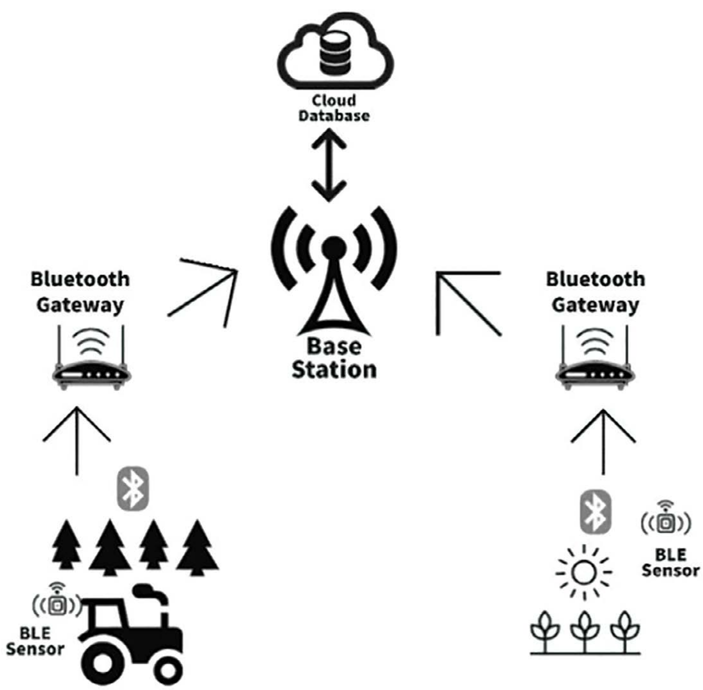

FIGURE 12.4
Bluetooth-enabled sensor communication.

FIGURE 12.5
Zigbee-enabled sensor communication.

2.45 GHz. The periodic data transmission takes place at the low data rate range of 40 kbps to 250 kbps. As shown in Figure 12.5, there are three different types of Zigbee devices: router, coordinator, and end device, which helps for precision farming. The Zigbee routers act as intermediate nodes which permit the data to pass over from one node to the other node [9]. The coordinator node handles the data storing and its transmission operation within the network. The end device has limited functions on the coordinator and router nodes which directly reduces the power consumption. All three ensure the reliable operation of the network functionality by concentrating on the power consumption of each node specifically. The sensor used here is the Soil sensor in which the air, water, salt, and soil minerals (potassium, magnesium, iron, calcium, sulfur) are the major constituents of soil. The volume of water content present in the soil is measured by a soil moisture sensor. Based on varying factors such as temperature, soil type, and geographical area, the measured soil moisture content will vary. It is useful for soil health monitoring, plant ecology, and plant disease forecasting and for increasing the crop quality in different plant growth stages.

12.4.3 Wi-Fi

In addition to these technologies, IEEE 802.11 Wi-Fi standard technology operates at 2.4 and 5 GHz frequency bands with the data rate of 1 Mbps to 6.75 Gbps. It helps to distribute the access points load to avoid the interruptions between the individually connected devices supported for 20–100 meters. Wi-Fi is one of the best supporting wireless protocols for Agro-IoT. Real-time weather forecast data update to the farmers is possible with the help of various wireless sensor nodes communicating through Wi-Fi will reach the end-user using the intermediate gateways as shown in Figure 12.6. There are various Wi-Fi standards such as 802.11 a, b, g, n, ac used for diverse applications. The varying characteristics of different standards are data rate, signal interference, cost, etc. The selection is made based on the data transfer requirements. The sensor used are: (i) Temperature sensor in which the periodical temperature variance is observed. It is helpful for remote ambient condition monitoring for harvesting. (ii) Measurement of moisture content and air temperature all these sensors will be helpful for the remote ambient condition monitoring for harvesting. The applications like drip irrigation are in need of accurate measurement of moisture content, which supports the growth of plants and indoor vegetation.

Wi-Fi HaLow (802.11ah) is the unlicensed band focused on the extension of network coverage by using relays and optimization in power consumption using the predefined busy/idle period. The contention is also getting reduced via station grouping. The Wi-Fi wavebands highly facilitate the interoperability feature.

12.4.4 WiMAX

IEEE 802.16 is the standard named WiMAX (Worldwide Interoperability for Microwave Access), which helps for long-distance communication up to 50 km [10]. Orthogonal

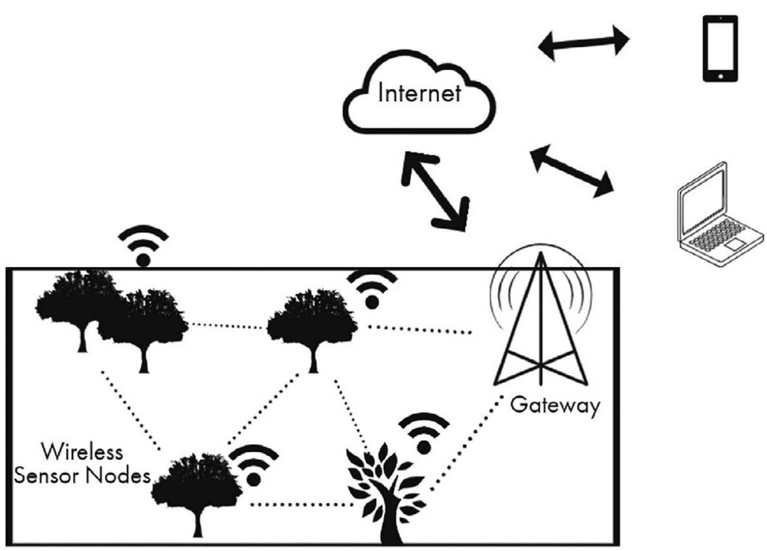

FIGURE 12.6
Wi-Fi-enabled sensor communication.

Frequency Division Multiplexing (OFDM) is the modulation concept involved in WiMAX, which enables multicarrier parallel transmission at a high data rate with better connectivity to ensure efficiency. The range of data rates from 1.5 Mbps to 1 Gbps is scalable under varying channel bandwidth. For the frequency of 10 MHz the data rate will be 25 Mbps in downlink and 6.7 Mbps in uplink using Time Division Duplexing (TDD) scheme. It also supports a very high data rate of 74 Mbps when operating at 20 MHz. This kind of wireless broadband will be a better alternative to achieve long-distance communication; thus it is a better suitable technology for crop area monitoring, as detailed in Figure 12.7.

12.4.5 LoRaWAN

For better interoperability features the Long-Range Wide Area Network (LoRaWAN R1.0) is used, which helps to achieve the minimum energy consumption for the multi-layer architecture of IoT scenarios [11]. It is a technology that supports a long-distance communication range of 10 to 20 km. LoRaWAN has a data rate from 0.3 kb/s to 50 kb/s with an operating frequency of 868 MHz and 900 MHz [12–14]. The sustained battery limit is up to 10 years which is very adaptable for IoT enabling networks. The end-to-end security provision using the AES algorithm is the best feature of LoRaWAN. The information of the leaf wetness sensor is being communicated among the nodes and the collected information reaches the receiver end through gateway collector communication using LoRAWAN as given in Figure 12.8. The sensors used are: (i) to measure the minute water

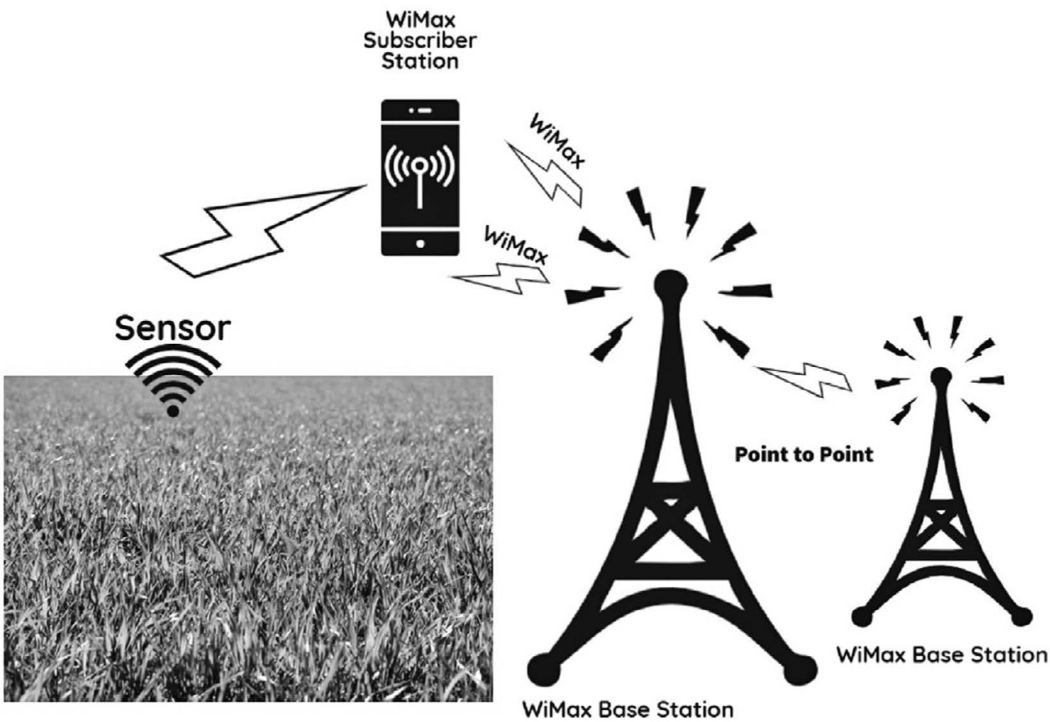

FIGURE 12.7
WiMAX-enabled sensor communication.

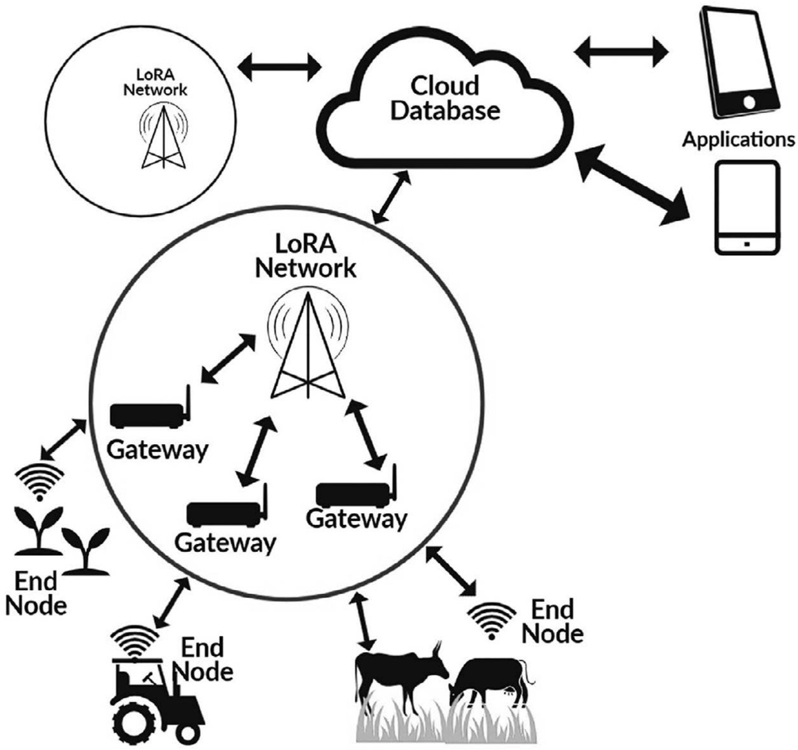

FIGURE 12.8
LoRaWAN enabled sensor communication.

TABLE 12.1

Agro-IoT Applications for Different Communication Standards

Standard	Application
Bluetooth (IEEE 802.15.1)	• Water pump and gate valve controllers • Bluetooth-enabled boundary tracking like intruder alert system in agri-land
Zigbee (IEEE 802.15.4)	• Field maintenance sensor communication such as the soil moisture content, nutrient level, and detection of viruses in the plants
Wi-Fi (IEEE 802.11)	• Monitor the environmental conditions • Drone operations – seed, fertilizer, water, and pesticides
LoRaWAN (LoRaWAN R1.0)	• For capturing and storing water • Irrigation scheduling • Organic farming • Increasing crop yield
WiMAX (IEEE 802.16)	• Remote diagnosis of the farming system-productivity tracking • Fault diagnosis in agri-machines and fields
RFID (ISO18000-6C)	• Greenhouse regulation – water consumption, fruits and vegetables nutrient level identification, and harvest time detection • Animal detection using unique ID

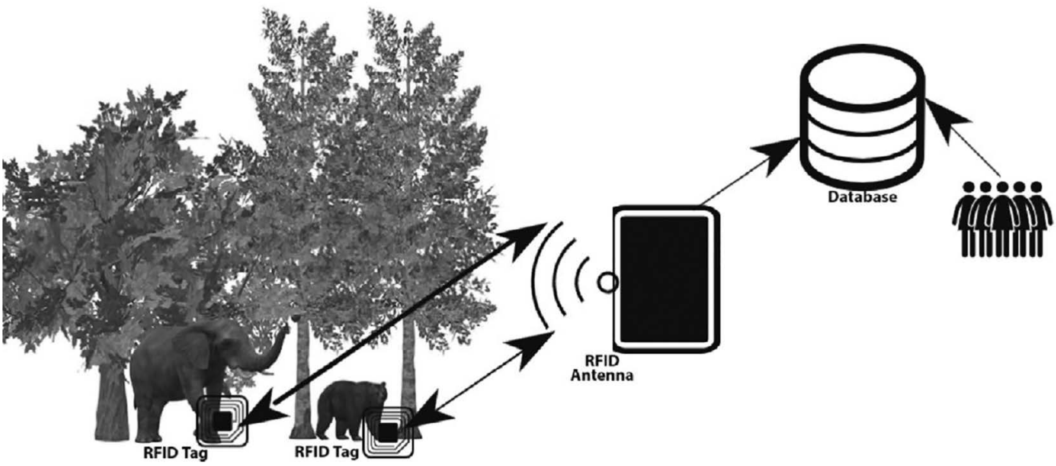

FIGURE 12.9
RFID-enabled sensor communication.

drop content to quantify the water level and predict when to spray the crop; (ii) the water conservation and preservation for smart irrigation systems and weather condition monitoring is required to determine the excessive rain condition which causes floods carried by the rain sensors.

12.4.6 RFID

Object detection will be quite efficient in the case of Radio Frequency Identification (RFID) (ISO18000-6C) usage with unique IDs to identify and track the object or event [15, 16]. It supports calibration if the sensed data is inaccurate. For example, the sensors that have been buried into the soil have to measure the designed parameters like temperature, humidity to maintain the quality of the crop for production and animal tracking [17]. The sensed information will be forwarded to the end-user database with the help of an RFID tag and signal transceiver, as shown in Figure 12.9. If anything, what the user needs then that will be directed to RFID as a command to the sensor. It helps the farmers abundantly with various factors such as time and money for better crop yield.

12.5 Performance-Measuring Factors

12.5.1 Packet Loss Percentage

Due to poor network connection, there may be a loss in transmission of information; it is measured by the following formula:

$$LP\% = \left\{1 - \left(\frac{TRP}{TTP}\right)100\right\}\%$$

where TPR is total received packet and TTR is total transmitted packet.

Packet loss will generally reduce the speed or throughput of the given packet.

12.5.2 Node Connectivity

Node connectivity is used to transmit and receive the data between two nodes. It quantifies the direct connectivity between sensor nodes on the basis of used communication standards like Bluetooth and Zigbee.

12.5.3 Transmission Throughput

Throughput is a performance measure to indicate the successful transmission from the source node to the destination node.

12.5.4 Scalability

Scalability refers to the number of nodes involved in the transmission range of the network for communication with respect to distance. It is based on communication standards involved in the network. It is a capability of optimal working even if the traffic increases; thus poor scalability leads to poor network performance [18].

12.5.5 Interoperability

The network integration challenges are overcome with the help of the characteristic nature of interoperability. It helps to enhance the Quality of Service (QoS) with respect to the network configuration.

The comparison of various supportive communication technologies (Bluetooth, Zigbee, Wi-Fi, WiMAX, LoRaWAN, RFID) for Agro-IoT is discussed in Table 12.2.

12.6 Comprehensive Overview of Communication Protocols

More consideration is given to the protocols listed in Table 12.3 thus helps to select it for the intended applications of Agro-IoT.

12.6.1 MQTT

The IoT network is in need of bandwidth optimization that can be achieved by using MQTT, a message transferring protocol. It is expanded as Message Queuing Telemetry Transport protocol. It follows the publish/subscribe [19] conceptual scheme as illustrated in Figure 12.10. The node which has the information starts publishing the topic – message to the intermediate nodes called brokers. If any node is interested to get that information it will subscribe through the broker. Then that subscribed node will receive the message from the broker node. MQTT brokers will receive all the messages from the MQTT clients, then filter and forward them to the interested MQTT clients, which will be considered as the appropriate receiver. It supports bidirectional communication to broadcast the message from one point to another point. The control information such as header, trailer, and

TABLE 12.2

Comparison of Various Supportive Communication Technologies for Agro-IoT

Protocol	Loss of Packets (%)	Node Connectivity	Transmission Throughput	Scalability	Inter-operability
Bluetooth	2%	Star topology and mesh topology	0.7–2.1 Mbps	Eight nodes can be involved in the network basis to carry out the Bluetooth communication. The network covers 10-meter distance	Yes
Zigbee	7.80%	Mesh topology	10–115.2 kbps	Due to the mesh topology the network can be extended to several hundreds of nodes for communications with a distance of 10–100 meters	Yes
Wi-Fi	5%	Mesh topology	>100 kbps	Using the mesh topology 32 nodes can be connected with a 100-meter distance in standard Wi-Fi. With the help of wireless extender, it is possible for several thousand nodes to be in connection	Yes
WiMAX	4.3%	Mesh topology	10–15.84 Mbps	Since the nodes are mobile in nature and multi-hop relays ensure the transmission of about 50 km for broadband complementary network	Supports WiMAX equipment. Does not support other vendors' equipment
LoRaWAN	2–25%	Star topology	7.80 bytes per second	High density of 120 nodes can be in a range to carry out the communication of 10–20 km	Yes
RFID	5–10 %	Star topology and point-to-point topology	180 bytes to 800 bytes per second	Depends on the implementation of Agro-IoT platform	Yes

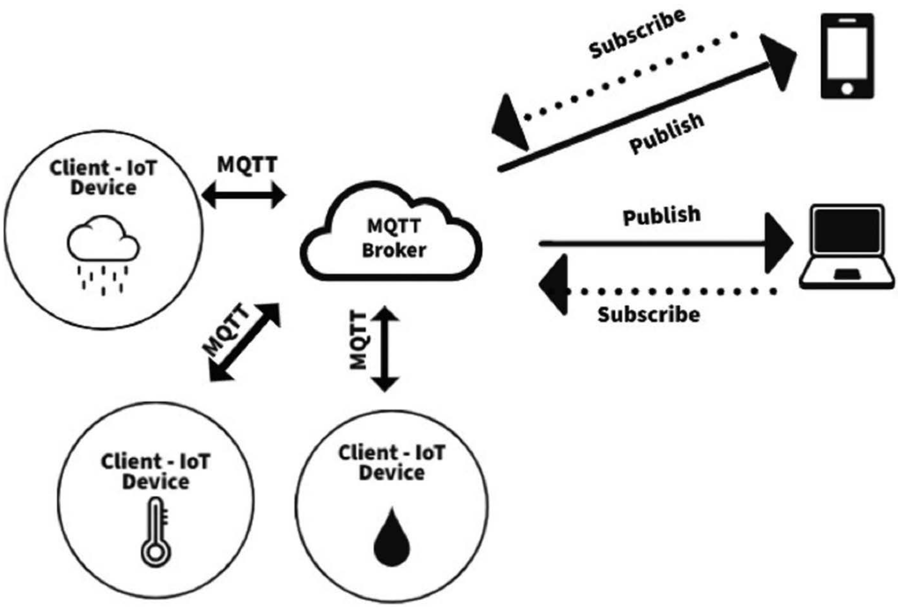

FIGURE 12.10
Architecture of the publish/subscribe mechanism and transportation of messages between devices in MQTT.

other information needed to make the actual message reach the destination is considered to be less; thus MQTT has less overhead. Whenever there is a necessity of control over the system then this protocol paves the way for it.

There are two use cases in IoT that are reliable and unreliable in nature. Reliability is the major factor that is considered to be essential in Agro-IoT networks if the nodes are connected in a wireless manner. There is a chance for the node to be affected by various environmental factors. In that case the network can be recovered if the node has the feature of reliability. MQTT broker serves as an MQTT server, holds the information, and is not dispatched when the receiving MQTT clients are not connected properly, called an unreliable network. After the acknowledgement is received from the broker only the topics (e.g., temperature sensor in the agri-field) will be forwarded to the intended receiver. The essential requirements and new features incorporated in MQTT are categorized into different types: MQTT 3.1.1 and MQTT 5. This protocol is applicable to the temperature, humidity, and soil monitoring sensors. In order to improve the network quality, the QoS is a parameter that has to be maintained in an optimal way. The QoS includes bandwidth, delay, data rate etc. There are three different QoS messages. If the QoS message carries the value of 0 then it indicates at most once; if the value is 1 then the condition is at least once; if it is 2 then it is exactly once. It is considered to be the security-enabled protocol that helps encrypt the actual message using TLS and the authentication process is done by executing a mechanism called OAuth.

12.6.2 DDS

For exchanging the data in real time, the Data Distribution Service (DDS) is required. It is one of the standardized protocols in which peer-to-peer basis communication is being carried out [20]. The discovery mechanism involved here is that the peer will discover and

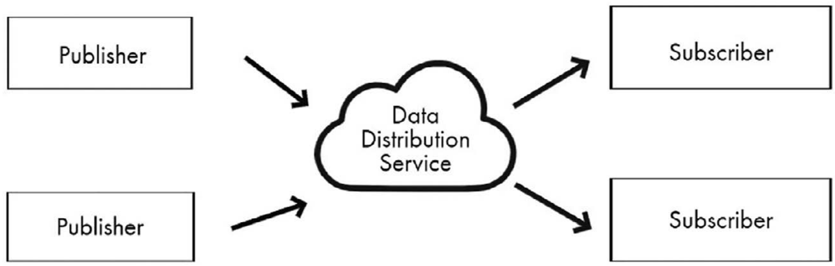

FIGURE 12.11
Interoperable DDS mechanism for machine-to-machine communication.

identify the matching peer with its flexible QoS configuration and topic name. Basically, it applies to a data-centric network. Similar to the MQTT protocol DDS also follows the publish/subscribe mechanism for transferring messages. The discovery mechanism is dynamic and the endpoints are automatically discovered through DDS. The only difference is that there is no broker between the clients since it has the direct data bus between the publishers and subscribers, as shown in Figure 12.11. It leads to less complexity. Adding a new DDS participant is a simple process since it supports scalability [18]. Even if the nodes are not reachable at the receiver side the communication will not be affected because of the multicasting nature and node's reliability in the network. Hence it is best suitable for machine-to-machine communication and uses minimum energy resources and low cost for deployment. It is widely used in mission-critical applications because of the major consideration of security. It supports intelligent farm management in Agro-IoT.

12.6.3 CoAP

One of the specialized application protocols is a Constrained Application Protocol (CoAP). It is discovered by the IETF standard elaborated as Internet Engineering Task Force. Basically there are many constrained devices in the IoT network such as minimum bandwidth, low battery, minimum latency, and less power consumption of the network. A simple node that helps to have communication is a battery-constrained one that can convey its message using the wider internet with CoAP, as represented in Figure 12.12.

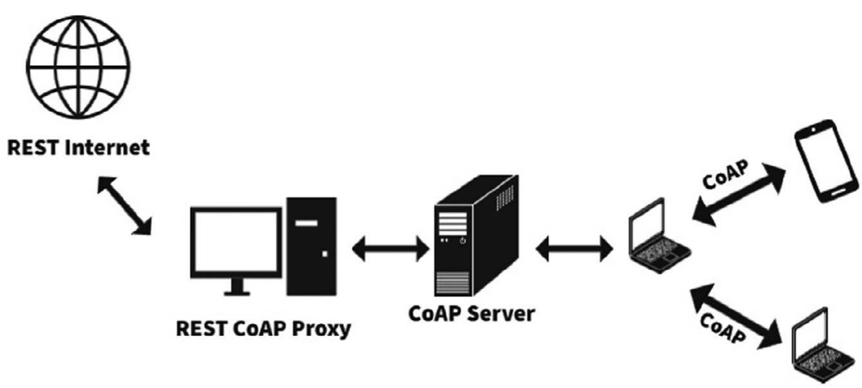

FIGURE 12.12
Generic web transfer mechanism of CoAP.

It is an application layer protocol famous for machine-to-machine communication runs on User Datagram Protocol (UDP). It is similar to HTTP, which is based on Transmission Control Protocol (TCP). CoAP logically deals with asynchronous message transfer through request/response mechanism. The client sends one or more requests to the server and services the requests via the response message by the server. The sequence of numbers from 0 to 8 is considered to be a token to match the requests with the response. It supports both unicast and multicast data transmission. It has four bytes of header addresses along with the data, which provides the minimum overhead feature in the network. Each message holds a message ID that helps detect duplicate messages that are being transmitted to the receiver. Reliability is an optional header added to make the message a confirmable (CON) message; it supports having retransmissions in case of time-outs, and it automatically resends the message until the acknowledgment is being received by the transmitting node from the receiver. The acknowledgment is an ID which is the same message ID used while initiating the transmission. Even if the message does not want reliable transmission, then without acknowledgment the transmission takes place with the message type as a non-confirmable (NON) message called unreliable message transmission. Here also the message ID is used for identifying the duplication of the same message. If a NON message is not getting processed then the Reset (RST) option will be preferred. It has control over simultaneous data transmission. Datagram Transport Layer Security (DTLS) is the security model designed for CoAP communication. Proxying is an intermediary concerned with forwarding the request and responses, caching operations, and protocol translation, useful in resource-constrained networks in order to minimize network traffic, improve the network efficiency, utilize the resources that are under sleeping condition, etc.

12.6.4 AMQP

AMQP is a location-based protocol, expanded as Advanced Message Queuing Protocol, supports the compact messaging application and communication pattern. The message transmission between sender and receiver in a distribution system is by a hardware or software architect infrastructure support called message-oriented middleware, simply known as MOM, used at the API level for standardization in AMQP [21]. The messaging pattern used here is the publish/subscribe mechanism where the publishers are called senders who will not send the message directly to the receiver, called the subscriber, who will receive only the interested message subscribed.

If the messages are passing continuously among the nodes, then there is a chance of getting overloaded by the nodes, so the message used for later purposes is stored in a message queue through the channel, as shown in Figure 12.13. The storing is based on data exchange type and binding. The binding is the set of rules to route the message to a queue based on the exchange type. The message attribute is declared as at least one for transmission. There are four exchange message types for AMQP 0.9.1 broker: direct, fanout, topic, and header. Using the application interface the nodes in different networks can communicate easily. This is known as interoperability. Here binary protocol and wire level protocol are used to transmit data from one point to another point and perform the data operation in a distributed system.

AMQP efficiently supports flow control over transmitted messages and ensures the message delivery via floating the acknowledgment message. The message delivery guarantee from one point to another point is by using three verticals: at most once – the message gets delivered once or never, at least once – minimum one message has to be delivered, or it

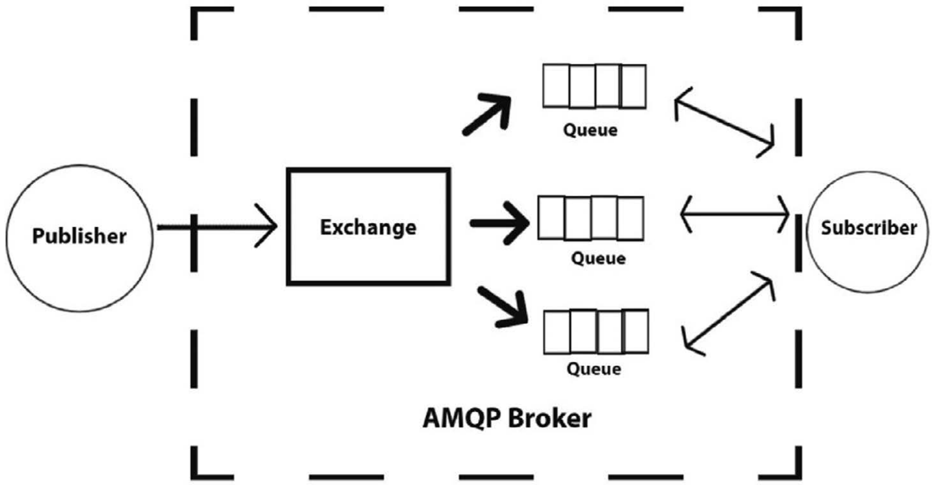

FIGURE 12.13
Transmission perspective of AMQP protocol.

can be multiple times, exactly once – only once. TLS and STLS are the encryption methods used in AMQP to secure the message while transmitting. The newer version of AMQP 1.0 supports to direct the message with little less intervention of brokers through the mentioned address containing routing key as a field. Reliability and extendibility and security are the important features and the major advantages of AMQP.

TABLE 12.3
Pros and Cons of IoT Protocols

Protocol	Advantages	Disadvantages
MQTT	• Ensures message delivery with minimal network traffic • Consumes low power • Works well even with unreliable internet connection	• High latency, which affects the speed • Lack of security while transferring messages from one end to another end
DDS	• Supports interoperability • Holds the communication architecture with low latency • Secured connection	• Consumes twice the bandwidth as MQTT • Web service interface not supported
CoAP	• Consumes less power • Synchronous communication is not needed for data transmission • Reliable communication using the acknowledgment message	• The cost for additional security provision is high since it is an unencrypted protocol • CoAP messages get lost due to the use of UDP
AMQP	• Interoperability ensured via the use of wire-level protocol • Simple peer-to-peer communication • Secured connection using SSL protocol	• High bandwidth required • Unsupported discovery of network attributes

12.7 Security Protocols Used to Secure the Network

12.7.1 DTLS

DTLS helps to secure the Datagram-based network. There are various possible attacks to steal private information. Eavesdropping is one of the common attacks which will listen to private information without the knowledge of the users in the transmitting and receiving end.

12.7.2 TCP

It is a standard connection-oriented protocol used to establish a connection between the nodes and maintain the internet-based communication between sender and receiver. It helps the application program to exchange the data. It is a set of rules defining how the application data is segmented as packets, routing of packets to the destined nodes. It has the responsibility of flow control to control the flow of traffic with the help of exchanging control information like RTS (request to send) and CTS (clear to send) in case of additional device connection and overflow of data. It further ensures the uniformity of data being carried out. And error control is a functionality identification of error location and retransmission process at which the packet gets missed. TCP is a very important model that helps to exchange the data over the network securely with the help of SSH (Secure Shell).

12.7.3 UDP

It is a connectionless message-oriented transport layer protocol in which the entire data is divided into several data units, each addressed with a unique ID and forward toward the receiver by taking multipath. Since there is no end-to-end connection between sender and receiver the UDP feels tedious to order the forwarded packets at the receiver end. It is considered to be an unreliable network since it has no prior communication to set the data path for the transmission. UDP is applicable for the time-sensitive applications where there is no necessity for error checking and data handling during data transmission and even for the error checking case where the packet dropping is appropriate rather than retransmission of an errored data unit. It is supportive of broadcasting the data and multicasting is also possible in this packet switching network.

12.8 IoT-Based Solution for Leaf Disease Detection Using Machine Learning Classifiers for Precision Agriculture

The farm's output reflects the country's economy. It is necessary to provide the facility of better yield through automated processes. Prior knowledge about the quality of plant and its strength through observing the condition of leaves helps to achieve the optimum yield. Figure 12.14 describes the leaf disease detection process; it comprises pre-processing where the filtering is done. The filtering used here is a non-linear filtering method known as median filtering. It is a technique to remove the unwanted noise from the image by

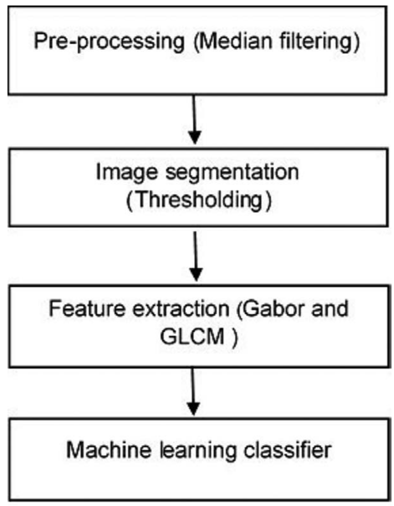

FIGURE 12.14
Flowchart of leaf disease detection and classification using machine learning algorithm.

considering the nearby pixels as the pixel value, then its own pixel as the median. So that the surrounding blurs are removed, and thus the edge points are sharpened through it.

After filtering the region of interest from the image has to be extracted through a technique known as segmentation. In segmentation, the entire image is divided into many portions, which leads to analyzing the required image in a clear way, which thus helps create the exact map of the analyzing part. The simplest thresholding method is used where the grayscale image is converted into a binary scale image and based on the average value the threshold is set and the analysis is done. The next process is a feature extraction where the desired attributes of the data are identified and driven with the non-redundant data for further process. The enhanced predictability is achieved through Gabor filter and Gray Level Co-occurrence Matrix (GLCM) statistical features. The Gabor filter is a band-pass filter in which it provides the frequency and orientation representations of an image. Gabor features are best and outperforms when compared to GLCM. The distinctive features are classified by using classification algorithms such as KNN, Naive Bayes, Random Forest, Decision tree, and SVM.

12.9 Implementation of Machine Learning Classifiers and Its Performance Study for Leaf Disease Detection in Agriculture Field

For the implementation, the tomato leaf disease detection dataset is opted and used for analyzing the quality of the leaf and its strength. The dataset comprises 10,000 trained images of healthy and disease-affected tomato leaves, in which 9 disease classes and 1 healthy class are present [22]. The images from each category are extracted and considered to validate the performance of the classifiers. The dataset contains 1000 images in each category that are extracted from the dataset. In this experimental setup, 70% from

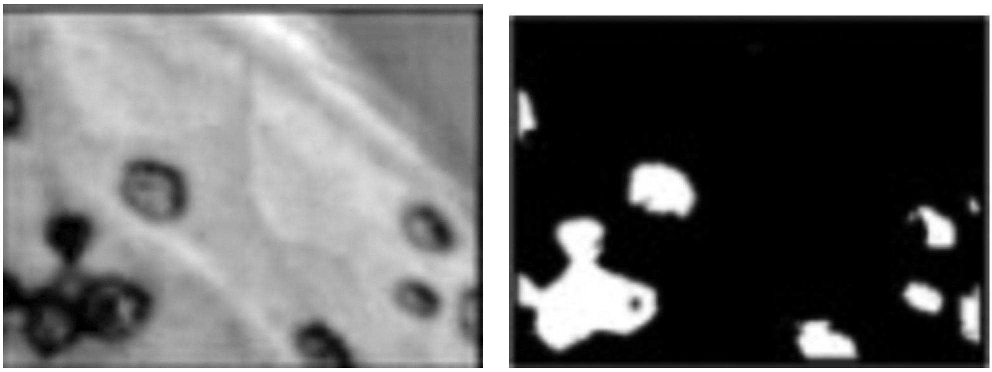

FIGURE 12.15
Segmented bacterial spot in tomato leaf image using thresholding.

each category is used for training and the remaining 30% is used for testing. The affected area of each image is segmented out through thresholding.

Figure 12.15 shows the segmented bacterial spot in tomato leaf image using thresholding. GLCM and Gabor features are extracted for each segmented test and train tomato leaf image and it is used as a feature vector for all the classifiers. The machine learning classifiers with GLCM and Gabor features are simulated for the abovementioned dataset and its performance measures such as classification accuracy, F-measure, precision, and recall are computed and compared. The performance comparison of machine learning classifiers with GLCM and Gabor features are shown in Tables 12.4 and 12.5, respectively. From the

TABLE 12.4
Performance Comparison of Machine Learning Classifiers with GLCM Features

Classifiers/ Performance Measures	Precision	Recall	F-Measure
Decision Tree	0.11	0.63	0.19
Naïve Bayes	0.15	0.72	0.25
KNN	0.18	0.79	0.29
Random Forest	0.20	0.84	0.32
SVM	0.22	0.91	0.35

TABLE 12.5
Performance Comparison of Machine Learning Classifiers with Gabor Features

Classifiers/ Performance Measures	Precision	Recall	F-Measure
Decision Tree	0.19	0.75	0.30
Naïve Bayes	0.21	0.81	0.33
KNN	0.24	0.86	0.38
Random Forest	0.26	0.92	0.41
SVM	0.29	0.97	0.45

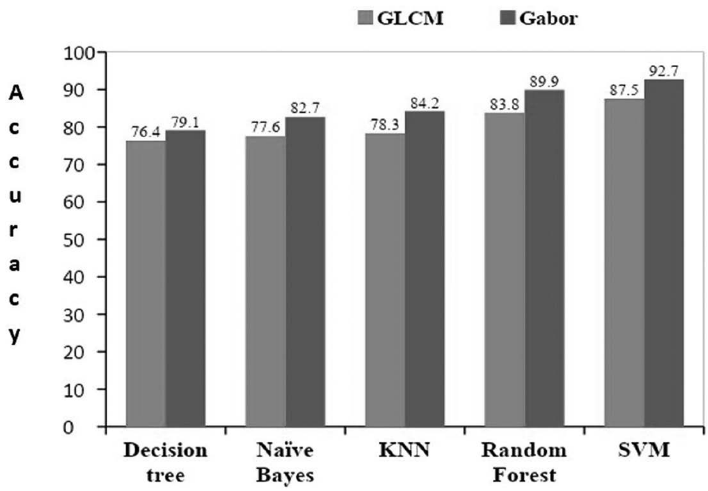

FIGURE 12.16
Performance comparison of classification accuracy (%) for various machine learning classifiers with different features.

simulated results, it is observed that SVM classifiers with Gabor features provide significant improvement in terms of precision, recall, and F-measure when compared to other classifiers with GLCM and Gabor features.

The performance comparison of classification accuracy (%) for various machine learning classifiers with different features is shown in Figure 12.16. From the results, it is observed that SVM classifiers with Gabor features efficiently classify tomato leaf disease when compared to other classifiers with GLCM and Gabor features.

12.10 Real-Time Processing of Sensor Data Using IoT

The top-level components of IoT are hardware, gateway, and cloud. At the initial stage the optical sensors capture the leaves' images, which are analyzed using machine learning algorithms to classify the healthy and unhealthy nature of captured leaves. IoT protocols such as MQTT and CoAP make sense for the data stored in the cloud and again respond to the farmer side with appropriate standards to make decisions further for the better way of crop yield. The scalability features of the protocols are tested with the help of the IoT Simulator. In which 20 sensors are considered to be active for publishing the messages using MQTT protocol with the public broker of IoT.eclispse.org [23]. The considered subscriber client is publicly available in Hive MQ. And the sensed data is generated every 10 seconds in the simulation and it is categorized using an SVM classifier to update the status of the plant to the farmer then and there for optimum yield with the help of IoT network. The overall analytics process is possible with the help of the salient feature known as interoperability which provides the sensor structured data integration [24].

12.11 Conclusion

This study is aimed at providing insights into various standards and protocols used for Agro-IoT. The findings are based on three verticals. First is about the technologies that pose its advances and its beneficial operations, which are useful for deploying an efficient Agro-IoT network. The dilemma on determining the standards and technologies to be deployed is considered and provided the solution based on applications. The communication technologies such as Bluetooth, Wi-Fi, Zigbee, WiMAX, LoRaWAN, and RFID developed by the standards like IEEE, ISO, and IETE are highlighted with their significant factors for use cases of Agro-IoT. Along with this the oversight on the scope and responsibilities of various sensors such as temperature, soil, humidity, leaf wetness, rain sensors, optical sensors that are useful for remote sensing of agriculture fields. Second vertical is about the most demanding phase in networks known as communication protocols. A detailed view of various Protocols such as MQTT, AMQP, DDS, CoAP, and its major constraints are examined and analyzed. The complications arose due to the fact that wireless networks in terms of security are controlled with the help of layered protocols such as DTLS, TCP, and UDP, which support secured communication from the sensor nodes to the end-user. Third vertical is about the comparison of various algorithms for analyzing the sensor captured image through classifier algorithms like KNN, Naive Bayes, Decision Tree, Random Forest, and SVM. The analysis is done based on the features like precision, recall, and F-measures. Through these measures the efficient classifier SVM holds accuracy values of 82.5% and 92.7% based on the GLCM and Gabor feature extraction methods applied for the process of exact diseased leaf detection. Based on the classified data the accurate result is obtained and passed to the farmer with the appropriate communication standards and protocols of IoT network for the suggestion on the composition of pesticide application on the affected plants in the field. As a whole the Agro-IoT is an area that has a great deal for field management and farm management with proper attribute setups through the deployment of sensors along with its communication standards and protocols.

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13

Research Issues and Solutions in Agro-IoT

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CONTENTS

13.1 Introduction

World population growth is increasing tremendously and is expected to reach 9.7 billion in 2050, according to the reports of the United Nations in 2019 [1]. The population growth coupled with global threatening news such as water shortage, land shortage, climate change, etc., will put additional pressure on agriculture to feed the population. Till now, farmers have been struggling a lot in monitoring and protecting their livestock and farms against natural disasters, damage, theft, etc. Adopting agro-based IoT technologies increases yields in farms, reduces theft of cattle, reduces human effort, and many more. As per Juniper Research, the number of IoT devices in agriculture is 38.5 billion in 2020, which is a major rise of 285% when compared with 13.4 billion devices in 2015 [2]. Even though Agro-IoT products offer numerous benefits to farmers, agriculturists, and industrial food producers; yet many challenges are associated with selecting, instrumenting, and integrating IoT devices [3]. As these IoT devices have the ability to connect and communicate

DOI: 10.1201/9781003185413-13

with each other in mobile and web-based application platforms, the interoperability of these devices is still a challenging issue.

When instrumenting livestock with sensors [4], the battery life of wireless devices is a major issue. The battery power and coverage range are interrelated. Because the selection of wireless devices highly depends on the distance the data needs to travel between the communicating devices. Figuring out sensors with enough battery life, choosing the range of wireless network, i.e., whether short distance RFID/NFC (100 meters), Bluetooth low energy (within 10 meters) or WAN (1000 meters), and positioning the sensors for effective communication remains challenging. Even though IoT resolved many traditional farming problems such as drought response, yield optimization, land selection, irrigation, pest control, etc., the installation, maintenance, and protection of electronic circuits during natural calamities is really problematic and also requires high cost. Since the farms are located in remote areas, internet connectivity, storing data in the cloud, and accessing data from the cloud also remains challenging [5, 6]. Providing Quality of Service (QoS), reliability, scalability, and efficiency in smart agriculture is still an unfolded issue. This chapter highlights the following issues and discusses the respective solutions in detail.

13.1.1 Issues and Challenges in a Nutshell

A smart agriculture system is framed by four main parameters: IoT devices, communication technology, internet, and data processing units [7–9]. Figure 13.1 specifies the collaboration of these parameters for the successful deployment of Agro-IoT technology. Here, sensors and actuators are used to collect information about the crops, and the communication technology transfers information to the cloud, then the cloud stores and processes information, and results are sent to the agriculturist for further action.

1. Various tools in smart farming do not follow the same set of standards; hence more and more gateways are needed to transform these smart tools into farmer-friendly platforms.
2. Big data centers and gateways consume enormous energy; hence smart agricultural tools should additionally focus on the energy depletion risks. Improper maintenance of these resources can also cause failure and damages.
3. Lack of IoT knowledge among farmers can also be alleviated by giving adequate training on tools/devices such as sensors, drones, and other technologies since the failure of irrigation sensors may lead to overwatering or under watering of crops which leads to huge irrecoverable loss.
4. Implementation of cloud services in farmlands with hilly terrains restricts data transmission and data storage; hence the solution lies in improving network bandwidth and speed.
5. Analyzing big data collected from smart farms every day requires skilled persons and smart agriculture demands the correct production function in order to optimize the output since the incorrect application of inputs will lead to sub-optimal results.
6. As the resources and tools provided by big original equipment manufacturer (OEM) may not be compatible with smaller OEM, hence migrating from an older platform to a new platform leads to compatible problems. Providing cross-platform migration solutions will address this issue.

The next section discusses each and every problem in detail and also provides respective solutions.

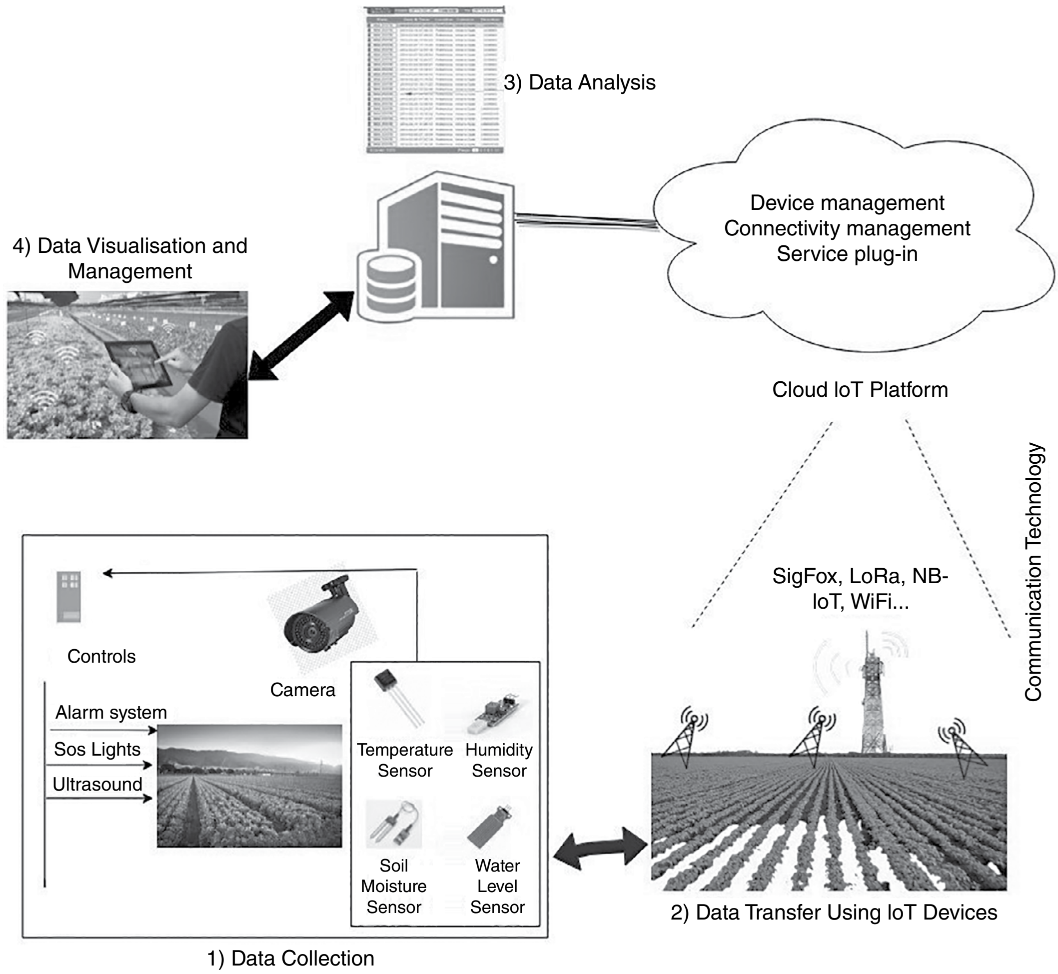

FIGURE 13.1
Smart agriculture system.

13.2 Integration/Communication Issues and Solutions

The new common agricultural policy demands farmers to reduce the use of herbicides and fertilizers under the new term called Greening. The introduction of new communication technologies in farming should reduce the use of chemicals and focus on traditional methods of agriculture in the growth of plants. The ultimate objective is to produce quality and healthy food products for the human community. Nowadays, the usage of modern technologies such as aerial drones, IoT agrosensors, drools, farm controller networks, cloud computing, multimedia view browsers, etc., are very common in agriculture [10]. But integrating these technologies remains challenging since each wireless protocol has its own communication paradigms and network mechanisms. In order to enable communication among these devices, a smart wireless network topology is needed.

Table 13.1 gives the various IoT technologies and their benefits in agriculture. Traditional wired and wireless networks options such as mesh networks, Bluetooth, cellular networks, Wi-Fi, etc., are not suitable for IoT applications as they cannot meet the cost, coverage and power requirements. In order to ensure reliable and scalable connectivity across heterogeneous networks, many new protocols have been proposed [11]. The protocols discussed in the next section serve as compatible products in gathering data about agricultural conditions at a lower cost, thereby increasing farming efficiency.

13.2.1 LP-WAN (Low-Power Wide Area Network)

This technology provides solutions for smart agriculture developments by providing the following promising services [12].

a. LPWAN offers high data reception rate by operating in licensed or license-free spectrum. LPWAN ensures high Quality of Service and reliability.
b. Day by day usage of IoT devices is getting increased; hence network expansion and addition of IoT devices are more essential. LPWAN ensures high scalability by providing a large network capacity.
c. LPWAN offers the integration of low-cost battery constraint sensor devices which consume low power to achieve more environmentally sustainable architecture.
d. LPWAN offers mobility by providing high-speed data transmission between the edge nodes and sink nodes in precision farming.
e. LPWAN offers high security by providing multilayer encryption solutions. It also provides secure authentication, end-user identification, secure data transmission, and high-level data integrity.

TABLE 13.1
IoT Technologies for Smart Agriculture System

	Impact in Agriculture	
IoT Technologies	**Support to Agriculture**	**Applications in Agriculture**
Embedded systems (devices that consist of both hardware and software)	Remote monitoring and controlling of equipment increases profitability and sustainability. It also decreases production costs.	Load shedding (solves electricity problems), water management and usage of drones.
Wireless sensor networks (sensor nodes with radio communication capabilities)	Tools to integrate different sensors. Facilitate collection and management of data from different sensors.	Livestock tracking, equipment tracking, soil moisture monitoring, and temperature monitoring.
Communication Protocols (backbone of IoT to establish connectivity)	By using various data exchange formats, these protocols are used to exchange data over different networks.	Supports long-range communication.
Big data analytics (process of examining and analyzing large data sets)	Providing schemas, dashboards, and analytical reports to farmers to take decisions.	Optimize usage of pesticides, farm equipment management, prediction of yield, and managing the problems in supply chain.
Cloud computing (a type of internet-based computing)	Services are available on demand. It provides real-time computation and data access to shared resources and also provides enormous storage capacity.	Crop-related information, soil information, farmers' data, and e-commerce.

The most promising LPWAN technologies that provide high-quality Agro-IoT solutions across the world are: (i) LoRa (Long Range), (ii) Sigfox, (iii) Narrowband IoT (NB-IoT), and (iv) myThings.

13.2.1.1 LoRa (Long Range)

This technology was mainly introduced for long-range data transmission using low power consumption. Its geolocation capabilities facilitate devices to exchange their operating locations with the help of gateways. It operates under a license-free sub-gigahertz radio frequency band and operates in different frequency bands in different regions such as 868 MHz (Europe), 915 MHz (Australia and North America), 865 MHz to 867 MHz (India), and 923 MHz (Asia). It provides data rates in the range of 0.3 kbits/s and 27 kbits/s. It operates at a range of 50 km [13]. Even though Wi-Fi/Bluetooth Low Energy (BLE) technology-based networks serve as an optimal solution for smart agriculture, it requires high bandwidth and high power, covers a limited range, and also demands line-of-sight proximity [14]. Its inability to penetrate deep environments as the interference may lead to the adsorption of RF signals.

Lora in precision farming:

1. Suitable for large farms where even 5G technology is difficult to penetrate the large physical structures in the environment. Moreover, the communication range of the LoRa WAN protocol is up to 30 miles. Hence it is more optimal for applications such as water and gas metering, asset tracking, supply chain and logistics, smart homes and buildings, and smart agriculture.
2. It uses unlicensed spectrum and ISM (Industrial, Scientific, and Medical) frequency bands for defining its architecture and communication protocol. It is used for quick deployment of private or public IoT networks using hardware or software anywhere. The physical layer in the protocol provides a long-range communication medium between different sensors and gateways in the precision farming environment [15].
3. It provides a good solution for security by providing end-to-end AES-128 encryption and solutions for mutual authentication, data confidentiality, and data integrity.
4. It provides quality of service by providing seamless handoff while maintaining communication between devices in motion.
5. It offers interoperability between different IoT devices and facilitates the quick deployment of IoT applications anywhere, anytime.
6. Minimizes battery replacement cost by offering low power consumption of IoT devices hence devices equipped with a lithium battery will long last up to 10 years.

13.2.1.2 NB-IoT

NB-IoT is a fast-growing and leading LPWAN technology developed and standardized by 3GPP (3rd Generation Partnership Project) in 2016. It is classified under 5G technology and can co-exist with 2G, 3G, and 4G technologies. NB-IoT has 26 frequency bands, and out of 26, about 18 to 19 frequency bands are in the sub-GHz frequency range and about 7 frequency bands are above 1800 MHz [16].

NB-IoT in precision farming:

- NB-IoT is highly robust in nature and can connect a large fleet of about 50,000 IoT devices, with low power consumption and increased network coverage. Since it satisfies the industry-based standards, it has a wide range of professional applications such as smartmetering, Object tracking, smart cities, fire alarms, and connecting industrial appliances.
- NB-IoT is highly resource efficient i.e., by minimizing the power consumption, it extends the battery life of IoT devices to about 10 years. It also serves as a low-cost communication protocol.
- NB-IoT is less sophisticated and easy for OEMs to design, develop and deploy compared to cellular networks. When compared with LTE M1 (Long-Term Evolution machine-type communications (MTC)), NB-IoT can have good communication among devices with deep penetration in indoor, underground and rural areas.
- NB-IoT offers similar security features as that of LTE networks such as user-based authentication, user confidentiality, device identification, and data integrity.
- NB-IoT is characterized by its optimal network architecture and it eliminates the need for gateway and serves as cost-efficient structure with spatial diversity of +20 dB.

13.2.1.3 Sigfox

Sigfox enables low power connectivity of inexpensive objects to communicate with the cloud infrastructure. Sigfox uses a co-operative reception strategy, where the devices are not attached to any base station. But it can transfer information through nearby base stations. Hence Sigfox enables coverage over large areas using the minimum number of base stations. It uses an unlicensed ISM radio frequency band and the range highly depends on location: In Europe the band used is 868 MHz, in Asia the band used is 433 MHz and in the United States the band used is 915 MHz, which is restricted to the national regulations. Sigfox provides coverage of 30–50 km, whereas in areas with a lot of obstructions it covers up to 3–10 km. Hence it is suitable for applications such as asset tracking, health applications, automotive communication in transport, and precision agriculture.

Sigfox in Precision Farming:

- Sigfox allows devices to communicate with a minimal number of base stations. It also uses the cellular network basics for the remote devices to communicate with base stations using internet. Hence if there is internet connectivity the devices can transfer, access, and control over the specified region.
- Sigfox facilitates devices to effectively communicate using low power consumption, i.e., 10 mA to 50 mA. It doesn't demand synchronization between devices for sending or receiving data, i.e., no pairing is recommended. This facility allows devices to run for a long time with minimal battery charge.
- Sigfox is highly resilient to interference. It utilizes 192 KHz Ultra Narrow Band (UNB), which allows transmission of signals under the presence of jamming signals. This anti-jamming feature is achieved when UNB is coupled with the base station's spatial diversity of +20 dB.

- Sigfox has an inbuilt security mechanism and provides secure authentication, data integrity, confidentiality, and anti-replay mechanisms for data exchanged over the network. Its in-built firewall facility secures devices from internet-related attacks.
- Sigfox provides a software-based computing solution where all data are computed and managed in the cloud creating an energy-efficient infrastructure.

13.3 Failure Issues and Solutions

Agro-IoT enables different components to communicate with each other by sending observed data to selected nodes, thereby instructing the actuators to perform the required change in the farming environment. Here, a diverse array of sensor devices are used to measure soil moisture, light intensity, water level, temperature, humidity, CO_2 rates, etc., and these devices are interconnected to monitor the system in real-time. Improper functioning of these devices leads to incorrect interpretation. Moreover, the lifetime of the entire network also depends on the energy level of these sensor nodes. The energy gets depleted based on the location of sensor nodes and the positioning of relay nodes. The poor internet connectivity in the region also creates data loss [17]. Hence in order to meet the challenges, the IoT environment must be resilient to the abovementioned problems. One of the approaches suggests that multiple redundant sensors can be used for failure detection, but the cost of deployment in large farms leads to a major concern [18].

13.2.2.1 Predictive Fault-Tolerant Systems

The main problem with sensors in the context of agriculture is the humidity and temperature. Because the temperature rise causes a huge impact on signal strength when there is a rise of above 50°C. Moreover, the radio wave propagation is affected by humidity, since the sensor nodes are deployed in open farms and are exposed to rain and irrigation. Additionally, many factors such as distance between nodes, the height of the antenna, and frequency range must be taken into consideration while deploying the transceiver in large farms [19]. Figure 13.2 specifies the list of smart sensors used in smart Agriculture.

It is highly challenging to manually detect faulty devices due to time constraints, and also these devices are easily subject to human errors. The Agro-IoT environment should have an automated mechanism to predict the faulty devices and also failures in service provision. Many fault prediction approaches are proposed to mitigate the failures before they occur. In these approaches, machine learning capabilities along with real-time complex event processing mechanisms are used for the prediction of device faults. But, a thorough knowledge of the following parameters is essential to construct the machine learning model.

- What kind of faults will occur in the system?
- How will the faults get classified?
- What is the severity of the fault?
- What will be the result of the fault?
- Which device is highly prone to risk or fault?

Here the machine learning framework will collect data in real-time and observe the patterns in them. The objective is to maintain an acceptable level of service even if faults occur in the system.

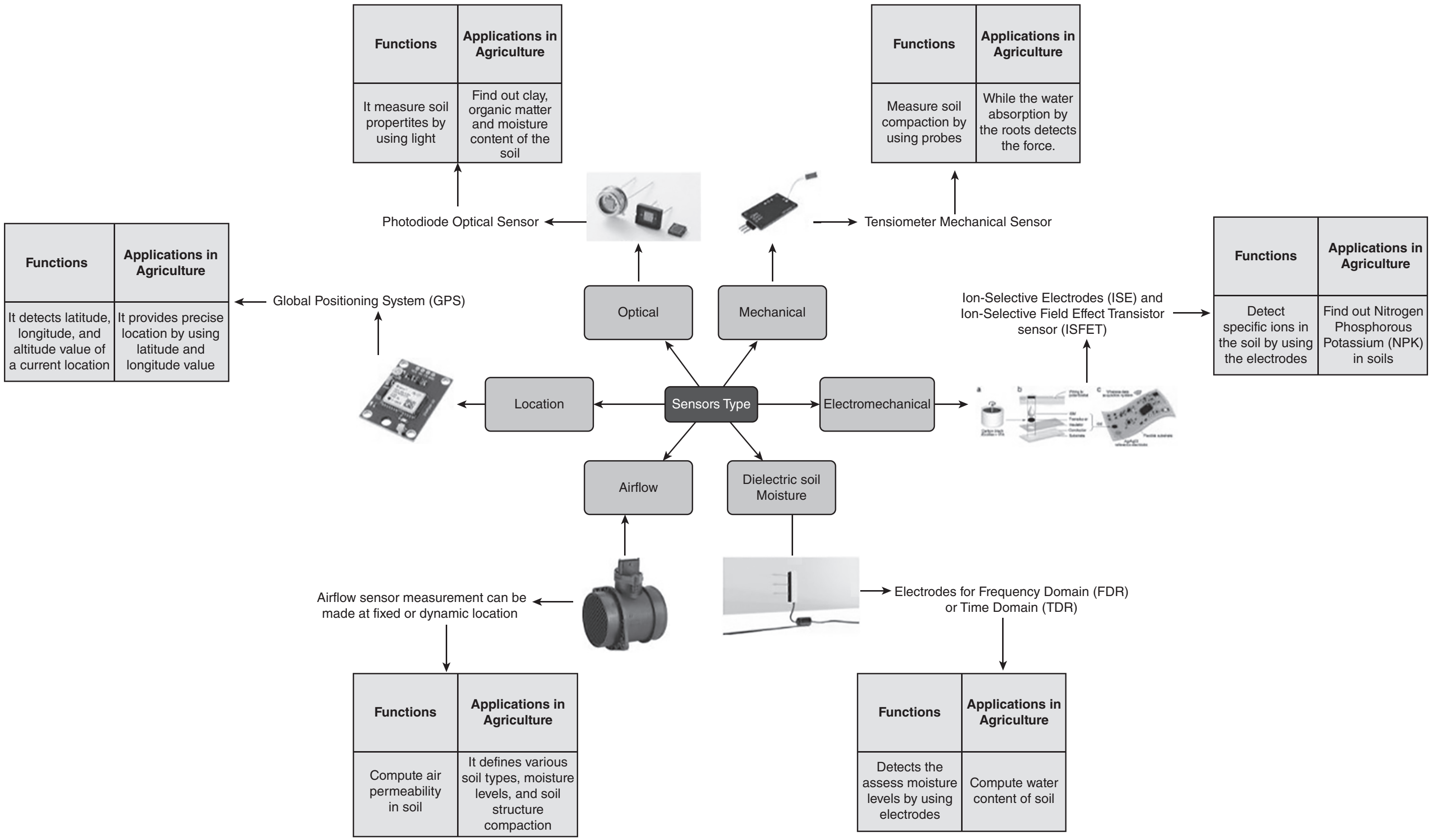

FIGURE 13.2
Smart sensors for smart agriculture.

13.2.2.1.1 Fault Anticipation System

Once the historical data related to the faults are gathered, a supervised learning classifier can use this training data to identify and classify the faulty devices by observing fault patterns in the real-time data collected from the system. As the classifier is trained on known faults in the system, the probability of device failure can be anticipated in good time so that the propagation of fault with the rest of the system is prevented. Many different classifiers are used to select the relevant set of attributes for failure prediction. (1) Perceptron – a more sophisticated kind of neural network classifier exclusively used by supervised learning model for binary classification and they are applicable only to linearly separable objects. (2) Decision tree – a non-parametric supervised learning classifier used for classification and the regression models in which a learning model predicts the value of the target variable based on simple decision rules inferred from the attributes of the dataset. (3) Logistic regression – a linear regression model which uses logistic function particularly to classify list of observations to the discrete set of classes. (4) K-nearest neighbor – an on-demand or lazy classifier that belongs to the category of supervised learning algorithm, which predicts the class of a particular object based on K nearest neighbors to the selected object. (5) Support Vector Machines – a vector space model in which the objects are represented in N-dimensional space and a decision hyperplane is formulated which separates the objects in two different classes; here the prediction is based on the relative position of the object in the hyperplane or decision surface.

13.4 Data Management Issues and Solutions

As agriculture is experiencing the digital revolution with the use of IoT devices, a huge amount of information is passed as data [20]. As data is transmitted wirelessly across several miles, data management involves gathering data from several sources, processing the data, figuring out the information such as receiving mobile alerts, remote monitoring, remote servicing, tracking the device failure, etc. [21]. Even though it is simpler in today's scenario, yet some challenges arise as a result of data sharing and transmission. These challenges need to be addressed. This section presents the challenges and solutions associated with managing IoT data.

- Data security
  When data is interpreted at the control center, there may be a possibility that data gets tampered which leads to incorrect interpretation. This may lead to making wrong decisions in field monitoring. Additionally, there may be a situation where the entire control of the farm can be allegedly handled by an intruder and he can do anything that leads to collapsing the farm. Hence addressing this issue requires employing high data encryption standards and providing strong authorization and access control mechanisms. Today's advanced artificial intelligence techniques can be deployed to perform security audits over the farm regularly.
- Scalability
  Every day enormous amount of data is collected from IoT farms and this is expected to grow exponentially; hence before installing the infrastructure, an agriculturist should have answers to the following questions:
  i. Whether the infrastructure will support the growth of data for the next five years?
  ii. Will the infrastructure handle large volumes of data in terms of zettabytes?

iii. Which platform is suitable for analyzing large volumes of data?
iv. Who is allowed to access and manipulate the data from the cloud?

It is more important to educate and train agriculturists about IoT solutions, data management, IoT success stories, etc.; hence, hiring tech-savvy personnel to maintain data across cloud infrastructure will ensure effective IoT adoption and execution in large farms.

- Reliability
When there is a power failure or any problem in the local ISP, then the entire IoT system will go down. During that time data collection, monitoring, and reporting processes will get interrupted. Natural calamities also make devices unusable. In order to ensure reliability in this adverse condition, two important features like low power support and offline support should be addressed by the IoT market. This facilitates to achieve reliability to utilize sensors and devices under unexpected power or weather conditions.
- Energy Consumption
Agro-IoT devices are intended to operate 24/7 with no exception; hence all electronic devices require energy to operate continuously. These devices should actively participate in data transmission to and from the network adapters, gateways, etc. Apart from cloud storage, all devices require minimum physical storage capacity to handle data. Also remote servers located in large farms need to house the digital content and require excessive energy to operate continuously. Under heavy loads these data centers require a large-scale cooling system that in turn leads to the demand for huge electrical power. In order to meet out these challenges, solar energy source is the best alternative solution. Nowadays, the cost of installing solar is almost declined.

13.5 Security Issues and Solutions

Even though IoT-based agrosystems benefit the agriculture industry, it is highly prone to security breaches and cyber-attacks. For example, while using aerial drones the intruders can take control of drones in spraying pesticides and fertilizers in large amounts leading to the damage of the crops resulting in poor productivity [22]. The intruders can also control the underground sensors and surface sensors to maliciously update the data during transmission. This will affect the growth of crops resulting in the exploitation of the country's economy. When these types of attacks occur on a large scale over smart agricultural system may lead to agroterrorism [23]. Security vulnerabilities are characterized under the following major categories:

i. The most common attacks targeting smart farming are (1) Data injection attack, where the data collected from several sensor devices are modified to take wrong decisions. (2) Malware injection attack, where the software installed in the smart devices can get infected, leading to improper functioning of devices.
ii. The next category of attacks that occur on the farmer's side when accessing web portal at the entry level includes weak authentication mechanisms, open ports, and poor update policies.
iii. Another category of attacks that targets WSNs such as node compromise, open ports, eves dropping, and location tracking are common threats for the destruction of the functionality of IoT devices.

The following solutions may be adopted to address the security issues:

- Lightweight privacy-preserving data aggregation methodology can be deployed in smart agriculture systems that will integrate cryptographic techniques such as homomorphicPaillier encryption Chinese remainder theorem and one-way hash chain. The mean and variance of data collected from edge nodes are calculated using the Chinese theorem. The report received from IoT devices gives huge information about sensing data. This data is encrypted using homomorphicPaillier encryption. Additionally, IoT devices achieve Lightweight authentication through a one-way hash chain technique. Hence false data injection can be avoided.
- Anonymous and privacy-preserving data aggregation protocol (APPA) provides anonymity and unforgeability. This APPA protocol uses the Paillier cryptosystem along with signature-of-knowledge to prevent false data injection attacks and eavesdropping attacks.
- The Agro-IoT enables the collection of data from different sensor sources, which leads to issues concerned with farmers' data privacy. Dynamic privacy protection (DPP) model provides privacy by means of classifying the privacy protection levels. Blockchain-based PKI is also available to provide privacy.
- User anonymity is achieved by deploying hybrid linear combination encryption among IoT devices during communication in order to avoid DoS and impersonation attacks.
- Colluding and inference attacks can be prevented by providing dummy locations that are identified using a greedy algorithm.
- Delegated authentication is required as data is forwarded through many untrusted networks. It is provided by Semi-outsourcing privacy-preserving (SOPP) policy, which incorporates applied elliptic curve cryptography to acquire one-way authentication. SOPP avoids invalid data access and imparts a high level of data integrity.
- The sensor data of Agro-IoT should be equipped with privacy-preserving protocol and also provisioned with authentication codes (Message Authentication Codes [MAC]). This solution ensures that the data received by the farmers is not tampered with during communication.
- Lightweight label-based access control (LACS) provide authentication to Agro-IoT user by substantiating the data integrity while using 5G network. The label-based authentication is used against two attacks, namely, disturbing attack and ignoring attack.
- Secured access to data is enabled by lightweight integrity verification (LIVE) architecture. Merkle Hash Tree algorithm is used to generate tokens that provide access to data through various security levels.
- The Fair Access framework deploys blockchain technology to provide access control such as grant, get, revoke and delegate permissions to use data.

13.6 Summary

To summarize, this chapter provides various issues and solutions in adopting Agro-IoT technologies. Agro-IoT-based technologies provide continuous transformation in the agriculture sector worldwide. If the abovementioned challenges are treated effectively, then the benefits will be more evident and more sustainable. The IoT devices protect the ecosystem and nature of soil by ensuring the proper usage of fertilizers and pesticides. They serve as a win-win solution model by feeding the growing population and preserving nature.

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14

Renewable Energy Sources for Modern Agricultural Trends

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DOI: 10.1201/9781003185413-14

14.1 Introduction

Agriculture is one of the main sectors, which play a crucial role in the economy of most of the countries. In India, nearly 17% of total GDP was credited to agriculture and also it provides 60% of the employment in the country (Arjun, 2013). Despite the importance of it, the issues faced by the farmers in agriculture were enormous due to the various natural calamities. These natural calamities could cause a great loss to the economy of the individuals as well as to the country. To overcome this, various modern advanced technologies like polyhouse farming (La Notte et al., 2020), shade net farming (Saran et al., 2019), polybag farming (Kasirajan et al., 2012), hydroponics farming (Samreen et al., 2017), aeroponics farming (Tiwari et al., 2020), and sprinkling-based farming (Tarjuelo et al., 1999) were used in the agriculture by the farmers. This has certainly enhanced productivity as well as the barrier for natural calamities. In addition to this, information and Communication Technologies were also integrated in recent years to increase the efficiency, service, and productivity of agriculture products (Nyarko et al., 2021).

Though the technologies are advanced, the sustainability of agriculture is still a problem in terms of quantity with quality aspect. Also, the availability of electricity and water sources could play a vital role in agriculture, which is one of the major drawbacks faced by farmers in recent years. To avoid this, solar energy was integrated with agriculture to provide various functions like electricity (Pascaris et al., 2021) for irrigation, to drive the agriculture machinery (Gorjian et al., 2021; Chadalavada 2021) and to provide a cooling system for storing agriculture-related products (Sadi et al., 2021). Despite the wide usage, there is still greater opportunities for renewable energy sources (solar, geothermal, wind and biomass) in agriculture.

Internet of Things (IoT) is a rapidly emerging technological paradigm over the past decade in which internet plays a significant role to connect the object around the world from anywhere. This is achieved by deploying IoT-associated devices to various domains such as smart homes, wearables, healthcare, and agriculture (Figure 14.1). Rapid deployment of IoT devices becomes easier due to the fast growth in communication technology and decreased cost of sensor devices available in markets.

Sensors were the building blocks of IoT and it can be deployed in agriculture farm fields to improve productivity and to reduce the total cost of farming. It is an undeniable fact that the impact of IoT on connected devices cannot be segregated in this modern world. Today, IoT plays a significant role in almost all domains, especially in agriculture. The deployment of IoT in the domain of agriculture ensures the farmers not to rely on horses and plows. Recent advancements in IoT ensure not to depend on age-old methods and to rely on the idea of IoT-based agriculture and farming. Also, IoT deployment in agriculture not only automates the manual labor but accelerates the farmers to effectively utilize and manage the resources with appropriate precaution in maintaining, monitoring, and predicting the environment. Thus, IoT deployed in agriculture helps the farmers to utilize smart farming gadgets and to have control over the procedure of growing crops. IoT adopted

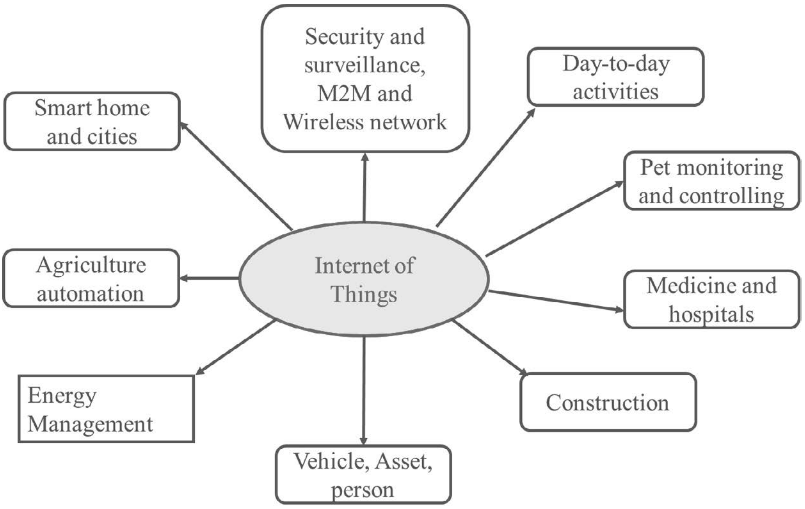

FIGURE 14.1
Domain-specific IoT.

in agriculture predicts the installation of IoT devices may reach 75 million during 2020, which grows by 20% annually and the size may be tripled in 2025. The advancement in IoT technology paves the way for the farmers to cultivate efficiently by suitably deploying appropriate sensors to monitor the field. IoT with its conventional networking standard was enabled suitably using the wireless, Bluetooth, RFID, radio protocols, NFC and Wi-Fi technologies.

Agriculture IoT is explored to focus on water management, soil monitoring, field monitoring, and machines for routine operations. IoT-based smart irrigation system improves crop yields and saves water by determining soil moisture level (Figure 14.2). Also, it determines the amount of water be released when the moisture level goes down using soil sensors and Wi-Fi-enabled computing systems. Moreover, IoT deployed in agriculture

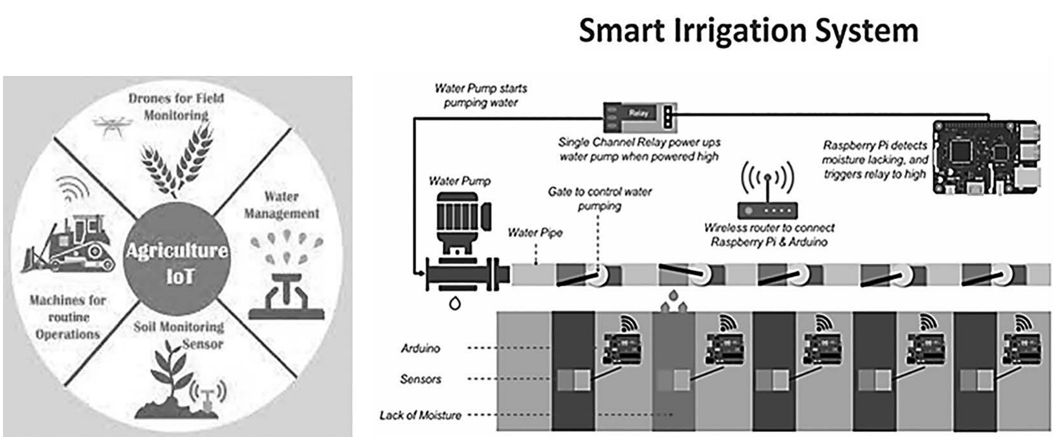

FIGURE 14.2
IoT in agriculture and smart irrigation system flow.

improves productivity by controlling the temperature, humidity, moisture level using actuation devices. Data collected through various sensors are stored, analyzed, and correlated to the yield to improve productivity by optimizing and applying appropriate control strategies.

Also, the effective use of renewable energy like solar, wind, voltaic, solar pumping, and solar space heating improves the yield further and decreases the energy consumption in the modern agriculture system. In addition to this, integrating IoT with modern agriculture enhances productivity, decreases the maintenance cost, and helps to manage the virtual network through online proctoring efficiently. So, the overview of modern agricultural technologies in this chapter could aid the farmers, researchers, and academicians to know and apply IoT and renewable energy in modern agriculture integrated, which could enable a green environment in the near future.

14.2 Polyhouse Farming

Polyhouse technique is one of the modern agricultural greenhouse techniques where different types of covering materials like polythene (polyethene), ethyl vinyl acetate (EVA), and polyvinyl chloride (PVC) are used to provide a safe environment for the crops to grow in a controlled environment (Figure 14.3). This can be done by filtering the harmful radiation from the sun and thus protecting the crops from the adverse effect of natural calamities (Maraveas, 2019). The schematic of the most popular polyhouse structure is depicted in Figure 14.4. Recent research uses various structural modifications to improve the yield, which includes a walk-in tunnel (Figure 14.4(a)), insect-proof net house, gothic roof (Figure 14.4(b)), slant roof, sawtooth (Figure 14.4(c)) and flat roof. Among the various control parameters, thermal environment control and humidity control plays a vital role in improving the crop productivity of polyhouse farming (Von Zabeltitz, 2011).

Renewable energy can be used as an effective choice in polyhouse cultivation by governing the thermal environment and humidity inside the roof structure. Humidity control is

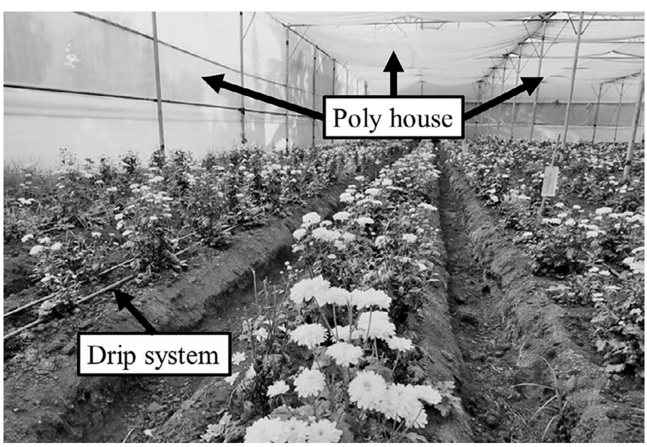

FIGURE 14.3
Actual polyhouse farming (Yelagiri Hills, Tamil Nadu, India).

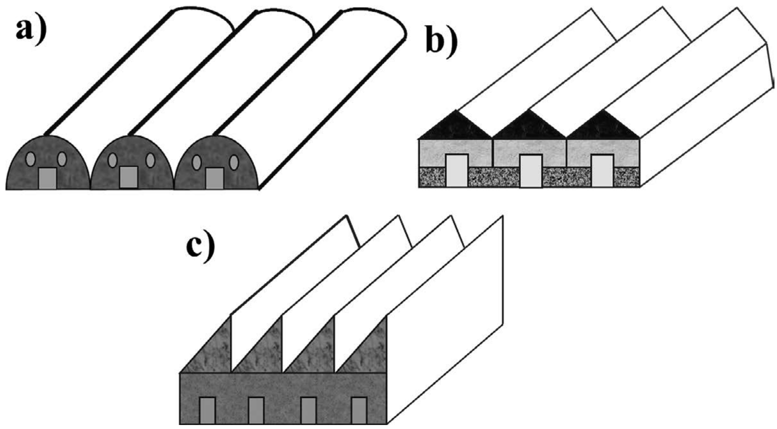

FIGURE 14.4
(a) Walk-in tunnel, (b) gothic roof, and (c) saw tooth.

one of the main aspects of polyhouse farming due to its inevitable control over plant transpiration, photosynthesis, and carbon dioxide exchange between air and leaves (Panwar et al., 2011). This humidity controller can be assisted with the solar photovoltaic (PV) technique for providing the necessary source of power either from a stand-alone PV or grid-connected PV depending on the application and necessity.

Thermal energy storage is a proverbial technique that is getting boomed in the various applications for maintaining the temperature (both hot and cold) during summer and winter seasons. Sensible heat and latent heat are the two techniques used to store the heat energy from the sun during the peak sunny time and release the heat energy during the nocturnal hours. A thermal energy storage tank with latent heat energy storage materials can be integrated into the polyhouse farming structure, which can store both heat energy and cold energy from the sun and atmosphere, respectively (Sarbu et al., 2018). Phase change materials can be used to store the heat energy from the sun and release them during the on-peak period. Depending on the operating environmental parameters such as operating temperature and ambient temperature, the selection of phase change materials can be made for different seasons (summer or winter) to enhance the yield. A sensor can be used to monitor the temperature inside the polyhouse roofing and when the sensor gives a signal, the energy either heat energy or cold energy from the thermal energy storage tank will be released to the enclosure to maintain a controlled environment inside the roof structure.

14.2.1 IoT-Based Polyhouse Farming

This section describes various IoT-based software solutions with highly efficient sensors and internet gateways for storing the track of various data collection points within the environment of poly-house. These data points are connected with the cloud environment or server for analysis. This analysis will identify and provides information about the climate changes inside the polyhouse. If the climate condition exceeds the particular threshold value, an automated alert can be generated and passed to the managerial person. The collected data from sensors can be accessed by the farmers at anytime from anywhere through remote login. The following section explains different kinds of sensors, which are required to enhance polyhouse farming in a better way.

14.2.2 Temperature/Humidity/Light Monitoring Sensors

Temperature, humidity, and light sensors are commonly used sensors for measuring the indoor conditions of polyhouse on a regular interval and this information will be stored as digital data. The collected data is then transferred to IoT applications hosted in a cloud over wireless communication. The climate changes are analyzed based on the threshold value set by the farmers (for the crops). An alarm message will be generated by the cloud server based on the measured data. The immediate change in the Temperature level inside the polyhouse can be maintained by deploying the sprinkler automation. Sprinklers within the polyhouse can be used for temperature control and to improve the ease of maintenance.

14.2.3 CO_2 Level Monitoring Sensors

To improve the growth of plants and to get faster yields, CO_2 enrichments are critical in polyhouse farming. The CO_2 level inside the polyhouse might decrease faster since the crops and plants inhale CO_2 and emit oxygen. Farmers plan to handle this crucial situation and maintain CO_2 levels without jeopardizing worker safety. Periodically, the CO_2 level has been measured through IoT-based CO_2 sensors deployed in the polyhouse environment.

14.2.4 Soil Temperature Monitoring and Drip Irrigation

The soil temperature and humidity are important aspects, which govern the growth of the crops. Drip water irrigation is a globally accepted approach for providing sufficient water supply in farming with a minimal water supply and achieving more profit. The modern polyhouse environment requires an automated drip irrigation approach for maintaining accurate soil conditions. IoT-based soil sensors are deployed in the polyhouse fields farming areas to gather the soil temperature and automatically controls the water supply based on the need.

14.2.5 Rodent Monitoring Sensor

The grasp motion detection can be detected by using proximity sensors in polyhouses to track the people or animal movements at regular intervals. It also checks and alerts in case of rodents entering into the polyhouse structure. IoT technology deployed in polyhouse helps to establish a healthy polyhouse for harvest.

14.3 Shade Net Farming

The shade net farming uses a net house structure (Figure 14.5), which is enclosed with various poly nets to filter the required amount of moisture, sunlight, and air to pass onto the soil. This will also create an appropriate microenvironment for augmenting stable plant growth. Table 14.1 elaborates the various advantages and disadvantages of shade net farming. The major drawback of shade net farming is the presence of high moisture in the soil and plant decay during the winter (Lenka, 2020). Though the soil moisture encourages plant growth, it is important to control its level to avoid the decay of roots of the plants.

FIGURE 14.5
Shade net house farming (Yelagiri Hills, Tamil Nadu, India).

Till now, there is no initiation on overcoming the plant decay during the winter season due to overwatering. Also, overwatering could cause more plant diseases like leaf scorch/burn, edema, and water-soaked spots. This will affect the quality and quantity of the fruits and vegetables during the winter, which leads to the price rise of these products in the market. So, it is important to resist plant decay during the winter to increase the yield of the products. This limitation can be overcome by integrating renewable energy technology with shade net farming. Here, the shade net forming structure will be coupled with the air drier driven by solar energy. The flow path of the heated air from the solar drier will be forced (forced convection) to pass through the way just near the plant to evaporate the required amount of water from the soil to the atmosphere. The rate of hot airflow, the volume of the hot air, the moisture content will be governed using a data acquisition system through which the moisture level will be constantly monitored and the process of the airflow will be stopped once the soil reaches the required moisture. This can be further advanced by employing artificial intelligence with the tri-generation system.

14.3.1 IoT-Based Shade-Net Farming

The invention of emerging technologies paves radical change in the growth and production of crops in the agriculture sector. A protected structure is one among the technology in which shade net is widely used by farmers for cultivation. Initially, the type of the crop,

TABLE 14.1
Advantage and Disadvantages of Shade Net Farming

Advantages	Disadvantages
• Microclimate cultivation. • Suitable for all types of plants (spices, foliage, flower, vegetables, and medicinal). • Increases moisture content. • Can be used for nurseries and raising forest species. • Quality drying. • Prevents pest attacks. • Effective graft saplings with low mortality can be produced during summer. • Suitable for tissue culture.	• High-labor cost. • High-production cost. • Difficult in drying the soil during the winter. • Plant decaying due to overwater during the winter.

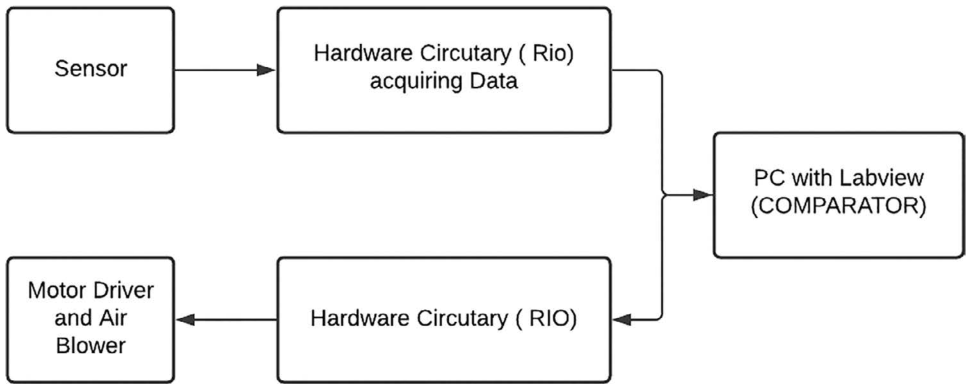

FIGURE 14.6
Functional architecture diagram for IoT-based shade net farming.

climatic condition, and availability of the materials should be analyzed and investigated before the next step i.e., commissioning. Also, the site selection, orientation, and shade-net structure play a significant role before processing the shade-net farming. Varying the percentage of shade factor determines the light intensity, which is chosen based on the crop variety. Choosing appropriate shade-net material is purely relies on the crops being grown such as vegetables, flowers, fruits, and ornamentals. To overcome the deficiencies incurred during winter, IoT-based assistive technologies (Figure 14.6) were deployed in shade-net farming to have better cultivation.

Such integration of shade net farming with IoT devices will monitor soil moisture level (Figure 14.7) and ensures to offer the standard soil moisture level by enabling/disabling the hot airflow with the help of renewable energy resources. To prevent dew formation,

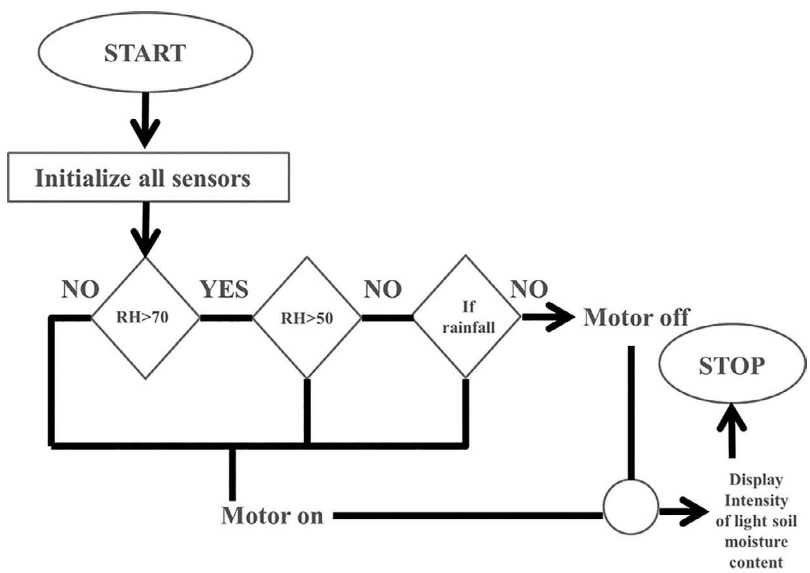

FIGURE 14.7
Flow-chart to control the soil moisture in shade net farming.

the plant leaf may only need 59 degrees Fahrenheit for moisture. So, the soil moisture is recorded in the database by measuring the relative humidity (RH) and temperature through sensors. The ideal humidity for shade net farming is 50–70% RH, but it's tolerable even if it is in between 60% and 80% RH.

This limitation can be overcome by integrating renewable energy technology with shade net farming. Here the shade net forming structure will be coupled with the air drier driven by solar energy. The flow path of the heated air from the solar drier will be forced (forced convection) to pass through the way just near the plant to evaporate the required amount of water from the soil to the atmosphere. The rate of hot airflow, the volume of the hot air, the moisture content will be governed using a data acquisition system through which the moisture level will be constantly monitored and the process of the airflow will be stopped once the soil reaches the required moisture. This can be further advanced by employing artificial intelligence with the tri-generation system.

14.4 Polybag Farming

Polybag farming (Figure 14.8) is one of the effective modern farming techniques that can be implemented in the shorter area space. For example, this type of farming can be used on the terrace of the houses. Polybag farming utilizes polybag materials to store the soil for plant growth. A sufficient amount of soil is mixed with the natural cocopeat and used in the polybags to grow the plants (G Pantuwan et al., 2002). Since cocopeat is mixed with the soil, the moisture along with the nutrition can easily penetrate the roots of the plants and enhances plant growth. Based on the amount of soil and cocopeat is mixed, the growth of the plant can be controlled. Also, the water holding capacity of cocopeat is larger as compared to the normal soil. Hence, it can be very useful in the summer season to maintain the moisture level in the soil. Since individual bags are used for plant growth, the amount of water consumption is greatly reduced for polybag farming as compared to the other modern farming techniques. In addition, if there are any diseases in the plant, they may not transfer to the other plants as they are placed in a separate medium, which is also found to be one of the major advantages of Polybag farming (Al-Shrouf, 2017).

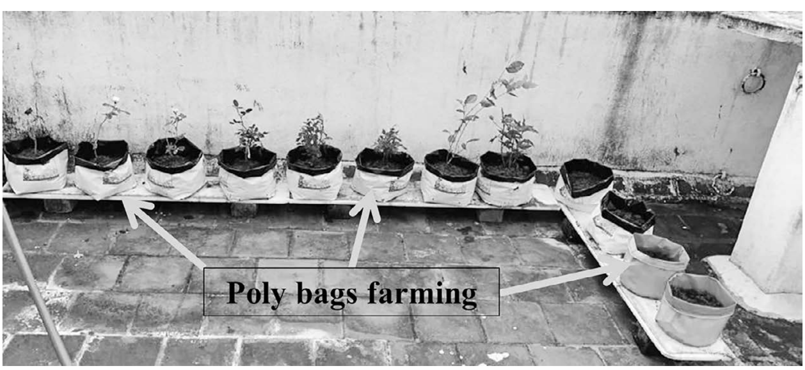

FIGURE 14.8
Polybag farming (Yelagiri Hills, Tamil Nadu, India).

The renewable source of energy like solar photovoltaic or solar thermal can be integrated to govern the temperature of the entire system. Cheaper energy storage materials can also be used in this system to provide the necessary temperature inside the system. Also, when all these systems are integrated, the solar PV or wind turbine technology can act as a primary or secondary source of energy for providing the required amount of power to run the pump thereby the pump work may get reduced which in turn improves the efficiency of the system. Though we have several advantages, polybag farming has few disadvantages like adjusting the nutrient composition, recyclability, soil contaminants, and supporting the weight of the plant. Generally, cocopeat consists of natural salts, which could offer a high cation exchangeability to enhance plant growth (Xiong et al., 2017). However, these salts are not suitable for recyclability and hence, after the utilization, the cocopeat was thrown as waste into the environment. Among the various drawbacks, nutrient composition and soil contaminants play a vital role in plant growth. Hence, it is important to monitor the nutrition composition and soil contaminants regularly to overcome the major drawbacks of polybag farming. For effective integration of the above-said components like cocopeat, solar PV, solar thermal unit, AI plays a vital role in governing the entire circuit and to monitor the same.

14.4.1 IoT-Based Polybag Farming

The role of IoT-based software solutions provides a greater way in polybag farming by applying appropriate sensors along with the internet to collect data from various points from the polybag environment. IoT-based polybag farming is thus improved by monitoring the entire system and improves its performance. To deploy IoT-based polybag farming, the following section elaborates on the various sensors needed to enhance polybag farming efficiently and effectively.

14.4.2 Soil Moisture Sensor

Soil moisture sensors are designed to measure the volumetric water content in soil with indirect measurement. Since the direct gravimetric measurement of free soil moisture requires removing, drying, and weighing of a sample, soil moisture sensors measure the volumetric water content indirectly by using the properties of the soil, such as electrical resistance, dielectric constant, or interaction with neutrons as a proxy for the moisture content. The relationship between the measured property and soil moisture must be calibrated and it may vary depending on environmental factors such as soil type, temperature, or electric conductivity. Reflected microwave radiation is affected by soil moisture and is used for remote sensing in hydrology and agriculture. In some places, portable probe instruments may also be used for measuring the moisture content of the soil.

14.4.3 Lysimeter Sensor

Lysimeter is used to measure the amount of actual evapotranspiration which is released by plants (usually crops or trees). By recording the amount of precipitation that an area receives and the amount lost through the soil, the amount of water lost to evapotranspiration can be calculated. Lysimeter can be classified based on weighing and non-weighing techniques. These techniques can be employed in polybag farming for the effective measurement of evapotranspiration.

14.5 Hydroponic Farming

Hydroponic System is the most advanced farming system used in today's modern agriculture. Hydroponics farming grows the crops without the use of soil and is often referred to as soilless farming (Figure 14.9). The roots of the plant are fully grown inside the liquid nutrient solution.

In the hydroponic system, the plant roots generally grow in a liquid nutrient solution or inside moisture inert materials such as vermiculite and Rockwool. There are five foundational elements like freshwater, oxygen, nutrition, root support, and light which are required for the hydroponic system (Maucieri et al., 2019). Among the five, water is the basic stuff for the hydroponic system. Freshwater with a pH of 6–6.5 is more suitable for the plants to grow healthily. Hence, it is mandatory to maintain the pH level in the hydroponics system to increase the productivity of the crop. Also, the oxygen supply at the roots is required to provide the respiration process. So, it is complicated in designing the hydroponic system to oxygenate the container, where the plants are placed. The lack of nutrition like calcium, phosphorus, and magnesium could also influence the health and productivity of the plants. From the five foundational elements, it is very clear that the process of controlling the pH, oxygen, and nutrition could enhance the productivity of the plants in hydroponics farming (Trejo-Téllez et al., 2012). Solar energy can be used to maintain a certain temperature in the hydroponic system. Also, the oxygen extractor/separator (from air) filter can be used which can operate using the renewable power source (solar/wind) rather than conventional. Thus, the oxygen level, nutrition, and water can be maintained in the system using renewable sources of energy. IoT can also be integrated with hydroponics to increase crop production.

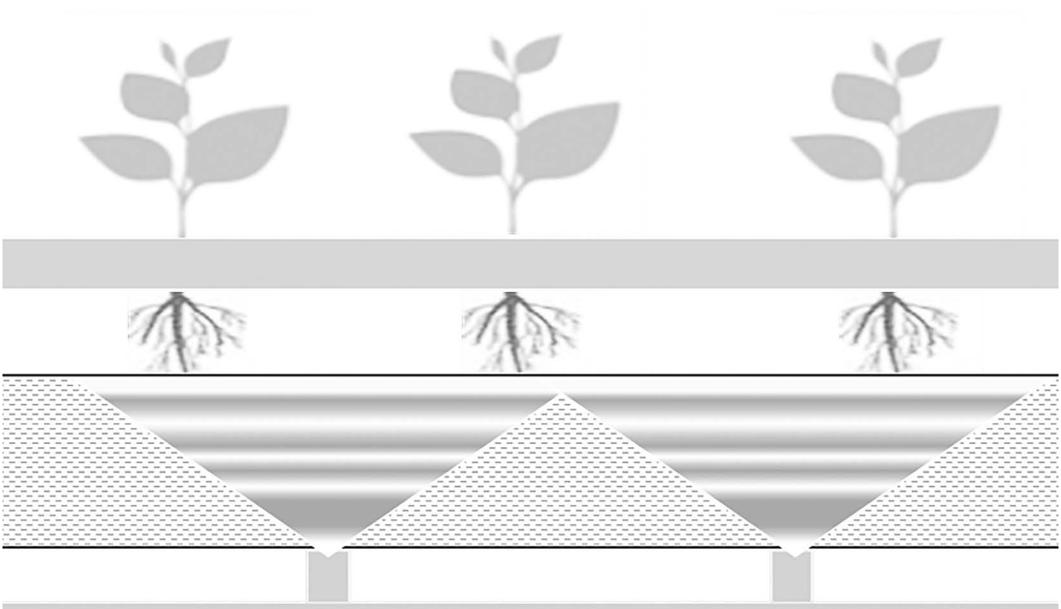

FIGURE 14.9
Hydroponics farming.

14.5.1 IoT-Based Hydroponics Farming

A hydroponic farming system typically contains three water tanks to hold clean freshwater i.e., nutrient-enriched water, pH-controlled water, and wastewater. The nutrient-enriched and pH-controlled water comprise the growth medium for the plants. The pH level and nutrient composition in this water reservoir are controlled using valves and pumps to add nutrients, carbon dioxide, or freshwater. Draining wastewater from the nutrient-enriched water reservoir helps to maintain consistent water levels while adjusting the nutrient concentration and pH.

To set up a hydroponic farming system, conductivity sensors and pH sensors should be installed in the water reservoir that will be used to supply it to the plants' growth medium. The pH controllers and conductivity controllers give signals for the opening and closing of valves or the operation of pumps based on the measurement data from the sensors. For example, if the nutrient concentration in the water reservoir became too high, the conductivity controller could turn on the freshwater pump to dilute the nutrients. Conversely, if nutrient concentration became too low, the conductivity controller could turn on the nutrient pumps. Similarly, if pH became too high, the pH controller could open the solenoid valve, allowing carbon dioxide to flow into the water reservoir. Carbon dioxide reacts with water to form carbonic acid, which lowers the pH of the solution.

- High nutrient concentration > high conductivity reading > add fresh water
- Low nutrient concentration > low conductivity reading > add nutrients
- Overly alkaline solution > high pH reading > add carbon dioxide.

14.6 Aeroponics Farming

Aeroponics farming is the advanced form of hydroponics farming, where the plants are grown completely in the water and nutrition medium (Figure 14.10). The utilization of water in aeroponics farming was nearly 98% lesser than conventional farming and the productivity was 30% higher than traditional farming. Aeroponics farming was suitable for all types of species as in conventional farming (Lakhiar et al., 2018).

Similar to the hydroponics farming system, pH, oxygen, and nutrition are the mandatory requirements for aeroponics farming. However, one of the major drawbacks of aeroponics farming is maintaining the freshness of the water. The water has to be changed continuously to avoid root decay. This type of aeroponics farming gives high quality of vegetables which are mostly leafy crops. Here, the automatic spraying and the closed-loop water circuit play a vital role in the functioning of the entire system. Renewable energy can be employed in automatic spraying and water circulation system by proving the necessary power from solar and wind energy. When this farming is carried out near a system that produces waste heat, the produced waste heat can be utilized to heat or cool the greenhouses, which reduces the energy input to the system and thereby improve the efficiency of the system (González-Briones et al., 2018). The whole system can be integrated with AI for efficient management. Hence, monitoring the freshness of water and providing the actual values of pH, oxygen and nutrition are important in aeroponics farming, which makes IoT come into the picture for ease of use.

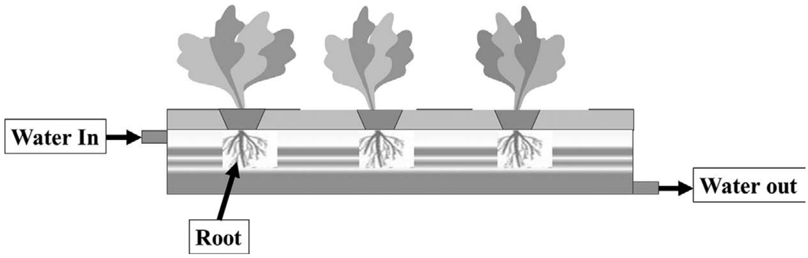

FIGURE 14.10
Aeroponics farming.

14.6.1 IoT-Based Aeroponics Farming

Aeroponics is a culture technique where the plant roots are suspended in the air and are spasmodically sprayed with a nutrient solution. This technique has been used both for research study and to harvests profitable production. Aeroponics presents excessive benefits over traditional agriculture methods. This kind of method reduces the consumption of water and nutrients, increases the growth rate and plant density.

The system should continuously monitor the energy consumption, the level of the nutrient solution and the correct operation of pumps and valves, which can be performed through the application of IoT. The following paragraph describes the methods of monitoring aeroponics using wireless sensors.

14.6.2 Humidity Sensor

Humidity sensor used for measuring the humidity level of water present in the air. The amount of water vapor in the air can affect human comfort as well as many manufacturing processes in industries. The presence of water vapor also influences various physical, chemical, and biological processes. In agriculture, the measurement of humidity is important for plantation protection (dew prevention) and soil moisture monitoring. In agriculture applications, humidity sensors are employed to indicate the moisture levels in the environment.

14.6.3 Temperature Sensor

A temperature sensor is a device, usually a resistance temperature detector (RTD) or a thermocouple that collects the data about temperature from a particular soil and environment. This will be converting the measured data into an understandable form to a device or an observer.

The most common type of temperature sensor is a thermometer, which is used to measure the temperature of solids, liquids, and gases in the agricultural land. The water content of the soil and environment can be changed based on the measurement value. This control can be activated through IoT-enabled devices from the remote or nearby place.

14.6.4 Pressure Sensor

A pressure sensor is a device for pressure measurement in gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding and is usually stated in terms of force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed. The water pressure level can be changed in the planted area to reduce or increase the pressure to help the system to get back to the default mode/condition.

14.6.5 Water Flow Sensor

Water flow measurement is the quantification of bulk fluid movement. Flow can be measured in a variety of ways. Positive displacement flow meters accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure the flow. In the planted area, this reading is used to maintain the water flow in a normal mode. This measurement is used to improve the water level by regulating the controller, which can be done through IoT.

14.7 Sprinkling-Based Farming

Sprinkled-based farming (Figure 14.11) is also the advanced farming and irrigation system used by farmers in recent years. Sprinkling irrigation has some major advantages over the drip irrigation system (Figure 14.12). In this system, the water is irrigated to the farms through sprinklers, which is similar to natural rainfall (Patel et al., 2020). Also, it will create a moisture environment, which is required for plant growth during the summer season. However, in comparison, the utilization of water is slightly higher for sprinkling-based farming than that of drip irrigation. In addition to the moisture environment, the supply of essential nutrition could also augment the growth process of the plants. Here, renewable energy can be coupled with sprinkling-based farming to replace the fossil power source with a renewable power source for pumping and irrigation. Hence there will be a substantial reduction in greenhouse gas emissions and annual economic uplift in the livelihood of the farmers by reducing the cost of kerosene, diesel, and petrol.

14.7.1 IoT-Based Sprinkling Farming

Effective water management is a vital aspect and needs to be addressed in the agriculture sector because around 60% of water spent on agriculture is wasted due to various

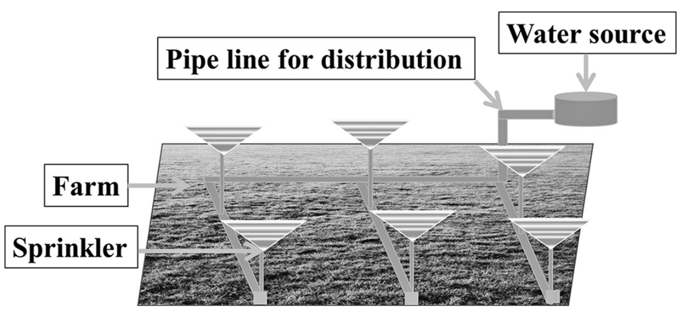

FIGURE 14.11
Sprinkle-based farming.

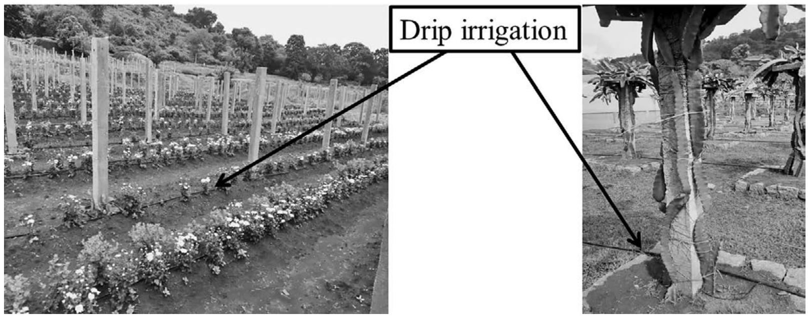

FIGURE 14.12
Drip irrigation (Yelagiri Hills, Tamil Nadu, India).

reasons such as contamination, overwatering, runoffs, and other related issues. Moreover, the crops were damaged due to either overwatering or under-watering. To overcome this deferred scenario, the technology deployed should be improved and optimized with the deployment of IoT in the agricultural field with advanced sensors to observe and monitor the field.

The fundamental requirements for irrigation of crops should be estimated along with the soil moisture content level. Based on the need, the system should effectively utilize water resources. Sprinkling-based farming added the advanced features of IoT technology to effectively monitor the moisture level of the field and to control the sprinklers with smart irrigation controllers for watering.

For the deployment of IoT devices in agriculture, a user interface is to be modeled to read/observe the value of the sensors used in the field through the service platform. This platform records information such as temperature, humidity, pH balance, nutrient levels, LED lights, and water levels (Kern et al., 2017). The service platform facilitates a web interface that accesses the data using mobile and saves the gathered sensor information using the connected IoT devices (Figure 14.13).

Raspberry PI Zero is used to gather information from the sensor to control the water pumping or dosing. Sequential query language (SQL) queries are used to transmit the saved information to the data server for processing. Also, this Raspberry PI Zero is connected with various sensors to record the temperature, humidity, water level, LED light, dosing pump, and submersible pump. IoT devices connected with the sensors gather the associated information and triggers appropriate action through relays. For example, if the nutrition level is lower than a certain threshold value, the connected dosing pump starts to work till the expected threshold level is reached. Similarly, it works in the same manner for all the rest of the cases.

To ensure objective irrigation, controllers are installed in the system to minimize water usage. Based on the type of crop field, either a channel system or sprinkler system or drip system will be used for efficient farming. In sandy soils, a sprinkler system is used even when the available water quantity is small. An irrigation controller consists of a mesh network that works at 868 MHz ISM frequency band (Figure 14.14) is designed to consume low energy with transmitting data capacity up to 15 km. This model is designed to consume less energy with a wide bandwidth for acquiring data through IoT devices (Cambra et al., 2017).

To process the data collected through various sensors and to make quick and smart decisions, a service-oriented architecture is applied using an intelligent farming system

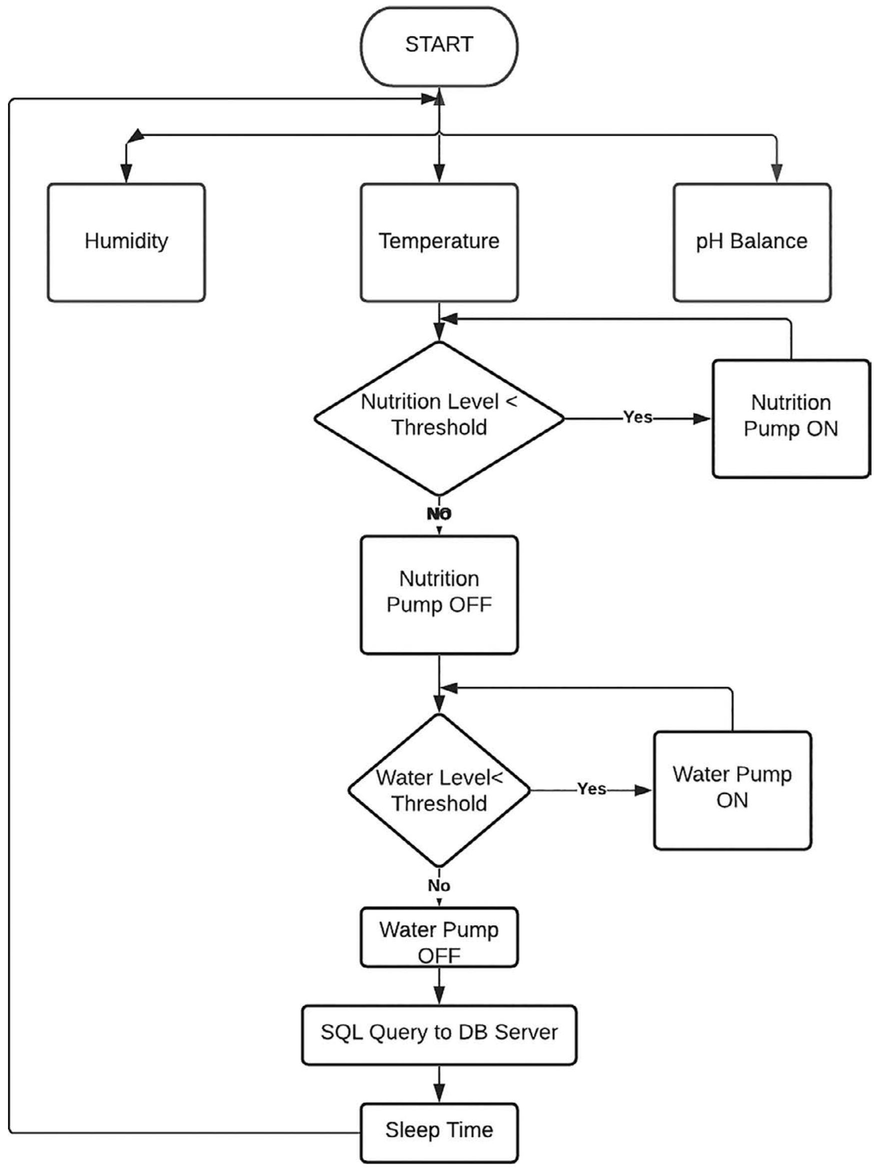

FIGURE 14.13
Flow diagram for IoT device.

(Figure 14.15), that eliminates the relationship between the service provider and farmers. Such intelligent farming comprises a service cloud, a service consumer, and a server. Service cloud deals with all sensor data, service consumers determine relevant services by exploring the cloud.

The server has major components such as application and rule container. The application component helps to register the sensor data in the system. The rule container uses a rete pattern matching algorithm. The objective of the algorithm is to reduce or remove redundancy and allows deleting the memory when facts are withdrawn.

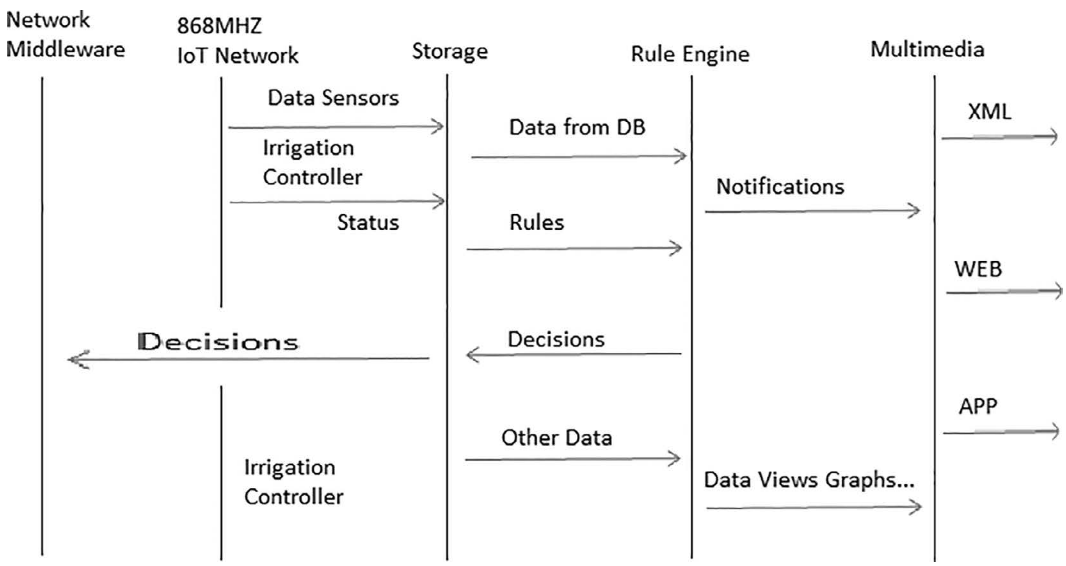

FIGURE 14.14
Data annotation process path.

14.8 Conclusions

The following conclusions were drawn from the detailed discussion on the various types of modern agricultural techniques, which can be integrated with renewable energy and IOT:

- Renewable energy could be an effective method in polyhouse cultivation for controlling the thermal environment and humidity with the help of solar photovoltaic (PV). Through IoT, an alert can be generated if the climate condition exceeds the particular threshold value. In addition, the various sensors for controlling the temperature, humidity, light monitoring, CO_2 level, soil temperature monitoring, and drip irrigation can be employed through IoT in polyhouse farming.
- The integration of IoT devices with shade net farming will monitor and control the soil moisture level. This ensures the required moisture level inside the system by enabling and disabling the hot airflow with the help of renewable energy resources.
- Renewable energy sources like solar PV or solar thermal can be integrated to control the temperature inside the polyhouse farming. The sensors like soil moisture sensor and lysimeter sensor can be used for the indirect measurement of volumetric water content in soil and the amount of actual evapotranspiration from the system.
- The nutrient of liquid or moisture inert materials is important for hydroponic farming. This can be achieved by maintaining the nutrient and oxygen level inside the farming house. For this, the oxygen extractor/separator (from air) filter, which operates using the renewable power source (solar/wind) can be preferred. The conductivity sensors and pH sensors are preferred to control the water reservoir.

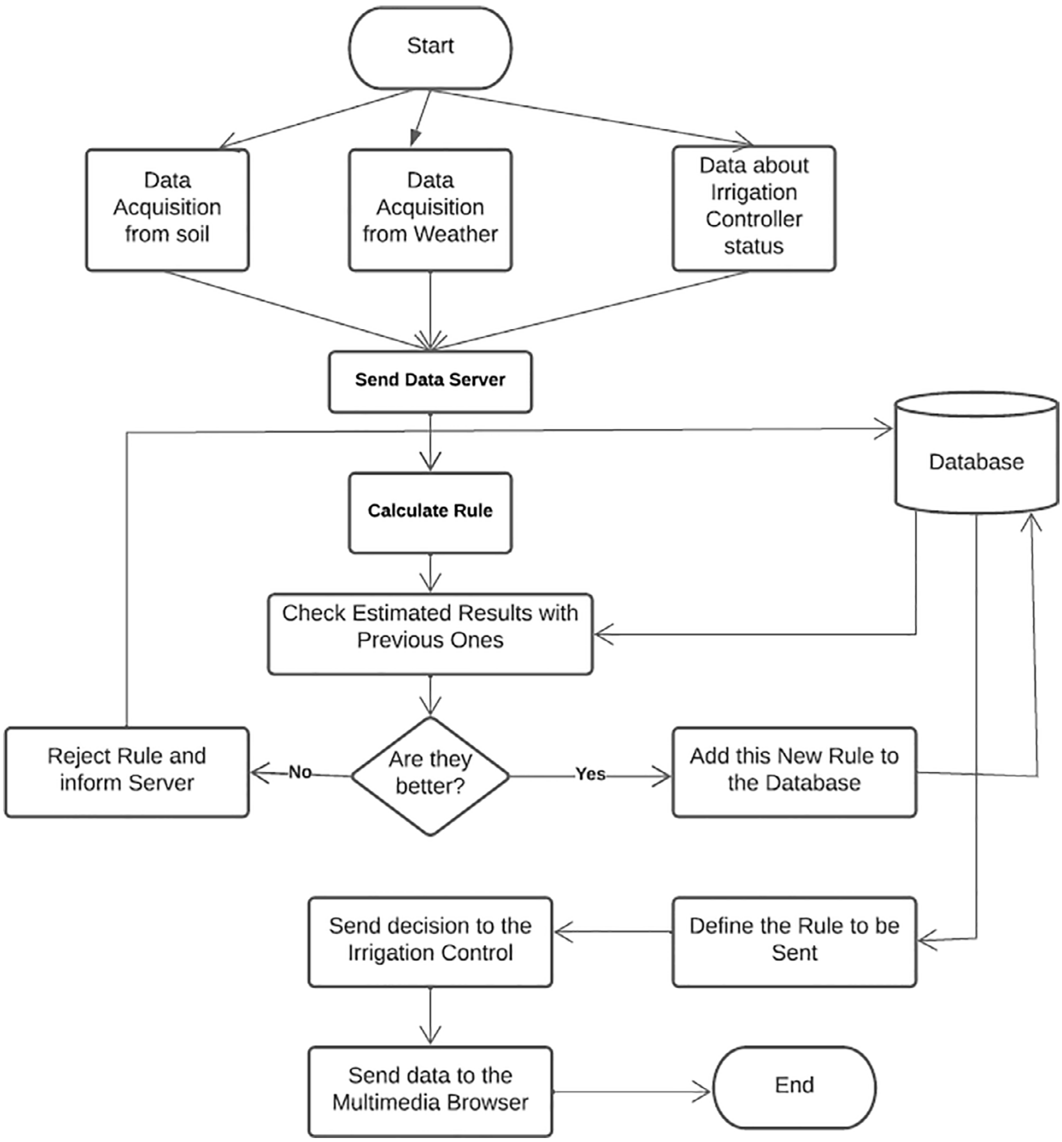

FIGURE 14.15
Flow chart for precision agriculture.

- Water management is the main advantage of drip irrigation. To control this with intelligent farming, the service cloud, service consumer, and a server is designed. Service cloud mainly deals with all sensor data and service consumers determine the relevant service by exploring the cloud, which ensures the minimal usage of water for irrigation.

It is thus concluded that each farming technique has unique functioning characteristics, and hence, the specific renewable energy and IoT can be preferred for the effectiveness of the farming and to improve the plant life, growth, and yield.

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15

SPLARE

A Smart Plant Healthcare System

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CONTENTS

15.1 Introduction

With the increasing use of the Internet of Things (IoT) in day-to-day life, objects around us are becoming "smart," such that they can transmit data and automate tasks without significant human intervention [1]. With applications ranging from something as small and simple as a smart clock to a smart home to even a large-scale variance in the form of smart cities, IoT is the future of this generation. As a part of one of the IoT-based solutions, the idea is to develop a smart plant healthcare system named "SPLARE," which is, as it sounds, an automated system to not just water plants in an efficient manner but also keep a check

DOI: 10.1201/9781003185413-15

of their health (including factors such as pH of soil and soil nutrient content). The aim is not inclined toward a large-scale smart irrigation system for agriculture purposes (which is already vastly used today) but toward a common man's domestic household. Growing plants at home for a wide range of purposes is a very common and popular phenomenon these days, and people admire such personal mini gardens, which form our target audience.

The intention is to tackle a variety of real-life problems. First of all, addressing an urgent issue of water scarcity. With existing irrigation systems such as drip irrigation and sprinkler irrigation, water wastage is reduced to a great extent in agricultural fields. However, with people's growing care and interest toward their own mini personal gardens or keeping plant pots, the agenda of water wastage kicks in on this level too. Imagine if thousands of such households are not able to efficiently control the amount of water needed for their plants? In case more than required water is used, along with affecting plants due to excessive moisture, some of this amount is wasted too. On the other hand, less than what is required can make the soil dry and consequently affect the plants and their growth [2]. With an efficient smart system, the agendas of soil moisture monitoring and creating an automated water supply are beautifully handled. Other than that, there shall also be a check on the surrounding temperature as well as the soil nutrient content of the plant. If either of these has any alarming or insufficient levels, an automated notification can be sent to the user stressing the current status and suggesting required actions (if needed) to restore a healthy habitat. By implementing this feature, a "smart watering system" can be extended to an overall smart healthcare system.

15.1.1 Objectives

The various objectives of this study include:

- To simplify and automate the plant watering system. The system will determine soil moisture content, temperature and humidity, amount of nitrogen, phosphorous, and potassium in the soil, pH of the soil, and the atmospheric pressure for each plant.
- A set of customized thresholds will be set for each plant for all the parameters mentioned above. Based on these thresholds, along with readings from respective sensors, the solenoid valve will be either turned on or off.
- Weather conditions can also shorten the life of the garden, as some crops/plants might perish due to a lack of rainfall, extreme heat, and humidity, among other things. We will also include the overall care properties and precautions of well-known plants, which will be displayed as a recommendation in response to certain parametric values, as a result enabling users to take better care of their plants.
- Along with other features, the system can be integrated with any cloud-based service like ThingSpeak, Firebase, or Blynk for easier tracking and user convenience.

15.2 Related Works

New systems based on sensors, software, and communication protocols for the automation of certain tasks have been developed using IoT concepts and knowledge [3]. One such exploration involved implementing an automatic plant irrigation system to control the measure of water utilizing Arduino Uno R3 and soil moisture sensors and controlling the system consistently via the observing station [4]. Another unique system from a study to monitor and operate a watering system employed an Arduino mega 2560 that has been modified with GSM technology, allowing the Arduino setup to receive/send SMS to/from the mobile phones of farmers/homeowners based on the soil's demand for water or the user's instructions [5]. However, these models took no measure to check soil fertility, nutrient levels, and environmental conditions. If we think about it, nowadays, water quality and pH play a major role in determining the soil's health – hence, indirectly, the plants' health. By not detecting these features such as the NPK value and temperature of the surrounding environment, direct watering based on just the soil moisture cannot just harm the plants but also affect soil dynamics. Moreover, extensive involvement of manual work in sending messages boils down to the problem of relying on the controller's remembrance, lethargy, and awareness for timely watering and maintenance of the plant.

The goal of another study was to create an autonomous watering system including hydroponic fertilizers, with the goal of developing, building, and testing a system that can automatically water plants, drain hydroponic nutrients, and fog the plant environment, as well as monitor the temperature in the plant house [6]. In this research, the model sprays the nutrients according to the needs of the plant. Again, here, there's a complete dependency on the "spray," a glitch in which can make the soil acidic/basic. The spray quantity, range, and management also add to the overheads. In our new model, we use a pH sensor to detect the pH value of the soil and all the details are sent using a third-party application. Hence, we get the information about the pH of the soil and all related information and if there is anything suspicious happening with our system, we can fix it.

One work was aimed at smart irrigation through intelligent control and decision-making based on precise real-time field data. It also included monitoring of the operations using an Android application [7]. There was indeed a very close application also explored here; dropping of moisture level would cause the Arduino board to activate a water pump. Sensing the water level in the water tank and sending this information to the microcontroller to fill the tank incorporated the benefit of reducing manual work as well as facilitate better watering. However, the problems that creep in here are mainly weather-related. Not accounting for the surrounding pressure, temperature and humidity can stultify the sensors' readings, often leading to the overflowing tank, water wastage, over or under watering the plants.

The primary goal of another system was to use color sensors to identify the levels of nitrogen (N), phosphorus (P), and potassium (K) in soil and adding appropriate quantities whenever required [8]. Similar implementation was depicted using optic sensors and Arduino Uno by passing a particular intensity of a particular wavelength through a soil sample and recording this intensity and shift in wavelength at the receiver end to determine the concentration of ions in the soil sample [9]. Although these implementations reduce the burden of measuring the amount of nutrients in the soil at a higher cost, there is still potential to give way to the use of unnecessary fertilizers in the soil and reducing the system's accuracy. This is because of sole reliance on NPK sensors, as well as not accounting for surrounding conditions. Moreover, failure to respond to the readings in an automated manner or linking the details to any cloud-based service makes the setup extremely inefficient and non-responsive. A soil moisture sensor was used to determine whether the watering pump should be turned on or off, controlled by Arduino, which would send a high or low signal response to the relay module [10, 11].

The threshold was set to 35% after certain computations, which was, however, only based on the readings from the soil moisture sensor and did not consider any other factors or sensors (as discussed earlier in this study). No application of any cloud-based system also made it difficult to track the estimated moisture level via any service. After considering other environmental factors and nutrients measurements, the appropriate threshold has been updated in this study.

A variety of sensors to evaluate soil and environmental variables was employed and compared to a threshold to determine whether the plant needs to be watered using a decision model, also considering many development circumstances for forecasting a plant's health and its maximum growth [12]. Including automatic start and stop of an electric motor based on a water threshold value, a flame detector with a buzzer to sound a warning in the event of a fire, etc., the computational complexity of the find-S algorithm was reasonably low, with a time complexity of $O(n)$. The same is applicable for our study with enabled cloud-based environment and services.

15.3 Methodology

15.3.1 System Architecture

Figure 15.1 shows the block diagram of the proposed system. It shows a basic data flow of the system and indicates how the various components are interconnected. NodeMCU facilitates as a central hub. All other sensors, actuators, and components are directly connected to it. Details of the components are discussed under Section 15.3.2.

Figure 15.2 shows the actual logic that's backing SPLARE. Once the system is initiated, data is collected and processed from all the concerned sensors. Based on this processed data, a preset threshold condition is checked and the solenoid valve is either turned on or off as required. Simultaneously, this processed data is uploaded to a third-party cloud-based service every few minutes so that end users can view it via a proper GUI.

15.3.2 Technical Specifications

Given below are the Specifications of the required components.

NodeMCU: NodeMCU is an open-source Wi-Fi development board on LUA. Its default version embeds an ESP8266, but other variants like ESP12 are also available. "MCU" in NodeMCU stands for Microcontroller Unit.

ESP8266: The ESP8266 is a low-cost Wi-Fi microchip that has full TCP/IP stack and microcontroller capabilities. The ESP8266 module enables any kind of microcontroller to connect to a single band Wi-Fi with a frequency of 2.4GHz, using IEEE 802.11 bgn.

Soil Moisture Sensor: A soil moisture sensor is used to measure the water content in the soil. Soil moisture sensors have two probes, which are responsible for the flow of current through the soil. Knowing the values of potential difference and amount of current flowing, the resistance of the soil can be calculated. This in turn, helps to measure the moisture level of the material (or soil in this case).

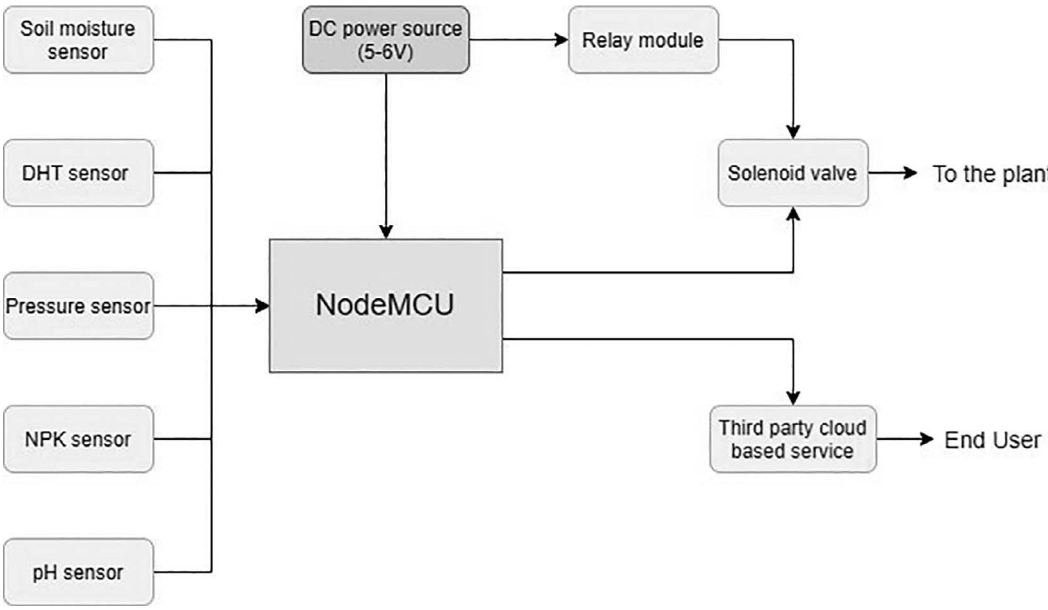


FIGURE 15.1
Block diagram of the proposed system.

Temperature and Humidity Sensor: The principle by which temperature and humidity sensors work is through changes in electrical currents due to changes in humidity and temperature in the air. A capacitive humidity sensor measures relative humidity. This is achieved by placing a thin strip of any metal oxide between two electrodes. The metal oxide's electrical capacity is altered with the atmosphere's relative humidity.

NPK Sensor: Used for detection of Nitrogen, Phosphorus, and Potassium nutrients of soil by using optical transducers. This optical transducer is implemented as a detection sensor consisting of three LEDs as a light source. The photodiode is used as a light detector. The wavelength of each of the LEDs is chosen to fit the absorption band of each compound.

pH Sensor: The working principle of this sensor depends upon the amount of exchanged ions from a sample solution to the inner solution, which is a pH 7 buffer.

Pressure Sensor: This sensor works by converting the pressure of the atmosphere to analog electrical sensors. The sensor is initially calibrated to a base value. Once a change in pressure is detected, an electric signal is generated. The magnitude of this signal helps in measuring the amount of change in the pressure.

Relay Module: Relays are basically electric switches that use electromagnetism to convert small electrical stimuli or pulses into larger electric currents. These conversions occur when electrical inputs activate an electromagnet inside the relay module to either form or break an existing electric circuit.

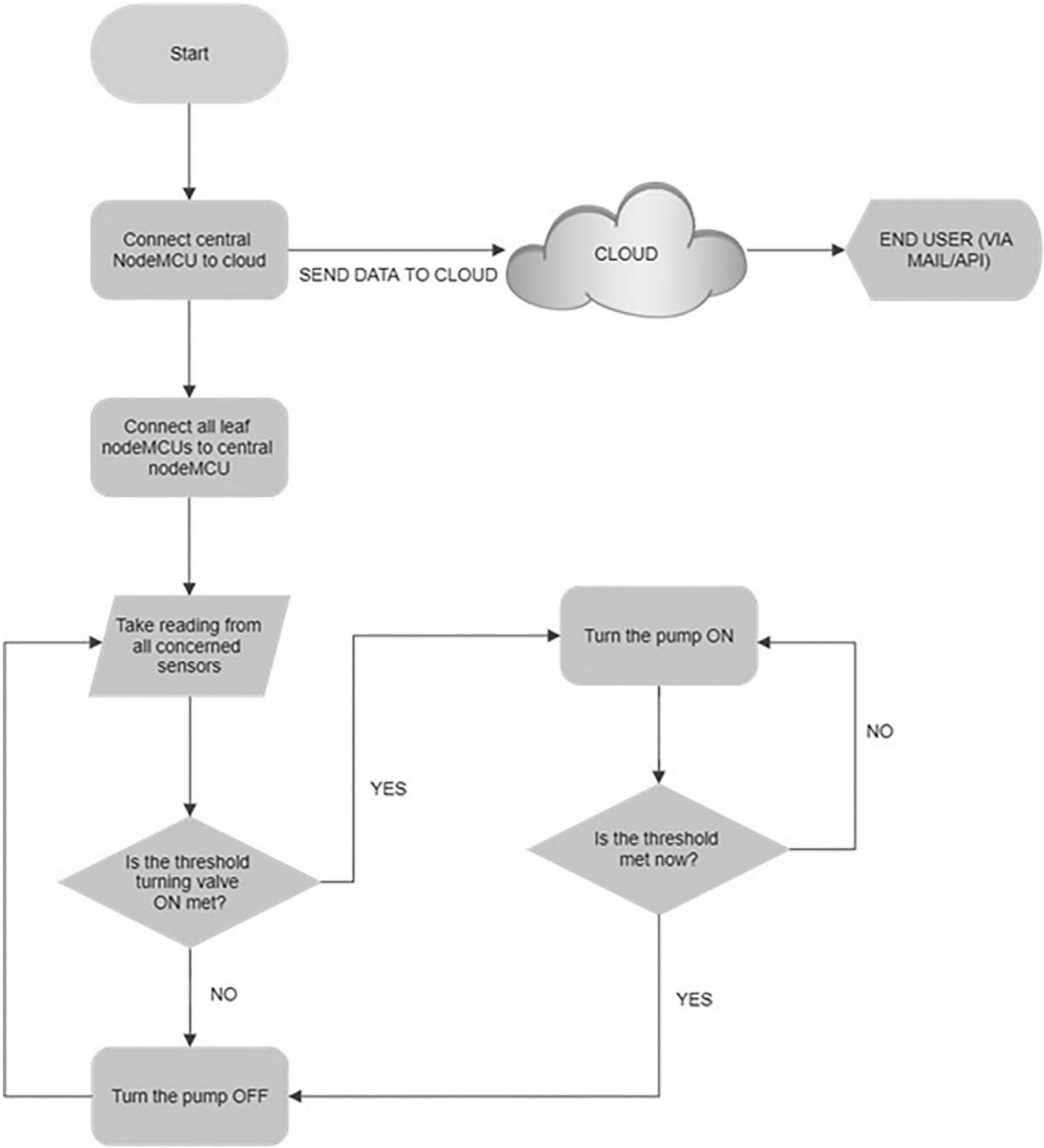


FIGURE 15.2
SPLARE working model.

Solenoid Valve: A solenoid valve is an electrically controlled valve. It is used to regulate the flow of water by applying a voltage over the coil. Due to the force on coil created by EMI, this coil is lifted up and the valve opens so that the liquid can flow through. Solenoid valves are also sometimes called electromagnetic valves.

Water Pump: The use of the water pump is to supply water to higher grounds in case the water source is at a comparatively lower level, as gravity would not help in such cases.

15.3.3 Virtual Simulation

Major concerns in the existing solutions were analyzed and worked upon to avoid the same. Before actually implementing hardware circuits, these were tested in a simulator (Proteus 8) and the overall design is shown in Figure 15.3. This was done as, even if there is a minor fault in the circuit, it can damage the microcontroller and other sensors, thus shorting them out. Initially, individual sensor circuits were built and tested. This includes the DHT (digital humidity and temperature) sensor, NPK (nitrogen, phosphorous, and potassium) sensor, pH sensor, soil moisture sensor, and pressure sensor (barometer based). Once all individual circuits worked as expected, a final circuit was built. This circuit consisted of all the sensors and other required components such as a solenoid valve and relay module. All the circuits which are a part of the entire setup have been developed and included below for reference.

There were certain changes that had to be made in the simulation circuit due to the unavailability of a few sensors and components in the software simulator used:

- Arduino Uno was used for simulation as NodeMCU is not supported by Proteus 8.
- Instead of actual NPK, pH, and soil moisture sensors, digital potentiometers were used for simulation. This was done due to the unavailability of support for these sensors in Proteus 8.

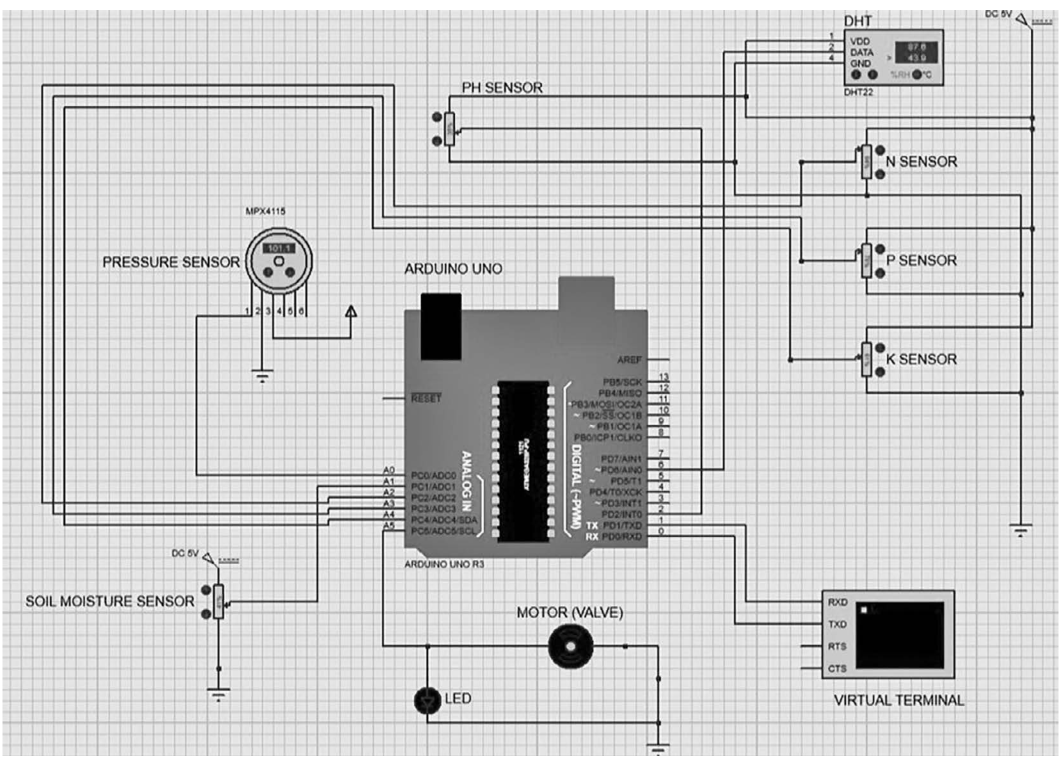


FIGURE 15.3
Proposed system circuit design.

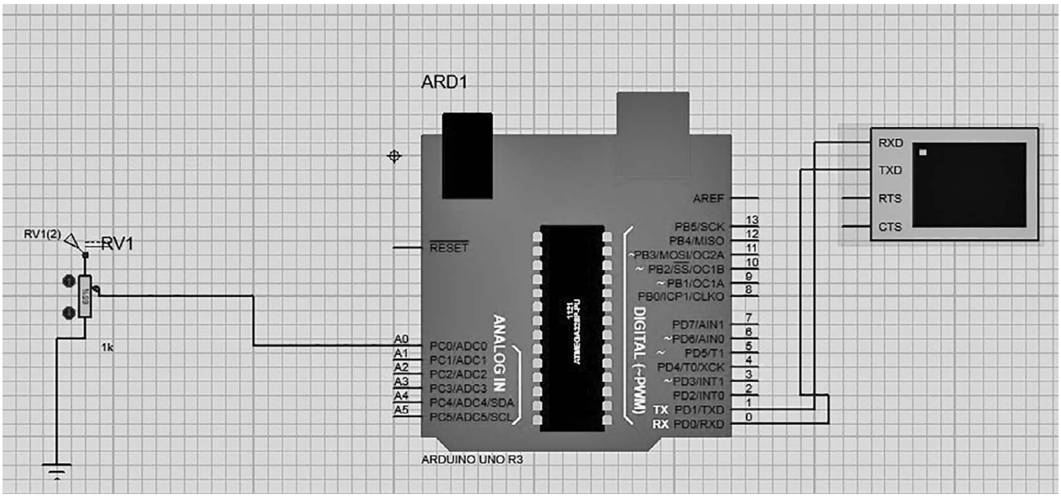


FIGURE 15.4
Soil moisture sensor virtual circuit.

- Instead of a solenoid valve, a DC motor was used in the simulation. This was done as Proteus 8 has no support for solenoid valves.

It was ensured that these changes had similar results as actual sensors and components.

Figure 15.4 presents a clear view of the connections and flow, i.e., virtual circuit of soil moisture sensor implemented using Proteus 8 software.

15.4 Hardware Implementation Procedures

The entire virtual simulation has to be replicated for the hardware implementation. As a sample, a smaller module with just soil moisture sensor and solenoid valve will be discussed in this section. This will help in making the rest of the implementation clear and easy to execute.

After collecting the equipment required, the circuit module has to be built (see Table 15.1). Soil moisture sensor is analog in nature. Hence, the data pin should be first connected to a potentiometer module and then to analog input of the microcontroller (A0 pin on NodeMCU). The NodeMCU (see Figure 15.5) has just one analog in pin, which might

TABLE 15.1
Connections to/from NodeMCU

Pin on NodeMCU	Connection
A0 (Pin: A0)	Input from soil moisture sensor
3V3	To Vin Pin on soil moisture sensor unit
GND	To GND Pin on soil moisture sensor unit
D1 (Pin: GPIO 5)	Control relay module
3V3	To Vin Pin on relay module
GND	To GND Pin on relay module

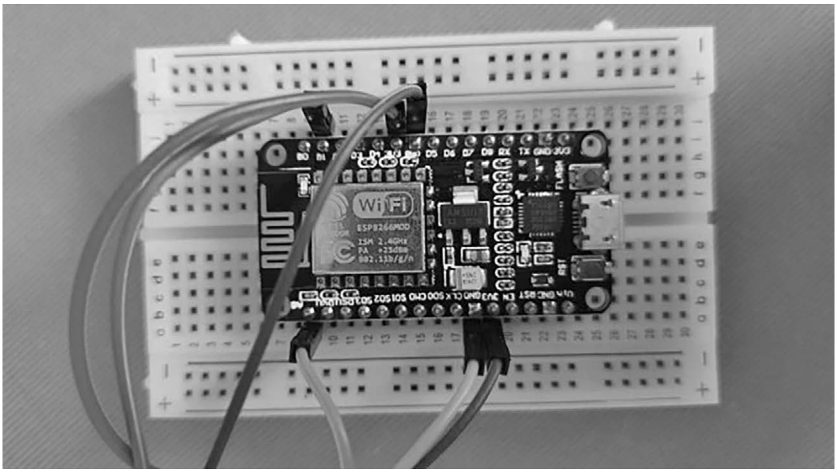


FIGURE 15.5
NodeMCU as microcontroller.

already be occupied by the soil moisture sensor (see Table 15.3). Hence, the alternative is to get a multiplexer that could serve as an extension to the analog in pin (for connection with other sensors).

Once the sensor is in place, the next step is to connect the solenoid valve to the NodeMCU, which will serve as a water outlet for plants. But as the node is capable of handling just 3.3V in output pins, a relay module is used to operate the solenoid valve, which requires an external power source of about 6V (see Table 15.2). After all the connections are set up,

TABLE 15.2
Connections to/from Relay Module

Pin on Relay Module	Connection
Vin (input side)	3V3 on NodeMCU
GND (input side)	GND on NodeMCU
Data Pin (input side)	D1 (Pin: GPIO 5) on NodeMCU
Neutral (output side)	+ve terminal of solenoid valve[a]
NO (normally open Pin, output side)	–ve terminal of solenoid valve[a]

[a] The terminals of the solenoid valve are not polarity sensitive. Hence these can be exchanged

TABLE 15.3
Connections to/from Soil Moisture Sensor Unit

Pin on Soil Moisture Sensor	Connection
Vin (potentiometer output side)	3V3 on NodeMCU
GND (potentiometer output side)	GND on NodeMCU
Neutral (potentiometer input side)	Any terminal of soil moisture sensor[b]
Positive (potentiometer input side)	Any terminal of soil moisture sensor[b]

[a] Make sure the connection is via analog input pin only (A0) and not digital input pin (D0).
[b] The terminals of the solenoid valve are not polarity sensitive. Hence these can be exchanged

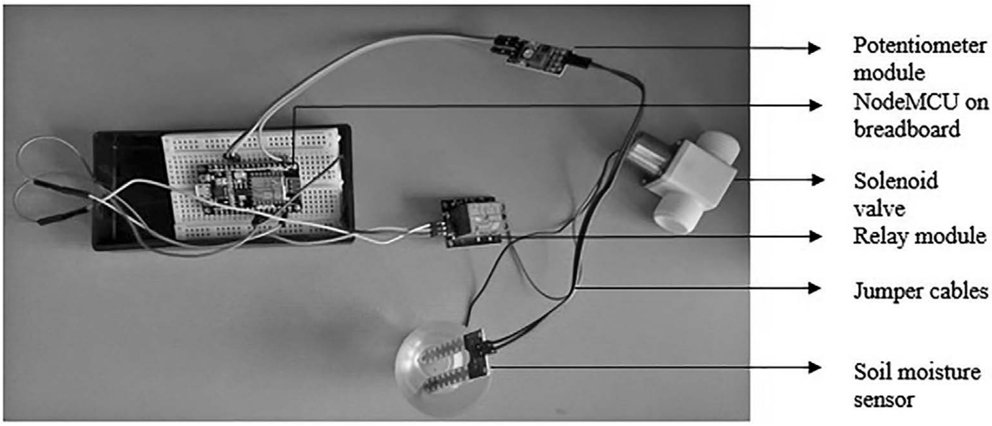


FIGURE 15.6
Soil moisture sensor–based hardware circuit.

verify the Arduino sketch and upload it to NodeMCU. The default baud rate is serialized at 9600. This has to be changed to 115200 to avoid garbage values and attain complete functionality of the system.

All the setup described was for one single module (see Figure 15.6). Figure 15.6 also contains all the components used in the setup and are labeled for reference. Eight such modules were implemented for eight different plants (see Figure 15.7). The proper working of the entire setup would guarantee that the system will work well for a mini-garden or a number of potted plants in an individual's house. The individual modules work

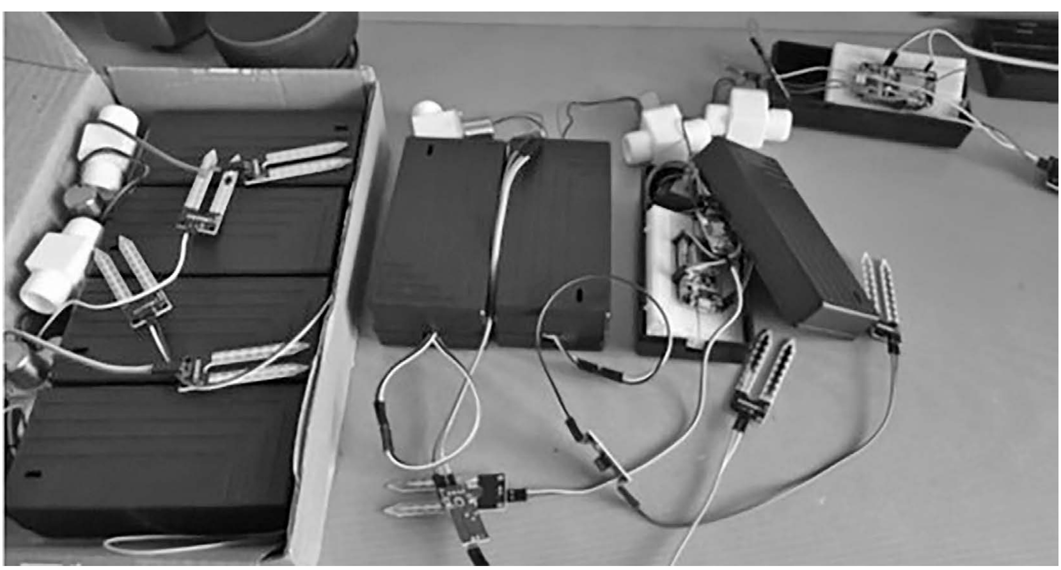


FIGURE 15.7
Replicated setup for eight different plants.

independently, hence, not affecting the working of other modules. Similarly, any damage in one particular module will not affect the others. The threshold was also dynamically set as per plant requirement.

Following are the tables that show all the connections in this system on NodeMCU, relay module, and soil moisture sensor unit.

Images of the working hardware for this smaller module are shown next in this section. These components were used to build a working model for detecting soil moisture and auto-watering different plants based on that. For the implementation of the entire hardware module, connections and other components shall be added to this smaller module itself.

As already mentioned, the soil moisture sensor is connected to the NodeMCU on the breadboard via the potentiometer. Similarly, the solenoid valve is connected via the relay module. This valve has two openings:

- First opening (from which water will enter) shall be connected to a water source with a pipe (preferably to a tap at a level higher than that of the plants if water pump or motor is not used, so that gravity assists the flow of water). However, in the case of a system containing multiple plants (like the one in this study), it should be connected to a central or branched pipe system, arranged using fittings/adapters and various lengths of the pipe, which in turn is connected directly to the water source.
- The second (water outlet) is to water the plants using another piece of pipe.

By using individual setups for each plant, they will be watered based on their characteristic requirements. The opening or closing of one valve will not affect that of another.

15.4.1 Power Supply and Testing

One major challenge would be the power source. As USB power sources and batteries can't be used everywhere, an alternative was adopted for individual powering. The same has been explained here:

- AC to DC step-down converter was used to convert 240V AC to 5V DC.
- A voltage stabilizer and regulator were further attached to maintain max output potential difference at 5V and cap the current at 2A.

In this case, it would be possible to create a steady-state power source (i.e., directly from AC Mains supply), instead of relying on batteries and using cables. This would simplify the circuit as well as solve the issue of power running short.

NodeMCUs are highly electrostatic sensitive devices. Hence, just a sprinkle of water could damage it beyond repair. To overcome this problem, each module was sealed in a plastic enclosure to prevent water and moisture damage (see Figure. 15.8).

Once this was done in the above setup and there was a constant power supply, the only thing left to be done was to attach individual modules to plants and turn them on and see plants get perfect care without human intervention. Figures 15.9–15.11 show the testing of the setup. For this testing purpose, water in a container has been used.

The relay module has LED indicators (just 1 in this case). The default setting for relay is low logical output, indicating that the valve is closed and hence LED is not turned

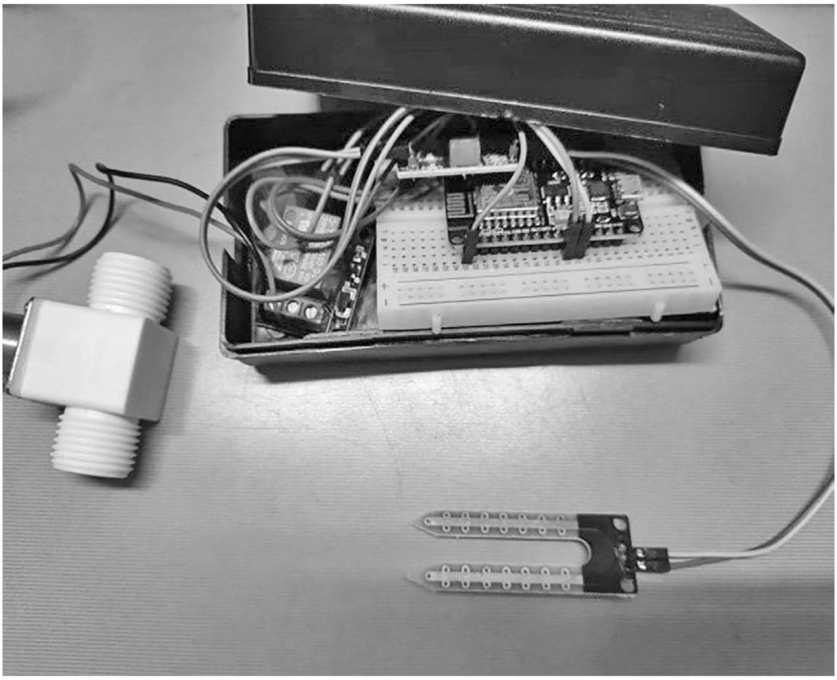


FIGURE 15.8
Setup inside each plastic encasing.

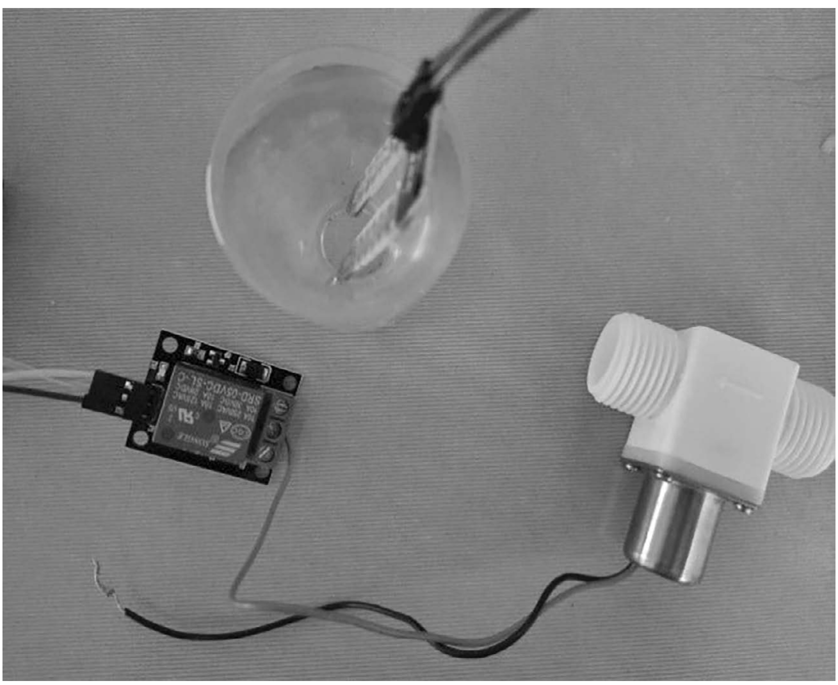


FIGURE 15.9
Valve closed (LED off).

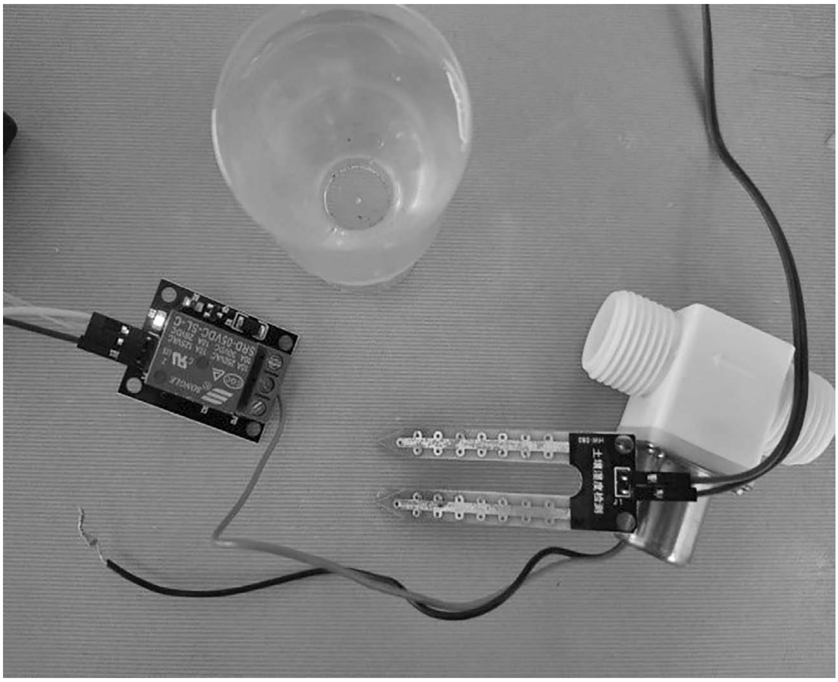


FIGURE 15.10
Valve open (LED on).

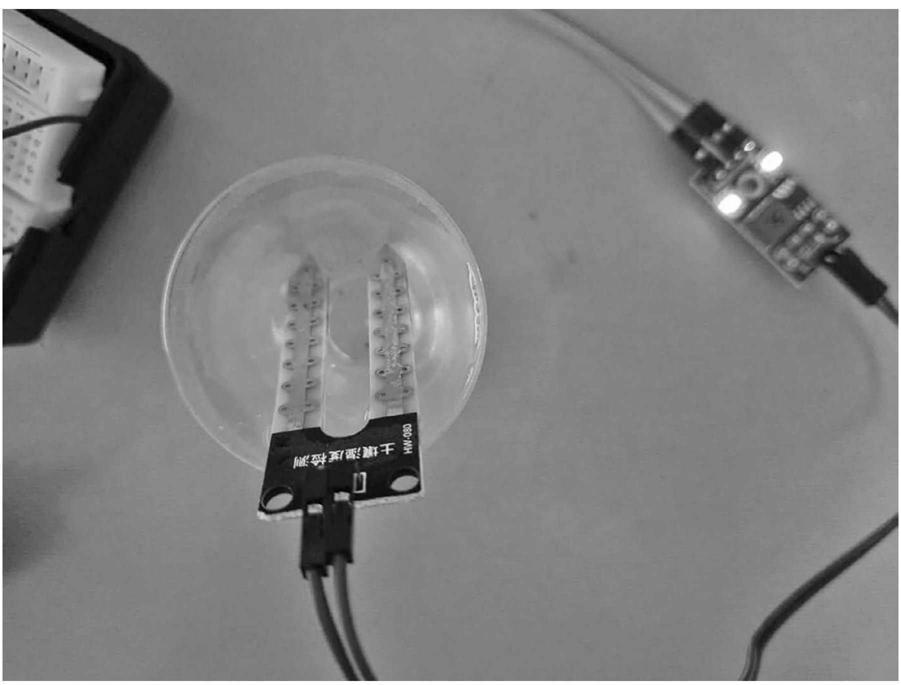


FIGURE 15.11
Working state of soil moisture sensor.

on (see Figure 15.9). When the relay has high logical output, this LED is turned on (see Figure 15.10), indicating that the valve is open (or powered). The potentiometer also has LED indicators. These LEDs are turned on when the analog sensor attached is working correctly (Figure 15.11).

15.4.2 Connecting to Cloud-Based Service

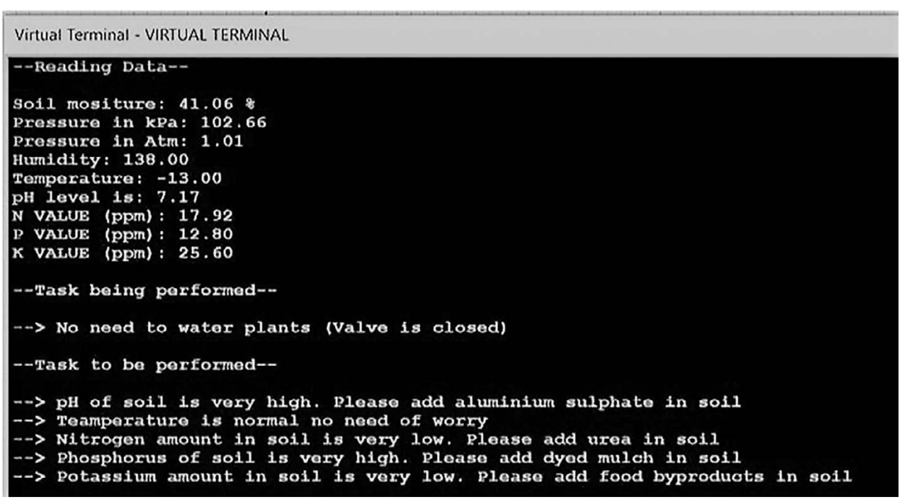
When the NodeMCU is uploaded with code and starts working independently, there is no way for the user to monitor the actual soil moisture level and if everything is working as expected. To tackle this problem, any third-party application which enables connecting IoT devices and writing data directly to the cloud can be used. This ensures that the actual moisture level and status of the system can be viewed by the user from anywhere around the world. The following can also be implemented by forming a local cluster and only the cluster head will send data to the cloud. This is more resource critical and efficient than all nodes sending data at the same time, but equally complex too.

One such application – ThingSpeak, was used in this scope (see Figure 15.15).

15.5 Results and Discussion

The screenshots for the simulations conducted and corresponding outputs obtained are given below. Figure 15.12 shows the output of the proposed system design (see Figure 15.3). Table 15.4 shows the output of each sensor in the proposed system design (results directly obtained from software simulation). This includes pH sensor, soil moisture sensor, NPK sensor, pressure sensor, and DHT sensor.

Table 15.4 shows the output of all the sensors used for simulation. Each of these readings is recorded after a particular time unit (1 time unit = 10 s here, hence total time of observation = 10 × 6 seconds = 1 min) for one particular sample.


```
Virtual Terminal - VIRTUAL TERMINAL
--Reading Data--

Soil mositure: 41.06 %
Pressure in kPa: 102.66
Pressure in Atm: 1.01
Humidity: 138.00
Temperature: -13.00
pH level is: 7.17
N VALUE (ppm): 17.92
P VALUE (ppm): 12.80
K VALUE (ppm): 25.60

--Task being performed--

--> No need to water plants (Valve is closed)

--Task to be performed--

--> pH of soil is very high. Please add aluminium sulphate in soil
--> Teamperature is normal no need of worry
--> Nitrogen amount in soil is very low. Please add urea in soil
--> Phosphorus of soil is very high. Please add dyed mulch in soil
--> Potassium amount in soil is very low. Please add food byproducts in soil
```

FIGURE 15.12
Virtual terminal output of the final circuit.

TABLE 15.4
Output of All the Sensors Used for Simulation

Time Unit	pH Sensor Output	Soil Moisture Sensor Output	NPK Sensor Output (N, P, K)	Pressure Sensor Output (KPa, Atm)	DHT Sensor Output (humidity %, temperature)
1	7.00	594.00	676, 502, 604	102.55, 1.01	57.0, 24.00
2	7.00	594.00	676, 481, 604	102.66, 1.01	60.0, 25.20
3	7.00	604.00	674, 472, 626	102.88, 1.02	62.0, 26.30
4	7.00	666.00	646, 355, 475	102.66, 1.01	57.0, 24.50
5	7.00	686.00	676, 471, 600	102.88, 1.02	60.0, 20.00
6	7.00	669.00	670, 460, 600	102.50, 1.01	65.0, 22.00

As already established that soil moisture sensor is analog in nature, the output varies for each sensor and has to be calibrated as per requirement. In this case, the range for soil moisture sensors varies from 0 to 1024. The same applies to NPK sensors as well and they have to be calibrated before use. Pressure sensors, pH sensors, and DHT sensors usually do not require any further calibration and can be directly used.

In Figures 15.13 and 15.14, the virtual terminal of the actually implemented circuit can be seen (output of the hardware implementation explained above). In Figure 15.13, the status of the valve is closed as soil moisture level is > 40%, whereas, in Figure 15.14, it is open as soil moisture level is <40%.

Finally, Figure 15.15 shows the dashboard of the third-party cloud-based service (ThingSpeak here). This API is set up for four different plants (to show a sample). Each of them uses a separate channel. The readings from the soil moisture sensor and the status

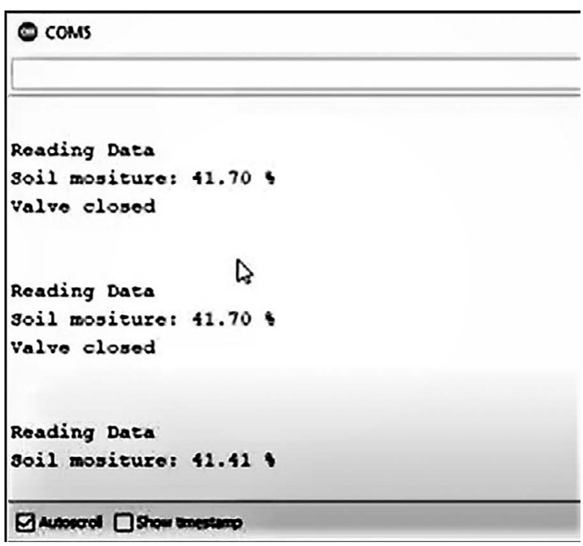


FIGURE 15.13
Serial monitor (valve closed).

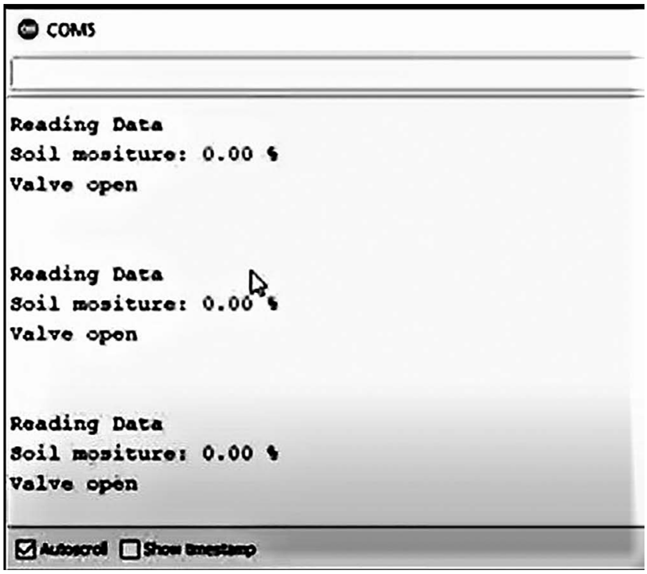


FIGURE 15.14
Serial monitor output (valve open).

of the solenoid valve will be updated here once every few minutes (can be customized) and can be viewed from any device with internet connectivity and authorization.

15.5.1 Analysis

After getting all the required levels from respective sensors, we can come up with the following inference and analysis.

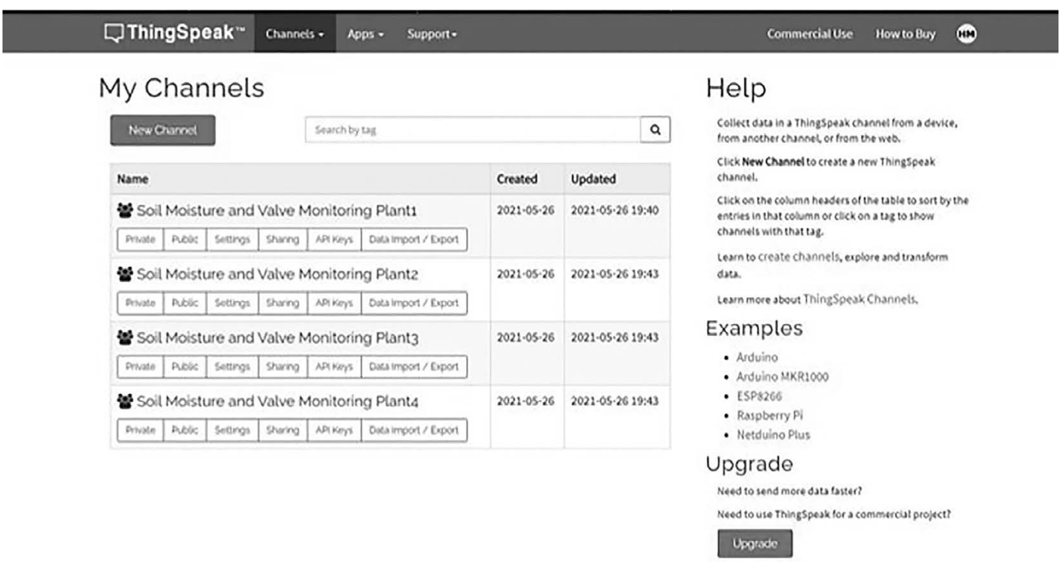


FIGURE 15.15
Dashboard of ThingSpeak.

TABLE 15.5

Results Obtained from Plant One

Soil Moisture Reading	Pressure in kPa	Pressure in Atm	Humidity %	Temperature	pH Level	N Value (ppm)	P Value (ppm)	K Value (ppm)	Valve Status
39.06%	102.66	1.01	63.8	26	7.17	17.92	12.8	25.6	On

Table 15.5 depicts a set of values obtained from the first plant.

- The soil moisture sensor reads 39.06%. So as per the thresholds set (which is 40% in this case), the solenoid valve should be turned on (as was observed).
- Humidity and temperature also play a slight role in determining whether the valve should be turned on or not. For example, if the temperature reading is too high or it crosses a certain threshold, then the valve should be turned on (considering a faster rate of evaporation).

Considering these two points, we can conclude that a combination of temperature reading and soil moisture reading should be used to determine the status of the valve.

Now, the other parameters will be used in determining the general health of the plant and what action needs to be taken.

- In this case, the pH of the soil was very high. Hence, to neutralize it, a suggestion that can be provided is: add aluminum phosphate to the soil.
- The N valve (i.e., the nitrogen content of the soil) was found out to be very low. Hence, a suggestion that can be provided is: add urea to the soil.
- The P valve (i.e., the phosphorus content of the soil) was found out to be very high. Hence, a suggestion that can be provided is: add dyed mulch to the soil.
- The K valve (i.e., the potassium content of the soil) was found out to be very low. Hence, a suggestion that can be provided is: add food byproducts to the soil.

These suggestions can directly be sent to the user via an API or a cloud-based platform that supports IoT (like ThingSpeak or Blynk), thus notifying the user if an action needs to be taken for a particular plant.

Consider another set of values for analysis, recorded from a different plant at the same time (as the first case) and the same is listed in Table 15.6.

Here, the current soil moisture level is at 46%, and hence the valve status is off (which was expected as the threshold was set to 40%). Other parameter readings such as pH valve, NPK values, and humidity and temperature were found out to be similar to the first set of readings. Hence, we can expect a similar kind of inference for the same. Also, the actions required and suggestions would be similar to that of the initial set of readings.

TABLE 15.6

Results Obtained from Plant Two

Soil Moisture Reading	Pressure in KPa	Pressure in atm	Humidity %	Temperature	pH Level	N Value (ppm)	P Value (ppm)	K Value (ppm)	Valve Status
46%	102.69	1.03	63.5	27	7.2	18.12	13.1	26.05	Off

15.6 Conclusion

Watering the plant and delivering information about the surrounding environment and soil nutrients could be accomplished by an autonomous watering system coupled with IoT platforms. A microcontroller (NodeMCU) is used to evaluate and convert readings from sensors into human-readable form. The entire system is programmed in such a way that the process of taking input of few parameters and deciding whether to start the valve or not is completely automated. With the use of NPK sensors, all essential soil radicals can be measured. Hence, the user has accurate real-time data of which fertilizer is currently required by the plant or if any other action is needed to maintain a healthy growing environment. This also solves the problem of adding more than required fertilizers which can hinder plant growth. In a similar way, the data from the pH sensor can be used to add an appropriate neutralizing agent if the pH of the soil is either too high or too low.

With slight modification, the current idea can also be exploited to determine whether the current soil type is suitable for a particular plant or not. To further enhance the system, small units consisting of fertilizers can be attached. With the help of this addition, the user needn't even worry about checking the nutrient content of soil and adding required fertilizers as the system will be able to do it as and when required.

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