Chapman & Hall/CRC Internet of Things

CLOUD IoT SYSTEMS FOR SMART AGRICULTURAL ENGINEERING

Edited by
Saravanan Krishnan
J Bruce Ralphin Rose
N R Rajalakshmi
Narayanan Prasanth

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Cloud IoT Systems for Smart Agricultural Engineering

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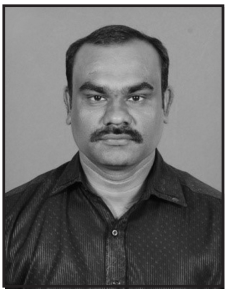
Preface

Despite people's perception of the agricultural process, the fact is that today's agricultural industry is more data centric, reliable, and smarter than ever before. The purpose of this book is to cover the need for smart agriculture and aid in the vetting and selection of research in smart agriculture. Recently, cloud computing, IoT, big data, machine learning, and deep learning technologies have been initiated to be adopted in smart agricultural engineering. This book deals with all aspects of smart agriculture with state-of-the-art cloud IoT systems in a complete 360-degree view spectrum. It presents the rapid advancement of the technologies in the existing agri-model by applying IoT techniques. Novel architectural solutions in smart agricultural engineering are the core aspects of this book. Several use cases with IoT and smart agriculture will also be incorporated. This book can be used as a textbook and a reference book. Readers will walk away with a deep understanding of complementary features of the cloud and the IoT paradigm in smart agriculture applications.

Automated farming is an engineering problem to be solved with agro-technology. This book deals with the automation of the data collection process using agricultural drones and robots, extending remotely obtained parameters of crops, and accessing real-time data from any device at any time. Precision agriculture is the application of information technologies. This edited book comprises the concept of precision agriculture to make the practice of farming more accurate and control inter- and intrafield variability of crops. The book also presents agro-IoT tools, open-source platforms, protocols, and techniques that will help researchers and students who are interested in developing precision farming applications.

The book includes the concepts of urban and vertical farming using agro-IoT systems and renewable energy sources for modern agriculture trends. Real-world challenges, complexities in agro-IoT and its advantages will also be discussed. The wide variety of topics presented herein make this book ideal for students, academicians, and researchers who are studying and implementing cloud IoT systems for smart agricultural engineering.

About the Editors



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He has also trained and interviewed engineering college students for placement training and counseling. He has conducted many ISTE workshops in association with IIT Bombay and IIT Kharagpur. Also, he has conducted NPTEL workshops for faculty and students. He is also a coordinator for the Indian Institute of Remote Sensing (IIRS) Outreach Programme. He has delivered more than 50 guest lectures in many seminars/conferences in reputed engineering colleges.

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1

Cloud IoT Applications in Agricultural Engineering

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CONTENTS

1.1 Introduction

Agriculture is the world's primary source of income, and it also contributes to the size of the nation's gross domestic product (GDP). Because the world's water resources are dwindling, it is critical to use proper irrigation system. Drip irrigation, also known as micro-irrigation or localized irrigation, allows water to drip slowly to plant roots via a network of pumps, pipes, or emitters, which prevents soil erosion and saves water and fertilizer. Micro-irrigation is a method of artificially supplying water to a plant's root system [1]. In dry regions and during periods of inadequate precipitation, irrigation has been used to help crop growth, maintenance, and re-vegetation of upset soils. Irrigation aids crop production by protecting plants from frost, suppressing weed growth in grain fields, and delaying soil solidification. Irrigation systems are also used for dust suppression, waste removal, and mining. Watering jars, water channels that had to be manually opened and closed, or rucksack sprinklers were all used in the past for irrigation [2]. In this procedure, a lot of water is wasted. There is

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TABLE 1.1

Comparison of Traditional and Automated systems

Agriculture System	Traditional Irrigation	Automated Irrigation
Workers	Yes	No
Water use	High	Low
Field surveillance	High	Low
Data collection	Low	High
Time	More	Less
Cost	High	Low
Yield	Low	High

a need to improve the existing or older irrigation systems. To improve crop water usage, an automated irrigation framework should be developed. An intelligent automatic irrigation system must include all the components necessary to monitor and regulate the amount of water available to the plants without requiring human intervention. In today's world, the majority of countries lack sufficient human resources in agricultural areas, which has a negative impact on the growth of non-industrial countries [3]. Thus, the present situation is an ideal opportunity to automate the area in order to overcome this problem. This system is primarily based on limiting labor and hardware costs, which are both fair for all users. The dirt level, dampness, and other elements must be physically estimated by an experienced person in the previous conventional system (Table 1.1).

The person should inspect the condition of the farm and manually turn on/off the engine to water the field. A person will check the water level in the tank, and they will have to start the engine each time to fill the tank. The methods of connecting people and the climate were devised by micro-irrigation systems using automation with or without Internet connectivity. Farmers will be able to control water system siphons and valves with the tap of a button in their phones, allowing them to monitor moisture levels and the status of water system valves from anywhere on the planet. Android phones are available and many people enjoy them due to their simplicity of use and low price. Only authorized users can monitor water system instruments and segments through a web-based remote water system robotization platform. Almost every Android phone has Wi-Fi, which will help farmers access the water system framework from their homes or from anywhere on the planet. The Wi-Fi protocol 802.11 has a low energy use, which is essential for battery life, as well as a safe convention to ensure privacy and the use of a flexible Android application with biometric and hidden password protection for controlling water device siphons and valves through the web [4]. The framework can be programmed to activate events under specific conditions, allowing the user to more flexibly monitor watering to the plants. Over the last decade, hardware cost reductions have aided the emergence of the Internet of Things (IoT) and its numerous applications. The framework proposed in this chapter employs data and correspondence advancements to allow users to examine and consider data collected by various sensors. Stickiness, temperature, dampness, and light are all measured using sensors. A mircoregulator receives feedback from sensors [5]. The mircoregulator sends the information to the user in a sequential manner. Sensor value icons will be displayed on the PC/smartphone side, and users can use the icon to turn on/off irrigation devices [4]. The data is sent to and managed by the user, who stores the sensor data in a database, allowing for simple and adaptable data transmission. Better farming practices, fewer water storages, and the development of a modern agricultural framework for the country are all possible outcomes of the anticipated framework [6]. Industrialists and analysts are working to create efficient and cost-effective automated mechanisms for monitoring various devices such as lights, fans, and climate control systems based on demand [7]. Automation saves energy, water, and a significant amount of waste [8]. Both water and manure are used in the trickle irrigation system. Water is steadily irrigated to the plants' underlying roots via thin tubes and valves, which is an excellent technique for watering plants. To avoid water logging, there should be no waste in the fields or pot plants, which could affect profitability [4]. Currently, there are frameworks for automatic trickle irrigation that water plants based on soil moisture, pH estimation, temperature, and light [9]. In large agricultural fields where crop efficiency is critical, these boundaries are crucial. Our proposed irrigation framework would be useful in small zones such as office buildings, house gardens, and so on, where watering plants at average stretch causes problems. This chapter demonstrates how to build a smart trickle irrigation system for watering plants using the Raspberry Pi and Arduino microcontrollers. The system is remotely managed via XBee, and automation is accomplished using the Python programming language. The framework requires no further maintenance after installation and is simple to use. Using intelligent IoT-enabled inlet gates capable of communicating with surrounding regulators, only the necessary amount of water is supplied to farms based on the sensor-based parameters, which is a wireless sensor network (WSN) device based on a microcontroller that allows communication between farm- and channel-level components [4].

1.1.1 Basic Architecture of IoT-Based Automated Irrigation Systems

Sensors for measuring soil moisture, humidity, and temperature are used to monitor the field in real time and send data to the "NRF24LO1" transmitter and receiver, as well as the webserver, through an "Ethernet connection" on the receiving end. A web application is used to evaluate and analyze humidity, temperature, and moisture data and threshold values. The server is responsible for deciding whether or not to water the plants [10]. The motor is turned on when the value falls below the threshold, and it is turned off when the value increases above the limit. The system architecture is shown in Figure 1.1.

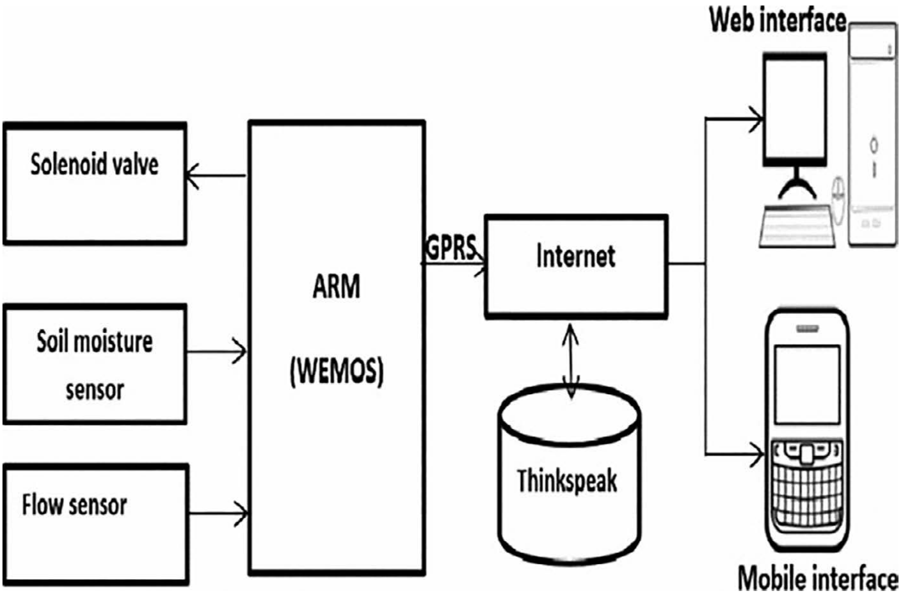

FIGURE 1.1
System architecture IoT-based automatic irrigation system [10].

Before being deployed in the field and put in a box, each sensor is connected to an "Arduino microcontroller" and programmed [11]. Two probes of the soil moisture sensor are used to pass current through the soil when the sensor is inserted into the soil. A moist soil has less resistance to current flow, while dry soil resists current flow and allows less current to pass. This resistance value is used to detect moisture. For humidity and temperature, a "DHT11" sensor is also used. Temperature and relative humidity are proportional; as the temperature increases, the relative humidity rises, and vice versa, and their readings are communicated to the user. For light detection, a "Light Dependent Resistor, LDR" is used, with resistance decreasing as light intensity decreases, and vice versa. To measure this resistance, a "voltage divider circuit" is used. The "NRF24L01 module," which has a 2.4 GHz transceiver with a "Nordic semi-conductor" and a data transmission rate of 256 Kbps/1 Mbps/2 Mbps and a voltage requirement of 1.9–3.6 V, is used for wireless data transmission [12]. The receiver and transmitter modules are both attached to "Arduino" boards, with the transmitter in the field and the receiver in the unit. An ID is specified for configuration, which is the destination address, and this is the same for all field transmitters. The webserver and the device's receiver are linked via Ethernet, an IEEE-802.11 standard for computer local area networks. The receiver receives data from the transmitter and transmits a request to the webserver through an Ethernet cable connected to the Arduino microcontroller, which assigns a specific IP address in the network range and transmits the request to the webserver. The data is saved in the database because the PHP script configures the webserver to insert values as required. The obtained sensor data is compared to threshold values that differ depending on the crop during processing [13]. They can also adjust due to climatic changes, so both of these variables are considered when calculating threshold values. The motor turns on automatically if the value of soil moisture falls below the threshold limit, or the farmer may turn it on using a phone or web application via relays, in which case control is moved from the web app to the electric switch.

1.2 Micro-Irrigation System with Internet Connectivity

Automation arrangement depends on two types of mircoregulators: the Raspberry Pi 3 and Arduino Mega. These are chosen as mircoregulators due to their computational capacity, cost, and ease of use. The variable boundaries are checked on a regular basis with various sensors, and depending on the crop type, suitable and specific irrigation is performed. Figure 1.2 outlines the conceptual work's significant empowering factors. The first

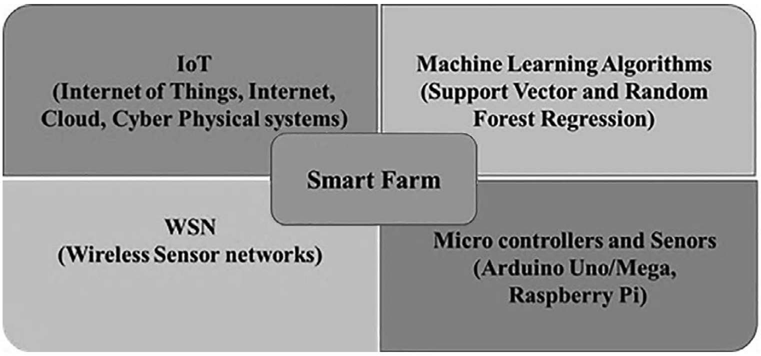

FIGURE 1.2
Conceptual parameters of a smart farm [14].

step in implementing a smart irrigation system for farm automation is to set up a remote sensor network field, in which each hub is encased in a Wi-Fi module and relays information over a typical worker, from which an automated Python programming can continue surveying the data and then send an alert/start signal for the required operation [14]. The general globally of various sensor hubs is depicted in Figure 1.3. However, the true global setup is determined by the state's socioeconomics.

Collecting data from various sensors placed in the field or nursery is the first step in building an automatic irrigation system (Table 1.2). All other sensor nodes will communicate via the Raspberry Pi 3 B+, which will act as the communication hub. Each Arduino system includes an advanced soil dampness sensor, Wi-Fi module, GSM module, Bluetooth (BT) module, temperature and humidity sensor, MQ2 gas sensor, water level pointer, alarm, clock module, battery, and relay module [15].

Any hub can send data to the Raspberry Pi 3 passage hub/base station. The Python content on the Raspberry Pi will be able to store data in the worker/cloud, from which it will be sent to the end-user via an application layer. Since Internet is not required for information transmission from the Raspberry Pi to the worker, an intranet can be used instead. Intranets are often used in areas with no or restricted Internet connectivity [14]. To connect different sensors to the mircoregulator, the basic concepts of beneficiary, transmitter, field, and positive are used; the majority of connections are made in the same way, and the Arduino Mega has a sufficient number of RXD, TXD, optical, and simple pins, as well as various VCC and GND pins. The primary period of the suggested application is completed after determining the setup's globally and collecting details. The processing of data from

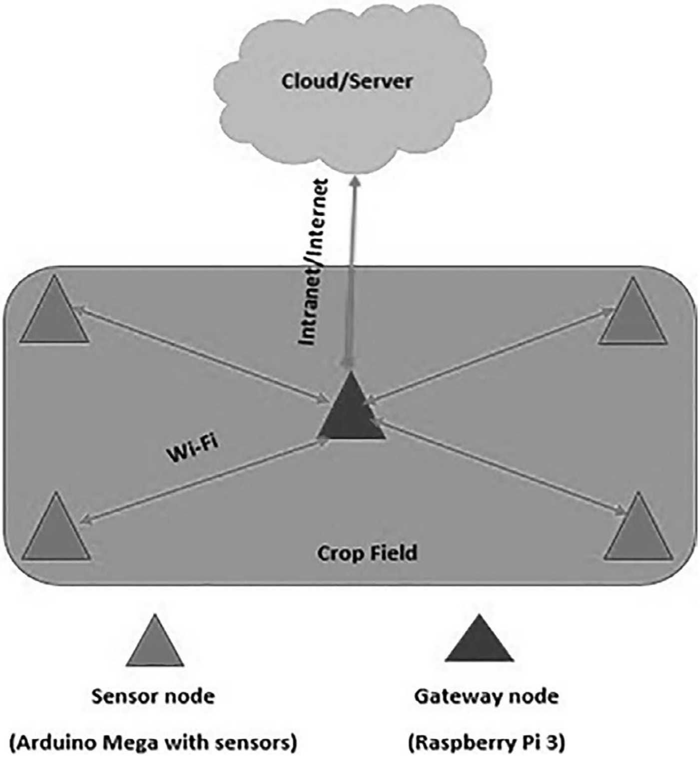

FIGURE 1.3
Wireless sensor network (WSN) [16].

TABLE 1.2

Communication Technologies Used in Automatic Irrigation Systems

Reference	Wireless Protocol/ Technology	Frequency	Data Rate	Communication Range	About
[17]	ZigBee (IEEE 802.15.4)	868/915 MHz and 2.4 GHz	20, 40, and 250 Kbps	100 meters	ZigBee is a low-cost, low-rate, and low-power-consuming device that aids in the secure and efficient transmission of data from source to destination. When a ZigBee-based wireless sensor network is applied to an agriculture field, data about the field's conditions is properly transmitted to the user at a high data transmission rate.
[18]	Bluetooth (IEEE 802.15.1)	2.4 GHz	1–3 Mbps	10–50 meters	Bluetooth is a low-power, short-range wireless sensor network device that allows data to be transmitted from one user to another.
[10]	Wi-Fi (IEEE 802.11)	2.4 GHz	11–54 and 150 Mbps	100 meters	Wi-Fi is the most successful wireless sensor network technology. Wi-Fi was previously only available on laptops, but it is now widely available on cellphones.
[19]	GPRS/3G/4G	900–1800 MHz	Up to 170 Kbps	1–10 kilometers	GPRS provides high speed of data transmission to the users.
[20]	LoRa (IEEE 802.15.4g)	868/915 MHz	50 Kbps	5 kilometers	LoRa is a long-range communication technology that consists of LoRa end devices, LoRa gateways, and LoRa network servers.
[21]	SigFox (IEEE 802.15.4g)	868/915 MHz	100 bps	10 kilometers	SigFox is an ultranarrow band wireless cellular network with low data rate applications.

various sensors is the first and the most important step in the information preparation process. Every hub requires a mircoregulator, which in this review is recommended to be an Arduino Mega because it better suits the scope of the setup, but other options such as Arduino Uno R3 and Node MCU can also be considered depending on the size of the execution. Water is supplied to the drip irrigation system from this tank through pressure and gravity, as required, and this need is determined by microcontrollers controlling valves [16]. The main drip-line is constructed as piping and is connected to a water tank over a four-meter length. Three evenly spaced drip sub-lines for a total of three crop ridges are also installed horizontally to the mainline, each with ten evenly spaced drippers for direct water distribution to the roots of ten crops, all operated by an “Arduino” microcontroller. Along each drip sub-line, a sensor box is mounted, which contains an Arduino

Uno microcontroller that reads analogous measured data about soil humidity from the sensors [3]. Five sensors are placed at an equal distance apart for each subline. The microcontroller reads the values and converts them to a percentage along with the range of values from 0 to 100. In this way, the average value for soil humidity is measured, which is then sent to the central master-control Arduino Mega via a radio transmitter – NRF24L01 – after each Arduino is given a unique identification code to distinguish it from the others. After receiving the value, the master Arduino runs an algorithm specific to the crops and opens the subsequent valve, allowing water to flow into sub-lines for field irrigation for a set period of time before closing it automatically. For large-scale agriculture, as well as for business and non-business stages, several frameworks for remote and automated irrigation monitoring and control, as well as irrigation motorization, have been planned and developed [4]. The IoT's automation and distance control have benefitted irrigation automation, security frameworks, and in-home automation. There has been a considerable amount of research into automated and remote irrigation monitoring and control all over the world, using various levels, some of which have already been listed. The most significant feature of inaccessible control and computerization is the ability of users to track devices and hardware from anywhere and at any time, as well as it results in minimizing human exertion and mediation by the use of devices and sensors.

1.3 ZigBee Wireless System

With its low-duty period, the ZigBee wireless protocol is ideal for water conservation, irrigation tracking, pesticide and fertilizer control, and is one of the most effective technologies in agricultural production [22]. The sensor nodes on the XBee Series-2 will communicate with the router over long distances of up to 100 meters in farms, while the communication range is increased to 30 meters in greenhouses or indoor fields. Numerous studies on various crops and farms were conducted in order to determine its range of communication [13].

The experiments include that on palms and orchids, for example, to investigate the signal propagation model using received signal strength indicator (RSSI), the ZigBee-wireless protocol's signal strength indicator. As a result, it was suggested [17] that a wireless channel propagation model be investigated before deploying sensor nodes in the field in order to achieve strong signals. The method of cattle localization was also investigated using this technology [18]. The link quality indicator (LQI) relation is used by ZigBee for distance calculation [23]. The weather conditions in the greenhouse were monitored and managed using ZigBee technology and GSM/GPRS [24]. When used in a WSN-based greenhouse, the ZigBee star topology is combined with artificial intelligence to save energy by switching between active and sleep modes, lowering energy consumption, and extending the battery life of sensor motes.

1.4 Bluetooth Wireless System

The BT standard was designed to enable mobile and compact devices, such as PCs, to communicate over short distances of up to 10 meters [18]. Due to its inevitability and versatility in most cell phones, BT has been used to meet multi-level agricultural requirements. Climate data, soil moisture, mechanical device location, and temperature are all verified remotely using the Global Positioning System (GPS) and BT technologies. The proposed framework [25] was created in order to use a water system to improve field profitability and control water. Using the BT remote correspondence convention, the water system framework is designed to collect field data on a continuous basis. Many technologies and devices have been developed to track overall humidity and temperature in nurseries with BT connections [4]. The BT module was used in an integrated management manner that linked soil and climate data to monitor the water system structure in nurseries, and this innovation improved [26] the leaf range, tallness, dry weight, and new weight of red and cos lettuce in nurseries. The outcome of the assessment for water use and power was also upgraded into an integrated management technique using BT technology, in contrast to the conventional technique [27] i.e., clock management process. Due to its low energy consumption, broad accessibility, and convenience for farmers, the cellphone-based BT technology has been used in a variety of agriculture applications, including dominant water system frameworks, perceptive soil and environment conditions, and dominant pesticide and fertilizer use [28].

1.5 Wi-Fi Wireless System

In the modern era, the most commonly used remote technology is the wireless local area network, which is available in portable devices such as laptops, cell phones, PCs, and work areas. A communication distance of 20 to 100 meters is deemed acceptable in both indoor and outdoor situations. A wireless local area network in agriculture broadens multiple models by interfacing various types of computers, suggesting an impromptu entity [10]. Using wireless local area network and 3G remote developments, the agricultural applications of cell phones were investigated [2]. Remote access and fast text administrations are frequently used for dominant and observant protected crops. Soil temperature, soil dampness, ambient temperature and humidity, daylight energy, and CO_2 were all stored in a very door before being transmitted to a device via an agricultural data wireless local area network setup. A Wi-Fi-based (IEEE 802.11g) sensible wireless computer network is planned for breeding check-in [H] [29]. The system includes three hubs: server, switch, and worker. In the nursery or the farming field's atmosphere, stickiness, temperature, vaporized tension, light, water level, and soil dampness are all measured. The same work focuses on lowering costs, reducing wiring links, and increasing the movability and usability of investigative work in wireless computer networks.

1.6 GPRS/3G/4G Technologies

The General Packet Radio Service (GPRS) is a GSM-based mobile phone data management system. The number of customers who share similar communication channels and properties is based on the number of customers who experience variable delays and throughputs while using GPRS. In Ref. [19], a programmed crop water system framework based on data collected by temperature and soil moisture sensors mounted at the root zone of plants using a GPRS module and a wireless computer network was built, and this framework could be viewed as a smart and realistic response to rising water quality in precision agriculture [30]. Estimating soil moisture was used to assess the feasibility of a trickle water scheme. The Arduino board was captivated by associated data, resulting in the development of a model system and a WSN-GPRS approach. The WSN-GPRS door connects the WSN and GPRS networks, allowing WSN data to be exchanged with the user. Ref. [2] presents GPRS-enabled remote hubs for measuring and transmitting soil, plant, and environmental data. The remote hubs have unrestricted independence due to their autonomy and use of solar-powered energy. A number of sensors could send data to a remote location through a GPRS network for further analysis on tablets, cellphones, or PCs. All farming devices are attached to the sensor board in order to collect data. Such information is transmitted to a distant employee for further investigation via the GPRS board, which is dependent on a GSM/GPRS transportable entity.

MICRO-IRRIGATION SYSTEM WITHOUT INTERNET CONNECTIVITY

1.7 LoRa Technology

The irrigation framework's automation also faces the challenge of data transmission over long distances [31]. The information transmitted through Wi-Fi and other radio communication devices is intended for a target individual (Figure 1.4).

The SX1278 handsets come with a LoRa long-range modem that offers super-long reach spread range correspondence and high impedance resistance while limiting current use. LoRa uses spread-spectrum ingenuity to achieve synchronization [3]. This method will transmit data up to a distance of 20 kilometers. LoRa is a low-power, wide-area radio tweaking method with a small trill spread range [32]. It is a WAN configuration that uses permit-free, sub-GHz radio-recurrence classes like 196, 433, and 868 MHz in Europe and 915 MHz in North America to enable long-range, low-piece rate communication between "things" (i.e., connected objects like battery-powered sensors). A low-power wide-area network (LPWAN) may be used to build a private remote sensor network or a third-party help or device to enable the screening and tracking of the running and turning on and off of irrigation siphons for farmers who live far away from their lands. The gadget is made

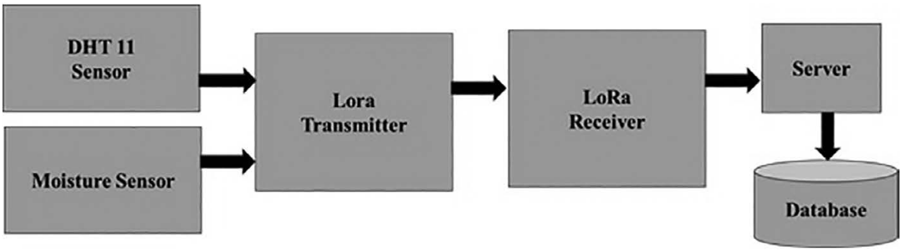

FIGURE 1.4
LoRa implementation [3].

with the most recent developments in current interchanges in mind (LoRa technology). The small size, low cost, and ability to track devices from a distance of up to 10 kilometers without the need for pinnacles for communication or other extra costs are all advantages of this invention [33]. This system is powered by a battery that lasts more than five years and burns at a low intensity level. A LoRa ESP32 for sending and receiving data, an exceptional circuit to track the electrical voltage in the setup, and eventually, an exceptional circuit to regulate and kill the electric siphon make up the primary circuit (control circuit).

1.8 WiMAX Technology

Worldwide Interoperability for Microwave Access (WiMAX) is a form of radio communication that links the Local Control Unit to the internet. It uses the IEEE 802.16 standard to provide internet connectivity to areas where conventional digital subscriber line (DSL) administration is still difficult and costly to set up or where 3G signals are unavailable. The reason for selecting WiMAX is that in certain areas of the region, such as far from midtown, there is often a lack of infiltration of media transmission lines or radio correspondence inclusion [19]. In the best-case scenario, the radio connection would span up to 70 kilometers with a clear line of sight (LOS) [11]. Different advancements, such as 3G, satellite correspondence, Wi-Fi, or asymmetric DSL (ADSL), may be used to understand distant correspondence, but none of them can match WiMAX's capabilities. Satellite correspondences provide global coverage at a considerably higher cost than WiMAX or 3G, with the exception of ADSL, which needs a link that may be prohibitively costly in these regions, and Wi-Fi, which has a very narrow range of coverage (under 100 meters). The latter is not really dynamic in these areas because building a 3G network is not lucrative for the operator [34]. WiMAX is a viable choice for this application because of these factors. This will also encourage the SC worldview to spread in places that are not technically classified as "city." In our system, researchers distributed WiMAX single transporter time division duplex (TDD) administration using a base station (BS) at 3.4845 GHz population recurrence with a transmission capacity of 10 MHz. The BS communicating reception apparatus is an Argus tilt board radio wire model SPPX310M.

1.9 Ham Radio

A WSNs' radio frequency (RF) parts distribute power more equally than information-processing devices like microcontrollers and microprocessors. Various researchers have used various radio improvement plans or strategies, such as (i) transmission power control (TPC), (ii) modification strategies, and (iii) psychological radio, to minimize the power utilization of the RF parts of agriculture sensor hubs. In the TPC scheme, sensor hubs adjust the send ability to save energy, allow interference avoidance, and set up a correspondence interface. TPC can be used in the agricultural sector, where the RF-communicated strength of sensor hubs can be adjusted to minimize power consumption by separating the sink hub and the sensor hub [8]. The use of TPC to reduce the power used by sensor hubs in precision agriculture based WSNs is being investigated. A few power levels and various collector affectability levels are thought to play a role in the said cycle. The organization layers and MAC convention in a WSN (due to CC1110) for the agriculture area are obtained to further minimize the sensor center's power utilization. The findings show that power sparing using various methods of transmitted power can be increased by around 10% as compared to the conventional model. On the other hand, increasing the send speed of the CC2420 specialized gadget improved the sensor hub's lifetime by over 8.5 [3]. An intelligent radio is a sharp remote correspondence network that can effectively pick up remote correspondence direct in the range band. An intelligent radio needs more energy than other gadgets because it uses advanced and complex battery capacity. An energy-efficient intellectual radio organization presents challenges in this way, especially in terms of battery energy consumption [8]. In remote correspondence, the electromagnetic spectrum is almost entirely used, with only a few groups remaining underutilized or unused. The use of a cognitive radio, which allows for the use of range openings, is recommended in this situation. Intertwined fluffy justification control (FLC) and a ZigBee remote sensor entertainer organization (wireless sensor actuating network [WSAN]) can detect environmental factors and respond as quickly as possible while not being obstructed by crops. In terms of adaptability, capability, profitability, and job obstruction, FLC assists masters in managing complex systems that are more in contrast to conventional control techniques. Two critical nursery environment factors (stickiness and temperature) are measured during the day and evening. An FLC focused on smart procedures would substantially increase the WSAN's life expectancy, according to the findings. As a result, the WSAN will run for a long time on a 210 mAh battery, thanks to the FLC combined with WSAN. The control boundaries can be changed to match the ideal qualities of radio modules in order to reduce their usage by the base power [8]. To limit the sensor hub's all-out power use needed to submit given information packets, the balance techniques of frequency shift keying (FSK) and minimum shift keying (MSK) are investigated. Based on their thorough testing, the developers concluded that MSK outperforms FSK in terms of forcing use. A few tweak plans cannot be included in the ZigBee 2.4 GHz remote convention because it only supports a single modification storey. In particular, the ZigBee remote convention employs offset quadrature phase-shift keying (OQPSK). The method is focused on radio streamlining plans that were previously used in agricultural applications.

1.10 Discussion and Conclusion

A survey of WSN-based agrarian applications was presented. Wi-Fi, BT, ZigBee, GPRS/3G/4G, LoRa, and SigFox were used to establish a connection between various remote innovations or conventions. The ZigBee and remote conventions were found to be more advantageous for rural applications than the others due to their low power usage and equal correspondence range for ZigBee and long for LoRa. There was also a description of energy-efficient methods or measurements, as well as energy-gathering techniques. As a result of the scientific categorization, we show that a wide variety of energy-efficient and energy-gathering methods can be used in the farming space. In order to find the best solutions for keeping the framework going, previous research was compared and contrasted with exploring the momentum problems in WSN-based farming applications. Difficulties and constraints for plan reflection were posed later in the LoRa module. To analyze cutting-edge IoT approaches in farming applications, different sensors, actuators, gadgets, IoT levels, and system layers were investigated and compared. A variety of benefits of an automatic irrigation system include low cost of operation and substantial reduction in water consumption. Furthermore, maintenance requirements are limited. An automated Internet-based irrigation system can also save you a lot of money on electricity. It can be used in greenhouses as well as areas where water shortage is a significant issue. As a result of this process, crop production increases while useless crop production decreases. The computer mechanically measures the water requirement in this system threshold. This estimate is dependent on the evaporation pan's water level dropping. Drought stress and fungal and bacterial infections are not a concern with this approach. The farmer may also use the mobile application to check the condition of the field from afar without having to physically visit it. Furthermore, human- or labor-related errors are reduced, and the optimum water sum is regarded as the best on the planet for crop quality and water conservation. Another Internet-based system for automatic irrigation is WSN, while protection is provided by a Raspberry Pi-based security system. Data from sensors at each node in the built system is used to track field parameters, especially soil moisture, and water flow can be controlled by the user from any location using any Internet-connected device. This device is very successful even at a low cost, since Internet connectivity in rural areas is now available at low prices. As a consequence, the most useful application is a web-based irrigation system based on the "Arduino Uno" and Raspberry Pi. Various field parameters such as humidity, temperature, and soil moisture can be monitored from a webpage using "HTML and PHP." The required action is taken based on the displayed state of these parameters on the web page. The device has proven to be useful in another Internet-based agriculture application because it is attentive to any animal intervention in the field, which is a major cause of crop yield reduction. At all times, you must have access to the Internet. An intelligent water-saving irrigation system is created by combining WSN and a fuzzy control system. This unit effectively monitors and regulates the ground from afar. The board's nodes are powered by solar energy and lithium battery devices, which solve the problem of inadequate power by allowing nodes to self-organize with low energy consumption and consistency by employing several hops. There is a network protocol for communication. Using a fuzzy-logic toolbox for the development and evaluation of the system, which consists of one fuzzy output for two inputs, showing a relationship between the system's input and output, the control method is made more scientific. By automatically opening valves when a threshold limit is reached, this system achieves the purpose of a water-saving irrigation system. As a consequence, it is a water-saving, productive, and reliable system. The intelligent IoT-based automated irrigation system uses Arduino and Raspberry Pi 3 as microcontrollers and preparing devices. Furthermore, soil dampness and temperature data are transmitted from sensors to detect temperature and soil dampness levels. These sensors are connected to an Arduino microcontroller, which receives data from the sensors and processes it. The water siphon actuator is also connected to Arduino for water siphoning in addition to these sensors. The detected data is then sent sequentially via sequential correspondence to the Raspberry Pi 3 control unit, where machine learning K-NN (K-nearest neighbor) calculations are performed [35]. The AI measurements are saved in the Pi 3 control units, which are used to prepare data on dampness and temperature for a variety of soil conditions, including dry, minimal dry, wet, minimal wet, and forecasted needs. The expected yield is sent to Arduino as a control signal, causing the siphon to trigger and the field to be watered as required. Finally, farmers can access the data from the flooded field via a cloud webpage. This entire model is based on the Raspberry Pi 3 climate arrangement, which is an edge-level processor where astute examination is completed by using K-NN machine learning calculations for foreseeing the dirt condition based on captured soil dampness and temperature information and on prepared informational collections relating to soil dampness and temperature for various types of soil that are dry and mounds of soil. As technology progresses, more efficient and successful work is needed, such as using "data mining algorithms," to predict crop water requirements automatically. More research is required in this area to develop a cost-effective method, as prediction is useful in deciding the correct amount of water to supply. Furthermore, rather than using mobile apps that rely on the Internet for updates, the need for constant Internet access can be avoided by creating a system to alert users directly via SMS on a cellphone using the "GSM module." A statistical model is required for a cloud-server-based irrigation system since all system information is stored in the cloud server, including values recorded by sensors, previous irrigation date and duration, and total evaporation between successive irrigations. Since the entire system is interconnected, if the power supply is cut off or a shortage occurs, the entire system, including recorded sensor values and Internet connectivity, is disrupted. As a result, future research would necessitate the use of solar-powered batteries as well as the installation of additional instruments such as an anemometer and more efficient soil moisture sensors. Furthermore, the data transfer rate and area coverage of wireless communication networks can be enhanced for better system establishment.

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2

Urban and Vertical Farming Using Agro-IoT Systems

The Ingredient Revolution – A Sustainable Production System for Urban Population

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2.1 Introduction

Vertical farming is the practice of growing crops at an intermediate level [1]. This often includes eco-agriculture to promote plant growth and non-essential solarium techniques such as hydroponics [2–5], aquaponics [6, 7], and aeroponics [8]. Other system options for vertical farm landing processes include buildings, containers, pits, and dumped mines. By 2020, there were approximately 30 hectares (74 acres) of agricultural land standing in the world. It was Dixon who introduced the modern concept of vertical farming in 1999. Despommier, a professor of public hygiene at Columbia University, and his students developed a sophisticated high-rise building that could feed 50,000 people. The design has not been built yet, but it has been able to spread vertical farming ideas. The vertical agricultural application, together with other modern technologies, such as today's LED lighting, has produced the following results: 10 times the traditional yield [9].

The main advantage of the vertical agricultural sector is that the required area is small for a crop to grow. Improve your ability to grow different varieties at the same time. Farming is one of the most sought-after benefits because the harvest does not share a single one. In addition, plants are resistant to time risk, leading to the demands of the domestic department to use natural resources, increase, or energy that cannot make additional tapas.

With the population density of Metro Manila rising to 20,785 people per square km and the population increasing to 12.88 million by 2015, there may be an impending call for area and resources, in particular meals and water. Mindanao drops about 90% of its local produce to deliver the needs of Luzon and Visayas, causing charges to boom because of expenses of the shipping and maintenance of those sources. Local farmers and investors are concerned about transportation because of first-class supply to the market and an excessive fee of transportation from the location to important city markets, and approximately 11–12% of lettuce coming from Mindanao are misplaced because of spoilage, which has a great effect on the profitability of wholesalers and wholesale retailers.

The idea of imparting meals in towns already exists, but the concept of a whole building packed with plants is new. The concept of vertical farming is largely city farming of various agricultural plants in an enclosed area that is designed extensively to house plants for the usage of hydroponics [2–5]. The layout is supposed to develop the plant's interior in a vertical setup while integrating aeroponics [8]. Also, for the setup, minimum area and water are needed without sacrificing the yield.

In recent years, the Internet of Things (IoT) [10, 11] has been one of the subjects that may be observed in more than one research work today. As such, a group of gadgets communicating with different gadgets in the long run ledding to smarter decisions. Through the usage of IoT, gadgets may be managed remotely through current communication technologies such as Bluetooth, Wi-Fi, and RFID. Also, this technology of the rising era has been implemented in a diversity of industries including transportation, domestic automation, forecasting, health, and security. The data from the gadgets can also be saved and processed on a data server, which also can be used while interfacing with exclusive gadgets.

Agriculture is likewise observed alongside the traces of the aforementioned industries. Plants are very dependent on how successfully factors such as light, nutrient levels, and temperature are monitored and maximized [8]. Hence, every issue has to be monitored intently through IoT well to implement automation inside an agricultural enterprise and to allow people living in city areas to have grown domestic food.

Vertical farming [12, 13] is usually designed to grow crops in modern technology homes, usually housed in city center buildings. This is a modern agricultural system with a perfect climate that eliminates traditional external environmental factors. Vertical farming can be cultivated in any building that enhances the climate of the earth, regardless of current conditions such as rain or cold season, but it should be noted that it does not rely on the use of large amounts of land.

Vertical farming [10, 14] also helps reduce the risk of burnout during soil preparation by causing burnout during this process and removing all fruitless farmland and trees. The fog and dust generated by this work cause delays. Plants that kill them for sunlight also create adverse conditions for the local or global environment.

Vertical farming [15, 16] can produce crops grown in a processing environment that can be described as mechanical engineering in agriculture. Agriculture is very important to the population, and the benefits of agriculture are clear from a human point of view. Vertical farming allows barren lands to return to their original habitat while reducing pests. Vertical farming may utilize excess space that is inactive or unused in developed cities. The presence of standing crops enables food production throughout the year. In addition, it can create an environment that supports the sustainable and healthy urban lives of those who choose to live in urban areas. In the future, agriculture will focus on urban agriculture as well as that in rural areas.

When designing a vertical garden system [11] for indoor planting, the focus is not only on planting in vertical positions or platforms but also on taking into account irrigation systems [17], room conditions, and soil conditions. Vertical farming produces minerals and organic enzymes to ensure plant growth and promote the growth of minerals essential to the nutritional value and taste of the final product produced during breeding. Therefore, direct local integration and IoT applications are important for effective plant health monitoring. Due to the manual control of the fishing industry, it is difficult to extract frozen fish that consume oxygen and produce too much ammonia nitrogen, and contaminated water makes the fish sick. When people eat this fish, it causes health problems. Smart aquaculture [7] has been developed, designed, and implemented to address key fishing industry challenges such as environmental pollution, water scarcity, and healthy aquaculture [7] conditions, consumer prices, and labor costs. This fish farm has great advantages: cleaning to improve water quality [4, 18].

The world is changing rapidly in many ways, many of which are positive, but some of these changes are challenging. Climate change can lead to disaster. By a large margin, we are bound by the original technology of the Revolution. Improving the legacy system and creating new strategies and tricks to make them sustainable is the driving force behind the cyber-physical system (CPS)/IoT revolution [19]. With the increase in global population, 90% of our diet will be expected to come from 10% of agricultural region in the world. Applying an expansion model will be one of the pillars of sustainable food production.

Vertical agriculture is defined as a multifaceted representation of the "biological" nature of agriculture, where production and integration are integrated into one system. There are four new technologies needed in the ecosystem to make this possible. The use of renewable energy is the reduction of fossil fuels, the use of green technology such as LED lighting, and the use of waste as fertilizer to reduce environmental impact, efficiency, and simple implementation. Cultivation, processing, and distribution will reduce waste samples with damage, intrusion, cooling, and transportation. This is enough to maintain a self-control system that can control the power and waste water [20].

In addition, a third backup power system is also working independently with its renewable energy source, battery storage, and backup line. While the system can automate the switching to the mains power line during a shortage of power, excess energy from the other vertical farm may not be used. Load sharing can help maximize excess energy and make sure power is provided to the vertical farm. Excessive energy consumption can reduce not only carbon dioxide emissions but also costs. A careful and balanced system requires the efficient use of energy. Renewable energy mobile microwave networks and battery storage providers have shown that sharing can reduce costs. Thus, the study of this method of urban farming will soon be essential to mankind. Furthermore, it will possibly lead to researches that will support food production outside of the earth. Further study of this applied to urban farming becomes significant as space studies on alternative human habitats are booming, implying that farming can be done anywhere. However, vertical farming cannot be optimized as without automation some plants are not easy to harvest because wall gardens are usually tall and inaccessible. In addition, producing a crop without planning the process leads to a long time taken before harvest. The application of these tasks is a cost-effective solution for crop yields [21].

The rapid development of urban housing results in overcrowding, degrades housing quality, and raises questions about the impact of temperature on urban islands. Another unusual phenomenon in Taiwan is that temperatures in the north are higher those in the south. Many meteorologists say the rising capital city of Taipei has less green space, which could cause less climate change than global warming. One of the challenges of a highly developed city is finding ways to expand vertical wall and roof space to create green space. One of the best ways is to combine green walls with roofs to create an urbanized agricultural setup and increase the influence of green vegetation [5]. This method works well with environmental management, food supplies, gardens, recycling, and food waste, in addition to life skills.

In the early stages of rooftop greening, the development process dominates. Next time, the roof will dominate, providing room for ventilation in areas with very poor urban conditions, and many appreciate its value. [22].

New roof-to-roof construction focuses on roof urban agriculture, which has become one of the most effective and efficient public health strategies for public development. The size of areas with urban agriculture ranges from small urban crops to several hectares of produce. Researchers focus on improving the quality of the greenhouse cultivation method through a series of experiments. A system developed by the researchers allows users to control micro-climate signals that activate electrical and electronic equipment when settings such as temperature, water level, and humidity are entered. The amount of data that can be managed by farmers makes it easier for farmers to assess the condition of their plants. In addition, automation can perform the fieldwork.

Urban farming, or vegetable farming, is the way to grow, process, and distribute food in suburban areas. Urban agriculture is also a term used for animal husbandry, fish farming, urban beekeeping, and vegetable farming in the cities. Suburban agriculture may have different characteristics. Urban agriculture [1, 18] can reflect different economic and social development levels. It can be a social movement for community sustainability where food processors, "foodie" and "Rocabourg", build social networks based on the common spirit of nature and society. These networks can be upgraded with government support and will be integrated with local urban systems as a "transitional city" for sustainable urban development. For some, an abundance of food, nutrition, and income generation are the main motivations for implementation. In all cases, direct access to fresh vegetables, fruits, and meat through urban agriculture can improve food security.

With the growing population of cities in different countries, it is important to design cities in a modern way that allows more space to be used. At the same time, it is important to design cities with an environmental approach so that ecosystems are not affected by the introduction of new technologies. The role of information and communications technology (ICT) is very important in designing smart cities [10].

As urbanization comes and citizens often migrate from villages to cities, government planning and building blocks of different countries need to develop cities with new modern technologies to serve them well. IoT must be implemented in cities so that past data can be collected and distributed to residents [23].

ICTs are applied in vertical agriculture, but catastrophic growth, food waste, and public inclusion have yet to be considered. Food waste educators include food prices and ignorance of the origin of food due to globalization, which consider them to be fundamental factors and separate from the food culture environment. Therefore, the growth of non-autumn crops and families causes investment in the food environment, and since food is considered a product and not an essential part of survival, various things create emotions with the charm and distraction of food [24].

2.2 Literature Survey

The ingredient revolution of this 21st century has made the agriculture sector equipped with technologies to sow and reap in a precise manner. The chapter "IoT Applications in Agriculture: A Systematic Literature Review" states the automation involved in agriculture and its vital utility by agriculturalists. The IoT technologies will enhance the throughput of the plant by assisting through technology for nurturing and monitoring its ecosystem [20]. Intensive monitoring of various systems includes remote monitoring, threshold level maintenance, smart irrigation systems, prevention from extreme weather conditions, and plant multiplicity system. The proposed work assists researchers and agriculturalists in gaining knowledge regarding the IoT. Local agriculture in the countryside and non-rural areas employ the usage of hardware and software resources and immense parameters relevant to agriculture. Crop observation assists in figuring out crop disease. Smart irrigation extremely encourages the supervision of specifications that promote huge yield for farms like humidity, temperature, and moisture-incorporated sensors [12]. IoT immensely assists farmers in monitoring the crops at all their stages, from anywhere on the globe. Inclusion involves wireless sensor networks like a wireless camcorder to monitor the status of the crops in real time and actual drones to enhance particularity agriculture and smartphones to renovate the particulars to the farmers. This ensures the 24/7 status of the farm as the entire approach is automated.

India ranks second in the world in terms of population. To proffer proper nourishment facilities, it is necessary to increase food productivity. The chapter "Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming toward Urban Greening: A Review" coins emerging techniques like the IoT that come into existence to meet the demands in agriculture through effective utilization of resources. The proposed work incorporates sensors to collect gestures and offer appropriate decisions based on the particulars from the sensors and inclusive of farming techniques that can offer resources when required. The sensor monitors the pH range, temperature, and humidity level in the farm. The system promotes IoT to provide automation which depends on various gestures from the sensors and it does not depend on manpower and assists in the reduction of cost. IoT techniques offer tremendous strength to farmers from a technology perspective. The proposed system in inclusion focuses on soil fertility, water requirement, and herbicides.

The suburban farming method is used on the terrace of the building and indoor cultivation of the building is performed. The farmers in the suburban space are not much aware of traditional methods of farming and they have marginal participation in professional agricultural practices. The chapter "Smart Urban Farming Service Model with IoT Based Open Platform" explains the deployment of information technology inclusive of cloud assistance. A lot of agriculture requirement tasks are automated and requirements of human interference for monitoring and supervising sensors are incredibly reduced. The proposed suburban farming method accommodates cloud assistance with IoT-enabled sensors. The proposed work encompasses sensors like CO_2 sensor, soil knowledge sensor, nutrient sensor, sun sensor, rain sensor, and wind sensor. Gadgets other than sensors include heater, flow fan, CO_2 controller, web camcorder, heater, ceiling, weather station, recording device, and uninterruptible power supply (UPS) device. Once the particulars are gathered from the gadgets the smart greenhouse management system acquires the cloud assistance and transfers the particulars to the cloud and the mobile phone through GSM.

In 2050, the global population is predicted to be around 10 billion. Almost 60% of the population stays in cities, owing to this sustained standard of living in areas with good air and healthy food being quite an arduous task. In conclusion, there is not enough area to cultivate in suburban areas. This idea is briefly explored in the chapter "Smart Indoor Vertical Farming Monitoring Using IoT" [9, 25]. Incorporating human resources for monitoring and cultivating is an exhausting practice. Terrace or balcony gardening is the practice of expanding cultivation in the human habitat. The proposed system adopts artificial photosynthesis, which involves the assistance of flourishing light comprising red and blue LEDs as it suits indoor planting. Agriculturists can monitor the crops through mobile phones with GSM capability. The proposed system can also be employed in suburban areas where there is not enough acreage for horticulture [5, 17].

The IoT has deployment in all fields. Dominant employment of IoT requires gigantic framework coordination in terms of hardware, software, and communication systems to assure conversation between smart gadgets. The chapter "CPS/IoT Ecosystem: Indoor Vertical Farming System" [9, 19, 25] promotes IoT framework credentials for leading operations comprising smart parking, intelligent agriculture, and smart architecture. The proposed work focuses on indoor cultivation systems. Four major categories are in indoor cultivation systems: The hydroponics system [2–5] is growing crops without soil. Aeroponics [8] involves the flora being suspended in air and the water drizzled in the roots of the plants. Aquaponics [6, 7] employs water for both florae and inducing fisheries.

Indoor vertical farming [25] is an action of growing plants in an artificial habitat. The traditional routine of lengthening flora is in exigency of topology locale, meteorological conditions and the field implanting plants is out of the way from the equator to experience lessening frosty climes, sunshine, and to acquire the superior consequences. The proposed system proffers adequate sunlight, nutrients, water-assisting sensors, and actuators for providing the hygienic habitat to grow plants and to obtain finer yields from the crops.

Hydroponics is a tactic of flourishing plants wanting soil [2–5]. The system involves manipulated habitat specifications inclusive of appropriate limits of temperature and moisture extent for the finer provision of crops. The chapter "A Sensor-Based System for Automatic Environmental Control in Hydroponics" proposes the use of sensors and controllers to have supervision over the habitat climatic zone. The system minimizes the consumption of water with the assistance of a technique named drip irrigation. Automatic environmental control investigates the temperature and humidity level to determine if temperature and humidity level are beyond the threshold values. If the temperature is recognized to be above the threshold value and the humidity value is below the threshold value, the system turns ON the fans and investigates the temperature and humidity value in predetermined intervals. Once the temperature values are below the specified threshold and the humidity level is above the threshold, the system automatically turns OFF the fan. If the temperature and humidity compete for the attention of the controllers the temperature is given a preference.

At present agricultural provinces encounter protests due to arduous progression. The new techniques like the IoT, precision agriculture, and blockchain assisting in incorporating smart agriculture, in turn, pave the way to meet future requirements. The chapter "VegIoT Garden: A Modular IoT Management Platform for Urban Vegetable Gardens" [5, 15, 17] comprises a brief and protracted communication protocol to enhance the vegetable nursery administration, assisting in gathering, monitoring, investigating sensor reading changes in temperature and humidity, and investigating of particulars relevant to the specification of flourishing plants [13]. The framework concluded upon the internet facilitated Home Node, an iPhone Operating System device with mobile applications to monitor the stature of plants. The proposed work is verified for seven days and the system assists in detecting the causes of diseases in vegetables and hugely reinforces that we should expect, in the future, transition in climatic conditions, and essential resource reduction. The proposed system incorporates the IoT that grants to gather integration agriculture particulars from flora, fauna, and gases from the environment. Home Node, along with a Raspberry Pi furnished with low-power long-range and GPS communication systems, is planted in the farmer's house. The system also gathers weather variations for IoT platforms and assigns the particulars to the cloud.

The global population count is drastically increasing at present. It seems a hellacious responsibility to proffer nourishment to the people in the upcoming years. The chapter "Farm to Fork: IoT for Food Supply Chain" states that it is necessary to provide sufficient yield from farming methodologies [21]. The proposed system uplifts the IoT in the food chain to face the requirement. Depletion of nourishment due to transportation from farm to vendors as the food products are subject to changes in environmental conditions like temperature and rainfall has a huge influence on food insufficiency. The depletion of food resources results in the demolishment of resources, including water, land, air, and human labor, and the exchange of greenhouse gases. Research says most deaths occur because of food deficiency and malnourishment. Nourishment chains flow from the farmers to the vendors, from vendors to the consumers. In the future, there will be a huge demand for resources that would lead to water assets anxiety, the inadequacy of cultivation, variations in climatic conditions, an increase in global temperature, and an increase in sea level. Smart farming with IoT hugely assists in preventing nourishment deficiency and enables the effectual deployment of resources. The equipment employed in smart farming comprises drones, sensors that promote smart farming, intelligent irrigation facilities, remote monitoring systems, and cattle monitoring systems and reduces the requirement of human expediency. The livestock management incorporates sensors that are attached to keep on monitoring the body temperature of cattle, the disease that may occur due to weather conditions in the cattle. The system does not require any human power to take care of cattle. Drones assist in preventing the wastage of water, detect the area that is not provided with water supply, and provide intelligent irrigation to the fields with the assistance of mobile applications employed by the farmers. IoT accompanying RFID are housed on the heavy goods vehicle. GPS is incorporated in the gadget set up to locate the location of the heavily loaded goods vehicle. The system immensely assists in incorporating smart farming to provide accommodation to the farmers.

2.3 Existing System vs. the Traditional System of Cultivation

Vertical farming is a cultivation medium for sowing and reaping plants in a soilless platform supported with a mixed nutrient solution in a water medium. As the soil is replaced by various mechanical structures to support the plants, the absorption of the nutrient is a cautious one in such cases, as improper feed may result in hindrance to plant's growth. The nutrient solutions are prepared from bird, animal, fish manure or chemically generated solutions like general flora series. The grow bed in the vertical farming technique includes materials like gravel, wood, stone, metal, rock wool, concrete, and solids. The bed system must be exempt from sunlight as it may result in resistance to the growth of the algae in the system.

For sufficient growth of the plant both in soil-based cultivation and vertical farming method, we need to nurture it with a good amount of nutrients. Plants have different nutrient combinations for each stage of growth. The plant's growth cycle demands 16 supporting elements as follows: nitrogen, carbon, oxygen, potassium, hydrogen, sulfur, magnesium, phosphorous, iron, boron, calcium, manganese, molybdenum, chlorine, copper, and zinc. Plant's intakes of nutrients are classified according to their absorption into macro- and micronutrients. Macronutrients such as nitrogen, phosphorous, and potassium, known as NPK, form a crucial in a plant's growth. Micronutrients like copper, nickel, iron, zinc, manganese, boron, calcium, and molybdenum play a role in a plant's good health and fruit development. As the nutrient absorption directly reflects in the growth of the plant, vertical farming techniques such as hydroponics [2–5], aquaponics [6, 7], and aeroponics [8] prove to be better than soil-based cultivation. In these methods, the absorption rate is considerably found in direct proportionality to the number of concentric nutrients absorbed by the roots of the plants in it.

2.3.1 Different Types of Vertical Farming

Vertical farming is classified into three major types of systems based on the structure of cultivation: (1) skyscraper buildings, (2) mixed Skyscraper buildings, and (3) stacked shipping containers.

2.3.1.1 Skyscraper Buildings

In this structure, the vertical stacking of grow bed shelves results in increased production of crops within the closed structure with the usage of controlled environment techniques.

The grow bed shelves are not directly exposed to external climatic conditions like wind, sunlight, and temperature. The skyscrapers are completely shielded with agro-technical needs. One good advantage of vertical farming is mass production in a single space. So, it can be implemented in urban areas to meet the demand of the population. It can also be integrated into a renewable source of energy like solar energy and wind energy due to its structural advantage [12].

2.3.1.2 Mixed Skyscraper Buildings

This method of vertical farming is an integrated one in developing traditional farming techniques with modern farming techniques. This structure has both a controlled cultivation system and open cultivation system. The natural source of light is used to a greater extent in the top space and open space of the building. This method gives exceptional performance in attaining a biased production system.

2.3.1.3 Stacked Shipping Containers

The shipping containers serve the purpose of stacking upon one other in a row fashion for the cultivation of various veggies and exotic food crops like strawberries and blueberries. The shipping container is altered in such a way that it has LED lighting systems, ventilation systems for climatic balance, and sensor systems to surveil the changes and maintain a balance in growth level.

2.3.2 Three Types of Processes in Vertical Farming

2.3.2.1 Hydroponics

This is the predominant method of cultivation in vertical farming techniques [2–5]. This system enables to grow plants without soil but is supported by a rich nutrient solution. Here, the root structure of the system is immersed into the solution and it is refilled again by the water pump from the reservoir tank to the grow tray. This is completely automated with a timing circuitry system. The timer adjusts itself according to the nature of the plant to be cultivated. Once the nutrient solution is flooded in the grow-tray, the excess one is driven back to the reservoir tank through gravity. All micro- and macronutrients are available in this nutrient solution and it supports plant growth. The hydroponics system setup is shown in Figure 2.1.

2.3.2.2 Aeroponics

This system is a quite improved version of the hydroponics system [2–5], where the root structure of the plant is exposed to air with very little water content in it or mist without the soil medium. The challenges in constant exposure to the nutrient solution may result in excess growth or decay of roots. To overcome this drawback in a hydroponics system, the aeroponics system is used [8]. Here, the roots of the plants are nurtured with the solution in the root structure continuously with the help of a nozzle sprayer. This helps the roots to absorb the proper amount of oxygen from the air. This method is more efficient than the hydroponics method [2–5] as it supports not only nutrient solution but also oxygen to root structure. It helps in supporting the good life cycle of roots. Here, only 10% of water is used with a two-fold yield, which proves that the plants are potentially more nutritious in yield. Figure 2.2 is an aeroponics setup system [8].

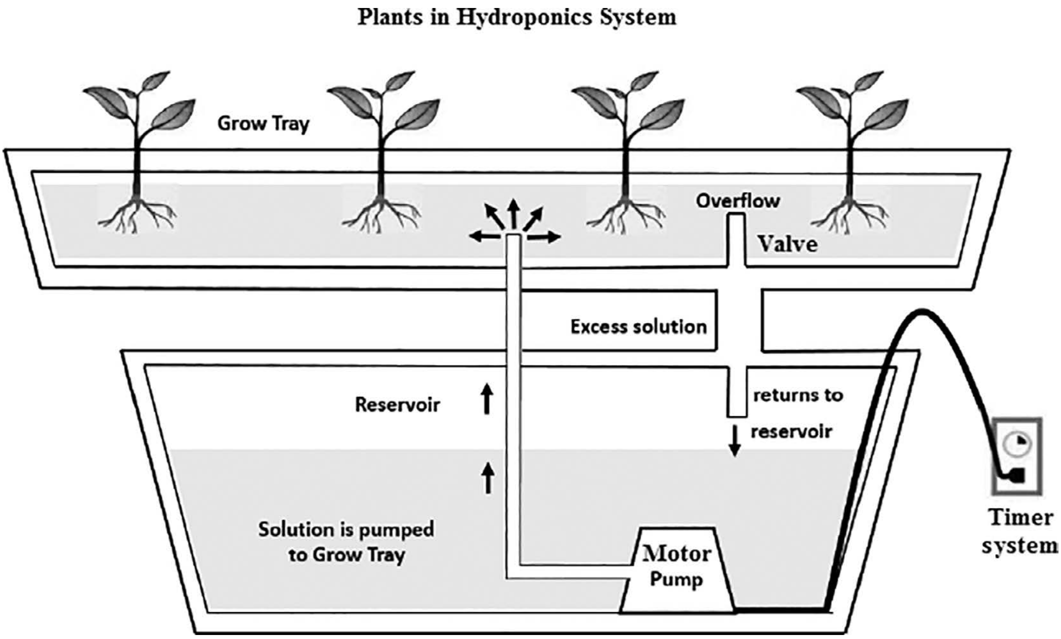

FIGURE 2.1
Diagrammatic view of hydroponics system.

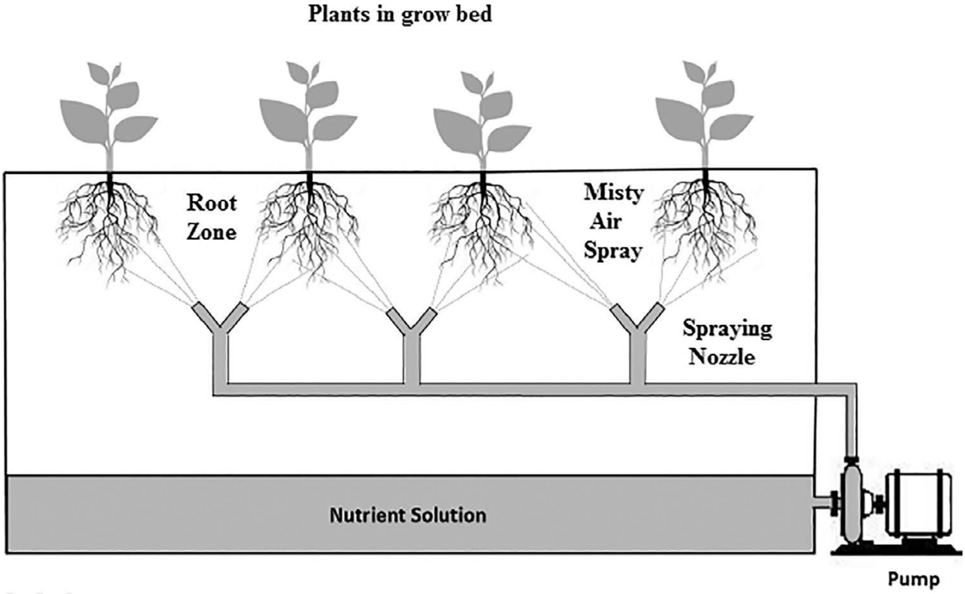

FIGURE 2.2
Diagrammatic view of aeroponics system.

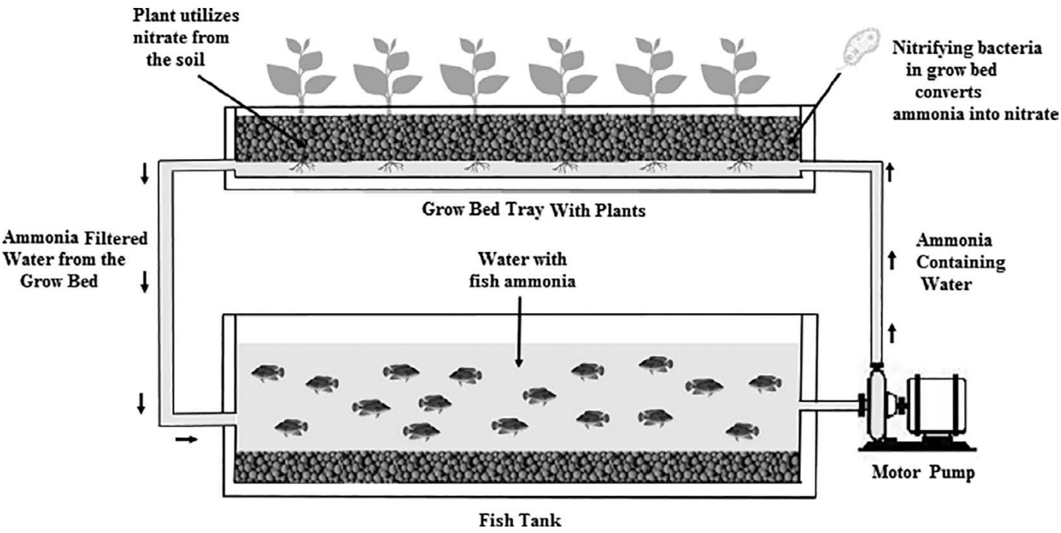

FIGURE 2.3
Diagrammatic view of an aquaponics system.

2.3.2.3 Aquaponics

Aquaculture is a combination of the fish aquarium with a hydroponics system [6, 7]. It is an ecologically balanced system between fish and grow bed. The fish in the fish tank excrete waste in the tank, which is highly nutritious to plants. So it can be used as a growth supplement for plants. The plants absorb the nitrate from the grow bed and filter the water. The process of converting ammonia into nitrite is done by nitrifying bacteria in the medium. The filtered water is driven back into the fish tank. The ammonia-rich water acts as a nutrient solution to the plants in the grow bed. The nitrifying bacterium is the key player in fixing the conversion. The ammonia solids are turned out to vermicompost, which acts as a biofertilizer to plants. Now, the ammonia-rich water is recycled back as freshwater to the fish tank. The major concern for this system is to maintain a stable pH level and ammonia level throughout the life cycle of both fishes and plants. Figure 2.3 presents a working model of aquaponics.

2.4 Proposed System of Vertical Farming

In the aquaponics [6] method of vertical farming veggies like lettuce, spinach, and mint grow well. Here, the proposed model exhibits mint plant cultivation. Mint plant belongs to the herbal variety and it is used for its flavor and aroma. Urban gardeners grow mint in their backyard and balcony through the vertical farming method. Mint plant grows successfully in a humidity level of around 70–75% and a temperature of about 22°C to 28°C and exposure to sunlight about 12 to 14 hours/day.

The proposed model chooses nutrient film technique (NFT) to grow mint plants. Here, the mint plant saplings are placed over the alluvial soil balls present in the plant holder. The NFT layering depends on the count of the production system. The NFT layering for the mint saplings is two parallel structures with a holding capacity of eight. The NFT system is directly attached to the fish tank. Here, the tank is governed by a dissolved oxygen meter to measure the oxygen level in the fish tank. Then, it is aerated with a motor pump to maintain the balance of dissolved oxygen. A timer control unit is placed, supported by a microcontroller unit to sense the data and govern the automation. By this aerated water maintains a good life balance in a fish tank and nitrated water to the mint plants helps to reach its full potential of growth. This system of mint cultivation can be increased by providing organic micro- and macronutrients to the plants through the water. Here, it is a must to closely monitor the system as it has both aquaculture and hydroponics setup [2–5].

2.4.1 Category of Models

In models used for cultivating plants, we go for different varieties according to their nature of usage. They are stated below as follows.

2.4.1.1 Fixed Solution System

In a fixed solution system, the plants are cultivated in containers with nutrient solutions. The containers can be glass jars (in-home applications), tanks, tubs, or plastic buckets. As the water is replaced only after the harvest, tender aeration must be given to the nutrient solution. Here, the water must be at a pH level around 6.5–8.5. This is because of the stagnation of water in the system. The alkaline level increases day by day, which may result in frequent replacement of water in the system. The alternative method for water replacement is aeration. And the level of the solution must be kept below the roots as this helps the roots to get adequate oxygen from the air space available between them and the solution. In this system of approach, the solution is fixed in container space. The container can be of any size and space depending on the need, such as tubs, buckets, and tanks. To maintain a healthy root life cycle, the solution must be aerated well. The dissolved oxygen helps the roots to maintain their metabolism. If the solution cannot be aerated, then it must be in a lower level with roots exposed to air. The bed system is placed above the container space. The plant's presence in the bed system is designed according to production needs. The cultivator needs to decide concerning the nature of the plant grown in it. The plant's circumference and height decide this selection system. The container space must be enclosed completely with black-colored sheets or with materials that filter the sunlight. This is done to avoid the formation of algae in the container space. Here, we need to measure the nutrient solution and its composition each week. This must be done throughout cultivation. The balancing of nutrient solution is done by increasing either the solution or water content. The floating nutrient solution should be constantly monitored with sensors to know its change in composition. The raft system is used in large-scale commercial sectors. It is floating above the solution and the root structure is completely exposed to the solution. So, we need to give an external aeration system for good maintenance. If the aeration ca not be provided frequently, then we can move toward a continual flow system (Figure 2.4) [10, 11].

2.4.1.2 Continual Flow System

In the continual flow system, the roots get immersed in the nutrient solution. Here, automation is relatively easier than the fixed method system. The temperature is keenly noted to govern the inflow and outflow of the solution. As the system is in a flow state, the concentration of the nutrient solution is stored in potential distribution space. The commercial

FIGURE 2.4
Depiction of the fixed solution method.

success of this method involves the NFT version. The streaming nutrient solution through NFT helps the plants for their continuous growth. Here, recirculation is done again and again through the NFT setup to maintain the pH at 5. Less water is consumed when compared to a fixed solution system. The roots exposed to the nutrient solution are supplied with a large amount of oxygen content through the aeration process. The NFT system can be placed in any design concerning gravity. Gravity plays a major role in this process of recirculation. The NFT system is best suited under continuous electric supply or battery power. As nutrient solution recirculation is the heart of the system, it must be taken into account. This can be managed by solar power backed up by a battery system.

Usually, the NFT system is designed with an average flow of nutrient solution at the rate of 1 L/min. During the full growth of the plant, it reaches up to 2 L/min. This flow rate must be taken care of, or else it may create a serious issue in nutrient disproportion. When we go for multi planting system, an extra subsystem must be attached with the NFT system for a nutrient supplement (Figure 2.5).

2.4.2 Method of Selection

The method of selecting a system to nurture the plants is classified based on the variety of adaptations in the design of grow beds.

2.4.2.1 Water Culture System

Here, we implant the plants in a platform and make them float on the nutrient solution in connecting with an aeration system to protect the roots with oxygen. Here, alkalinity is

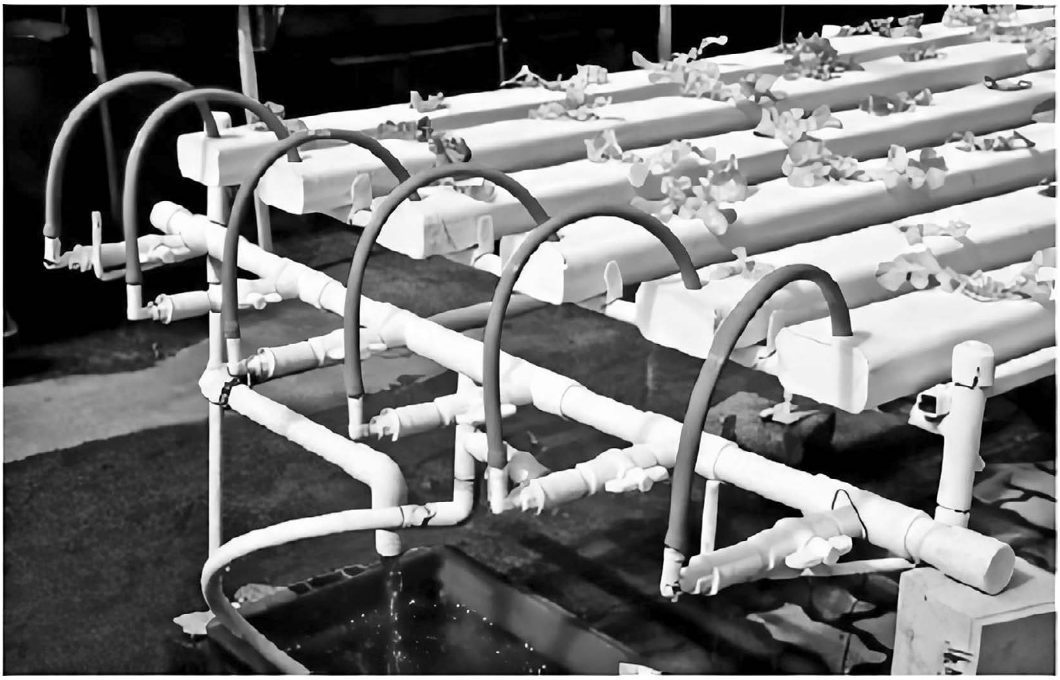

FIGURE 2.5
Depiction of the continual flow solution method.

increased due to the long duration of the cultivation process. So, we need to give nutrients with acidic components to neutralize them. This must be done carefully else it may turn out to imbalance the ecosystem (Figure 2.6).

2.4.2.2 Ebb and Flow System

The working of the ebb and flow system is to make the nutrient solution get flooded below the tray. The excess solution is drained back into the reservoir. A system with a timer is imparted to monitor the pumping rate of the solution from the reservoir to the system and again back to it. Here, alkalinity and salinity are addressed with the balance of

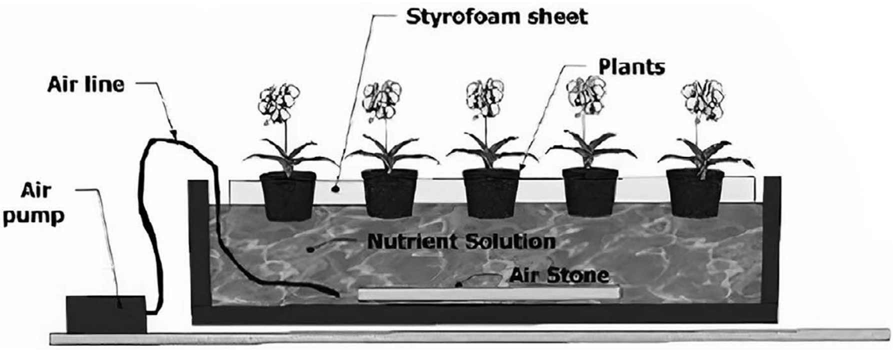

FIGURE 2.6
Depiction of the water culture system.

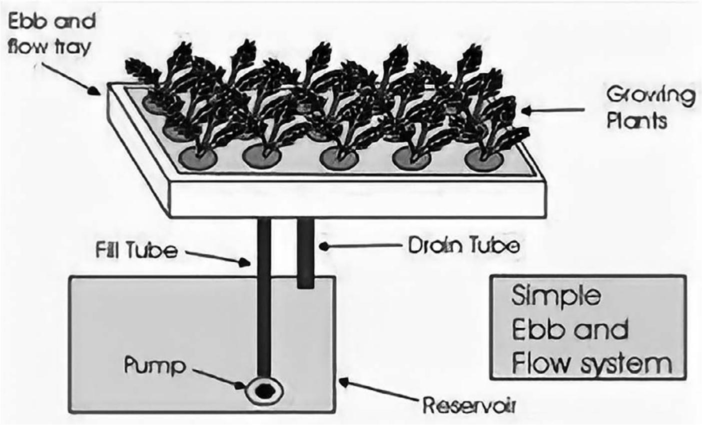

FIGURE 2.7
Depiction of ebb and flow system.

bicarbonates in the growth tray using the nutrient solution. Excess solution is drained out and a pH of 6.5–8 is maintained in the system (Figure 2.7).

2.4.2.3 Drip Systems

This is the most commonly used method of irrigation system for the plants. Here, a submersible pump is placed in the water, and as usual, a timer control unit is placed along with it. The water is dropped in the base of the plant and it is distributed to all the pipelines, which is one of the best methods comparing to previous methods. The pH balance is around 5.5–7 due to the continuous flow of water and nutrient solution (Figure 2.8).

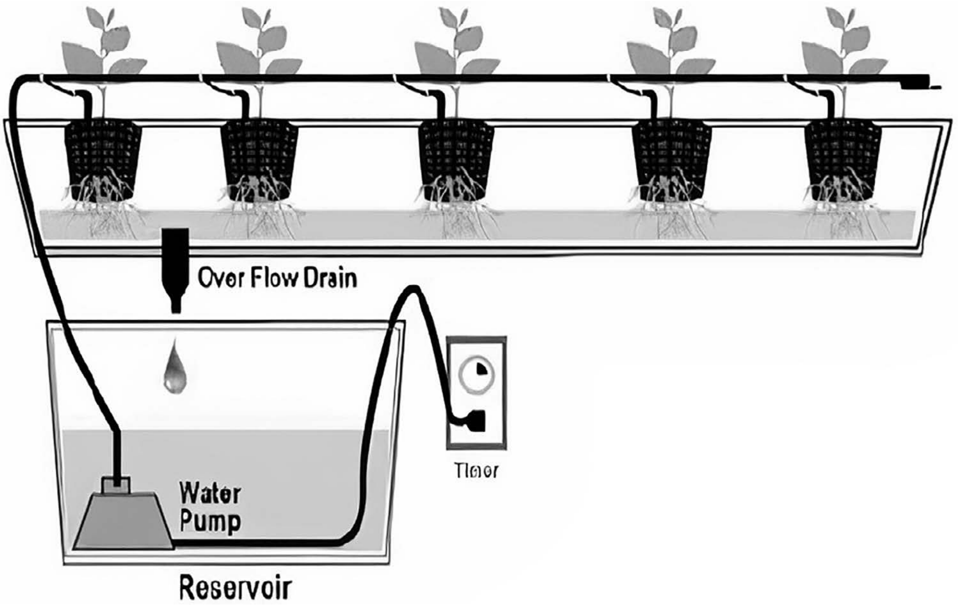

FIGURE 2.8
Depiction of the drip system.

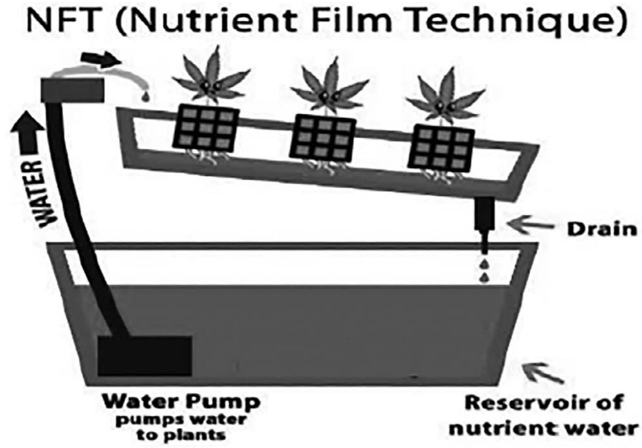

FIGURE 2.9
Depiction of the NFT system.

2.4.2.4 Nutrient Film Technique Systems

This is a well-known method in the process of hydroponics [2–5]. Here, the NFT system uses the method of inflow and outflow in a continuous loop. It is made up of plastic material, and in a few cases, the pipe is coated with black color to avoid algae formation. Here also, the pH is maintained at 5.5–7. The setup is closely similar to drip irrigation. The only difference in the system is the modeling of NFT in a cultivation fashion (Figure 2.9).

2.4.3 Building Structure Based on Plants

In building a structure for cultivating plants, the balance of the ecosystem is a necessary one. Here, the plant, fish, and bacteria are in a unique balance to establish equilibrium among them. The structure of aquaponics proposed is built through an NFT system integrated with a fish tank (Figures 2.10 and 2.11) [3].

2.4.4 Light – A Factor in Cultivation

Light is called a cultivation factor because of its life forcing energy. The exposure of the plant to sunlight makes it grow with good metabolism. The plant will express its nature of growing with abundant photosynthesis. The size of the leaves will be increased with the metabolic activity. It happens only through constant exposure to sunlight and water. The mint plants have shown a promise-able growth concerning this model [3]. Here, the nitrite is supplied from aquaculture to the mint plants. This acts as a nutrient dose to the plants (Figure 2.12).

Vertical farming has the proposal of cultivating plants in an indoor area by using an LED lighting system. Light has a variety of spectra, among which plants use only necessary spectra like red spectrum for their growth and blue spectrum for their flowering state. Here, the plant's red spectrum is further classified into a red and far-red spectrum. The plant saplings use the red spectrum to grow in their initial state. The plant, upon receiving a far-red spectrum, stops the photosynthesis process and distributes the starch to maintain its metabolism. By this process, the artificial LED lighting system provides the respective spectrum for the metabolism of the plants. This is used in indoor vertical farming [9, 19, 25] skyscrapers. The powering up of the lighting system must be backed up by a solar power system. This helps us to unleash the power of an LED lighting system for the plants in indoor cultivation.

FIGURE 2.10
NFT structure for the cultivation of the mint plant.

2.4.5 Recycling Unit for Sustainability

The recycling in the proposed model refers to the process of exchanging the values of the nutrient solution to the plants and clean water solution from the plants to the fish tank. This is the process for a sustainable production system. Various parameters such as temperature, pH levels of fish waste tanks, and dissolved oxygen are observed using sensors from the proposed model. They insinuate from the data observed that temperature must be around 26°C–28°C. When the temperature increases, the pH level starts to decrease

FIGURE 2.11
NFT structure attached with the fish tank.

FIGURE 2.12
Mint plant growth in NFT.

gradually. As pH level is the basis for the existence of fish life cycle, it must be restored at a value around 6.8–7.6.

The second governing factor of temperature is dissolved oxygen present in the water. Oxygen is the fundamental one for life's existence [17]. Dissolved oxygen is the broken-up oxygen available in the water. Dissolved oxygen levels must be constantly maintained to have a good force of production. The size that the plants grow to is directly proportional to the size of the fish. In Figure 2.13, we could examine the mint plant growing from a small sapling to a full-size plant.

In the proposed system of cultivation, the plants must have varying pH levels when compared to the pH level in the soil. The soil is a good nutrient provider with its microorganisms, soil air, soil water, and minerals and salts in it. To compensate for the contribution of soil in vertical farming, we need to continuously monitor the pH level. This case is sensitive when aquaculture and hydroponics [2–5] are combined.

2.4.6 Technological Role of IoT

Nowadays, we use modern technology in place of traditional mechanized methods. The technology relies on the data collected from the environment through sensors and actuators. Data collected from the sensors and actuators are stored in the cloud storage space or independent hardware data spaces. By using artificial intelligence and machine learning algorithms such as deep neural networks, the complete automation of farming can be done. Here, automation gives rise to microcontroller boards like Arduino, Rasberry Pi, and

FIGURE 2.13
Fully grown mint plant in NFT system.

BeagleBone boards for the process of control and monitoring. The microcontroller boards help us to connect directly to cloud data storage through the wireless network.

Here, in this automation process, the nutrient solution tank (fish tank) must be checked with proper levels of pH and oxygen content. The system is built with nutrient conversion forms from ammonia to nitrogen. In the proposed model, mint plant cultivation is automated with an Arduino board as a controller with ThingSpeak cloud platform as a storage platform. The Arduino board is connected to the DHT11 temperature and humidity sensor along with other sensors such as pH sensor and dissolved oxygen sensor. The temperature is directly proportional to the pH level of the system. The temperature is varied along with the pH of the system and it is keenly shown in the graph. The ThingSpeak cloud platform uses algorithm status of change in pH with respect to temperature. It has been reflected in the working algorithm in the microcontroller used. The dissolved oxygen sensor in the fish tank is integrated with the pH sensor to calibrate the balance of pH levels in the water. When the pH level is stabilized between 5.5 and 7, then the growth rate is in measurable form. The plant has shown a consistent increase in growth with respect to the size of fish in the tank.

The data collected from the pH sensors in the fish tank and NFT system is shown in Figure 2.14. Here, the data show variations in levels concerning temperature and dissolved oxygen. The entire system has a balancing nature in the pH value with the aquaculture and NFT system. Hence, the continuous monitoring of pH levels in the case of soilless cultivation is achieved through techniques such as IoT, data analytics, and cloud computing [2–4, 17].

2.4.7 Future of Urban Farming

Currently, companies like General Electricals, AeroFarms, Nuvege, and Ecopia Farms have structured their vertical farms in a way to meet the demands of the world. AeroFarms has taken a good initiative of turning out a used steel factory into a vertical farming factory. It sounds to be 75% more productive than the soil-based farming technique. It consumes only 5% of water for its productivity. Here, the highly motivating thing is that AeroFarms

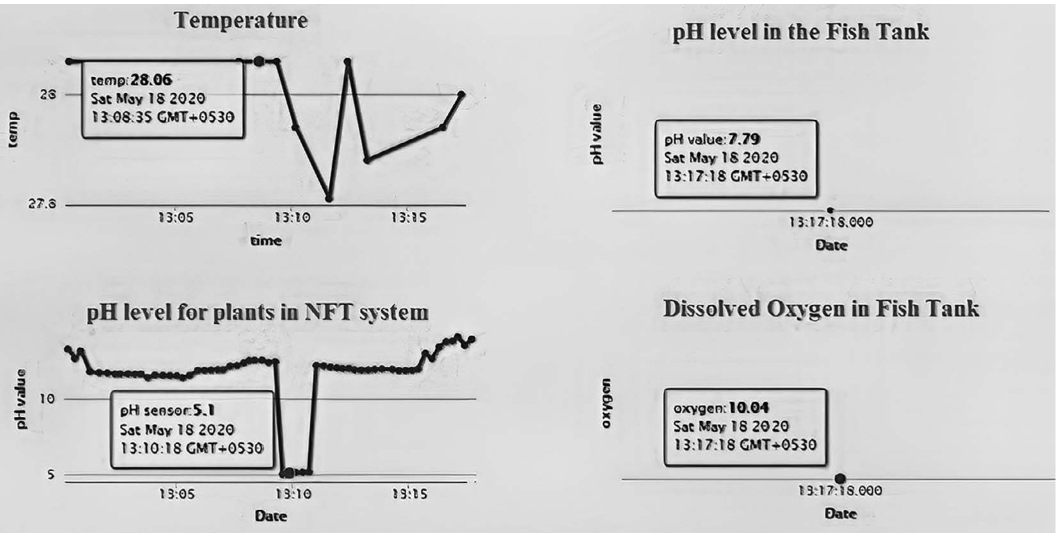

FIGURE 2.14
Data chart of the proposed system from various sensor sets.

cultivate non-genetically modified seeds with the elimination of pesticides and insecticides. This is possible because of the closed-loop system approach in vertical farming.

In Singapore, Sky Greens Farms have started the vertical farm in the year 2009 and experimented with it in a 30-feet tall tower for growing leafy vegetables. The tower can produce around 0.5 tonnes of veggies per day [18]. In Japan, during the earthquake crisis in 2011, the country faced a critical shortage in the food supply. General Electricals and Mirai jointly opened up an indoor farming system to go for a quick fix. In that farm, LEDs with the necessary spectrum for plant growth are used rather than using the full spectrum of light [23]. Philips and General Electricals combined work on the usage of the light spectrum for better growth of different plants. Mirai and General Electricals combined exposure in Hong Kong and Russia to establish vegetable factories [17].

Few local governing bodies of the different countries such as Portland and New York in the United States, United Arab Emirates, China, and South Korea have collaborated with corporate companies like General Electricals to establish vertical farming in their cities of their countries. The state universities, along with local governing authorities of the state, are developing joint venture research centers in vertical farming. One such example is the Illinois Institute of Technology in Chicago, United States. The institute established research prototypes in vertical farming. In their practice of vertical farming, methods like hydroponics [2–5], aeroponics [8], and aquaponics [6] have recorded an increase in production of up to 23 times from the traditional method and 30 times decrease in water usage [24]. These data give us the promise of being able to scope in the establishment of vertical farming for both personal and business purposes in urban areas.

In India, a Mumbai-based startup named Herbivore Farms is the country's first hyperlocal farm implementing the hydroponics method [2–5]. It can be used to grow 2500 types of plants in controlled environmental conditions and is established in a warehouse of an old industrial estate building in Andheri East in Mumbai. It grows superhealthy varieties of green leafy vegetables such as kale, lettuce, and Swiss chard.

Yet another hydroponics company in Chennai named FutureFarms has established itself as one among the agristartups in the country to use the hydroponics method [2–5] of cultivation and setting up farm structures on the rooftop to produce quality crops. It has done 32 commercially successful projects for the enterprises such as Adani Group, Dabur, Aries Agro, Parry Agro, Kalpataru Group, and many in the pipeline. FutureFarms has successfully cultivated 16 varieties of crops under English, Asian, and Indian exotics in 15 acres of land spread across 10 states of our country.

2.4.8 Disruption of Farming through the IoT

The production of crops in vertical farming involves huge data to be processed and analyzed for their effective growth. The day-to-day operations need to be taken care of based on effective usage of data from collection to analysis. This helps the system make intelligent decisions based on the data collected. It reduces human intervention in the process of indoor cultivation. Vertical farming with modern technologies appears to be a promising one, but it has its challenges. Due to its infrastructure investment, the return on investment seems to be a crucial one. With technological support such as automation of the entire process from seed to crop, we can achieve maximum yield from the crops. Bitmantis, a Bangalore-based firm, has created a solution based on the IoT termed to be TheGreenSAGE. It provides apt temperature conditions for the good growth of veggies. It provides automaticity in control of light, water, and other parameters for the growth of plants. The management of growth factors such as nutrients, irrigation, and light management are completely automated [23].

This automation is governed by technological supports such as the IoT, simulation modeling, and big data analytics. It consistently monitors, tests, and reviews the analysis. IoT forms the potential ground in vertical farming. Technologically sound companies can opt for wireless sensors and actuators to receive data from environmental factors such as light, heat, and moisture. Controlled environment automation of crucial governing factors like reducing the intensity of light, switching between the spectra, temperature control cover-structures, and pH balancer can be incorporated in vertical farms backed up with the power of technology. This helps in the proactive management of vertical farming [11, 12, 25].

Few veggies demand good aeration for their growth. In such cases, we go with monitoring the level of carbon dioxide, moisture level, and nutrient value in the solution for sustaining optimal growth, and it is achieved by integrating computerized management and operation system. This computerized mechanism uses an IoT framework for the integrated management of different layers such as sensing, delivering, and controlling. The sensing layer senses environmental conditions like temperature, pH, and soil moisture. Say, for example, a light detection sensor could show real-time variations in the intensity of light. Here, video sensors monitor the height of the plant to know its adaptability for growth. We could use more advanced analysis like spectral analysis to find out the biological stress undergone by the plants. In the delivery layer, information is acquired from the previous layer with various protocols like Zigbee, Wi-Fi, 6LoWPAN, Z-wave, Ethernet, Bluetooth low-energy near field communication, and mobile technologies (2G, 3G, 4G). The next layer comprises intelligently controlled cloud computing systems and individually operated personal digital assistants (PDA). This layer is solely responsible for rising to a better yield by using simulation modeling. It gives varieties of observations and data references for a compact analysis with various constraints like evapotranspiration, soil moisture, weather forecast, bio-stress, and crop management. These large sums of data are taken for data mining by the research groups in companies to predict the futuristic necessity of the crops. This indirectly produces employment opportunities in data science and analytics. In this way, we can use technology to fire up the performance of vertical farming for our food in the future.

The proposed model uses a simple protocol method to establish communication between the sensors and the microcontroller. The sensors are digital sensors that communicate with the microcontroller board through digital control pins in the board and it is processed through the proposed model working algorithm to channelize the output via the internet to the cloud platform. In a cloud platform, the performance analyses of sensors are taken with their data. Thus, the proposed model turned out to be a successful prototype.

2.5 Advantages of Proposed Model

Aquaponics is a combination of hydroponics [2–5] and aquaculture [6]. Here, the presence of aquaculture makes the water a nutrient solution to the plants. The metabolism of fish in fish tanks produces organic waste turning out to be a nutrient solution. The water from the fish tank is passed through a mechanized filter that removes solid substances and passes through a bio-filter that consists of gravel pebbles to convert ammonia into nitrate. The nitrated water is absorbed by the plants and recycled back to the fish tank as purified water. Here in this process, the gravel pebbles act as a bio-filter in the nitrification process.

In this nitrification process, the ammonia in fish waste is broken down into various stages of nitrogen components such as ammonia to nitrate and then to nitrite. Nitrite is the absorbable form of nitrogen by plants. Now, it seems to be an organic nutrient solution to the plants. The recycled water enters the fish tank and it is aerated by a submersible pump to have a good balance of dissolved oxygen in it. Now, the process of removal of ammonia in the water prevents it from being toxic to the fish. The nitrifying bacteria, fish, and plants all combine to make a balanced healthy environment (Figure 2.15).

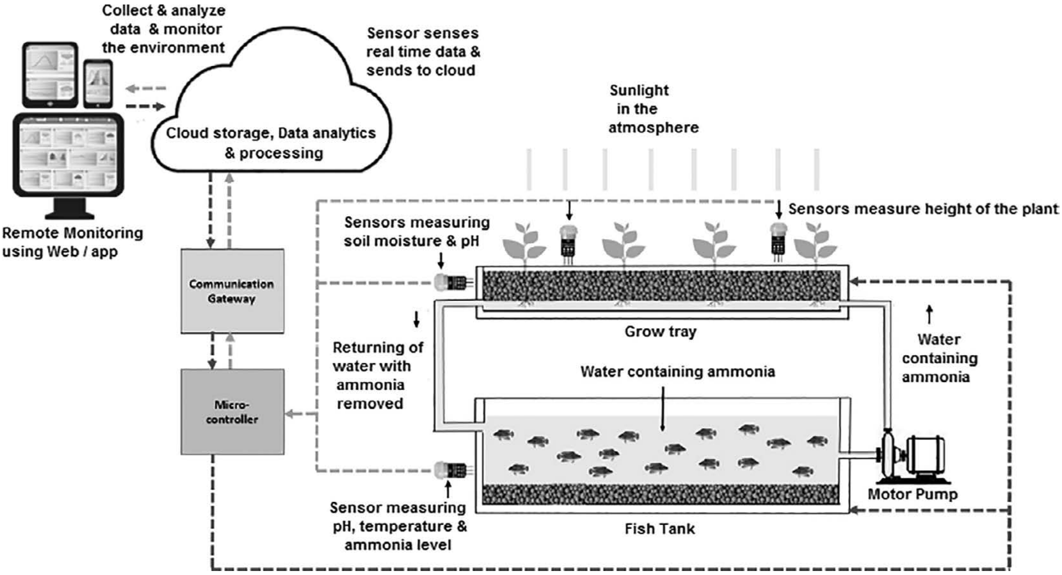

FIGURE 2.15
Diagrammatic view of the proposed model.

2.6 Conclusion

Crops, in traditional farming, are subjected to various natural challenges like global warming, climatic changes, and calamities. Here, the expectation of nature to feed the population is increasing day by day. Moreover, discrepancies in basic amenities for traditional cultivation like the shrinking of farming land and water resources and the lowering of crop yields make farming a challenging one. Here, vertical farming appears as the best alternative to sustainable production. Advanced technologies such as artificial intelligence, machine learning, and data analytics assist vertical farming in achieving technological success in managing it. The motto of technology-enabled vertical farming is to integrate the smart indoor farming system and it is governed by the controlled environment concerning customer demands. Research groups, startups, Non Government Organizations, and technologists have joined together to turn vertical farming into a cost-efficient production system with robotics, analytics IoT, and agri-simulation tools.

In vertical farming, though it has better reliability than many other techniques of farming; live monitoring for the crops is highly demanded. To overcome this demand, a smart farming technique is proposed by incorporating artificial intelligence and machine learning–based algorithms. This makes farming a smarter one as it does not require human monitoring. The idea of the proposed chapter is to make household farming possible with improved monitoring techniques. A mint plant was cultivated based on the proposed technique and tested for results. This mint plantation is made independent by the providence of a smarter environment. Parameters such as water input and growth of the plant are automated and live monitoring is provided. Higher-end challenges like pollination between plants (nature's job) need to be mechanized with automation. On the whole, it is a power-intensive system of farming. To compensate for this, intelligent artificial intelligence–powered systems must be incorporated for the sustainable existence of this farming technology.

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3

Sustainable Smart Crop Management for Indian Farms Using Artificial Intelligence

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CONTENTS

3.1 Introduction

With increasing demands and the need for sustainable agriculture, farmers, and other stakeholders must invest heavily in expertise as well as more sophisticated machines and equipment. Smart farming objectives must address concerns such as how much fertilizer to

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apply, when to apply it, and where it should be applied, as well as the resources needed for plant protection and other related issues. Agricultural companies can better monitor the condition of their crops and receive recommendations that can help them minimize pollution and pesticide use by using the Internet of Things (IoT) to gather data on their crops and then analyzing the data with technologies like machine learning. These advances make farming not only more sustainable but also more productive and profitable. The IoT offers a potential approach to these issues. By adding tracking devices to their crops and sending the data back to a central center that the farmer can access, agricultural companies can track their crops in real time and with greater precision. Artificial intelligence (AI) is being used to diagnose pests, predict the best time to plant, and measure production costs. A novel automated quality assessment method based on convolutional neural networks (CNNs) will be used to evaluate crop quality in the Indian context in this report. The challenges of implementing CNN-based quality assessment in India are complicated by the large amount of data needed to train the models.

3.1.1 Significance of Big Data in Agriculture

Big data applications in agriculture are addressing critical issues such as sustainability, global food security, protection, and increased productivity. Traditional players such as technology and input suppliers provide forums and solutions to farmers. Farmers will either become franchisees in interconnected long supply chains or will partner with suppliers and the government to participate in short supply chains as a result of the application growth of big data in agriculture. Data from GPS-equipped tractors, soil sensors, and other external sources assists in improved crop, pesticide, and fertilizer management, as well as increased production to feed the world's rising population. Sensor data collection removes inaccuracies in manual labor and provides useful insights into yield forecasting. Data-driven farming has minimized crop failures caused by changing weather conditions. By detecting microbes and other pollutants early, data on temperature, humidity, and chemicals can help to reduce the risk of food spoilage. The agriculture industry saves a lot of money thanks to AI and data analytics–driven farming.

3.1.2 Role of AI in Indian Agriculture

AI technology has already begun to change the agriculture market. Large-scale farmers are now harnessing the power of technology, such as autonomous tractors that use GPS, satellite imagery, and AI to plant crops more effectively. Many companies are employing automation and robotics technology to assist farmers in seeking more effective ways to practice sustainable farming, such as avoiding the use of pesticides for weed control, harvesting crops, and diagnosing soil defects, among other things.

Emerging technologies play an important role in allowing farmers to continue on their path to sustainable agriculture. In the current pandemic scenario, technology can be an efficient way to keep farming ongoing by overcoming all restrictions. In addition, problems like population growth, climate change, and food security necessitate novel approaches to increasing crop yield. As a result, comprehending AI's application in agriculture becomes essential.

3.1.3 Significance of AI and IoT in Agriculture

According to a recent market research study, by 2024, the AI agriculture market will have expanded at a compound annual growth rate of 28.38%. Farmers had previously

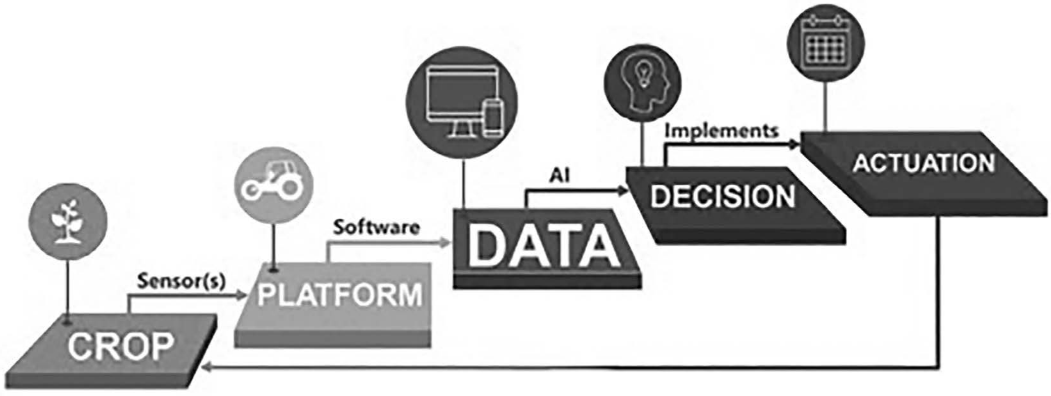


FIGURE 3.1
Overview of AI and IoT toward smart farming.

relied on manual data collection during their working hours to gather information about their crops. This resulted in two major issues. For starters, when doing something by hand, there is usually more space for error. Second, manual monitoring should only be done in intervals, should the farmer spend the whole day checking on the crops and ignoring the rest of his or her responsibilities. Agribusinesses can better track the condition of their crops and obtain recommendations that can help them minimize contamination and pesticide usage by using the IoT to collect data on their crops and then analyzing the data with technologies like machine learning. Both of these problems can be solved by the IoT [1]. However, thanks to software-as-a-service (SaaS) cloud systems, smart farming technology has the ability to go beyond individual farms. In particular, SaaS and IoT hardware can be combined to collect data and provide insights into how farm operations can be handled. To name a few examples, this includes details on crop conditions, weather cycles, harvesting, and soil quality. All of this information will be processed in the cloud, where it will be organized and available at all times, allowing field operations to be tracked from anywhere and at any time. Figure 3.1 depicts how IoT sensors are used in the field and data is stored in the cloud, providing an overview of AI and IoT for smart farming. How the data is analyzed using AI techniques for prediction and decision-making is also addressed [2].

3.2 Deep Learning for Smart Farming

Deep learning is commonly used in a variety of areas including medicine, industry, and transportation, and agriculture is no exception. Shallow learning suffers from a lack of feature speech as well as dimensionality issues. Furthermore, the features must be produced by human experts [3]. Deep learning addresses these issues by automatically extracting these features from raw data. Deep learning is a new AI research direction. Various applications like image recognition, natural language processing (NLP), text processing, facial recognition, and voice recognition, and a variety of other fields have all seen success with it. There are various deep learning architectures like CNNs, deep belief networks, and

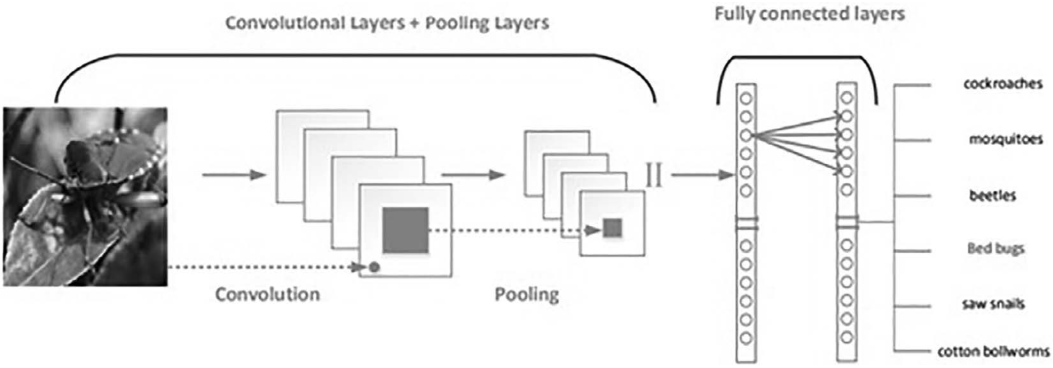


FIGURE 3.2
CNN model for pest identification.

recurrent neural networks. A CNN is a popular supervised learning model that has a lot of adaptability and is frequently used to process image data [4].

3.2.1 Convolutional Neural Networks

A CNN is a multilayer feed-forward neural network consisting of learnable parameters such as weight and bias. In each layer the neurons receive a huge number of inputs and weights and then forward the weight to the activation node. It works on the principle of convolution. Each neuron in this layer is only bound to a part of the actual input image. The mapping of weights shared by all the neurons in the output of the convolutional layer is referred to as a "feature map."

A traditional neural network receives its inputs as a one-dimensional vector, though the CNN processes the inputs as multichannel images. The CNN is built on two fundamental ideas that enable it to perform complex tasks such as image classification and recognition, object detection, object segmentation, and localization. Figure 3.2 depicts a sample CNN model for pest identification for reference [5, 6].

3.2.1.1 Pooling Layer

This layer is the CNN's most powerful and basic building block, which can minimize the number of parameters in the network by reducing the spatial scale of the input dimension. The pooling layer, also known as the downsampling layer, is extended to all layers if the computation expense needs to be reduced. There are three different pooling methodologies available: Min, Max, and Average pooling. The pooling layer is considered to be one of the primary network layers that avoids overfitting and enables the network to be used as a basic model.

3.2.1.2 Activation Layer

The purpose of this layer is to generate some amount of non-linearity between the input and output. This layer's main job is to transform a node's associated signal degree into a signal that can be used by the next layer in the stack. The signal would be nothing more than a simple rectilinear regression function if the activation function was not used.

It is a simple method to decipher, but it is limited in terms of power and complexity. Furthermore, if this activation function is not used in the neural network, then the network cannot learn and model complex data like images, videos, and audio and voice, among other things. Sigmoid, Tanh, Rectified Linear Unit (ReLu), Leaky ReLu, and Maxout are some of the activation functions used.

3.2.1.3 Sigmoid

For binary classification, the sigmoid activation function is used, with values ranging from 0 to 1.

3.2.1.4 Tanh

A shifted version of the sigmoid hyperbolic function is the tangent hyperbolic function. Since the range of the tanh function is between –1 and 1, it is not a zero-centered function, making optimization much easier. Even though it is a major improvement over the sigmoid feature, it still has diminishing gradient issues.

3.2.1.5 Softmax

When there are a lot of classes in a multiclass function, softmax is used. The softmax is simply a probability function that predicts outcomes as a specific class with a predicted value.

3.2.1.6 Rectified Linear Unit

In CNN, ReLU is commonly used as an activation mechanism to prevent vanishing gradients and increase training speed. The following is the definition of ReLU's function:

$$\text{ReLU}(x) = \begin{cases} x, \text{if } x > 0 \\ 0, \text{if } x \le 0 \end{cases}.$$

3.2.1.7 Flatten Layer

The flatten layer transforms n-dimensional vector representations into a single-dimensional column vector to operate at dense or fully connected layers. The function map is converted into a flatten output by the flatten layer (column vector).

3.3 Related Works on CNN-Based Smart Farming

A review of potential applications using deep learning techniques, specifically CNN, are analyzed and outlined below in Table 3.1 for various smart farming applications.

TABLE 3.1

Existing Works on CNN-Based Smart Farming

Type of Problem	Article	CNN Model Used	Accuracy (%)
Plant detection and localization	Ref. [7]	VGG-CNN-VD16 and VGG-CNN-S	73.07
Plant segmentation	Ref. [8]	CNN-based segmentation approach (U-net)	84
Leaf detection, localization, and counting	Ref. [9]	CNN	88.5
Leaf segmentation	Ref. [10]	Mask R-CNN	91.5
Leaf tracking	Ref. [11]	R-CNN	91.8
Land cover identification	Ref. [12]	FCNN	–
Classification and regression of mutants and treatments	Ref. [13]	CNN	96.8
Weed management	Ref. [14]	CNN	98
Pest management	Ref. [15]	CNN	81.4
Disease diagnosis	Ref. [16]	VGG-FCN-VD16 and VGG-FCN-S	97.95 and 95.12, respectively
Precision livestock farming	Ref. [17]	YOLO-v3	98.46%
Smart irrigation	Ref. [18]	R-CNN	80

3.4 State of Art CNN Architecture

Figure 3.3 displays an overall model of the proposed CNN, where the data is divided into training and validation datasets. The images are 64 × 64 RGB images, which are given as input to the deep neural network. The process of convolution is performed for a filter size of 128 and kernel size of 3. The Leaky ReLu activation is applied to find the probability of prediction and further, Maxpooling is performed. This process is repeated with a convolution filter size of 256 and 512. An uncertainty matrix is used to measure the performance assessment metrics [19, 20].

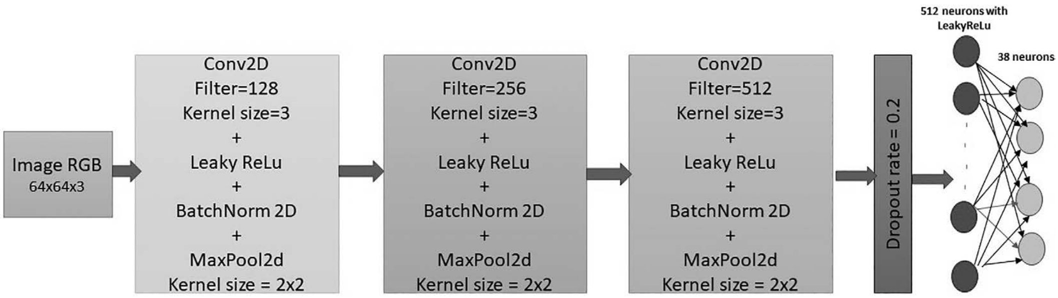


FIGURE 3.3
State of art CNN model for disease classification.

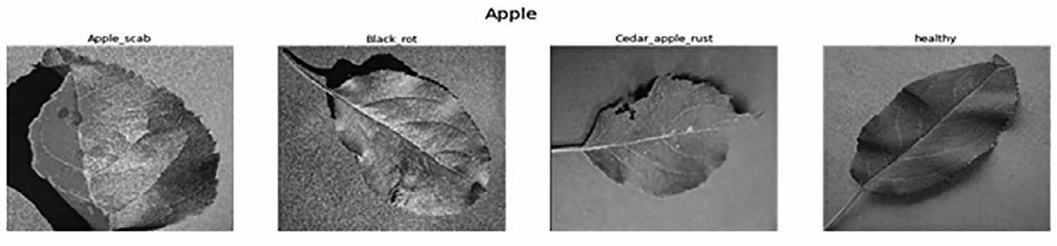


FIGURE 3.4
Sample dataset.

3.4.1 Dataset Collection

The plant village dataset is collected from Kaggle for this study. This dataset contains approximately 87.5K RGB images of stable and diseased crop leaves that are divided into 38 classes of species and diseases. The entire set of data is divided with an 80/20 split, where 80% belongs to the training dataset and 20% belongs to the validation dataset. The training set has 70,295 images and the validation set has 17,572 images. The sample image dataset is given in Figure 3.4 and the split ratio of the dataset based on training and validation is depicted in Figure 3.5.

3.5 Result and Discussion

The proposed state-of-the-art CNN was constructed and evaluated using the parameters stated in Table 3.2.

The performance metrics for the model using CNN are obtained by running the model till epoch 25 and the corresponding values are outlined in Table 3.3. The learning rate for the model is also given in the table. From the data, it can be deduced that increasing the epoch leads to an increase in accuracy as well as a decrease in loss when compared to

FIGURE 3.5
Split-up ratio for the dataset.

TABLE 3.2

Existing Works on CNN-Based Smart Farming

Type of Optimizer	Adam
Learning rate scheduler	Linear wise, step size = 5, gamma = 0.2
Amount of loss	Categorical cross entropy
Value of learning rate	0.001
Epochs	25

previous iterations. Table 3.3 displays the effects of running the model for epochs from 1 to 25 and the hyperparameters are adjusted to improve the efficiency with the Adam optimizer.

3.5.1 Confusion Matrix

A confusion matrix is a table that shows how many right and incorrect predictions a classifier made. It's a metric for evaluating a classification model's results. It can be used to calculate various metrics to determine the performance of a classification model. The uncertainty matrix, also known as an error matrix, is a tabular format that displays how well a classification model performs on validation data when the positive values of the validation dataset are available. The matrix is used to measure the following parameters:

- **Error rate**: The total number of incorrect predictions divided by the whole dataset.

$$\mathbf{Error\,rate = (False\ \ Positive + False\ \ Negative)/(Positive + Negative)}$$

- **Accuracy**: A measure of total number of correct predictions made.

$$\mathbf{Accuracy = (No.\ of\ true\ positive + No.\ of\ true\ negative)/} \\ \mathbf{(Tot.\ no\ of\ positive + Tot.\ no\ of\ Negative)}$$

- **Sensitivity:** A measure of the fraction of actual positives ranging from 0 to 1.

$$\mathbf{Sensitivity\ \ or\ \ Recall = True\ \ Positive/Positives}$$

- **Precision**: A measure of the fraction of actual positives predicted as positive.

$$\mathbf{Precision = No\ of\ True\ Positive/(Tot.\ no\ of\ True\ Positive + Tot.\ no\ of\ False\ Positive).}$$

TABLE 3.3

CNN Performance Analysis Using Adam Optimizer

No of Runs (Epoch)	Training Accuracy	Validation Accuracy	Training Loss	Validation Loss	Learning Rate
10	99.68	98.22	0.02	0.05	0.002
15	100	99.14	0.006	0.03	0.00004
20	100	99.37	0.005	0.027	0.000008
25	100	99.38	0.004	0.026	0.0000016

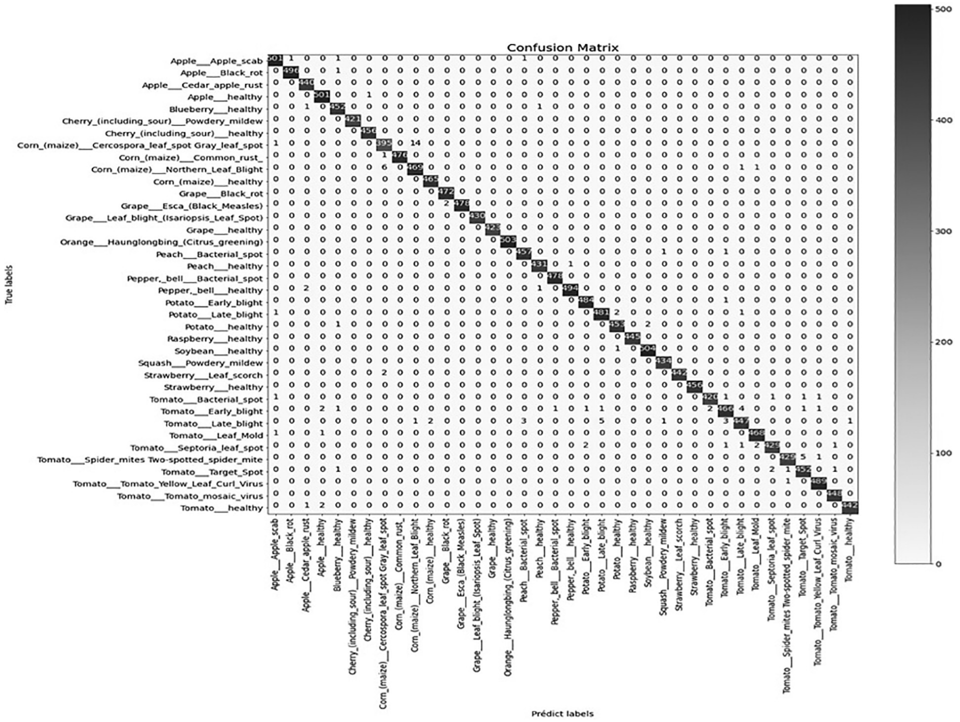
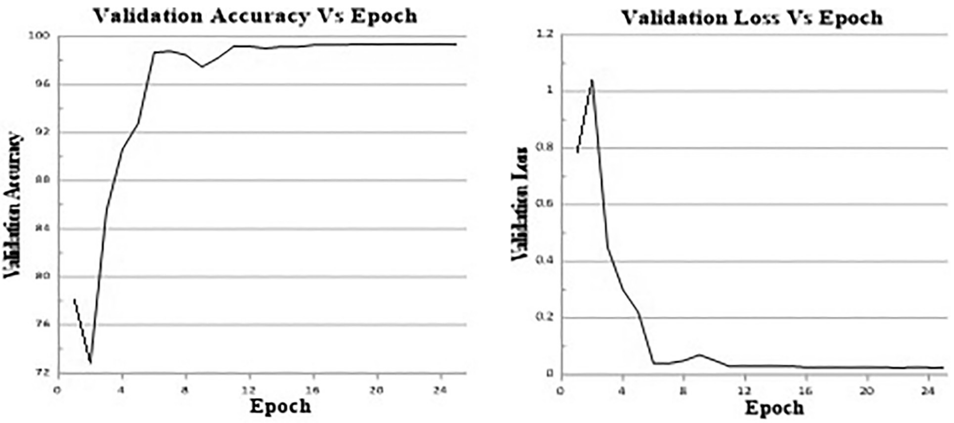


FIGURE 3.6
Confusion matrix.

The matrix known as the "confusion matrix" is considered in order to test the efficiency of the proposed procedures and it is illustrated in Figure 3.6. All the accuracy values of total positive calculations of all 38 classes of unhealthy classifications are obtained over the diagonal.

Due to hyperparameter tuning, an accuracy of 99.38% is achieved by the proposed model, Figure 3.7(a) and (b) shows the final validation loss and accuracy graph after epoch 25, respectively.



(a) (b)

FIGURE 3.7
(a) Training loss at epoch 25. (b) Training accuracy at epoch 25.

3.6 Conclusion

Data-driven agriculture, aided by IoT technologies that incorporate AI techniques, lays the foundation for future sustainable agriculture. Currently farmers and food producers are battling the Covid-19 pandemic to explore new opportunities for smart farming. This study emphasizes the importance of using a deep learning CNN architecture for a variety of smart farming applications involving data analysis, image analysis, and computer vision. In this chapter, the significance of IoT in smart farming has been explored and an illustration of how AI plays a vital role in the prediction of healthy and unhealthy plants is done using CNN. The experiment was performed using the standard plant village dataset from the Kaggle repository. The model's performance was analyzed for over 25 epochs with necessary hyperparameter tuning and it achieved improved accuracy of 99.38% with minimum loss. Indian crops face huge sustainability problems and this can be overcome using smart farming technologies like AI and IoT. And hence this model is applicable in scenarios where smart prediction is highly required.

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4

Smart Livestock Management Using Cloud IoT

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CONTENTS

4.1 Introduction

Livestock refers to domesticated animals raised in an agricultural locale to generate labor and commodities such as wool, leather, milk, egg, and meat. The livestock species plays an inevitable economic and socio-cultural role in the economic upliftment of the rural population. Often farmers face many problems due to health issues of livestock, theft, etc. They have to continuously monitor the activities, location, and health condition of

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the livestock so that they do not face a higher sum of mortality loss. Usually, the monitoring of livestock is done manually, which is less reliable and prone to more human errors when it comes to large farms. This necessitates reliable monitoring of livestock that supports the farmers by providing an efficient system that utilizes the recent advancements in computing and communication technologies. The management and tracking of livestock have been made more expedient by deploying the Internet of Things (IoT) and cloud computing paradigm [1, 2].

Livestock management, also known as livestock monitoring or precision livestock farming (PLF) [3], involves deploying IoT devices to track and monitor the health status of livestock. PLF is defined as: "the application of process engineering principles and techniques to livestock farming to automatically monitor, model and manage animal production." The major scope of the PLF is to make livestock farming economically profitable to the farmer, which is made possible by comprehensive management of the farm by continuous monitoring and control of the livestock.

The confluence of the cloud and the IoT has paved the way to a new perspective technology termed cloud IoT, where the services offered by both the technologies are aggregated. Recent research presents many efficacious cloud IoT-based smart livestock management systems that are affordable and easy to use [4]. These technologies have enhanced livestock management by collecting both physiological and environmental parameters that affect the health of the livestock through the sensors and providing vital information regarding them to the farmers via the cloud. The desirable design characteristics of livestock monitoring systems discussed in various works of literature are:

- Low cost
- Robustness
- The design of the device not affecting the behavior of the animal
- Energy consumption of the device
- Reliable communication
- Very less packet loss

The key benefits of smart livestock management using cloud IoT are as follows:

- Creating a census of livestock by providing them with a unique identification (UID) number
- Monitoring the health levels of the livestock and quickly treating the animals and preventing the spread of many contiguous diseases and illnesses
- Automated feeding system to monitor the quantity and quality of food intake by the livestock
- Enabling remote monitoring and tracking of the location of animals and aiding in the prevention of animal theft
- Collecting and storing the data of the livestock on the cloud for future traceability
- Identifying the patterns in cattle health or trailing the transmission of infectious diseases by analyzing historical data available on the cloud
- Voice-based assistants create a user-friendly system to control and monitor the livestock

In this chapter, a comprehensive overview of the existing livestock monitoring system available in the current scenario is detailed. Most of the literature provides solutions for the following three major management components:

- Monitoring the health status of livestock in real-time
- Tracking the location of grazing animals and identification of livestock using a UID for animals
- Smart feeding system

The succeeding sections provide a detailed description of the deployment of cloud IoT for the components listed earlier.

4.2 Monitoring the Health of Livestock

There is an essential need to oversee the health status of livestock to prevent and diagnose diseases before a large number of them get affected. The conventional health monitoring system involves the manual inspection of farm animals to identify the symptoms of disease or any wounds that are prone to the occurrence of more inaccuracy. IoT-enabled livestock management provides enhanced solutions to monitor the health of livestock [5]. Normally they are wearable devices attached to the animal while the built-in sensors help data acquisition and notify farmers about several factors that may eventually affect the livestock health.

This section discusses the layered architectural model for health monitoring that implements cloud IoT for better efficiency. The architecture consists of four layers, as seen in Figure 4.1.

- Sensing Layer
- Communication and Edge Computing Layer
- Cloud Computing Layer
- Service Layer.

4.2.1 Sensing Layer

This layer consists of various sensors to monitor the health of the livestock. The sensors present in this layer monitor the following details to predict the well-being of the livestock:

- Vital parameters of the livestock
- Environment of the livestock
- Behavior monitoring of the livestock.

4.2.1.1 Vital Parameters of the Livestock

The vital parameters measured in general include temperature, blood pressure, heartbeat, and rumination. These parameters are measured by the appropriate sensors [6–8] and data is sent to the cloud through edge nodes. The section below gives a brief outline of sensors that are commonly used for monitoring.

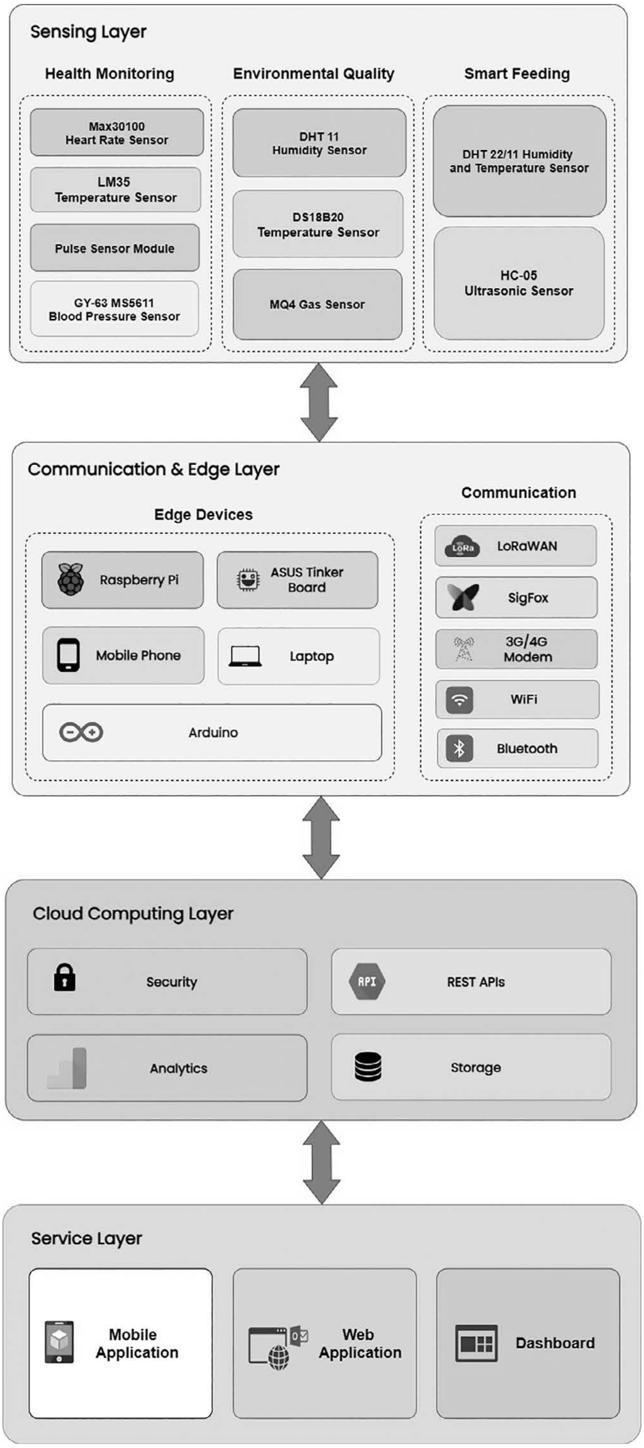

FIGURE 4.1
Architecture of health monitoring system.

4.2.2.1.1 Temperature

The health status of livestock can be predicted by monitoring the temperature as it is a primary indicator for many diseases. The normal temperature of livestock ranges between 38.5°C and 39.5°C. Fluctuations in core temperature can lead to many infections in cattle. Hence it is inevitable to monitor the temperature of the cattle. When the temperature is below the lower limit, diseases like indigestion, milk fever, and poisoning can occur. Similarly, if it exceeds 41°C, foot and mouth diseases, anthrax, influenza, etc., may occur.

Another important factor monitored among livestock is heat stress (HS). The increase in temperature is also a sign of increased heat stress which leads to less milk production that indirectly affects the farmer's profit. The increase in stress level may even lead to the death of the livestock as it causes an increase in temperature and respiration rate. Temperature also has a major impact among livestocks on issues regarding fertility. The time recommended for artificial insemination is 16 hours at a particular temperature, and hence it is essential to monitor the temperature. This ensures that optimum time is utilized for making the procedure of artificial insemination successful.

Different types of sensors that operate at different temperature ranges and varied efficiencies are enlisted below. The sensors chosen based on the requirement are connected to microcontrollers and utilized for monitoring the temperature.

- DS18B20 Body Temperature Sensor Cable – has a unique one-wire interface that provides easy communication.
- ISB-TS45D – an infrared thermometer sensor that measures the body temperature of the livestock; small size, low cost, and better accuracy are the features of this sensor that make it the most commonly used one among such health monitoring applications.
- The LM35 – an integrated circuit temperature sensor that operates between the range of –55°C and +150°C. The temperature output measured by this sensor is directly proportional to the output voltage. The different models of the LM35 sensor operate on different levels.

4.2.2.1.2 Heartbeat

The heart rate of the animal is one of the vital parameters to be constantly monitored to assess the health status of the livestock. The rate of heartbeat per minute acts as a predominant factor in evaluating health status. The normal heart rate of the adult cattle ranges between 48 and 84 beats per minute (BPM). Stress, exertion, anticipation, anxiety, increased movement, and various diseases occur when there is a significant change in the range of heartbeat. The beat per minute for different animals is given in Table 4.1.

The heartbeat of the livestock is normally measured by an electronic device known as Pulse Sensor KG011. The BPM is given as the output along with the live heartbeat waveform by this sensor. The sensor can be easily attached to the earlobes of animals and directly connected to an Arduino controller with necessary extension cables. The heart rate can be visualized as a graph in real time by using the mobile application provided along with the sensor. The pulse sensor enables faster and easier reliable pulse reading as it is enhanced with amplification and noise cancellation mechanism. A timer can be used to analyze the time difference between the digital pulses produced by the transmitter and receiver to provide a time basis for calculating the heart rate. Polar sport tester (PST)-based heart rate monitoring is also suggested as the best method to measure the heartbeat rate of cattle.

TABLE 4.1

Normal Pulse Rate of the Livestock in Beats/Minute

Sl. No	Animal	Heartbeat Per Minute (BPM)
1	Cattle	40–80
2	Young calves	100–140
3	Sheep/goat	70–130
4	Pig	90–100
5	Horse	35–40

4.2.2.1.3 *Electrocardiogram*

Electrical activity of the heart can be detected by using an electrocardiogram (ECG). It is a non-invasive test that records the rhythm, rate, and conductivity of the cattle's heart. The ECG module consists of three Ag–AgCl electrodes where a pair of electrodes are attached to the foreleg and another on the left hind limb. ECG pads and crocodile clips are used to attach the electrodes to the cattle.

AD8232 is an ECG sensor that can be integrated with Arduino, Raspberry Pi, etc., to acquire the electrical signals of the heart. This sensor can even be operated in noisy conditions that occur due to the cattle movement or remote electrode placement.

4.2.2.1.4 *Respiratory Rate Module*

When the respiration rate of cattle increases, it represents stress or pain or weakness or may be a sign of respiratory disease. If the temperature is high in the barn, the livestock may pant to compensate for the heat loss through evaporation. If a livestock pants for more than 100 breaths per minute, it is an indication of severe heat stress.

The rate of respiration can be measured by using a respiratory sensor and the respiratory rate for a different animal is given in Table 4.2. A relative pressure sensor and flexible belt fixed around the chest of livestock are the components of the respiratory rate sensor module. The inspiration and expiration of the lungs create pressure in the chest cavity, which is sensed by the pressure sensor. It calculates the pressure difference to estimate the rate of respiration.

4.2.2.1.5 *Rumination*

Rumination [9] is an essential activity of cattle through which the animal digests the food and it spends almost nine to ten hours for the same. When an abnormality is seen in the rumination process, we can easily conclude that the animal is suffering due to some illnesses like indigestion, metabolic calving, or mastitis. The direct and accurate health status of animals can be measured by monitoring the rumination.

TABLE 4.2

Normal Respiratory Rate of Livestock in Breaths/Minute

Sl. No	Animal	Breaths per Minute
1	Cattle	10–30
2	Young calves	30–60
3	Sheep/goat	16–34
4	Pig	32–58
5	Horse	10–14

Rumination can be monitored by using the following designated devices:

- Non-invasive accelerometers like ADXL 335 to record animal movement
- Built-in microphone for the acquisition of sounds
- Jaw movement monitoring by using pressure sensors.

4.2.1.2 Environment Monitoring

The environment is another important factor to consider in maintaining the health of livestock. The temperature and humidity of the barn play an indispensable role in the health of the livestock. Also, other harmful gases in the environment can harm the health of livestock to an unexpected level.

Air in the environment are a mixture of various gases such as CO_2, O_2, O_3, etc. Sensors are used to detect the air quality index to determine the quality of air and keep the livestock stay healthy. An efficient way is by using sensors to detect all possible harmful gases so that we can keep livestock from getting affected by infectious diseases. The architectural components of the environment monitoring module are as shown in Figure 4.2.

Some of those gases that are harmful to the livestock are:

- CH_4 (methane)
- H_2S (hydrogen sulfide)
- NH_3 (ammonia gas)
- CH_2O (formaldehyde)

To detect the above gases sensors such as MQ-4, MQ-136, MQ-137, and MQ-138, which help in detecting these gases, are used. Table 4.3 lists the sensors relative to the type of gas that they detect.

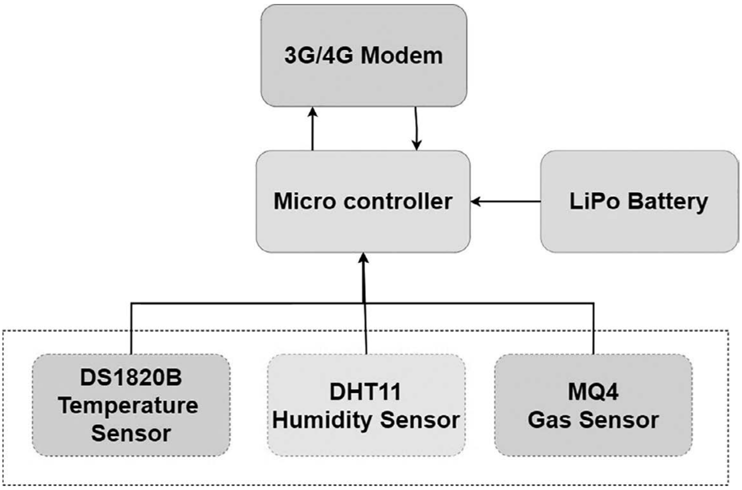

FIGURE 4.2
Environment monitoring module.

TABLE 4.3

Gas Sensors

Sensor	Detected Entity
SHT20	Barn temperature and humidity
MQ-4	Detects $\mathbf{CH_4}$
MQ-136	Detects $\mathbf{H_2S}$
MQ-137	Detects $\mathbf{NH_3}$
MQ-138	Detects $\mathbf{CH_2O}$

The barn of the livestock should be maintained at an appropriate temperature and humidity. The temperature and relative humidity values are combined to obtain the temperature–humidity index (THI), which indicates the stress that affects the livestock and directly affects milk production and reproductive efficiency:

$$\mathrm{THI} = 0.8\mathrm{T} + \left(\left(\mathrm{RH}/100\right)\left(\mathrm{T} - 14.3\right)\right) + 46.4 \tag{4.1}$$

where T is the air temperature in degrees Celsius and RH is the relative humidity expressed in a percentage between 0% and 100%.The normal THI value should be between 70 and 80. The details of variation in the THI and its indication in the health of livestock are given in Table 4.4.

4.2.1.3 Movement and Behavior Monitoring

The well-being of the livestock can be predicted by monitoring their movement and behavior. These sorts of observations, when done manually, provide less accurate results and delayed diagnoses. Hence there is a necessity to observe livestock farms using emerging technologies. Some of the monitoring systems and their scope available in the literature [10–13] are listed below.

- The abnormal movement of animals infers that they have some physical defects in their limbs.
- Deploying cameras that utilize motion detection technology at top angles in the barn to analyze the movement. Animals normally stand together closely when they face some threat. And also, they tend to move at a rapid pace at some time.
- Global Position System (GPS) and 3D collar–mounted accelerometers are used to supervise the behavior. Initially, behavior patterns are recorded and changes in patterns are analyzed to predict well-being.

TABLE 4.4

THI Stress Levels and Consequences

THI	Stress Level	Comments
<70	None	Optimum productive and reproductive performance
70–79	Mild	Increasing respiration rate, seek for shade, dilation of blood vessels
80–98	Moderate	Increasing body temperature, breaths per minute, and salival secretion
>98	Danger	Death of livestock

- The shaking motion of livestock during coughing is differentiated from other motions by using motion history image (MHI)-based technology.
- GY-25 is an accelerometer and gyroscope sensor that is used to monitor livestock movement.

4.2.2 Communication and Edge Computing Layer

The previous layer has an array of heterogeneous sensors to monitor the livestock, which leads to problems related to the management of devices, data acquisition, processing, and transmission. These constraints are solved by the edge computing paradigm. Edge nodes are capable of coordinating and managing all the resources in an IoT environment. Data collection from heterogeneous sources is also made possible through edge nodes which aid in effective data management through homogenization.

The edge layer [14, 15] is responsible for acquiring and pre-processing the information collected by the IoT devices in the sensing layer through low-cost microcomputers like Raspberry Pi, Arduino UNO, Raspberry Pi Pico, and Orange Pi. Even smartphones and laptops at the user end act as edge devices. Hence only the filtered information reaches the cloud for storage and further processing.

Edge-enabled services operate in two different ways. The first one is node-centric services, which operate independently of the cloud, and cloud-centric services, which rely on at least one service from the cloud for operation. Some IoT devices introduce delays due to intermittent connection. Based on this, another type of edge service called delay-tolerant edge service, which is also a cloud-centric service, is introduced that could withstand intermittent connection for a certain amount of time.

The addition of edge computing in between the sensor module and cloud computing offers the following advantages:

- Decreased latency
- Increased support for scalability
- Computation offloading
- Effective bandwidth utilization
- Modularity
- Reliability
- Data compression

The edge layer may also possess these add-on capabilities.

4.2.2.1 Distributed Ledger

The data collected by edge device is hashed and stored in the blockchain by using crypto IoT chips, thus ensuring traceability by maintaining the inviolability of the data. At the same instance, the data also becomes part of distributed ledgers such as Hyperledger, Ethereum, etc. Transmission costs and data traffic are reduced with the usage of distributed ledgers.

4.2.2.2 Machine Learning Techniques for Decision Making

Data analytics techniques are employed for pre-processing and filtering of the data and knowledge is generated at the edge where data is received to reduce the volume of data transferred. Machine learning frameworks such as TensorFlow Lite, Keras, scikit-learn, etc. are deployed for this purpose. Machine learning algorithms like multilayer perceptron, random forests, extreme gradient boosting, k-nearest neighbors, convolutional neural networks, etc. may be used as discussed in Refs. [16–18].

The communication between sensor nodes, edge devices, and cloud platforms is done by protocols [19–21] such as IEEE 802.11, IEEE 802.16, low-rate wireless personal area networks (LR-WPAN), Bluetooth, LoRaWAN, SigFox, and Narrowband IoT (NB-IoT). A suitable communication protocol is selected based on the range, energy constraint, and cost of the device.

4.2.3 Cloud Computing Layer

Cloud computing provides the necessary backbone infrastructure and extends a variety of services that are used by sensing devices, edge nodes, and users. The most common available cloud services are AWS IoT Platform, Google Cloud's IoT Platform, Cisco IoT Cloud Connect, Microsoft Azure IoT Suite, IBM Watson IoT Platform, Thingworx 8 IoT Platform, etc.

Each of these services is built as microservices that have specific tasks or operations to perform and are independent of each other. Communications between the microservices are through REpresentational State Transfer (REST) Application Programming Interface (APIs) [22, 23].

- Handling the pre-processed data obtained from the sensors through edge nodes and storing in the data storage provided by cloud
- Computational power is provided by the cloud to analyze the raw data and provide information about animal health, location, etc.
- Provides decision support system that makes a decision based on the data gathered from various sensors
- Alerts sent to the users to notify any perilous situation that may occur and impart suggestions to handle the same
- Provides data visualization techniques that facilitate the visualization of the data gathered in the form of a graph or relevant visuals
- Security services including authentication and authorization of users and the resources

4.2.4 Service Layer

The service layer acts as a user interface to all the services provided in this cloud IoT-based health monitoring system. All the services deployed in the health monitoring architecture are adopted by the end-users such as farmers, veterinary doctors, and animal welfare officials through this layer, which acts as the frontend. This interface is available either as a web-based application or an android application for obtaining the following services [24, 25].

- Registering livestock and the status of registered livestock can be monitored from any remote area.
- The sensor data stored in the cloud storage is analyzed and any findings are given in the dashboard. Suppose if there is a rise in temperature among the cattle that belong to the same area, a warning may be given to the authorities or farmers of that particular area for taking precautionary methods.

- Individual farmers receive messages about vaccination or health checkups for their livestock from the veterinary doctor. Queries from livestock owners are also sent to veterinary doctors through the same interface.
- Providing a visual representation of the information available and results to the end-users for better understandability. For example, the visualization of any vital parameter monitored among different groups of livestock in different locations may be represented as a graph. This will provide a vivid picture if there is an abnormality in the value of the vital signs among any herd. The concerned authorities can take proper precautionary methods and prevent the spread of infectious diseases based on the symptom.

4.3 Location Tracking System

Livestock location monitoring is a tedious process since the cattle do not stay in a fixed location. Traditionally the livestock is monitored by manual inspection and by fencing cattle. Fencing of cattle is considerably costly and it requires the physical presence of a farmer to keep an eye on the grazing cattle. The farmer needs to prevent the cattle from crossing the boundaries of the fence. The process of visual tracking and fencing is more time consuming and it is a backbreaking task for the farmers. Smart IoT-based livestock location tracking and creating virtual fences by using IoT devices, termed geofencing, can be used to monitor the livestock remotely without the physical intervention of the farmer. This kind of smart livestock monitoring system can reduce the cost of farming, prevent the cattle from infectious disease, and also enable remote tracking and monitoring. Real-time livestock location tracking and monitoring are made possible by advanced technologies [26, 27].

There are several methods to track the position of the cattle. The livestock can be extensively tracked by using navigation satellites and GPRS. The other technologies that are used for geofencing that help to keep the cattle in confined areas include radio frequency identification (RFID), wireless sensor networks (WSN), and low-power wide area network (LPWAN) [28].

It is more essential to monitor the location of livestock as it

- Is used to track the real-time location of livestock in a very large grazing area and bring back them to the barn,
- Notifies the farmers immediately in case of any emergency where an animal separates itself from its herd,
- Safeguards the cattle against theft,
- Enables remote monitoring by providing accurate data at any place, any time, and any environment too, and
- Segregates infectious cattle from healthy cattle and avoids the mass spread of disease among livestock.

4.3.1 Location Tracking Using RFID

Introduction of RFID-based techniques in precision livestock management has made data management and retrieval extremely efficient and offers some advantages like a decrease in recording errors, automation of farm implements, reduction in labor costs, overall productivity optimization, and cost-prohibitive to farmers. RFID [29] can be used to monitor and track livestock accurately and it is integrated with the cloud, which enables continuous tracking of livestock location.

The process of locating the livestock using RFID is as shown in Figure 4.3. Mainly active RFID is used to find the livestock across the farms and also the diseased livestock's location, if any. Here each animal is attached with an RFID tag and a unique ID is allotted to each animal. The RFID-based card reader is composed of a reader module, a microprocessor, and a wireless transceiver. The wireless transceiver sends the location of livestock from the RFID tag by generating a radio frequency signal to the reader. The microcontroller unit processes the information and the details are sent to the farmer's mobile device and also to the cloud storage.

4.3.2 Location Tracking Using WSN

The previous section detailed the use of RFID mechanisms to monitor livestock. Even though the RFID electronic tags are visible and they are easy to administer, one of the biggest demerits of using RFID ear tags is it fails to prevent livestock theft. The tags are easily susceptible to wear and tear. Moreover, the cattle must be within the range of its zone. There is also a chance of losing the tag when the animal is caught in fights or by tree branches. Therefore, this inaccurate history of movement of livestock results in moving to some other techniques like using WSNs and existing GSM networks for enabling real-time tracking and identification of cattle. In recent times, WSN has offered an opportunity to collect data remotely. WSN is a self-configured and infrastructure-less wireless network that has geographically distributed and dedicated sensors. It monitors and records surrounding environmental conditions and organizes the collected data at a central location.

For tracking the animal using WSNs [29] each cattle is given a UID. This UID is used to identify an animal among a group of livestock and the type of the cattle can also be identified. A WSN consists of sensor nodes that are equipped with a power supply, Zigbee module, and microcontroller unit, as seen in Figure 4.4. The master node is equipped with GPRS, which can send data via a mobile communication network to the controller. The sensors are connected to the master node through the Zigbee protocol. In addition, the

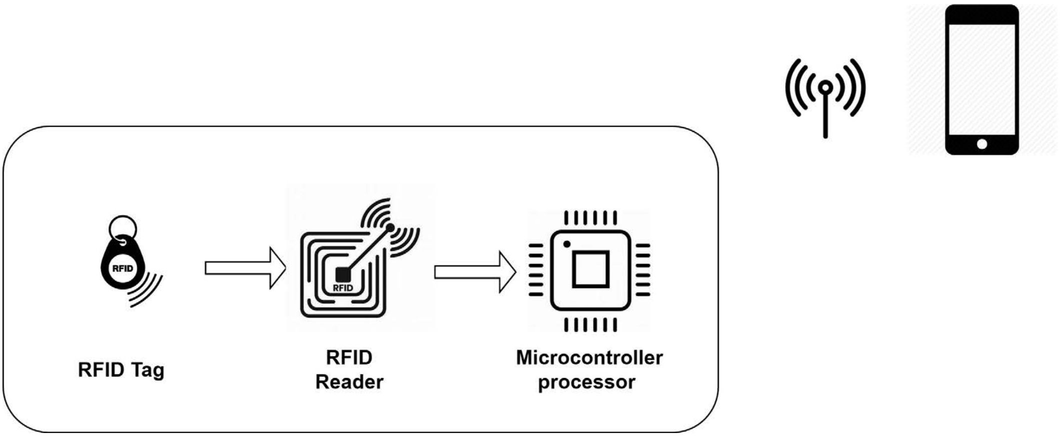

FIGURE 4.3
Location tracking using RFID.

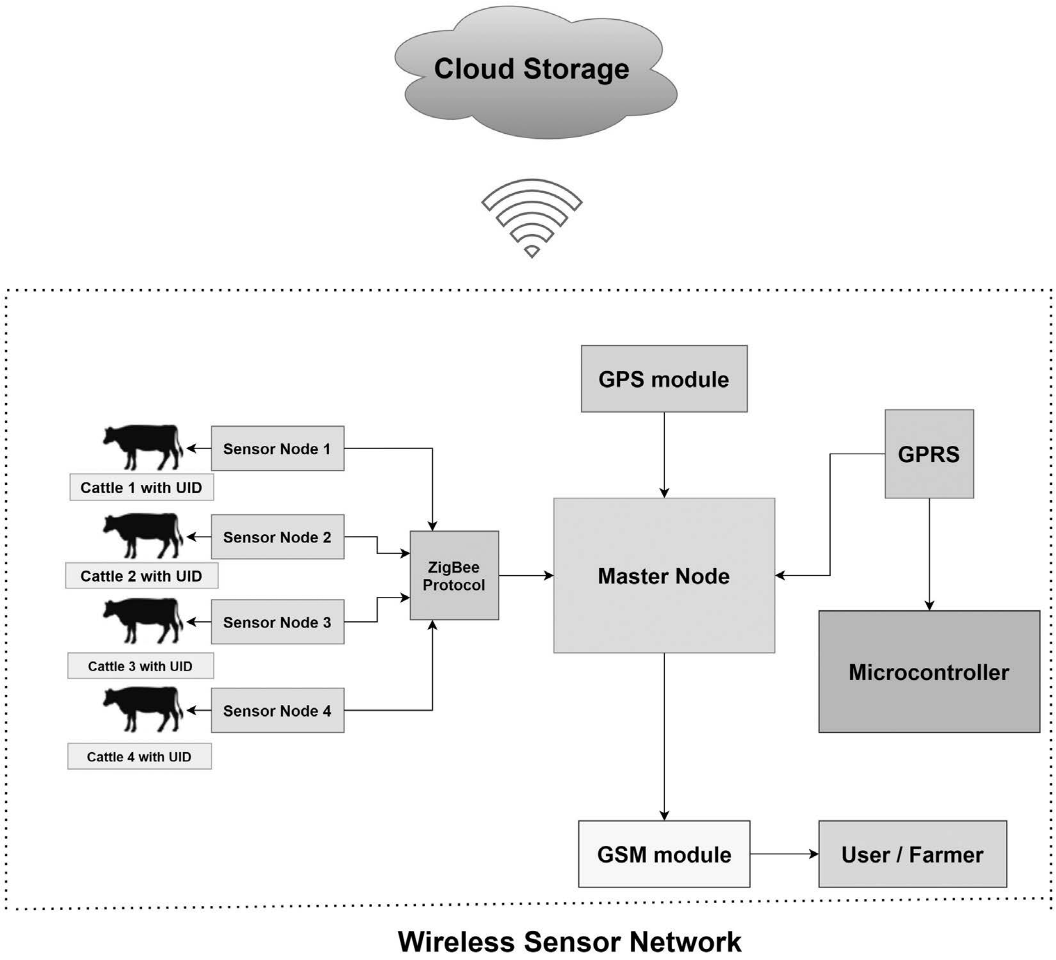

FIGURE 4.4
Tracking using a wireless sensor network.

master node is equipped with a block device called GPS, and the GSM module is connected to the master tracking node to give a proper alert to the user or the farmer. Using GSM, the coordinates of latitude and longitude of the animal's location are sent to the user.

Monitoring a wide, open field where usually the grazing of cattle occurs and tracking of animal movement are made easier by using the WSN. A WSN makes it easier for the farmers to know the exact location of the cattle in case of any emergency or cattle loss due to wandering. The activity and the behavior of the cattle can be monitored over a long range of distance and time-to-time communication between remote servers and tracking systems can be achieved effectively with the help of WSN.

4.3.3 Location Tracking Using Ultrasonic Sensor

Location tracking by WSN consumes more device power since it uses sensors like GPRS and GPS. An enhanced system to monitor and safeguard the livestock by providing a geographical safe zone for the livestock by using ultrasonic sensors is suggested as an

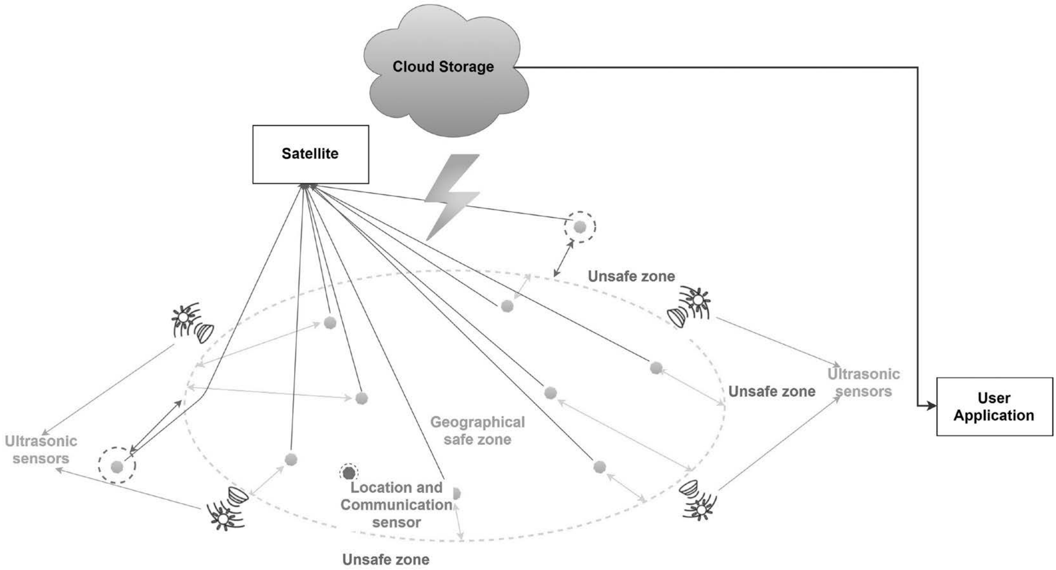

FIGURE 4.5
Geofencing using ultrasonic sensors.

alternate method. In this method, a virtual ellipse that is considered to be the safe zone for the cattle is created, which acts as a geofence. The virtual elliptical boundary consists of ultrasonic sensors which are used to propagate the ultrasonic waves to locate the existence of the livestock. To obtain the location of the livestock through navigation satellites, each animal is equipped with a navigation sensor. If an animal goes beyond the geographical safe zone and if the distance crosses the specified safe threshold value, then the communication navigator gets activated. Then the farmer receives a notification on his smartphone about the livestock crossing its boundary and its exact location.

The mechanism of creating geofencing [30] is explained in Figure 4.5. Consider a herd containing a variety of livestock. To receive the location coordinates and to connect individual livestock with communication satellites each cattle is equipped with a navigation sensor. The location of the livestock is identified by using the location coordinates sent to the satellites through a navigation sensor. By monitoring this location, the farmer can be notified if the cattle are not in the safe zone. The GPS sensor is activated to send the alert/alarm to the farmer if the ultrasonic sensor detects any cattle crossing the safe geographical boundaries. The geographical sensor communicates with the satellite to calculate the location coordinates of the cattle. The difference between the current location coordinates and the safe zone coordinates is calculated to find how far the cattle are from the defined safe grazing zone.

4.3.4 Location Monitoring Using Auditory Command

The livestock can be monitored by using digital or virtual auditory assistants powered by artificial intelligence. Based on voice command, an intelligent virtual assistant (IVA) can perform a task or a service. In livestock location monitoring systems, the AI-based virtual assistant acts as an entity that issues auditry commands or voice commands to the livestock, as in Figure 4.6. Already in the previous sections, we have seen various

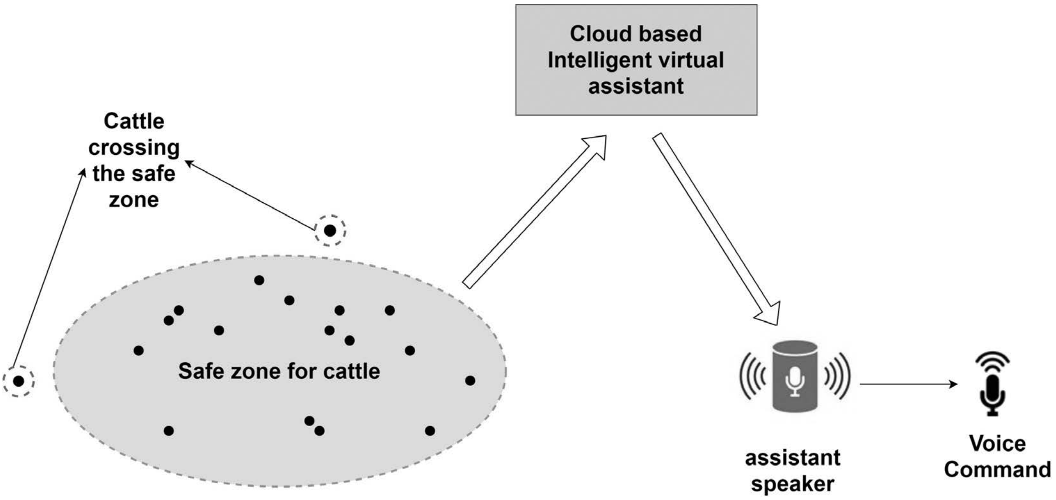

FIGURE 4.6
Monitoring through auditory command.

methods to monitor the location of livestock. The output provided by any of those techniques is fed as input for this IVA, which in turn issues voice-based commands to the livestock.

For example, if we are monitoring the livestock by using WSN, the output representation may be as given in Figure 4.6. When this image is received as input by the IVA, it identifies the livestock that is nearing the boundary of the safe zone. Then it sends a command through the speakers to the cattle that go beyond the geographical safe zone. Thus by deploying voice assistants livestock losses can be prevented, and also it does not always require the physical presence of farmers in the field. Today there are several virtual assistants available on the market. The most popular virtual Assistants are Google Assistant by Google, Cortana by Microsoft, Alexa by Amazon, and Siri by Apple.

4.4 Smart Feeding

Feeding the livestock plays a vital role in livestock management. It includes feeding at an appropriate time interval, quality of food, and the correct mixture of nutrients needed. Improper feeding of livestock affects behavior and health status. The food quality must be ensured as it may lead to many foodborne diseases [32]. Thus feeding and food quality of livestock accounts for the major part of livestock management. The significance of feed and feeding has not gained much attention and it needs more concentration to enable unrelenting livestock monitoring.

Smart feeding or precision feeding utilizes emerging information and communications technologies (ICTs) to increase productivity by associating appropriate feeding techniques to deliver feeds to livestock in a precise manner. Smart feeding enables feeding animals by integrating IoT devices, cloud platforms, and decision-making tools [33]. The smart feed system provides the following functionalities:

- Scheduled feeding of animals at proper time intervals
- The level of food in storage is informed to the farmer to ensure enough amount of food is available to feed the livestock
- The correct quantity of food supply provided to each livestock to avoid excess or less eating, which may lead to ailments like coli infection
- Monitoring the quality of the food to avoid foodborne diseases
- Remote monitoring of whether animals have acquired their food or not
- Suggesting a correct mix of nutrients to be added to the animal feed through data analysis
- Reduced human effort in feeding animals manually

An overall architecture for smart feeding is given in Figure 4.7.

The smart feeding system [34] is deployed with sensors to monitor the quantity and quality of the feed inside the silo. The smart feeding system provides the quantity of food at any instant inside the container by using the IoT device mounted at the top of the silo. It consists of a GH-311 RT ultrasonic sensor mounted on a servo motor that measures the distance between the top of the silo and grains at different angles to calculate the volume of the grain inside the silo. Apart from this, the DHT 11 sensor is also available to measure the temperature and humidity of the grain inside the silo, which implies the quality of the feed. An automatic timer triggers the filling of grains in an animal feeder at scheduled time intervals and a Wi-Fi module transfers data from these sensors to an intelligent cloud server that uses an agent-based architecture. This cloud application does the

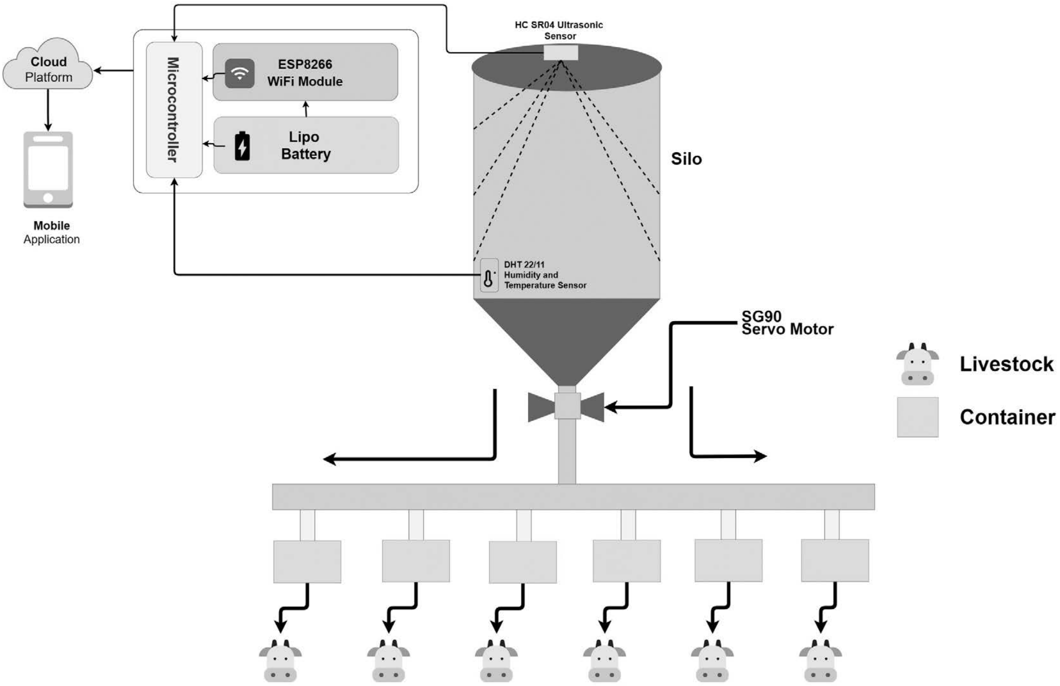

FIGURE 4.7
Architecture of a smart feeding system.

decision-making regarding refilling the silo and the quantity of food to be fed to animals so that excess or low feeding can be avoided and also ensures the quality of food inside the silo. The status of whether the livestock has consumed food or not is also monitored by knowing the volume of grains in the silo. The cloud server receives data from the sensors inside the silo at various time intervals. The data is analyzed and the inference can be viewed through an Android or web application. The farmer receives a notification whenever the volume of feed decreases in the silo. The farmer can refill the silo to prevent the scarcity of food. When the quality of feed deteriorates, the farmer is notified immediately such that feed is not supplied to the livestock. At proper time intervals, the livestock is automatically fed and status is informed to the farmer after every feed [35].

4.5 Conclusion

Precision livestock monitoring includes ensuring cattle health and well-being, prevention from infectious diseases, offering safer and nutritious food, and safeguarding from thefts by using the frontier technologies like cloud and IoT. The integration of these two provides better data storage, management, and data analysis, which aid in decision-making regarding livestock management. This helps framers effectively manage with less human effort and higher accuracy, even from remote locations. This chapter has provided a detailed study of various tools and techniques deployed through cloud IoT for efficient livestock management.

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