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IoT-Enabled Smart Crop Monitoring Systems for Sustainable Agriculture

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***Abstract*— The emergence of the Internet of Things has drastically changed precision agriculture by providing real-time monitoring and analysis of crop growth and health. In this article, we offer a thorough examination of IoT-enabled smart crop monitoring systems for sustainable and precise agriculture. Our analysis encompasses the most recent advancements in IoT and its applications in smart farming. We discuss the various protocols, network architectures, and platforms used for crop monitoring and sustainability. In addition, we investigate the obstacles and opportunities associated with IoT-enabled crop monitoring systems. To ensure the widespread adoption of IoT-enabled smart agricultural monitoring systems, we also identify a number of obstacles, including data security and privacy concerns, high implementation costs, and the need for specialised technical expertise. We also examine the potential for IoT-enabled intelligent crop monitoring systems to contribute to irrigation control, food security, and sustainable agriculture. This article provides a comprehensive overview of IoT-enabled intelligent crop monitoring systems and their potential to revolutionise precision agriculture. The purpose of this review is to inform future research in this field and to stimulate the development of new approaches and methods for sustainable agriculture.**

Keywords IoT-enabled agriculture, smart crop monitoring, irrigation control, precision agriculture, network architectures, Machine learning, resource efficiency.

I. Introduction

The anticipated world population by 2050 is 9.7 billion people, posing significant challenges for global food security [1]. To meet this demand, we must produce more food with fewer resources and minimal environmental impact. Internet of Things (IoT)-enabled smart agricultural practises offer a promising solution to these problems. IoT devices can gather data about the conditions of farming fields and use that information to take actions based on the farmer's input [2]. IoT technology has been categorized into various types of agriculture systems, incorporating farms monitoring and control systems, agriculture management of stocks systems, food safety systems, as well as supply system of supply management [3]. These systems use IoT devices to collect and analyze data related to farming operations. However, smart crop monitoring systems facilitated by the IoT provide real-time data on crop growth and health, which can be used to optimise resource utilisation and boost crop yields. These systems can monitor soil moisture, temperature, and humidity, as well as other environmental factors that influence crop growth. Additionally, they can detect pests and diseases early on, allowing for prompt intervention and reducing crop losses.

In the following article, we present a thorough review on IoT-enabled smart crop monitoring systems for sustainable and precise agriculture. Our analysis encompasses the most recent advancements in IoT and its applications in smart farming. We discuss the various protocols, network architectures, and platforms used for crop monitoring and sustainability. In addition, we investigate the obstacles and opportunities associated with IoT-enabled crop monitoring systems.

We emphasise the advantages of employing IoT in smart agriculture, such as, enhanced crop yields, and increased resource efficiency. To ensure the widespread adoption of IoT-enabled smart agricultural monitoring systems, we also identify a number of obstacles, including data security and privacy concerns, high implementation costs, and the need for specialised technical expertise.

Several strategies, including the use of open-source software and hardware, the development of standardised protocols, Also it is suggested that these challenges can be circumvented by using machine learning and artificial intelligence. We also examine the potential for IoT-enabled intelligent crop monitoring systems to contribute to irrigation control, food security and sustainable agriculture. IoT-enabled smart crop monitoring systems have the potential to revolutionise precision agriculture. Precision agriculture promises the possibility of significant production improvement with the use of few external inputs, particularly for small farmers in developing nations [4]. Precision agriculture or precision farming highlights the benefits and challenges of employing IoT in smart farming and proposes a number of solutions to these challenges. The purpose of this review is to inform further studies in this area and to stimulate the progression of new approaches and methods for sustainable agriculture.

II. CONTRIBUTION OF THIS STUDY

The contribution for this research review paper:

1. Provides a comprehensive overview of IoT-enabled clever crop monitoring systems for sustainable and precise agriculture.
2. Identifies the benefits and challenges of employing IoT in smart farming and proposes solutions to these challenges.
3. Presents insights on the most recent advancements in IoT and its applications in smart farming.
4. Covers the various protocols, network architectures, and platforms used for agricultural monitoring and sustainability.
5. Guides researchers and practitioners interested in implementing IoT-enabled smart agriculture monitoring systems.
6. Contributes significantly to the field of precision agriculture by providing a thorough overview of IoT-enabled smart crop monitoring systems and their potential to revolutionise sustainable farming practises.

III. PRIME COMPONENTS AND RELATED TECHNOLOGIES FOR IOT ENABLED SMART FARMING

Smart farming uses enabled by the Internet of Things (IoT) are revolutionizing agriculture by optimizing resource utilisation, increasing crop yields, and increasing sustainability. Smart agricultural systems powered by IoT give real-time data on crop growth and health, allowing farmers to make informed decisions about resource allocation and management. In this section, we will go through the key components and related technologies required for IoT-enabled smart farming.

1. Sensors: Sensors are the foundation of any Internet of Things-enabled smart farming system. These sensors are used to measure soil moisture levels, temperature, humidity, light intensity, and atmospheric pressure, among other environmental conditions that affect crop growth. They can also detect pests and illnesses early, allowing for timely intervention and reduced crop losses. The sensors are linked to the internet via a wireless or wired network, and data is sent to the cloud for processing and analysis. The paper by Ching-Ju Chen et al [5] combined environmental sensors through a wireless environmental sensor transmission platform and a cloud big data computing server system to collect environmental data.

2. Controllers: The Raspberry Pi is a development board featuring a computer's capabilities that makes use of the Linux operating system to carry out a variety of computing tasks. The Arduino Uno is an 8-bit microcontroller development board that features extra connection ports for external electronics and a USB programming interface. The ESP8266 is a wirelessly programmable microcontroller board that can link other devices via Wi-Fi thanks to an embedded TCP/IP protocol stack.

One of the earliest and most fundamental microcontrollers that can be utilized for straightforward applications is the 8051. A USB-to-serial converter, voltage regulator, and ESP8266 module are all included on the open source development board known as Node MCU.

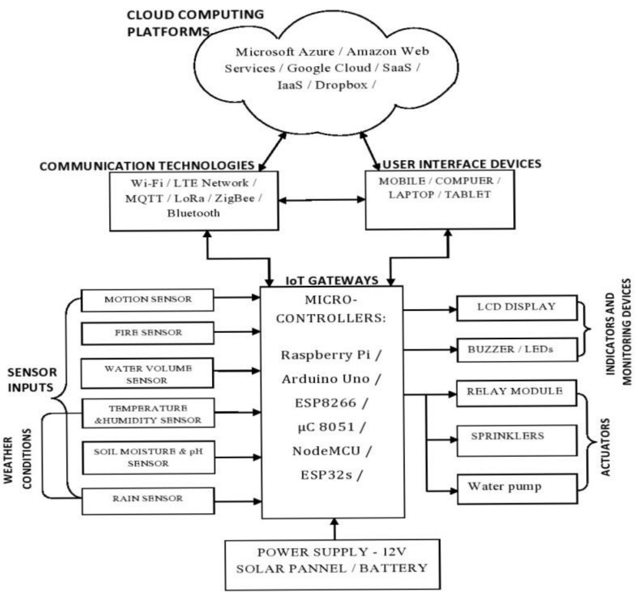
Controller name	Software used	Supported programming Language	RAM size	ROM size	Frequency	List of inbuilt peripheral devices	list of inbuilt features	Price in Rs. (approx.)	Reliability	Strengths	weaknesses
Raspberry Pi (4B+)	Raspbian Linux	Python, C, C++, Java	2 GB or 4 GB	Up to 128 GB	1.5 GHz	HDMI, Ethernet, USB, Audio, Camera	WiFi, Bluetooth, GPU	4200	High	can run complex algorithms and applications, can communicate wirelessly via WiFi or Bluetooth	High power consumption and cost
Arduino UNO	Arduino IDE	C/C++	2 KB	32 KB	16 MHz	PWM, Analog, I2C, SPI, UART	Ceramic resonator, ICSP header, Replaceable chip	1200	High	easy to program and debug , can interface with many sensors and actuators, can also use shields to add more functionality such as Ethernet or GSM	limited memory and processing speed , require additional components or shields to add more functionality or connectivity.
ESP 8266	Arduino IDE	Lua, C/C++, MicroPython	36 KB	4 MB	80 MHz	WiFi, ADC, PWM, I2C, SPI, UART	RTOS, ADC, PWM, I2C, SPI, UART	300	Medium	low-cost and low-power microcontroller , built-in WiFi module, can be used as a standalone device or as a WiFi bridge for other microcontrollers.	may not be able to interface with many sensors or actuators directly, some stability issues or compatibility problems with some libraries or devices
Microcontroller 8051	Keil uVision IDE	Assembly, C/C++	128 B	4 KB	12 MHz	Timers, UART, I/O ports	Software flags, Data bus, Address bus, UART	800	Low	can perform tasks like reading sensors or controlling actuators, Simple and widely available	very limited memory and features , unable to perform advanced tasks or functions.
Node MCU	NodeMCU firmware	Lua	36 KB	4 MB	80 MHz	WiFi, ADC, PWM, I2C, SPI, UART	PCB antenna, SRAM, Flash memory, RISC processor	400	Medium	Open source development board with WiFi module, programmed using Lua language which is easy to learn and use	few GPIO pins and ADC channels, have some stability issues
ESP 32	Arduino IDE	C/C++, MicroPython	520 KB	16 MB	240 MHz	WiFi, Bluetooth, ADC, DAC, PWM, I2C, SPI, UART	Bluetooth module, ADC, DAC, Ethernet MAC, CAN bus, Infrared controller	1000	High	Powerful with dual-core processor, support various protocols and modes, perform analog and digital operations using its many peripheral devices.	may have some bugs or errors in firmware or software that need to be fixed or updated regularly

A dual-core processor, Bluetooth connection, more GPIO pins, more memory, and more functionality are all included in the enhanced ESP 32 version of the ESP8266. These are a few of the well-liked and frequently utilized embedded system controllers. The following table will assist the researcher in choosing the controller based on its features and functions.

The above Table I summarize the various characteristics of the different controllers used in smart farming.

Table I: comparison of the characteristics of different controllers.

3. Wireless Communication: Wi-Fi, Bluetooth, Zigbee, and LoRaWAN are wireless communication technologies that are used to connect sensors and other devices to the internet. These technologies enable real-time data transfer and seamless connection between the many components of the smart farming system.



4. Cloud Computing: Data acquired by sensors is stored and processed using platforms for cloud computing like Microsoft Azure and Amazon Web Services (AWS). These platforms offer elastic and affordable data storage and processing options. They also give data analytics solutions that allow farmers to analyse data and make informed resource allocation and management decisions.

Figure 1: Generalized diagram for Smart Farming

5. Data Analytics: A vital component of any IoT-enabled smart agricultural system is data analytics. In order to evaluate sensor data and deliver insights regarding WEATHER CONDITIONS, crop growth, and health, data analytics tools and machine learning algorithms are utilised. Farmers can use this knowledge to optimise resource use and boost crop yields.

6. Actuators: Actuators are used to regulate numerous devices in the smart farming system, such as irrigation, fertilisation, and pest management. They are linked to the internet via a wireless or wired network and managed by a cloud-based platform.

7. User Interface: A crucial component of any IoT-enabled smart agricultural system is the user interface. It allows farmers to access and manage sensor data as well as control the numerous devices in the system. Web-based or mobile-based user interfaces can provide a variety of capabilities such as data visualisation, real-time monitoring, and alarms.

Smart farming systems, on the other hand, may offer a viable answer to the agricultural sector's difficulties, such as resource shortages and environmental effect. Farmers can optimise resource utilisation, enhance crop yields, and assure sustainable agricultural practises by using the power of IoT.

IV. Review of papers

The article by Prachin Jain et al [6] presents a novel approach to achieve energy-efficient adaptive data collection from wireless sensor networks (WSN) deployed in farms for precision agriculture. The paper proposes an adaptive model for the IoT gateway that uses crop-specific parameters to optimally configure itself to collect data from sensor nodes in the network, thereby maximizing energy-efficiency and network lifetime. The paper contributes to the field of precision agriculture by providing a cost-effective and scalable solution for fine-grained monitoring of micro-climatic conditions of farms using IoT. The paper concludes by discussing the weaknesses of the proposed approach, such as dependency on crop-specific parameters, limited scalability, and security issues.

The study by Nisar Ahmad et al [7] introduces a multi-parameter monitoring system for smart remote monitoring of Things (IoT) and wireless sensor network (WSN) technologies. The paper describes the design and implementation of a WSN system that collects data from sensor nodes deployed in fields, which measure various environmental factors such as soil moisture, UV index, rain, air pressure and humidity. The paper contributes to the field of precision agriculture by providing a low-cost, low-energy, and easy-to-implement solution for fine-grained sensing of agricultural parameters using IoT. The paper also discusses the limitations of the proposed system, such as security issues, scalability issues, and dependency on internet connectivity.

The paper written by Sanjeevi et al [8] offers a scalable wireless sensor network (WSN) topology to observing and managing distant farms and agricultural operations taking advantage of the Internet of Things. The paper's focus on water-efficient irrigation and optimal water resource utilisation, together with evidence that the suggested technique outperforms more traditional IoT-based agriculture and farming, are its strongest points. The proposed method's flaw is that it has limitations such as security issues, scalability issues, and dependency on internet connectivity.

The paper by Xue and Huang et al [9] explores Internet of Things (IoT)-based algorithms for node placement and WSN routing protocols for smart agriculture. The strength of the paper is that it proposes an improved routing protocol of Low Energy Adaptive Clustering Hierarchy and an upgraded DV-HOP positioning algorithm that beat the originals in terms of energy use, network lifetime, and positioning accuracy. The suggested method's shortcomings include dependencies on crop-specific characteristics, a lack of scalability, and security concerns.

The article by Deif and Gadallah et al [10] Examines the issue of temporal topology control (TTC) for wireless sensor networks (WSN) supporting important Internet of Things (IoT) applications. The paper's strength is that it suggests a TTCP that performs better than current TTCPs in terms of latency and the amount of time needed to find and fix SN faults. The weak spots of proposed approach are that it has limitations such as dependency on network density, connectivity, and synchronization.

The study by Pornillos et al [11] proposes an Internet-of-Things (IoT) platform for a smart irrigation control system that makes use of wireless sensor networks (WSN) and a specialised server. The paper's strength lies in its attempt to preserve water and lessen human work by automatically giving water to plants based on their needs. It also demonstrates how the smart irrigation control system is more effective and efficient than the traditional technique of irrigation. The weakness of the proposed approach is that it has challenges and limitations such as security issues, network interference, and power consumption.

The paper written by Pengcheng et al [12] discusses the use of compressed sensing technologies for big data processing using wireless sensor networks (WSN). The paper's merit is that it asserts compressed sensing technologies can get beyond the constraints of WSNs by reducing the data size and saving energy consumption and proposes a spatial expansion algorithm that can accurately locate objects, lowering node energy usage, increasing data processing power and computation speed, and tracking objectives. The weakness of the proposed approach is that it has challenges and limitations such as security issues, network interference, and power consumption.

The paper by Ullo and Sinha et al [13] gives a thorough analysis of the improvements in IoT and smart sensors used in agriculture and remote sensing applications. The paper's strength is its examination of cutting-edge smart sensor and Internet of Things technologies and its discussion of its advantages, disadvantages, challenges, and future trends. The weakness of the paper is not explicitly stated.

The article by Kundu et al [14] the strength of the paper is that it presents a making use of IoT, a cloud-based monitoring system for agricultural that aims to conserve water and reduce human labour. The weakness of the paper is that it discusses challenges and limitations such as security issues, network interference, and power consumption.

The study by Singh et al [15] provides an Internet of Things (IoT) platform for agriculture applications that leverages machine learning (ML) and LoRa wireless sensor networks (WSN) to create a smart irrigation system. The paper's strength is that it emphasises a smart irrigation system for agricultural applications employing ML and LoRa WSN. That aims to conserve water and reduce human labour. The weakness of the paper is that it discusses challenges and limitations such as security issues, network interference, and power consumption.

The paper written by Zhang et al [16] presents a smart irrigation system that uses LoRaWAN wireless sensor networks (WSN) and Machine learning (ML) as an Internet of Things (IoT) platform for agriculture applications. The paper aims to conserve water and reduce human labour by automatically supplying water to plants based on their requirements. The strength of the paper is that it presents a smart irrigation system using LoRaWAN WSN and ML for agriculture applications that aims to conserve water and reduce human labour. The weakness of the paper is that it discusses limitations such as security issues, network interference, and power consumption.

The paper by Wanninayaka et al [17] presents a smart farm and monitoring system and it aims to improve the efficiency and productivity of farming activities by collecting and analyzing environmental data such as temperature, humidity, rain, and soil moisture. As for the paper's strength is that it presents a smart farm and monitoring system using WSN and IoT for agriculture applications that aims to improve the efficiency and productivity of farming activities. The weakness of the paper is that it discusses limitations such as security issues, network interference, and scalability.

The article by Griva et al [18] gives an extensive review of LoRa-based IoT networks in multiple environments, including urban, rural, and parking lots. This research paper provides an extensive assessment of LoRa-based IoT networks in various settings and contrasts their performance with that of other wireless technologies. The paper discusses challenges and limitations of the proposed approach such as security issues, network interference, and synchronization.

The study by Alam et al [19] gives an in-depth review of cloud-based applications for the Internet of Things and how they fit within the concept of smart cities. The goal of the paper is to examine the advantages, difficulties, and prospects of cloud-based IoT applications for a variety of industries, including smart governance, smart energy, smart environment, smart healthcare, and smart transportation. The paper offers a thorough analysis of IoT applications based on cloud computing and the roles they play in smart cities, and presents case studies of cloud-based IoT applications in different domains. The paper does not explicitly mention any weaknesses or limitations of applications in smart cities that use cloud-based IoT.
The following Table II present a summary of key findings from a review of recent literature in this field.
Table II: An overview of some of the most recent work

V. Critical analysis of literature review

Key challenges addressed in the reviews of the Literature

It appears that using the combination of wireless sensor networks (WSN) along with Internet of Things (IoT) systems for smart remote crop surveillance can effectively address a number of significant difficulties based on the evaluations of the pertinent literature provided above. This first section discussed about the security, scalability, and dependency on internet connectivity. These challenges can be mitigated through the adoption of various measures and best practices.

Security is a critical concern when it comes to transmitting data between sensors and the cloud. To enhance security, encryption and authentication protocols can be used to secure data transmission. Data is encoded using encryption so that only those with the proper access permissions may access it. To do this, algorithms are used to transform the data into an unintelligible format that can only be decrypted by a person in possession of the necessary keys. Common encryption algorithms include DES, AES, and RSA [28]. Authentication protocols are used to verify the identity of the parties involved in data transmission. This ensures that only authorized personnel can access the data. Common authentication methods include password authentication and two-factor authentication [29]. To guarantee that only authorised personnel may access the data, access control methods can be put in place in addition to encryption and authentication processes. Access control entails approving or rejecting access to resources in accordance with a predetermined set of rules. For example, access to sensitive data can be restricted to a specific group of users or roles.

When designing a multi-parameter monitoring system for smart remote monitoring of crops using IoT and WSN technologies, scalability is an important consideration that should be taken into account. A system is said to be scalable if it is able to easily handle expansion and change and if it makes it possible for new sensors and devices to be quickly added into the system. Scalability can be addressed in a number of ways; one of them is by designing the system to be modular and simple to extend. This indicates that the system is made up of separate components or modules that can have their number increased or decreased depending on the requirements. Because of this, the system can expand and adapt over time without necessitating a fundamental rethinking or reorganisation of its components. Utilising standardised communication protocols and interfaces is one way to accomplish both modularity and expandability in a system. These make it possible for the various parts of the system to communicate with one another using a standardised language and a predetermined set of ground rules. New sensors and devices can be easily incorporated into the system if standardised protocols and interfaces are used. This will allow the system to expand and adapt as needed over time. However, scalability can be efficiently addressed by designing the system to be modular and easily scalable, as well as by utilising standardised communication protocols and interfaces. This will allow for maximum flexibility.

Paper name	Controller/ Technology	Working of Model	Contribution of paper	Weaknesses
Smart Farming – IoT in Agriculture- R Dagar et al [20]	Arduino Uno board, Wi-Fi	IoT sensors collect data from the farm and send it to the server via Wi-Fi, where data processing, analysis, and decision making are performed	Providing a low-cost and user-friendly IoT solution for smart farming	The paper lacks details on data processing and decision making algorithms, communication technology comparison
Smart Farming System using IoT for Efficient Crop Growth- Abhiram MSD et al [21]	NodeMCU, Wi-Fi	The system monitors temperature, humidity, soil moisture level using sensors connected to NodeMCU and sends the data to the cloud.	The paper proposes an IoT-based solution for monitoring the soil conditions and atmosphere for efficient crop growth.	. It does not conduct any experimental validation or user evaluation of the system.
Applications of IoT in Real-Time Monitoring of Contaminants in the Air, Water, and Soil- Abhiram SP et al [22]	Arduino platfor, LTE N/w	It allows modelers and stakeholders to visualize and analyze the data using web applications.	It claims that the framework can help to understand and simulate contaminant transport and proliferation,support sustainable use of natural resources.	It does not provide a literature review or a theoretical background for the proposed framework..
Smart Farming using IoT, a solution for optimally monitoring Farming conditions- J Doshi et al [23]	ESP32s Node MCU, Wi-Fi	The system monitors temperature, humidity, soil moisture, UV index, IR using sensors connected to ESP32s Node MCU	It claims that the technology can increase crop yields, save resources, and reduce crop wastage.	It does not discuss the ethical, social, or environmental implications of the system.
Flexible IoT Agriculture Systems for Irrigation Control Based on Software Services- E Palomar et al [24]	Computer simulation, LTE N/w	The system uses sensors connected to logging devices that send real-time data to the cloud using IoT systems for irrigation control.	It claims that the framework can help to monitor and manage irrigation systems using IoT systems in a flexible and cost-efficient manner.	It does not provide a literature review or a theoretical background for the proposed framework.
A Secure IoT-Based Irrigation System for Precision Agriculture Using the Expeditious Cipher- C Fathy et al [25]	NodeMCU, MQTT/TCP	The system uses sensors connected to logging devices that send encrypted data to the cloud using IoT systems for irrigation control.	The paper proposes a software framework that supports the design of the IoT systems' software based on software services in a client-server model with REST interactions.	It does not discuss the ethical, social, or environmental implications of the framework.
IoT-Enabled Precision Agriculture: Developing an Ecosys for Optimized Crop Management- S atalla et al [26]	COOJA simulator, LTE N/w or Wi-Fi	The system uses sensors connected to logging devices that send data to the cloud using IoT systems for precision agriculture.	It claims that the framework can help to monitor and manage farming systems using IoT systems in a flexible and cost-efficient manner.	lack of a detailed explanation of the data analysis
Monitoring and Control Framework for IoT, Implemented for Smart Agriculture- E Senoo et al [27]	Arduino Uno R3, LoRaWAN	The model consists of three subsystems: monitoring subsystem, control subsystem, and computing subsystem.	The paper demonstrates the utilization of the framework in a real-world use-case in smart agriculture	Some of the weaknesses of MCF are: - Limited range and bandwidth of LoRaWAN network

A multi-parameter monitoring system for smart remote monitoring of crops utilising IoT and WSN technologies can be dependent on internet connectivity to transport data from sensors to the cloud for storage and processing. This can be done by employing IoT and WSN technologies.

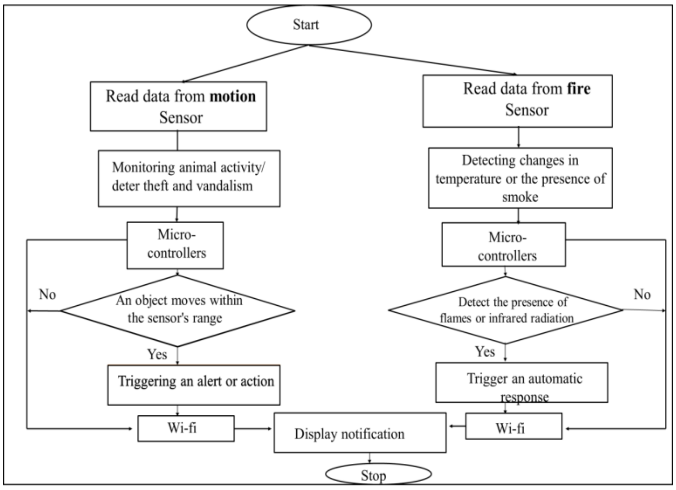
However, by implementing local data storage and processing capabilities, this dependency can be reduced. The practise of storing data locally, as opposed to transmitting it to a remote server in the cloud, is referred to as ‘local data storage’. Because of this, the system is able to continue operating normally even if it loses connectivity to the internet. Data can be saved locally until connectivity is restored, at which point it can be sent to the cloud to be preserved for the long term and analysed there.

Instead of depending on the cloud for data processing and analysis, local processing capabilities involve conducting these tasks on local devices or systems instead. Because of this, the system is able to continue operating normally even if it loses connectivity to the internet. Data can be processed and analysed locally, which enables decision making and action to take place in real time. In light of this, reducing reliance on connectivity to the internet can be accomplished by introducing capabilities for local data storage and processing. Because of this, the system will continue to operate normally even if it loses connected to the internet; data will be uploaded to the cloud as soon as connectivity is restored.

A further major challenge that may arise in the context of farming that is allowed by the IoT is network interference, which can make it difficult for sensor nodes and other equipment to communicate with one another. Techniques like frequency hopping and spread spectrum can be utilized to lessen the negative effects that interference has on the system, which can be helpful in resolving this issue. It is also possible to develop interference-insensitive synchronization systems, which can enable reliable packet identification even in instances including packet overlap. Implementing IoT-enabled solutions for intelligent remote agricultural monitoring is hampered by network interference and synchronisation issues. These issues must be effectively addressed to ensure reliable and accurate data collection and analysis.

Network interference can occur when multiple wireless devices are operating in the same frequency range, causing disruptions in communication between sensor nodes. To mitigate this issue, techniques such as frequency hopping or spread spectrum can be used to reduce the impact of interference on the system. Additionally, interference-insensitive synchronization schemes can be implemented to deliver efficient packet detection even in situations with packet overlaps [30].

Synchronization is important in a WSN to ensure that all sensor nodes are operating on the same time scale. This is necessary for accurate data collection and analysis. The network’s entire sensor nodes' clocks can be synchronised using time synchronisation protocols to solve synchronisation problems. As an example, the Glossy flooding architecture for wireless sensor networks takes advantage of the constructive interference of IEEE 802.15.4 symbols for quick network flooding and implicit time synchronisation [31]. Hence, by implementing measures such as interference-insensitive synchronization schemes and time synchronization protocols, issues such



as network interference and synchronization can be effectively addressed.

Figure 2: Proposed Smart farming flow

Networking standards utilised by IoT systems for smart agriculture

An interconnected system of physical objects, networking elements, and data analytic tools is known as the Internet of Things (IoT). This setup allows essential elements like sensors, networking equipment, and software systems to gather, share, and analyze data seamlessly [32]. IoT solutions for smart farming employ a variety of network protocols, based on the particular needs and features of the application. These are some of the most common network protocols:

- Bluetooth Low Energy (BLE): Several IoT networks make use of the low-power wireless communication protocol BLE, including smart farming applications. It can connect devices over brief distances and is designed to be highly efficient.
- CoAP (Constrained Application Protocol): It is a protocol designed for use in constrained environments, such as IoT networks. It is designed to be lightweight and simple to implement, which makes it a popular option for intelligent agricultural applications.
- MQTT (Message Queuing Telemetry Transport): It is frequently used in smart farming applications due to its minimal overhead and ability to function in low-bandwidth environments.
- ZigBee: Several IoT networks employ this low-power wireless communication technology, including smart farming applications. It is designed to be extremely dependable and efficient, making it ideal for use in environments with limited resources and power.
- LoRaWAN: It is a long-range wireless protocol designed for Internet of Things networks. It is extremely scalable and can connect a large number of devices over great distances, which makes it ideal for smart farming applications.

The choice of network protocol for a smart agricultural application will depend on a variety of factors, including the application's specific requirements, the available resources, and the deployment environment.

Review of recommendations from various recent studies

There is no single network protocol that is universally suggested by maximum researchers for smart farming using IoT, due to the fact that the network protocol choice will be impacted by a variety of factors, for instance the environment in which the application will be used, the specific requirements of the application, and the available resources. In other words, the literature does not reveal a consensus on the most suitable network protocol for smart farming using IoT. However, MQTT is a popular choice among researchers for smart farming applications-

MQTT is a lightweight messaging protocol designed to be efficient and dependable in low-bandwidth or unreliable network environments. MQTT is also extremely scalable and can connect a large number of devices across a variety of network topologies, making it ideal for smart farming applications. It is a lightweight publish-subscribe protocol capable of monitoring and collecting data from multiple sensors and devices [33].

In addition to MQTT, the following network protocols have been researched and implemented for IoT-enabled agriculture:

i. LPWAN: It is a wide-area, low-power network that can offer cheap long-distance connection for applications in smart agriculture [33][34].

ii. WSN: A wireless sensor network capable of collecting and transmitting environmental data including temperature, humidity, and soil moisture [35][36].

iii. Blockchain: It is a distributed ledger that can assure the security, transparency, and traceability of agricultural data and transactions [35].

Consequently, the choice of network protocol may rely on a number of parameters, such as the application type, the scope of the deployment, how much power it uses, how much bandwidth it needs, how secure it is, and how cost-effective it is. Therefore, various network protocols may have distinct benefits and drawbacks for IoT-based intelligent agriculture. Depending on the specific requirements and constraints of the application, other network protocols such as CoAP, ZigBee, LoRaWAN, and BLE may be more appropriate for certain smart agricultural applications. Therefore, it is essential for researchers to evaluate the various network protocols and select the one that is optimal for their specific application.

VI. Conclusion

This research study provided a thorough assessment of the most advanced IoT technology available at the time for smart agricultural operations. Furthermore, it emphasised the core elements of IoT solutions as well as the range of their use. This research study covers the challenges and concerns that have been identified by recent researchers and provides a variety of strategies and practises that are considered to be the best to alleviate the effects of these challenges and issues.

Agriculture is the foundation upon which our society is built. The IoT technology is being integrated into agricultural practises in order to make "farming" a more efficient and effective practise. Techniques from the internet of things are used in virtually every sector of agriculture, including farm monitoring, insect monitoring, irrigation management, and so on. The currently used methods for smart farming are categorised and analysed in this study. As a result of this research, it has become clear that future research should place a greater emphasis on the factors of security, scalability, synchronisation, food distribution, and dependency on connectivity. It has also been discovered that, in order for researchers to solve more problems that occur in real time, they should experiment with the strategies in outside settings. Overall, the results of this effort will help researchers more accurately comprehend the current state of affairs.

The current research also revealed that, in the latest work, the utilization of artificial intelligence, together with strategies that leverage the image processing and internet of things, has become increasingly common in efforts to improve the management of smart farming practices.

The monitoring of crops was shown to be the most popular use of IoT for smart farming, according to the applications that have been identified. This study also shows how many network protocols may be used simultaneously in IoT systems for smart farming. Then again, the network protocol that was recognised as being the most recommended by a large number of researchers was examined, along with the reasoning that underpinned that recommendation. Additionally, the study looked into possible fixes to issues related to smart farming that have been offered by a variety of scholars in recent times. This evaluation may be expanded in further work to include other publications of relevance, as well as complementing analyses of project costs, usability, and regional issues that are inherent to IoT applications.

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