IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Innovation In Agriculture With Wireless Communication Devices: A Survey Of Technologies

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Abstract: Agriculture is the process of growing food to feed the masses. In modern day, agricultural practices have been trying to adopt technologies that can give a better yield, predict returns and also mitigate losses. Farmers are adopting trends and are trying to catch up with the growing market requirements. Supply chains have to improve the nutrient content. Data acquisition and processing form the important challenges to improve productivity, resource utilization. The lands are generally enormous and communication can get tricky since there are costs involved. However wireless technologies such as LoRa, Zigbee etc are showing promise. This paper tries to understand the advancements made in agriculture in the recent times and the best practices that are giving good results.

Key Words: Agriculture, Wireless sensor networks, Security, AI/ML, Internet of Things (IoT).

I. INTRODUCTION

Land these days has become a non-renewable resource. Over exploitation of this resource has its share of catastrophic effects such as pollution, reduced fertility, soil erosion, etc to name a few. The population of the word has crossed over 7.6 billion by the year 2024. Income disparities are growing to raise. It is estimated that even the richest country in the world like USA has 12% of its population below the poverty line [1]. All this data is pointing towards one problem that we have to address as quickly as possible. It is all related to efficient utilization of resources and improve crop productivity. This will ensure better yield results per hectare. It will also promise good quality food for the people.

With the advent of technology, we can rarely think of industries that have not completely digitized till today. Agriculture is one such industry which falls into the category of not being completely modernized. Land generally runs in thousands of hectares which makes it a complex system. Gathering data from such a huge area is a daunting task when it needs to be done manually. We can run into many challenges such as location, weather conditions, climate and also infrastructure which cannot be infinitely scaled.

II. LITERATURE REVIEW

Precision agriculture becomes possible by wireless sensor networks (WSNs), which are now crucial for detecting a variety of agricultural characteristics like temperature, soil moisture, and humidity. By combining machine learning (ML) with WSNs, data processing is improved and precise forecasts for agricultural output, irrigation requirements, and insect detection can be rendered possible. Recent developments in IoT, edge computing, and deep learning have greatly increased the efficacy of these systems, despite obstacles like accuracy of data, energy efficiency, and model generalization. Wireless sensor networks and Machine Learning are working together to revolutionize farming methods and provide solutions for more efficient and sustainable farming [2]. The ability of wireless sensor networks (WSNs) to track and manage physical conditions in real time has generated a lot of interest. The paper offers a thorough analysis of WSN topologies, emphasizing issues with data aggregation, communication protocols, and energy efficiency. It investigates a number of application areas, including as healthcare, environmental monitoring, and the military. In order to handle the particular limitations of WSNs, such as low bandwidth and restricted power resources, the survey highlights the necessity of scalable and dependable network designs [3].

With an emphasis on their potential for monitoring environmental parameters including soil moisture, temperature, and humidity, this study examines the usage of Zigbee-based wireless sensor networks (WSNs) for agricultural applications. Zigbee is a beneficial choice for farming applications because of its low power consumption, affordability, and dependable connectivity. In order to increase agricultural productivity, issues like adaptability, transmission of data range, and Zigbee connection with additional technologies are also considered [4]. The fundamental restrictions of sensor network lifetime are examined in a particular emphasis upon energy consumption constraints. By analyzing elements like network structure, communication overhead, and node energy consumption, it provides theoretical upper constraints on the operational life of sensor networks. Under various topologies and energy usage patterns, the authors develop models to determine the amount of time a sensor network can function before energy depletion impairs its functionality [5].

It offers a novel approach to improve ZigBee network security by resisting threats like illegal access and data manipulation. In order to improve the overall reliability and secrecy of data transfers in the network, the authors suggest a mutual authentication mechanism that guarantees safe communication between devices. The study emphasizes the significance of strong security procedures in ZigBee WSNs, particularly in vital applications where data security is crucial, such medical treatment, smart houses, and factory automation [6]. It focuses on obstacles in implementing WSNs in agricultural settings, such as problems with energy usage, network dependability, data precision, and scalability. The authors stress the necessity for low-power, affordable solutions by highlighting several technologies for sensors and communication protocols utilized in agriculture. In order to increase the efficacy and efficiency of agricultural monitoring systems, the study also outlines important challenges such sensing failure, data transmission constraints, and integrating of WSNs with other technology used in agriculture [7].

A wireless sensor network (WSN)-based smart irrigation control system maximizes agricultural water use. In order to automate irrigation procedures, the authors examine the advantages of employing WSNs for real-time monitoring of temperature, soil moisture, and other environmental variables. The survey showcases different WSN-based irrigation systems with a focus on scalability, cost-effectiveness, and energy efficiency. The study also discusses important issues with smart irrigation systems, such as sensor dependability, data precision, and system integration with current agricultural infrastructure, and offers solutions to improve irrigation systems' sustainability and performance [8]. It examines the use of wireless sensor networks in agriculture, such as climate monitoring, pest control, and precision farming, highlighting the value of incorporating AI to improve decision-making. The report emphasizes how sophisticated algorithms are used for data processing, allowing autonomous systems to maximize crop management, fertilization, and irrigation. In order to increase the efficiency as well as sustainability of agricultural systems, issues including sensing calibration, data quality, energy usage, and the requirement for scalable, adaptable networks are examined along with possible solutions [9].

WSN-based systems for collecting data in real time on variables including temperature, humidity, and soil moisture to improve crop management, irrigation, and pest control. The authors go over several important issues, such as the necessity of dependable communication, sensor node energy efficiency, and WSN integration with different agricultural technologies. In order to increase agricultural productivity and sustainability, the study also looks into automation strategies that use sensor data to initiate processes like fertilization or irrigation [10]. Deep learning methods, including recurrent neural networks (RNNs) and convolutional neural networks (CNNs), in the analysis of big datasets are gathered via sensor networks, drones, and remote sensing. The report emphasizes how deep learning may be used to automate processes like weather forecasting, soil analysis, and crop monitoring. Along with new approaches to improve the effectiveness and flexibility of deep learning techniques in agricultural applications, issues including the integrity of the data, system generalization, and the requirement for sizable labelled datasets are also covered [11].

CNNs handle agricultural images from field cameras, drones, and remote sensing, allowing for automatic and accurate analysis. The review focuses on different CNN architectures and how they are used in agriculture-specific picture classification, object recognition, and segmentation tasks [12]. Deep learning approaches in the creation of smart farming systems, emphasizing how they may automate a range of agricultural duties like yield forecasting, crop monitoring, and insect identification [13]. Several big data frameworks provide the extensive gathering, storing, and analysis of data from agricultural sensors, satellites, and Internet of Things devices [14]. The difficulties associated with real-time analysis, processing resources, and data integration, while suggesting ways to resolve these problems and raise the efficiency of precision farming systems are also discussed[15].

This paper would like to survey all the widely used wireless sensor networks in the field of agriculture.

III. WIRELESS SENSOR NETWORKS

Wireless sensor networks [WSN] is a network of devices which are deployed on the field to gather data regarding moisture, nutrients and other conditions on the field to transmit them wirelessly to a centralized hub where data processing can take place. The architecture of WSN primarily consists of five layers. They are listed as:

a) Physical layer:

This corresponds to the radio channel which does physical transmission of data. It could be any 2.4Ghz / 868Mhz / 433Mhz radios such as Wi-Fi, BLE, Zigbee etc.

b) Data link layer:

This layer is responsible for packing data into frames which are exchanged between two or more nodes.

c) Network layer:

The third layer is the networking layer and it takes care of routing packets to their final destination. This means it takes care of addressing, ensuring that each packet is sent to the correct system. In addition, it provides flow control and congestion avoidance mechanisms that ensure data transmission is efficient and reliable.

d) Transport layer:

It handles flow control with minimal dropout. It is either TCP or UDP that is used here. If the user wants a connection-oriented protocol, then TCP is chosen if not UDP.

e) Application layer:

This is the final layer which provides services and applications to the underlying layers.

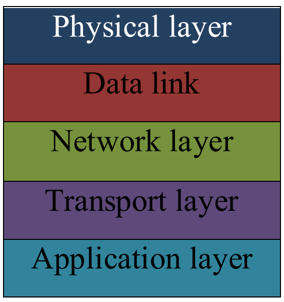

Fig i: Layers of WSN.

IV. MICRO-ELECTRONICS-MECHANICAL SYSTEMS [MEMS]

These are sensors deployed at the nodes of a network. These usually do tasks such as capturing data of various conditions relevant to improving agriculture throughput. Scaling of sensors needs to be done properly according to the demand. These sensors should be immune to environmental noise and be free from polluting or harming the soil. These sensors provide data regarding ambient conditions such as ;

A) Temperature
B) Humidity
C) Light
D) Soil pH etc

These should be low power devices such that their battery life lasts for long time to monitor the crop.

V. TYPES OF WIRELESS COMMUNICATION PROTOCOLS IN WSN

5.1 Zigbee

Zigbee is a popular wireless communication standard that is designed for low-power, low-data-rate, and long-range wireless communication which usually lasts 400 to 500 meters. Its wide range gives an edge to deploy along with WSN as a reliable communication protocol. Zigbee operates on the IEEE 802.15.4 standard and is known for its low power consumption, secure communication, and ability to support a large number of devices in a network. Zigbee is often used in scenarios where devices need to communicate wirelessly with minimal power consumption, making it a popular choice for Internet of Things (IoT) applications.

5.2 LoRa

LoRa, which stands for Long Range, is a wireless communication technology designed for long-range communication with low power consumption. It is often used in applications where devices need to communicate over long distances while conserving battery power something which is similar to a large agricultural field. LoRa operates in the unlicensed 433Mhz/868Mhz radio spectrum and is known for its ability to provide long-range communication making it suitable for applications such as smart agriculture.

5.3 Wi-Fi

Wi-Fi, also known as IEEE 802.11, is a widely used wireless communication protocol that enables devices to connect to a local area network (LAN) wirelessly. It operates in the unlicensed 2.4 GHz and 5 GHz radio bands and is commonly used for connecting devices such as smartphones, laptops, tablets, and IoT devices to the internet and other networks. However, the range of Wi-Fi is very low and needs multiple repeaters to reliably transmit data from various nodes. It is practically not possible to deploy Wi-Fi in a large area.

5.4 BLE

BLE, or Bluetooth Low Energy, plays a significant role in Wireless Sensor Networks (WSN) and agriculture due to its specific advantages and applications in these domains. Here are some key points highlighting the importance of BLE in WSN and agriculture:

a) Low Power Consumption
b) Short-range Communication.
c) Easy sensor connectivity.
d) Cost-effective Deployment: The low cost associated with BLE technology makes it an attractive option for deploying WSN in agriculture, especially for applications that require a large number of sensors distributed across a farming environment.
e) Integration with IoT Platforms: BLE can be integrated with IoT platforms, allowing for seamless connectivity and interoperability with other IoT devices and systems used in modern agricultural operations.

In summary, BLE's low power consumption, short-range communication, and compatibility with mobile devices make it a valuable technology for enabling efficient, cost-effective, and scalable WSN deployments in agricultural settings. It supports the collection of critical data, monitoring of environmental conditions, and implementation of precision agriculture techniques, ultimately contributing to improved resource management and increased agricultural productivity.

5.5 4G/5G/NB-IoT

The importance of 4G/5G/NB-IoT in agriculture Wireless Sensor Networks (WSN) lies in their ability to provide reliable, high-speed, and low-latency connectivity to support various agricultural applications. Here are some key points highlighting their significance:

a) Data Transmission: 4G/5G/NB-IoT networks enable the seamless and rapid transmission of data collected by agricultural sensors deployed in the field. This data can include information about soil moisture, temperature, crop health, and environmental conditions, which is crucial for making informed decisions in precision agriculture.

b) Remote Monitoring and Control: With 4G/5G/NB-IoT connectivity, farmers and agricultural professionals can remotely monitor and control irrigation systems, machinery, and other equipment in real time. This allows for efficient resource management and timely interventions based on the data received from the WSN.

c) Precision Agriculture: The high-speed and low-latency capabilities of 4G/5G/NB-IoT networks support precision agriculture practices by enabling the integration of real-time data from WSN with advanced analytics and decision-making tools. This helps optimize resource allocation, enhance crop yields, and minimize environmental impact.

d) Efficient Management: Access to high-speed connectivity facilitates the management of large-scale agricultural operations, including smart farming practices, predictive maintenance of equipment, and automated processes, leading to increased productivity and cost savings.

e) Scalability and Reliability: 4G/5G/NB-IoT networks provide the scalability and reliability required to support a large number of connected devices within the WSN, ensuring consistent data transmission and communication across the agricultural environment.

In summary, the integration of 4G/5G connectivity with agriculture Wireless Sensor Networks enhances data-driven decision-making, automation, and efficiency in farming practices, ultimately contributing to sustainable and productive agricultural operations.

VI. TOPOLOGY OF WSN

There are three popular topologies being used in the WSN technology.

a) Star topology – In order to connect various sensors, it is important to choose a topology

b) Mesh topology - n mesh topology, each device communicates with any other device within its radio range.

c) Cluster tree - In cluster tree topology, there is a single routing path between any devices.

Table 1 provides the comparison of various communication technologies and their advantages.

Table 1: Comparison of various wireless communication technologies.

	Bluetooth	WiF	Zigbee
Specifications authority	Bluetooth Special Interest Group (SIG)	IEEE Standards Association	Zigbee Alliance
Standard	802.15.1	802.11	802.15.4
Frequency band	2.4 GHz	2.4 GHz and 5GHz	2.4 GHz, 850 – 930 MHz
Data rate	1-3 Mbps	10-100+ Mbps	20-250 Kbps
Transmission range	Up to 100m	Up to 100m	Up to 100m

Power consumption	Very low	High	Low
Network topology	Ad hoc, point to point, star	Point to hub, ad hoc	Mesh, star, tree, ad hoc
Security	62 bit, 128 bit	Authentication service set ID (SSID)	128 bit AES and application layer user defined
Complexity	Very complex	Complex	Simple
Cost	Medium	Low	High
Application	Wireless audio streaming and data transfer, smart wearables and fitness trackers, beacon networks	Wireless local area network connection, broadband Internet access	Home automation and control, industrial monitoring sensor network

VII. INFUENCE OF AI/ML ON AGRICULTURE

After the data is collected from various nodes, it is then transmitted to a central hub where the part of AI/ML comes in picture. Various neural network models are used for crop monitoring, disease detection, yield protection, etc.

Some of the famous Neural Networks and their use cases can be tabularized as follows –

Table 2: Common NN's and their use cases in agriculture.

Type	Use case
Convolutional Neural Network [CNN] [12]	• CNNs are widely used for image/video based tasks for precision agriculture. They can be used for crop disease detection, weed identification and pest monitoring. • They are good at learning classified features from image/video datasets making them effective for analysing plant health and detecting anomalies.
Recurrent Neural Networks (RNNs) [13]	• RNNs are suitable for sequential data analysis, making them useful for tasks such as crop growth modelling, weather forecasting, and time-series prediction in agriculture. • They can capture temporal dependencies in data, allowing for more accurate predictions based on historical information.
Long Short-Term Memory Networks (LSTMs)[14]	• LSTMs are a type of RNN designed to address the vanishing gradient problem, making them particularly effective for modeling long-term dependencies in sequential data. • They find applications in crop yield prediction, weather forecasting, and anomaly detection in agricultural time-series data.
Generative Adversarial Networks (GANs)	• GANs are employed for generating synthetic data in precision agriculture, which can be useful for augmenting training datasets or simulating different environmental conditions. • They consist of a generator and a discriminator network trained simultaneously, allowing them to learn the underlying distribution of the data and generate realistic samples.
Autoencoders	• Autoencoders are used for dimensionality reduction and feature extraction in precision agriculture applications. They can compress high-dimensional input data into a lower-dimensional representation, which is useful for tasks such as anomaly detection, clustering, and visualization of agricultural data.

VIII. CONCLUSION

The current advances in the WSN technologies are benefitting the farmers a lot. They are able to learn more about various crops and improve yields. The challenges in deploying WSN's are related to one time setup costs along with long term maintenance costs. Only large and rich farmers are able to afford it. AI/ML is widely improving which could predict and influence the market. A farmer is benefitted and also the countries will be able to solve the problem of food shortage if they follow smart agriculture techniques deploying WSN's and use AI in their crops.

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