IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Wireless Sensor Network Based Machine Learning For Precision Agriculture

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Abstract: Precision agriculture is an evolving approach in modern farming that leverages technology to optimize agricultural processes. Wireless Sensor Networks (WSNs) have emerged as a valuable tool in precision agriculture, enabling real-time monitoring of environmental parameters and crop conditions. Machine learning algorithms, when integrated with WSNs, further enhance the decision-making process by analyzing data collected from the field. This paper provides an overview of the synergy between WSNs and machine learning in precision agriculture, emphasizing their applications, advantages, and challenges. A more productive and sustainable future for agriculture throughout the world depends on the use of sensors and the Internet of Things (IoT). New developments in the Internet of Things (IoT), Wireless Sensor Networks (WSN), and Information and Communication Technology (ICT) may be able to help this industry overcome some of its technological, economic, and environmental problems while also creating new possibilities. There is an increasing amount of big data with different modalities and temporal and geographical fluctuations as the number of connected devices grows. To achieve improved decision making, forecasting, and dependable sensor management, a deeper degree of knowledge base and insights must be developed through the intelligent processing and analysis of this massive data. This article provides an extensive overview of the many machine learning applications.

Keywords: Energy efficient, energy harvesting, precision agriculture, wireless communication Technology, WSN.

1.INTRODUCTION

Precision agriculture, often referred to as smart farming, leverages advanced technologies to increase agricultural efficiency and productivity while minimizing resource wastage. Wireless Sensor Networks (WSNs) play a crucial role in precision agriculture by providing real-time data on various environmental factors such as soil moisture, temperature, humidity, and crop health. When combined with machine learning, these data can be harnessed to make informed decisions about planting, irrigation, and crop protection, ultimately leading to improved crop yields and resource utilization.

Technology is essential to reducing the strain that the farming sector is under from causes including population growth, changing consumer demands, and expanding land, water, and energy shortages. Precision agriculture (PA) is another term for smart farming, which is synonymous with other machine-to-machine (M2M) based implementations like smart metering and smart cities. The main industry driver for IoT solutions, Libelium, predicts that the entire market value of PA solutions will reach $4.7 billion in 2021 nearly twice as much as it did in 2016.1. Compared to other industries, the agriculture sector has been sluggish to adopt developing M2M and IoT technologies, despite an increasing amount of intriguing research and new smart farming projects.2. Integration of sensor technologies that gather information from the crop, soil, different environmental factors, animal behaviour, and tractor status is necessary for smart farming. With the use of edge IoT computing and analytics, these sensor data may provide farmers with important information on plant and animal disease detection, yield prediction, crop monitoring, and weather conditions and forecasts.

Depending on the kind of farming being done, smart agriculture may or may not be implemented. Many embedded sensors, GPS-equipped smart tractors, and other farm vehicles are used in large-scale agricultural settings. Real-time data transmission is already possible through the use of data visualisation tools. In this context, where integrated sensors offer various forms of aerial imagery, field survey, and position mapping, drones play a major role.5 Spatially enabled mobile sensing technologies are being used in small- to medium-sized arable farming to give detailed analyses of field conditions in various soil layers, nutrient levels, and overall ambient environmental conditions.

Figure 1. An experimental testbed for smart farm with end to end IoT platform.

This paper's first goals are to demonstrate how WSN and IoT are used in agriculture and to provide an in-depth analysis of sensor and IoT data analytics using machine learning (ML) techniques for agricultural applications. A varying quantity of pertinent papers are delivered by members of the Electrochemical Society.

It also offers a case study on an experimental testbed that uses an end-to-end Internet of Things platform to look into how the food, energy, and water (FEW) system is interdependent. This paper's literature evaluation includes solely published publications that have been chosen within the last three years.

This paper's structure is set up as follows: The most recent developments in artificial intelligence (AI) applications in agriculture are shown in the AI in Agriculture section. The section on machine learning approaches explores some of the methods that are frequently applied in WSN-based PAs. Some of the most recent efforts applying the ML approach for WSN-based PA application are summed up in the literature review section.

2.IOT BASED SMART AGRICULTURE SOLUTION

This section goes into additional detail about a distributed WSN that was created utilising open-source hardware platforms, an Arduino microcontroller, and a ZigBee55 module to monitor and regulate factors including soil, weather, and environmental conditions that are crucial to crop growth. This experimental testbed is an off-grid small-scale smart farm test-bed that is supported by photovoltaic (PV) technology and also gathers water and energy data, as described in Ref. 6.

In order to address the current and future scarcity of FEW resources, the main goal of this experimental project is to learn more about the relationship between food, water, and energy. To do this, an Internet of Things-based farm system will be designed that will enable the production of more food with less energy and water using a basic automated system powered by solar panels.

By using IoT and data analytics, it also seeks to further the goal of integrated planning, policy, and management. It also aims to unite stakeholders working on various FEW system sectors by offering a user-friendly interface for tracking and controlling the system, as well as flexibility in system size to increase user base.

Sensor nodes: The wireless sensor units are made up of a sensor interface board and a primary functionality module board made specifically for Arduino microcontrollers. To detect soil moisture content, pH level, soil temperature, leaf wetness, ambient temperature, solar radiation, atmospheric pressure, humidity, and weather factors including wind direction, precipitation, and wind speed, the sensor board can be interfaced with a variety of sensors. It communicates with other nodes and transmits sensor data to the gateway through the XBee PRO S2 2.4 GHz ZigBee protocol. The Integrated Development Environment (IDE) can be used for programming and sensor integration. To handle power outages, each WSN is outfitted with lithiumion batteries with a capacity of 1150 mAh at 3.7 V.

Gateway for IoT: The IoT gateway is a mesh router running Linux, and all of the sensor data is recorded locally in a MySQL database. While the gateway is capable of supporting other wireless communication protocols, the sensor nodes in this project are connected through the ZigBee protocol. Additionally, it supports Ethernet and Wi-Fi connections, making it simple to synchronize local database data with an external database through TCP/IP over Wi-Fi or cellular networks.

Services and the cloud: The gateway pushes sensor data to the Microsoft Azure cloud platform, a limited paid cloud service platform, and Google Firebase, a free cloud service with a generous storage limit. The cloud provides convenient and flexible access to data for the intended user. It enables data access outside the farm network, long term applications like crop suggestions, and data analytics. Therefore, data from this smart farm system can be accessed through web-based applications and smartphones.

An external MySQL database housed in a virtual machine and the Google Firebase cloud are continuously synchronised with the sensor data kept on the local database of the IoT gateway. The successful implementation of pushing it to Microsoft Azure cloud services has also been accomplished. However, Google Firebase is chosen for this application due to storage limitations and cost. Green-Link Farming is a mobile application that is currently being developed for Android OS and will eventually be ported to iOS. The following is a summary of the GreenLink

1. A dashboard menu with soil moisture content, leaf wetness, and soil temperature, critical to the feedback response of irrigation events.
2. Insight into previously collected and real-time sensor data. These data are divided into five tracks: weather data, soil data, yield data, energy data, and water data.
3. Data visualization capability: sensor data can be viewed as a list view or are plotted to get insight on trends and patterns into the data.
4. Data analytics: predictive modeling of crop yield, weather, energy, and water using different ML techniques. The end objective for this is to eventually maximize food production through multiobjective optimization of the aforementioned variables. Additionally, it will explore the interdependent networks of food production on energy and water.

3. WIRELESS COMMUNICATION TECHNOLOGIES FOR AGRICULTURE

This section presents the different wireless protocols and standards that are used in agriculture. These wireless technologies are also compared to identify the most convenient technology in terms of power consumption and communication range, where the two metrics are posed challenges in current solution of agriculture application. IoT is a revolution for the future realm where everything that can utilize a connection will be connected. Cellular technologies are grown and developed to play a crucial role in the IoT realm . Narrowband-IoT (NB-IoT) is a new IoT system constructed from current Long Term Evolution (LTE) functionalities. Subsequently, NB-IoT is possible to share the spectrum of LTE without coexistence problems and to utilize the same pieces of equipment, as well as it is possible to connect seamlessly into the LTE main network. This permits all network facilities such as security, tracking, policy, charging, and authentication to be totally supported. The design goals of NB-IoT cover high coverage area, extended battery life (i.e., 10 years), high network size (52,000 devices/channel/cell), and low-cost devices. However, in the near future, NB-IoT technologies, such as Long Range radio (LoRa) will take place in agricultural applications due to low power consumption and preferably used when the agricultural information are to be transmitted over long distances.

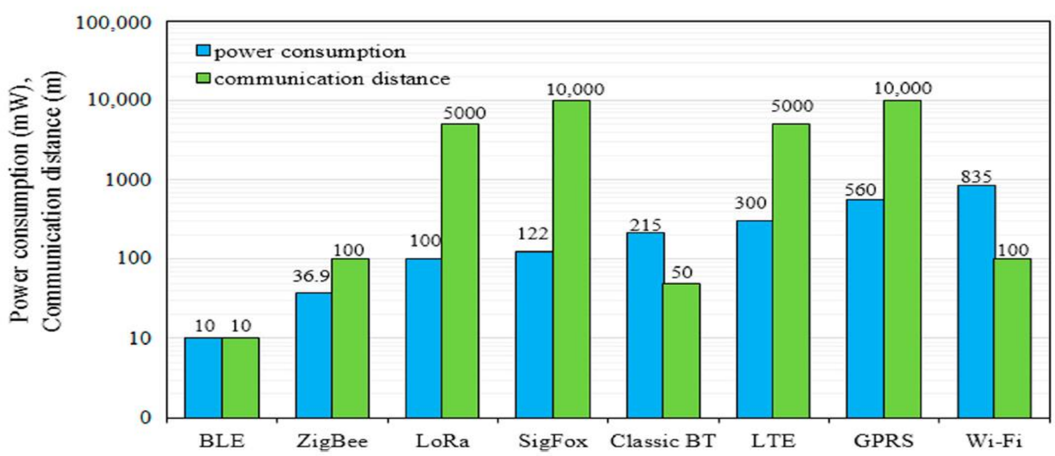

Figure 1. Different wireless technologies in terms of power consumption and communication.

Parameters	ZigBee	Classic BT	BLE	WiFi	GPRS
Standard	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.15.1	IEEE 802.11a,b,g,n	N/A
Frequency band	868/915 MHz and 2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	900–1800 MHz
Modulation type	BPSK/OQPSK	GFSK, DPSK, and DQPSK	GMSK	BPSK/OQPSK	GMSK/8PSK
Spreading	DSSS	FHSS	FHSS	MC-DSSS, CCK	TDMA, DSSS
Number of RF channels	1, 10, and 16	79	40	11	124
Channel bandwidth	2 MHz	1 MHz	1 MHz	22 MHz	200 kHz
Power consumption in Tx mode [5,40,56,59–61]	Low	Medium	Ultra-low	High	Medium
	36.9 mW	215 mW	10 mW	835 mW	560 mW
Data rate	20, 40, and 250 kbps	1–3 Mbps	1 Mbps	11–54 and 150 Mbps	Up to 170 kbps
Latency [62–65]	(20–30) ms	100 ms	6 ms	50 ms	<1 s
Communication range [48,66]	100 m	10–50 m	10 m	100 m	1–10 km
Network size	65,000	8	Limited by the application	32	1000
Cost [5]	Low	Low	Low	High	Medium
Security capability	128 bits AES	64 or 128 bits AES	64 or 128 bits AES	128 bits AES	GEA, MS-SGSN, MS-host
Network Topologies	P2P, tree, star, mesh	Scatternet	Star-bus	Point-to-hub	Cellular system
Application	WPANs, WSNs, and Agriculture	WPANs	WPANs	WLANs	AMI, demand response, HAN
Limitations	line-of-sight (LOS) between the sensor node and the coordinator node must be available	Short communication range	Short communication range	High power consumption and long access time (13.74 s)	Power consumption problem

Table 1. Different wireless communication technologies.

The IoT represents the visibility of a group of systems, technologies, platforms, and design principles for joining things, depending on the physical surroundings, through the use of the Internet. PA is an application that can employ the benefits of IoT to increase production efficiency, improve the quality of yields, reduce the negative ecological impact, prevent the prevalence of plant-eating pests or plant diseases, alert farmers about farm fires, and increase the profitability of several agricultural production schemes. Agriculture involves farming, planting, and animal rearing, and it has grown under the scope of IoT recently. Tracking of animals, monitoring of farms, and irrigation processes are the main domains of IoT for cultivation. Furthermore, feeding, rearing, medication, and vaccination are essential applications of IoT in the agricultural domain. Consequently, several IoT modular architectures have been proposed and implemented by scholars for PA monitoring.

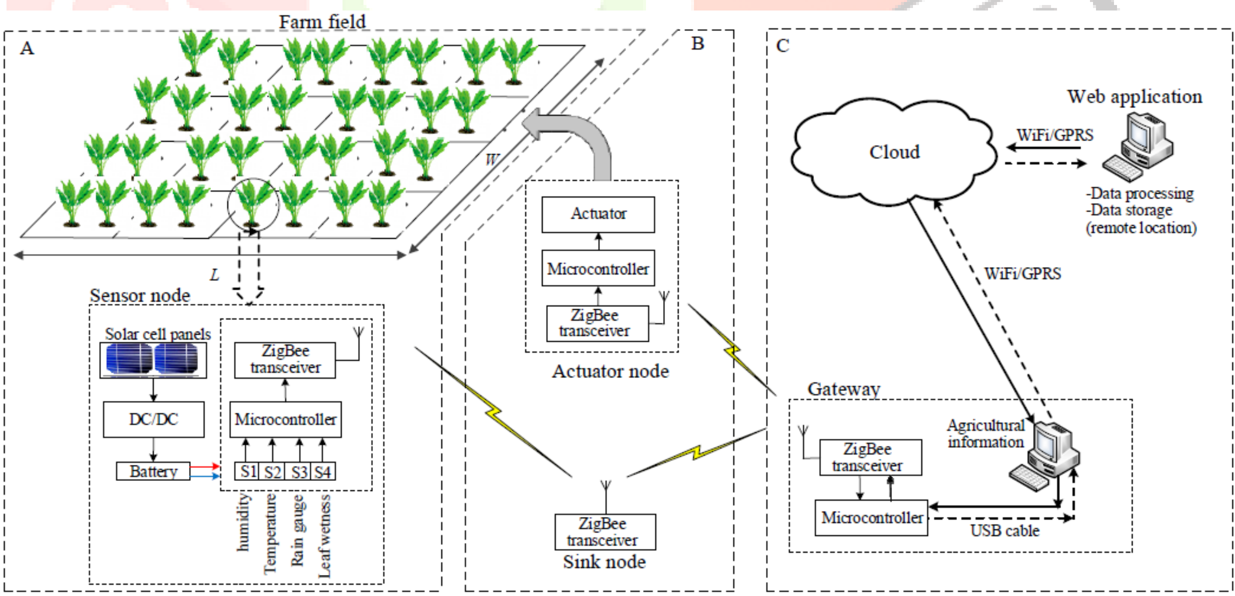

Figure 3. Example of farm field-based Internet of Things.

Real-time ecological information can be remotely gathered from the agricultural surroundings based on different sensors, which transmit the information to be processed to determine problems, take required actions using actuators, or store data.

4.MACHINE LEARNING TECHNIQUES

Machine learning is a type of AI that gives machines the ability to learn from experience. Its algorithms use computational methods to learn directly from datasets without depending on predetermined equations as a model. The algorithms progressively adapt to enhance their performance as the available number of training samples increases.28–30 ML approaches are powerful tools capable of autonomously solving extensive non-linear problems using sensor data
or other various interconnected sources. It facilitates better decision making and informed actions in real-world scenarios with minimal human intervention. ML techniques are constantly undergoing developments and are widely applied across almost all domains. However, they have fundamental limitations on their applications. The accuracy of the prediction is affected by the data quality, proper model representation, and dependencies between input and target variables.

There are two broad categories of machine learning algorithms: supervised and unsupervised learning. Supervised learning uses a known set of labeled data to train a model to predict the target variable for out of sample data. Classification and regression techniques are common applications of supervised learning. The list of common algorithms that fall under the different techniques is highlighted in Fig. 1. On the other hand, unsupervised learning relies on hidden patterns or intrinsic structures in data to draw deductions from unlabelled data. It is useful for exploratory applications where there is no specific set goal, or the information the data consists is not clear. It is also ideal as a mechanism for dimensionality reduction on data that have a number of features. Clustering is the most common learning model under this type of learning, and its application extends to exploratory data analysis, such as gene sequencing and objects recognition. Algorithm selection depends on the size, type, and expected insight into the data. There is, however, no general prescription for algorithm selection; in most cases, it is a trial and error work. Both supervised and unsupervised learning techniques are used extensively in IoT smart data analysis across various domains. Smart farming enabled by WSN and IoT is one of the domains where ML techniques are emerging to quantify and understand the big data in this field. ML application in PA can be categorized as crop management livestock management, water management and soil management application in crop management deals with yield prediction disease detection, weed detection and phenotype classification. This paper will further focus on WSN driven AI-based for agriculture applications.

Ensemble learning: Ensemble learning (EL) models strive at enhancing the predictive performance model fitting technique by creating a linear aggregate of a "base learning algorithm".1There are two principal strategies for designing ensemble learning algorithms. The first method is to form each hypothesis independently to create a set of hypotheses that are accurate and diverse. One of the common method for this is 'bagging' also known as "Bootstrap Aggregating" and random forest. The second approach deals with building the hypothesis in a coupled manner, so the weighted vote of the hypothesis generates a suitable fit to data. A common method like random forest algorithm, unlike DT, overcome over-fitting by reducing the variance of the decision trees. They are called 'Forest' because they are the collection, or ensemble, of several decision trees. One major difference between a DT and a random forest model is how the splits happen. In random forest, instead of trying splits on all the features, a sample of features is selected for each split, thereby reducing the variance of the model.

5.IOT BASED SMART AGRICULTURE SOLUTION

In this section, a distributed WSN developed using open-source hardware platforms, Arduino based micro-controller, and ZigBee55 module to monitor and control parameters critical to crop growth such as soil conditions, environmental and weather conditions is further discussed. This experimental testbed, as detailed in Ref. 6, is an offgrid photo-voltaic (PV) supported small-sized smart farm experimental test-bed, which additionally captures energy and water data as well. The main objective of this experimental project is to investigate more about the nexus of food, water, and energy by designing an IoT based farm system that will give the ability to produce more food with less energy and water using a simple automated system powered by solar panel in order to address current and future FEW resource scarcity. It further aims to advance the goal of integrated planning, policy, and management, by using IoT and data analytics; bring together stakeholders working on different sectors of FEW systems, by providing a user friendly interface to track and control the system; as well as flexibility in the size of the system, broadening the user base.

The farm prototype, as shown in Fig. 3 operate on distributed wireless sensor technology and is able to monitor and measure various environmental parameters, such as soil temperature and moisture, in real-time to schedule precise irrigation events. The system further collects real-time weather information in order to minimize environmental impact and make better decisions on how to manage resources such as water and energy. The information gathered is available in the local and external databases, and the users have the ability to retrieve the information using an intuitive mobile application. The intent of the mobile app is to allow users to monitor or interact with the farm infrastructure remotely. The overall system is implemented with design requirements to be power-efficient, cost-effective, and low maintenance, allowing the farmers/users to manage their farm or garden with little effort. This system is currently deployed at the FIU engineering campus area for development and testing purposes. The deployment includes a gateway, 6 WSN, and a weather console.

Sensor nodes: The wireless sensor units is a customized Arduino microcontroller consisting of the main functionality module board and a sensor interface board. The sensor board can be interfaced with various sensors to measure soil moisture content, pH level, soil temperature, leaf wetness, ambient temperature, solar radiation, atmospheric pressure, humidity, and weather parameters, including wind direction, precipitation, and wind speed. It uses the ZigBee protocol with XBee
PRO S2 2.4 GHz to transmit sensor data to the gateway and also to communicate among other nodes. Sensor integration and programming can be achieved via the Integrated Development Environment (IDE). Each WSN is equipped with 3.7 V, 1150 mAh capacity lithiumion batteries to take care of power issues.

IoT Gateway: A Linux-based mesh router is used as an IoT gateway where all the sensor data is saved in a local MySQL database. The gateway supports different wireless communication protocols, but this project uses a ZigBee protocol to communicate with the sensor nodes. Furthermore, it supports Ethernet or Wi-Fi connection where data stored in the local database can easily be synchronized to an external database via TCP/IP through Wi-Fi or cellular connection. Additionally, the gateway can push sensor data to a cloud platform. The gateway provides a user interface application to view recently captured data

6.PRECISISON AGRICULTURE

Precision agriculture is one of the solutions to ensure food security for the entire world. Precision agriculture also abbreviated as digital agriculture is a technology enabled data-driven sustainable farm management system. It is basically the adoption of modern information technologies, software tools, and smart embedded devices for decision support in agriculture as shown in figure 1. Mechanized agriculture and the green revolution are the two key components of the first and second agriculture revolution. Precision farming is an important part of the third agriculture revolution [5].

Now, the agriculture industry is widely adopting smart technologies like IoT and AI to efciently
cultivate organic products in limited land areas as well as to overcome the traditional challenges of farmers. IoT based smart farming system is built for monitoring soil nutrients and soil moisture using sensors. ML algorithms are explored for determining the optimum amount of fertilizers required for soils before the sowing of crops. Drones are revolutionizing the agriculture industry. These drones are cameras enabled and are used for different applications such as field and crop monitoring, spraying of pesticides, and drip irrigation. The images captured by the drones over the entire lifecycle of crops can be examined using DL and computer vision algorithms for disease and weed identification. Thereafter, these drones are used for spraying pesticides over the weeds and infected crops. Over the years uncertainty in weather conditions is the main concern of farmers. Drip irrigation using drones is an efficient AI-empowered irrigation system which is basically trained on weather pattern and can effectively reduce the water problems of farmers. AI-enabled robots can be used for harvesting the crops at a much faster pace and in large volumes. Robots can reduce human labour to a large extent and can be used along with drones for monitoring the field. Livestock management is another major concern for farmers. IoT based sensors can be deployed in the field for health monitoring of cattle.

In many countries, the farmers rely on the traditional ways of farming which is based on the reliability of the suggestions from the elderly and their experience. This method leaves farmers at the mercy of random climatic conditions which are already getting random due to global warming and uneven rainfall patterns. The manual spraying method for pesticides led to improper usage of resources and harms the environment. AI and IoT enabled precision agriculture removes the randomness and assist new age farmer to optimize every step of the farming process. Figure 2 presents a pictorial view of traditional agriculture and technology enabled farm management system. Gaitán [4] provided a systematic study of the impact of extreme weather events, such as hail events, cold waves, heat waves, and their impact on agricultural practices. The author reported floods, droughts, frost, hail, heatwaves, and pest outbreaks are impacted by climatic conditions. The AI systems are applicable in each farming operation as depicted in figure 3 and some of them even extend beyond the conventionally recognized steps. In this section we will discuss the state of art techniques proposed/implemented by various researchers and practitioners worldwide.

7.WIRELESS SENSOR NETWORKS IN PRECISION AGRICULTURE

WSN is the collection of spatially displaced sensor deployed to monitor the physical parameters of the environment and coordinating the collected data at central location. IoT transfers the recorded data to cloud which is further processed and analyzed through intelligent algorithms. In precision agriculture integration of artificial intelligence with WSN allows real time monitoring and intelligent decision making in agriculture fields. IoT sensor network which includes soil moisture senor, electrochemical sensor, optical sensors, etc. continuously monitor the field data and works as a training data for ML and DL algorithms. Edge computing enabled AI systems assist in reducing the amount of data to be uploaded to IoT cloud by identification of meaningful data to be communicated and discarding the redundant data. Intelligent processing of data generated from nodes result in better management of sensor network In [5] author utilized AI driven sensor network to classify land as suitable, more suitable, moderately suitable and unsuitable after every cultivation. In [6] author developed a power efficient WSN using Arduino microcontroller and ZigBee module to monitor and control essential parameters that effect crop growth such as soil and weather conditions in Florida, USA.

In [7] author integrating sensor nodes with AI systems to reduce the power consumption of nodes by optimizing the performance and data transmission of respective nodes. RNN based Long-Short term (LSTM) network was built which increases the runtime of a single sensor and guarantees 180 days autonomous operation using Li-ion battery. The proposed system continuously monitors the growth dynamics of plant leaves. In [8] author presents an autonomous system built with low power sensor nodes and IoT based cloud platform to estimate level of phosphorous in soil through ANN. Author incorporates dynamic power management system to maintain balance between energy consumption and estimation accuracy. In [9] author presents GA optimized WSN for precision agriculture applications. Thus, we conclude that integrating artificial intelligence with WSN, IoT plays a key role in assuring the best yield of crops.

8.CONCLUSION

By equipping farmers with technology, precision agriculture aims to achieve optimal results with exact inputs. One of the main technological breakthroughs that helped the agriculture business was the Internet of Things, which made smart sensors, actuators, robotics, drones, and satellite photos possible. These elements are essential for gathering data in real time and using that information to make judgements devoid of human assistance. The automation of intelligent behaviour, or artificial intelligence, is constantly improving the world and assisting people in many facets of daily life. The authors of this study have reviewed machine learning applications in precision agriculture. A quick overview of machine learning (ML) algorithms which are most frequently employed in precision agriculture is given before the influence of AI and IoT on smart farm management is explored. The foundation of agricultural production prediction, weather forecasting, and soil attributes is regression algorithms. In order to identify weeds and diseases in the plants, DL algorithms like CNN and ML classification algorithms like SVM, Decision trees, and RF were investigated. Precision agriculture relies heavily on intelligent irrigation systems and harvesting methods since they expedite tasks and minimise the need for human effort. For this job, robots and drones equipped with digital cameras are used. Globally, farmers are very concerned about livestock management. Livestock management is effectively handled by a knowledge-based agriculture system that uses AI technologies and smart IoT devices. Future research might focus on developing NLP-based chatbots for farmers and investigating additional ML, DL, and hybrid algorithms in the agriculture sector to ensure sustainable resource usage.

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