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Review

Internet of Things for Crop Farming: A Review of Technologies and Applications

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Abstract: Climate change, soil erosion, and degradation among others affect the growth and production of crops. Soil is suffering from intensive farming and unsustainable soil disturbance, leading to severe soil degradation. The Internet of Things (IoT) allows the monitoring of crucial environmental parameters such as soil nutrients, moisture, humidity, and temperature. A pre-understanding of these parameters allows agriculturists to use the optimum quantity of water and fertilizer for different types of soil. Soil fertility can be detected by using NPK sensors. The Internet of Things (IoT) brought a new face to the crop farming approach where conventional methods are automated and/or remotely controlled to improve crop farming. In this paper, a survey on IoT technologies for crop farming including sensors, communication, and network protocols in crop farming activities is considered. Additionally, applications of IoT technologies in soil management and monitoring, growth and yield estimation, and quality control mechanisms are presented.

Keywords: crops; Internet of Things; nutrients; sensors; IoT applications; yields

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1. Introduction

Modern crop farming practices are driven by technologies such as the Internet of Things (IoT) where electronics/electrical or even mechanical devices are interconnected to collect real-time information through wireless sensor nodes from the plant/crop ecosystem. The generic flow of how things are interconnected is presented in Figure 1. The IoT platform consists of (1) sensors, (2) information transmission, and (3) wireless technology [1]. For instance, IoT assists farmers in obtaining required parameters such as soil nutrients, moisture, and pH levels in preparation for sowing or planting. The collected data are sent to the processing unit which process and analyze the data.

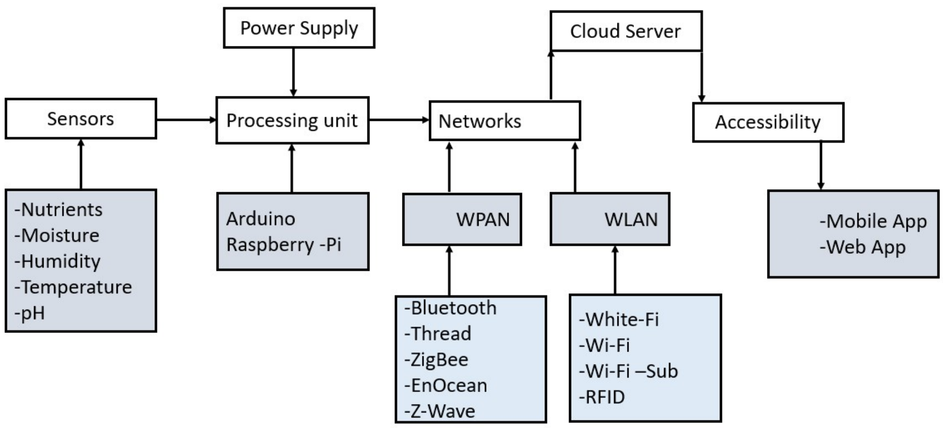

Figure 1. Generic flow of IoT technologies platform.

The processing unit could be Arduino or Raspberry Pi, and the data are transmitted through a local area network such as ZigBee or Bluetooth modules to the cloud server. Through the internet, the farmer/user is alerted on the web or mobile app to act accordingly or to know the action taken by the system. IoT systems are automated and do not require a human presence on the farm. The IoT system saves resources, such as water for irrigation, fertilizers, insecticides, and/or pesticides, etc. IoT plays an important role in crop farming and its applications are wide-ranging from soil management and monitoring, crop growth and yield enhancement, crop product quality control, etc. In terms of soil fertility/nutrient monitoring and some other applications, generally, the IoT sensors are buried in the soil to directly read the soil parameters. Authors in Ref. [2] presented the internet of underground things in detail, particularly the underground sensors for soil fertility monitoring, the type of connectivity technologies under as wireless personal area network (WPAN), and wireless local area network (WLAN). For WPAN, ZigBee technology consumes low power in comparison to other technologies, and this makes it one of the attractive features as powering IoT systems is a challenge. As for WLAN, Wi-Fi is commonly used but internet access is another limitation for most farmers. In ground things [3], an online system-based robot with IoT hardware is embedded in a mechanical structure. The mechanical structure is movable and can move forward, backward, right, and left to take moisture readings/data from the soil. The data are analyzed and the user is notified to take appropriate action.

For Africa, increasing food production is a priority because at least one in five Africans suffer from hunger and insecurity [4]. In other words, several nutrient parameters are required in these processes, most importantly soil and water. Water is essential for crop growth, but it has to be in optimum amounts. Excessive water due to heavy rain affects plant health in many ways [5], it affects the physiology of the plant, in which the leaf loses its chlorophyll, the roots thicken and shorten, and are unable to absorb the optimum amount of nutrients from the soil, leading to poor yield. A smart suction pump based on IoT is proposed in Ref. [5], which is utilized to suck out excessive water during heavy rain or floods. In addition, Ref. [5] also detailed the water irrigation pump which assists in watering the plants in dry conditions.

Nowadays, technology is developing quickly, it can be available and cheaper because of high competition. The adoption of IoT devices in the agriculture industry is growing fast annually. The opinion of this work is to ensure that farmers increase their adoption of smartphones in discovering agricultural solutions by using technologies that enable farmers to gain better information and make better decisions that will increase their production on the farm. Crop health monitoring involves not only nutrient and water analysis but also chlorophyll and growth analysis. A healthy plant has a large amount of chlorophyll, a substance that absorbs the sunlight, and keeps the green color in plants. The unhealthy plant has yellowish or pale leaves, which might be the result of a deficiency in the plant nutrients. A chlorophyll meter is presented in Ref. [6], which consists of a camera and IoT hardware. IoT assists the detection and monitoring of an insect/pest and or other intruders approaching the field.

2. Methods

2.1. Eligibility Criteria

For this systematic review, specific eligibility criteria were established to identify and include relevant studies. The review focused on research related to the utilization of Internet of Things (IoT) technologies in the context of crop farming. Key areas of interest encompassed soil management, plant health monitoring, intruder control, contemporary irrigation procedures, as well as weed detection and removal methods. The review primarily considered studies published within the last six years, encompassing the period from 2017 through 2022, including data up to the current year, 2023. Foundational knowledge from textbooks related to computer technology was included as needed, serving as an exception to the timeframe restriction to provide a comprehensive understanding of the subject matter.

2.2. Information Sources

To ensure a thorough and exhaustive search for the relevant literature, a multi-pronged approach was employed to identify suitable information sources. This included electronic searches within prominent academic databases such as Google Scholar, Science Direct, Scopus, and IEEE Xplore. Additionally, conference proceedings from the Science Citation Index, which encompassed materials from the Web of Science and Scopus databases, were included. This approach allowed for the incorporation of research findings presented at conferences and symposia, providing insights into emerging trends and developments in the field of IoT applications in crop farming.

2.3. Search Strategy and Selection Process

The search strategy was designed to comprehensively identify pertinent studies. Electronic searches within the selected databases employed a combination of keywords and controlled vocabulary terms specific to the subject matter, ensuring that all relevant articles were considered. Data collection involved extracting pertinent information from the selected studies, including details about IoT applications in crop farming, methodologies, results, and key findings. The selection process was meticulous, with a focus on inclusivity. This involved evaluating the quality of selected studies and considering potential sources of bias that may impact the review's findings. This process was conducted systematically and in accordance with established guidelines to maintain rigor and consistency throughout the review. The review's goal was to find out what techniques are currently being employed to improve crop cultivation and eventually boost productivity. During the search, important keywords like wireless connectivity, weed control, and smart irrigation were employed. Weed detection, weed removal, and plant health monitoring publications that mix IoT and machine learning techniques were chosen. Fifty-nine publications were used in the review, which was based on an in-depth analysis of the targeted technique.

2.4. Data Analysis and Synthesis

The chosen articles were filtered based on the main aspects that were retrieved for each subtopic discussed, such as an IoT-based system's effectiveness and communication flow. To highlight the discussion, block diagrams and/or tables were extracted from these articles.

2.5. Findings

The findings contained a summary of the knowledge gained from all the articles that were examined. This comprises plant health monitoring and disease categorization, weed management, and removal based on a mix of cutting-edge image algorithms and IoT. Security and cloud/fog computing, which are essential for data storage in the automation of crop yield enhancement process, were also summarized and discussed, along with IoT-based irrigation systems, the technology utilized in controlling and monitoring intruders at various stages.

3. Discussion

3.1. IOT Technologies for Crop Farming

3.1.1. Wireless Sensors

A device capable of gathering information and perceiving changes in any environment locally is otherwise known as the wireless sensor [7]. Various types of wireless sensors include sensors for temperature, liquid, proximity, motion, etc. Although more efficient in performing light data processing in a local environment, the power consumption is little and can last very long even on battery storage. Figure 2 depicts the architecture of a typical wireless sensor architecture and its application to farm crops and production. Wireless sensors are critical components of IoT. The record revealed that by 2025 over 22 billion devices will be driven by IoT [8]. Many industries will be transformed tremendously through internet connectivity at a not-so-high cost. One of these industries is agriculture.

Wireless sensors will drive crop farming and other agricultural activities. IOT is possible in farms to enable various activities on the farm to be captured and reported in real time through the use of wireless sensors. Wireless sensor infrastructures can be deployed on farm locations as emerging technology to assist farmers and the production of their farm crops. For instance, by seamlessly connecting various aspects of the farm, such as soil moisture levels, weather conditions, and pest presence, these sensors enable farmers to make data-driven decisions, including irrigation scheduling and harvest timing. Furthermore, these IoT-driven sensors can detect the presence of pests or diseases in the early stages, allowing farmers to implement targeted interventions. This, in turn, reduces the need for chemical pesticides and promotes sustainable farming practices.

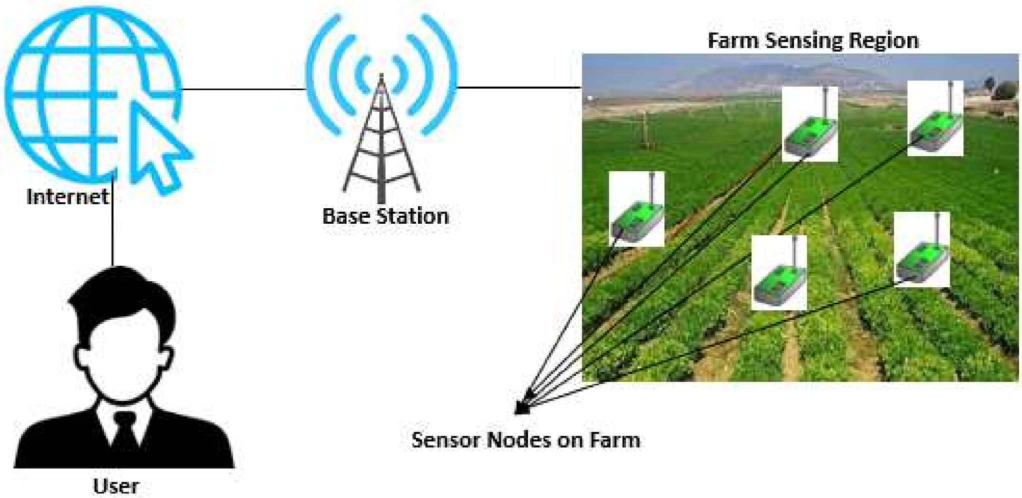

Figure 2. Typical wireless sensor architecture for farming.

Components of wireless sensors include sensors, used for environmental variable capturing, converting sensor signals to electrical signals [9]. Radio nodes are involved in receiving data produced by the sensors and passing it to a wireless local area network access point, transceiver, memory, microcontroller, power source, and possible software which will present the reports for analytical purposes. Beyond IoT, wireless sensors have found applications in monitoring for security purposes, detection of threats, and measuring other environmental parameters such as noise, air pressure, temperature, and humidity among others.

3.1.2. Communication and Networks Protocols

Communication and network protocols are interconnected. Without network protocols, communication will be difficult. Network protocols' primary functions are communication, Network Management, and Security [10]. Individual functions of the protocols use network devices in a safe manner and work together to simplify usage swiftly. It has been established that communication is very important in IoT concept, however, there are rules that govern how data is being exchanged and transmitted between various electronic devices and IoT devices. Irrespective of the differences obtainable in the design and architecture of the devices, network protocols have the capability to communicate effectively. This great future is very important in IOT as well as general agriculture and crop farming. Virtually all kinds of networks including Personal Area Network (PAN), Wide Area Network (WAN), Local Area Network (LAN), and Metropolitan Area Network (MAN) use network protocols [11]. In the world of the Internet, the Internet Protocol (IP) and the Transmission Control Protocol (TCP) are some of the most important protocols for data broadcast. Other protocols linked with these are the Post Office Protocol (POP), Simple Mail Transfer Protocol (SMTP), and Hypertext Transfer Protocol (HTTP) [12]. In communication both analog and digital are very important during file transfer and internet access. Large-scale processes in the communication stack are taken by network protocols, and broken down into small and concise tasks. Each sub levels of the network works together to complete a large task using protocols. Network protocols are driven by industry standards [13]. Agricultural activities that have existed in silos for a long time will no doubt be more effective with the application of communication and network protocols in IOT.

3.1.3. Cloud Computing/Fog Computing

Fog computing or fog networking as used interchangeably is a computer infrastructure decentralized using computational resources to perform extensive functions between source data and the cloud [14]. With this concept, workstations are made to process information from IOT terminals in real time. The concepts of fog computing arose from the need to extend cloud computing. It has local communication end points and data gathered can be routed to the internet. Today, in agriculture, the use of fog computing cannot be avoided since IOT is becoming more popular, real-time data and information are required to be explored in real time and accessed remotely [15]. Fog networking is crucial for the efficient deployment of IOT applications in smart farming processes in the crop farming industry. It is a backbone for real-time automation with numerous advantages including privacy, security, bandwidth, latency, productivity, etc., fog computing has found its applications not only in agriculture but also in smart cities, video surveillance, smart homes, and healthcare to mention a few [16].

On the other hand, cloud computing is the act of accessing and keeping data, programs, and information on a large computing infrastructure that is hosted online instead of having it locally on a physical server within the office or on a personal computer. Cloud computing is popularly referred to as Internet computing [17]. In agriculture, cloud computing concepts have been used at the base level in product dissemination, report writing, seeds, progress reports drafting, project management, etc. Files involved in the aforementioned activities are stored on cloud services. Cloud computing involves front and back end, communication, and Internet management. It involves three major layers infrastructure as a service, platform as a service and application as a service. Agriculture and crop farming are not exempt from the challenges of processing vast amounts of data. In the context of the ongoing industrial revolution, this research aims to leverage IoT and related components to address these issues.

3.1.4. Cyber Security

This is a practice of protecting data, information, and the entirety of its solutions from threats [18]. Cyber attacks are commonly intended to destroy critical information and infrastructures. When it is difficult to destroy, intruders tend to access information illegally, sometimes masquerade and change information, and request monetary proceeds from users. Attackers have developed smart solutions through viruses and ransomware against normal business interruption. The implementation of efficient cybersecurity measures is becoming more difficult because the number of devices is gradually outgrowing the human population while attackers are fast becoming more creative. As the agricultural sector strives to take advantage of technology especially IoT, to ensure that food production is secured with cutting-edge technology [19]. Cybersecurity tends to play a key role in the realization of such a target. In this research security assessment of crop production will be assessed within the scope of IoT and its components. Smart technology including cybersecurity will help grow the demands in feeding the nations. Farms are now tending towards being affected by cyber attacks due to the increased number of breaches across different sectors globally [19,20]. Food security across the supply chain is not to be trivialized, the health-related consequences attached to food make it unique and complex, and therefore, the role of cybersecurity is very important. Accounting for farm products is gradually being driven by software solutions, emails, and electronic and digital farm equipment are developing growing publicity to cyber threats. This way agricultural sector and its enterprise will be protected from the menace [18]. Cybersecurity is thought provoking for most industries, and with research of this nature; the problem can lessen the burden on agriculture and crop production significantly.

3.2. IOT Applications

3.2.1. Cloud Computing/Fog Computing

The soil is a heterogeneous mixture, comprised of numerous substances with different characteristics and parameters that contribute to its fertility, hence influencing the productivity or yields of any crop. The major parameters depend on the soil nutrients, pH, and moisture. Conventional approaches to crop farming focus on the productivity of a specific crop. Generally, farmers plant/grow the same type of crop over years, the soil becomes exhausted due to an imbalance of nutrients. It is important to monitor the soil nutrients for satisfactory yields [20–25], using NPK sensors for soil nutrients in addition to pH, temperature, and soil moisture sensors. The sensors are placed in the sub-soil, connected to the processors which alert the farmer to take appropriate action through networks and communication links. For better soil monitoring and management, IoT technology is coupled with machine learning models [26] to assist in analyzing soil type and recommend the optimum amount of nutrients required for a specific soil type. The soil can be analyzed according to its properties [27,28] such as texture, structure, porosity, color, resistivity, and consistency. Figure 3 summarizes a generic block diagram for soil parameters that require management and monitoring.

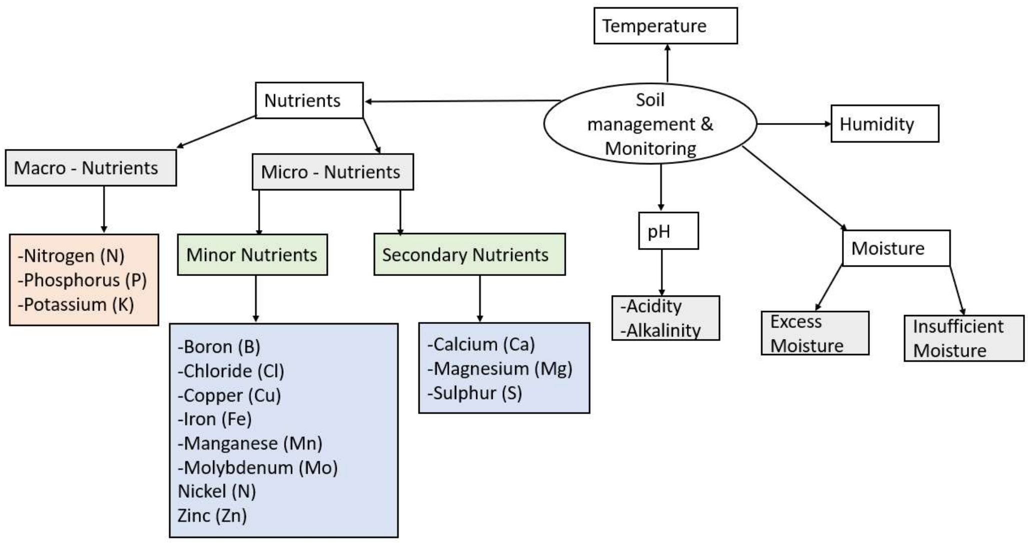

Figure 3. Generic block diagram for soil parameter's management and monitoring.

3.2.2. Crop growth and Yield Enhancement

The growth of the crop concept can be limited when water intake, nutrients, and oxygen fall below the expectation of the crop. The prevailing weather conditions can go a long way in the determination of crop growth conditions. Often, crops that suffer expected growth can be associated with the growing period length, reduced temperature, nature of the root system, and limited nutrient supply from the soil depending on the terrain. To complement some of the associated concepts with crop growth is yield enhancement which is a top priority when it comes to crop breeding. On the other hand, we can create crop models that identify the optimal growing conditions for various plant species and cultivars. These models consider factors like temperature, humidity, light duration, and nutrient availability. This plays a vital role in optimizing seed selection and crop adaptation to local conditions. Some factors identified for the purpose of this review include intruder control, irrigation, weed detection, and removal as well as health monitoring as presented in a generic form in Figure 4.

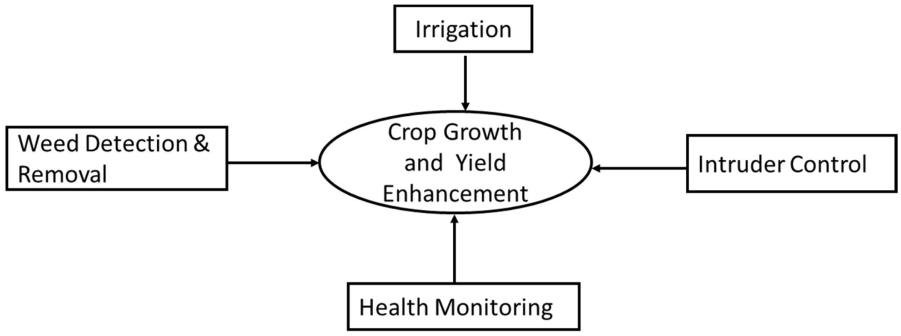

Figure 4. Crop growth management.

3.2.3. Irrigation Systems

Since the water nutrient is paramount to growth, the irrigation system can be improved upon for crop germination. A block diagram of this system is presented in Figure 5.

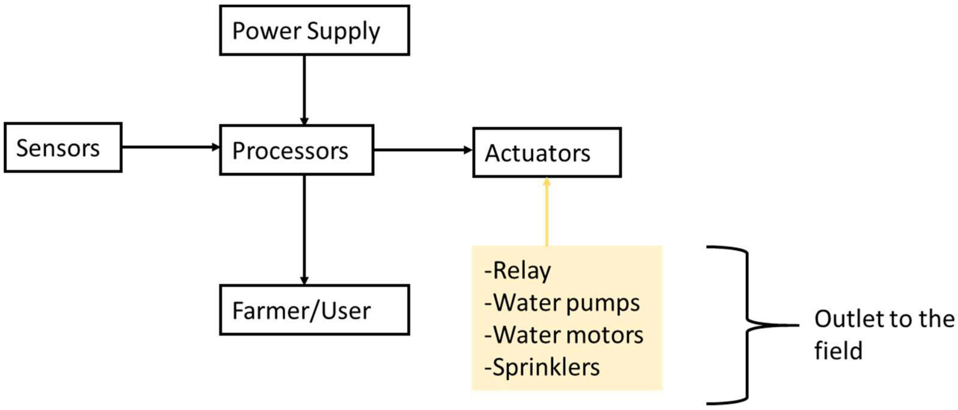

Figure 5. IoT irrigation systems.

With respect to IoT, modern irrigation systems will require a power supply, sensors, and processors, actuators, coupled with various water outlets (relays, water pumps, water motors, and sprinklers). Regarding intruder control.

Intruder control: crop intruders may include insects/pests, rodents, livestock, wildlife, and birds, which may attack and feed on the crops at different crop developmental stages as shown in Table 1.

Table 1. Summary of crop intruders at different stages.

Crop Stage	Intruders					Effects
	Rodents	Insects/Pests	Livestock	Wildlife	Birds	
Seed Planting of germination	✓	✓			✓	Poor Germination
Few leaves to stem elongation		✓	✓	✓		Poor Growth
Grain, Fruit, Vegetable filling/ripening		✓	✓	✓	✓	Possible destruction poor produce

The conventional method of controlling insects, pests, and rodents involves the use of costly chemicals that could harm the plant, the soil, or the air. IoT offers a quick and affordable method for spotting and controlling intruders [29]. Livestock such as cows and goats are usually kept and cared for by livestock farmers, so their chances of entering crop fields are minimal. Wildlife intruders are only encountered by farmers near wildlife parks, but parks are usually fenced to keep animals safe. On rare occasions, elephants leave the park to feed in the surrounding fields. The main concerns for intruders are insects/pests, rodents, and birds. They destroy roots, stems, and leaves and eat grains/fruits/vegetables during the filling or ripening stage. There are several ways to control/manage and eliminate intruders, including capture, repulsion, and tracking, control of fertility and physiology, and immediate killing. For animals and birds, it is usually best to catch, repel, or track them, but insects and pests are either quickly destroyed or their fertility and physiology are affected, resulting in population declines. Table 2 summarizes the technology used in controlling and monitoring intruders for different crops.

Table 2. Summary of technology used in controlling and monitoring intruders for different crops.

Ref.	Intruder Detected	Crop	Technology	Control Measures	
[30]	Borer insects	Tomato fruit	Camera, Robotic car, Hardware/Processor (Intel i3 32-bit core processor), Software operating system, (Microsoft Azure), Software application (Java)	Pesticides spray	detection
[31]	Locust, grasshopper		Hardware tools—(1) Node MCU (2) Raspberry Pi, (3) Relay module, (4) Sensors—(i) DHT11 temperature and humidity sensor, (ii) FC08 Resistive Soil Sensor Output devices—(1) water pump, (2) Vacuum pump, (3) Pestcide Pump, (4) UV light, (5) Speaker Software tools—(1) Arduino IDE, (2) Android Studio, (3) Python IDE, (4) ThingSpeak	Instantly kill locust using Malathion and Chlorpyrifos spray UV generator—kill locusts by emitting UV radiation	monitoring
[32]	Litchi stink bugs (Tessaratoma papillosa)	Litchi Tress	Hardware architecture—(1) Arduino Nano, (2) sensors: (i) GY-30 for light, (ii) YL-69 for soil, (iii) DHT22 for temperature and humidity, and (iv) BMP180 for atmospheric pressure, (3) DS3231 module, (4) Raspberry Pi 4, (5) LoRa transmission module. Transmission Mechanism: (i) LoRa—long-range transmission (ii) WIFI and Bluetooth—short-range transmission		
[33]	Red palm weevil (RPW) larvae	Date palm trees	Combination of IoT platform1sensing sound device, (1) cloud services (2) global positioning system (GPS) and (3) deep learning MixConvNet classifier		detection
[34]	Insect/pest		IoT technologies passive infrared (PIR) sensors	Spray pheromones—a spray that manipulates insects' physiological communication pathways, male cannot find female	
	Birds and rodents		IoT technologies passive infrared (PIR) sensors	Repel intruders from entering the field.	
[35]	Pest	Rice	Internet of Things (IoT) assisted Unmanned Aerial Vehicle (UAV) based		Detection and identification
[36]	Lepidoptera species: (moths and butterflies)	Tomato leaf	Optical sensors emitter-receiver per layer. e electronic funnel trap (e-funnel)—optical counter, emitter, receiver, wireless communication, LoRa radio protocol, pair of 8 emitting LEDs and 8 receiving photodiodes	Traps the species into a funnel with sex pheromone dispenser	Detection of a new infestation, Monitoring insects' population size
[37]	Insect/Pests i.e whiteflies, aphids and moths (fully grown EFSB).	eggplant	IoT technology (SSD Lite-MobileNet COCO v2. SDD-MobileNet model, Raspberry Pi), plus Deep and machine learning—TensorFlow and a camera		Detection, Identification, Counting

Table 2. *Cont.*

Ref.	Intruder Detected	Crop	Technology	Control Measures	
[38]	Rodents, grasshoppers and locusts, lacewings and moths	Crop field	IoT technology with ultrasonic sound emitter	Ultrasonic sounds: (1) confuse the pests and it affects their brain and nervous system. (2) reduces mating and reproduction (3) repel	repel
[39]	Buffaloes, cows, goats, birds	Crop field	IoT technology—PIR and ultrasonic sensors	The sound is played to divert the animal.	repel
[40]	Insects and animals	Crop field	IoT technology—Ultrasonic insects and animal Repeller that is embedded with Piezo-Electric Buzzer, an IR-Sensor and ATmega16 Microcontroller.	Creating ultrasonic sound drives away the intruder.	repel
[41]	Wild animals	Crop field	IoT technology—Ultrasonic sensors Camera, E-vehicle, Node MCU Microcontroller		Detects, image capture, monitor
[42]	Insects	Crop field	Hardware-raspberry-pi, infrared sensor, camera, insect chamber, tank Software layers—Arch linux, Python, Compression algorithms, network, Cloud layer—microservices, image processing Machine learning layer- tensor flow SciKit-Learn, NN Classifier, Naïve Bayes classifier	Detect pests of fields using a system to attract insects by creating several stimuli (chromatic, food, sexual, and UV light). takes a picture of the insect and uses Cloud Based Machine Learning (ML) algorithms to classify the image, then checks if the insect is dangerous to the crops or not.	Detects, image capture,
[43]	Animals or Humans,	Crop field	HC-SR04 Ultrasonic sensor, Arduino Uno Board ATmega328P. GSM 900A, Piezo Buzzer	Ultrasonic sensor to detect an intruder and GSM 900A is used to send a notification to farmer	Detection
[44]	Pests such as beetles, bugs, moth, and rodents including rats, squirrels, mouse, rabbits	paddy, wheat, cotton	IoT Technology: Passive Infrared (PIR) sensor, Image processing, Acoustic sensor, Microcontroller, Ultrasonic generator.	Detect the presence of insect Capture images of the pest Generate ultrasonic waves	Detect and repel
[45]	Wild animals like monkeys, stray animals especially cows and buffaloes, wild dogs, nilgais, bisons, elephants, deer, wild pigs, and even birds	fruit orchards	IoT Technology: passive infrared sensor (PIR sensor-based motion detectors.), Node MCU, LCD, Arduino, PIR Sensor, APR9600.	Generate sound to drive the intruder away. Sends a message to the farmers, takes the safety precautions	Detects and repel
[46]	Birds	Pearl, Millet, sorghum, maize	IoT Technology: motion detection using PIR(Passive Infrared) based motion detectors, Wemos D1: The Wemos D1 is an ESP8266 WiFi-based board that uses the Arduino layout with an operating voltage of 3.3 V, PIR Motion Detector Sensor, MicroSD Card, MP3 Module, Audio Amplifier, Megaphone or any other sound-emitting device, External Battery:	Detects motion Generate sounds of the predator which will drift the birds away from the field	Detects and repel

3.2.4. Weed Detection and Removal

Weed grows among the desired plants and compete for nutrients, and sunlight required by the plants. Weed control and removal based on advanced image algorithm are presented in Figure 6.

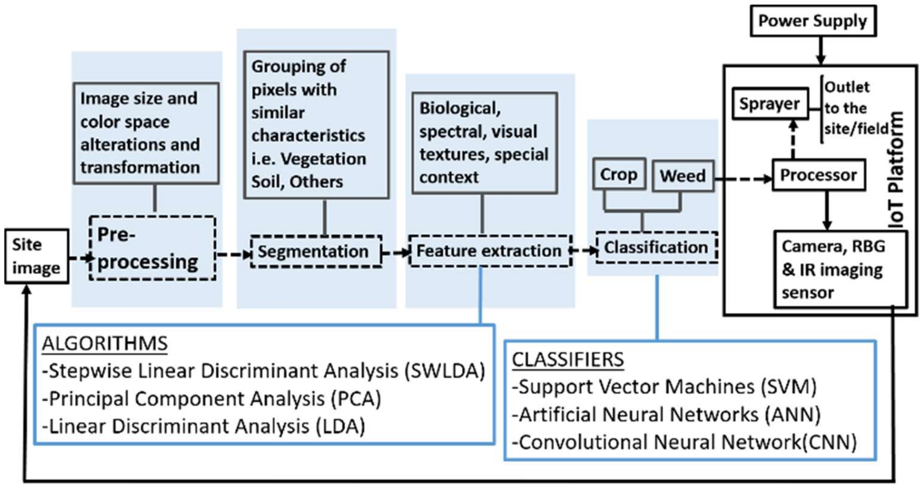

Figure 6. Weed classification and removal based on a combination of advanced image algorithms and IoT.

The traditional methods of weed removal are through mechanical and chemical means. Each method has its disadvantages and challenges. The mechanical method requires manpower to operate the mechanical tool in weed removal, a laborious and slow process. The chemical method requires chemicals that have a negative effect on the plant ecosystem and the entire ecological surrounding. More chemicals may cause skin and eye itches for the person spraying, and are capable of causing respiratory infections which may develop into severe diseases such as asthma [47]. Modern weed removal methods blend artificial intelligence and Internet of Things technology for automation. An automated weed removal system involves advanced image processing to process the image of the site/field and algorithms for feature extractions such as Stepwise Linear Discriminant Analysis (SWLDA), Principal Component Analysis (PCA), and Linear Discriminant Analysis (LDA) [48,49]. Classifiers such as Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Convolutional Neural Network (CNN) are used to classify or categorize weeds from the desired plants [46–53]. The IoT platform is made up of processor (i.e., Arduino UNO and Raspberry), fitted with a camera, RGB and IR imaging sensors to capture images from the site, and a sprayer to spray herbicide on the detected weed. The images serve as input to the system for processing, as indicated in Ref. [48], the classifier classifies the vegetation, (weed and crop), if the weed is detected, the processor activates the sprayer to spray on the weed. The process is presented in Figure 6 in the form of a block diagram to show the weed classification and removal based on a combination of advanced image algorithms and the Internet of Things.

3.2.5. Plant Health Monitoring

Food production can be maximized by utilizing technologies that enable the entire plant health monitoring. Although critical components such as moisture, temperature, and pH required by a plant can be monitored and controlled individually, it is important to monitor the health status of the complete plant. Plant health is observed through the leaves. The advancement of technologies allows leave analysis, through (1) IoT-based system applying image processing machine learning techniques [54,55] or (2) IoT-based system using optical analysis [56,57]. The condition of the plant, including any diseases or excess or deficiency in nutrients and water, is indicated by the state of the leaves. In addition, Refs. [54,55], take into consideration environmental parameters to monitor and classify plant diseases. Ref. [36] uses SVM to classify diseases while Ref. [55] applies the Azure custom vision machine learning technique for disease classification. This process is depicted in Figure 7. The plant-health-monitoring approach used in Ref. [56], monitors the plant based on a health cycle, by observing the leaves from green-yellow to completely dry. The authors first demonstrated the indoor implementation where the temperature and light are under control, the image of the plant is captured by RGB camera and multi-spectral data are captured with a micro spectrometer. The image of the plant was captured for 26 days when the leaves were fully fresh until they dried. It is observed from the RGB Images t"at f'r the first 13 days, there is a noticeable difference in the leaf color changes every day, but after day 13, the color changes difference is unnoticeable. The spectrometer images, on the other hand, display visible differences in the color changes, from day 13 as the leaf starts to dry. It is reported that the spectrometer comprises 288 channels with wavelengths extending from 340 to 850 nanometers (nm), covering three regions of the spectrum mainly the visible lights, ultra-violet, and the near-infrared region. In this experiment, the RGB images and multi-spectral images complement each other to fully demonstrate that as the plant becomes dry, it loses its chlorophyll. A robust plant contains a lot of chlorophyll, which is what gives the plant its green color. The plant loses its brilliant green hue, turns yellowish, and becomes dry if there is any shortfall or excess of the components it needs.

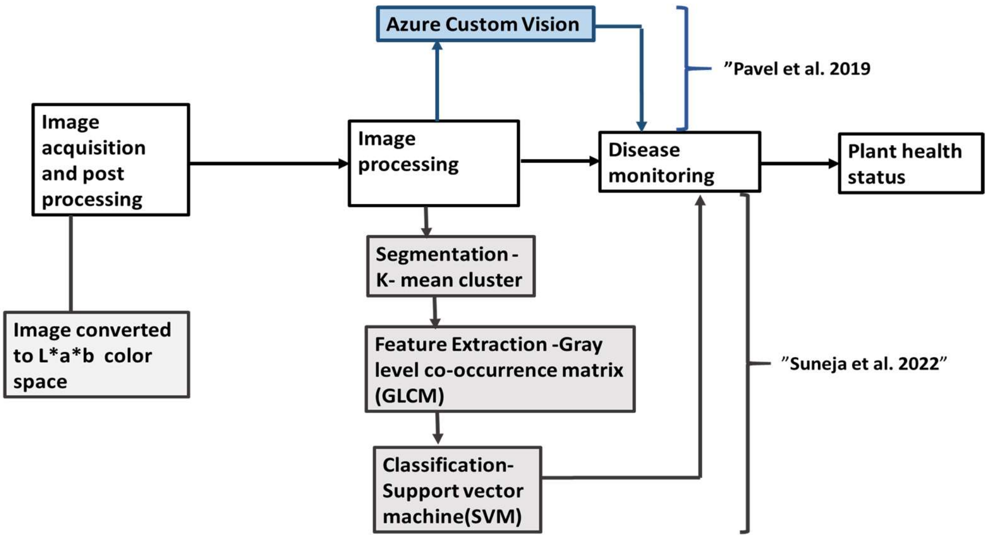

Figure 7. Disease classification approach in Refs. [54,55].

Moreover, the approach is extended outdoors, where the large area of farmland has to be considered. The images are captured using a multi-rotor unmannered aerial vehicle.

Optical image analysis is conducted in Ref. [57] where RGB and near-infrared cameras were used to capture images. The system computes the normalized difference vegetation index (NDVI), and with the supplementation of the IoT network, the approach monitors the plant health remotely.

4. Conclusions

The application of smart agriculture and ICTs leads to increased efficiency and reduced costs. The findings from this article suggest developing a mobile application-based IoT technology (IoT mobile App) to assist farmers in making informed decisions on different crops and climates [58,59]. This will help farmers to increase production and reduce costs, achieve profitability, as well as committing to environmental aspects and sustainability. Furthermore, this work discovered that most farms are located in far farmland and the IoT requires fundamental infrastructure such as a stable internet connection with fast transmission speeds and high hardware infrastructures to avoid any disrupted connection and loss of data.

To maximize harvests, plants need to be monitored during every stage of growth. According to numerous studies, IoT is essential for improving plant germination, growth, and production to guarantee food security. IoT is crucial for large-scale farming since automated processes like irrigation and soil nutrient monitoring are used. IoT systems assess the level of nutrients and moisture shortage and automatically open the actuators to deliver the necessary amount of water and fertilizer without human intervention. Weed prevents plants from growing because it uses the nutrients and water intended for the plants. IoT is used in conjunction with machine learning algorithms to distinguish between crops and weeds and take the course of action for weed removal. Monitoring and managing intruders in the large field is one of the major bottlenecks for crop farmers. These might include attacks from birds, insects or pests during crop growth, or rodents that might eat seeds at the germination stage. IoT offers numerous ways to repel these intruders, particularly birds and rodents. It can also eradicate insects and pests such as worms and locusts. In the future, robust data from farm fields will be analyzed using the proposed framework in this study.

For farmers, it is crucial to evaluate the actual cost and assess whether they can accommodate new methods on their farms. Costs vary depending on the location, region, and the level of technology adopted. To address this, we plan to conduct a survey to collect real-world data from farms. This will enable us to estimate the cost and return on investment (ROI) associated with the use of IoT in agriculture.

In general, the benefits of adopting IoT often outweigh the costs, primarily because IoT technologies can increase crop yields and reduce operational expenses. Additionally, the cost of IoT implementation has been decreasing due to high competition in the technology sector. The cost of implementing IoT in agriculture encompasses several key factors: Initial Implementation Cost, Technical Support, and Sensor Type. The type and quality of IoT sensors can influence both their initial cost and their expected lifespan. The total cost of implementing IoT in agriculture is significantly influenced by the scale of implementation. Larger farms with extensive IoT networks may incur higher initial and ongoing costs. When deciding how much to invest in IoT technology and how frequently to update or replace devices, it's essential to consider the return on investment (ROI). If IoT solutions lead to increased crop yields, improved resource efficiency, or cost savings, they may justify both the initial and ongoing expenses.

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