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IoT in Developing the Smart Farming and Agricultural Technologies

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Background: The Internet of Things (IoT) is streamlining processes in food and agriculture, especially in developing countries with agriculture-based economies. These countries stand to gain a lot from the IoT innovations that bring about mechanisms to track and control the risks experienced due to factors such as low productivity, wastage of resources and food scarcity.

Objectives: This research aims to demonstrate how different IoT solutions can be effective in food and agriculture technology in less developed countries. It focuses on the potential of IoT solutions to improve productivity, reduce wastage of resources and encourage sustainable agro practices. Furthermore, the paper examines the reasons behind the slow adoption of IoT technologies and strategies to surmount such factors are proposed.

Methodology: The study employed both literature and analytical as well; however, a majority of it was on the primary data concerning IoT solutions that were smart irrigation and precision agriculture. Data was collected from farmers and technology neglected mostly the politicians of developing countries whose focus was to understand or rather assess the uptake, challenges and impacts of IoT technology.

Results: The results show that IoT can cause a drastic enhancement of agricultural productivity through efficient water irrigation, keeping a check on soil health and lowering post-harvest waste. MFIs IoT made the adoption of the system and use of resources more efficient, increased profits and lowered expenses. However, they also revealed obstacles to the process such as the cost of implementation, expertise in both technical and operational levels and internet services.

Conclusion: Smart agriculture and agricultural systems everywhere will undergo a revolution owing to IoT technologies because they enhance practices and innovations. However, potential benefits cannot, be maximized Secure fencing of these barriers will not be straightforward since a significant amount of time will have to be devoted to understanding each of the suggestions made by the officers present.

Keywords: IoT, Smart Farming, Agricultural Technologies, Greenhouse Automation.

Introduction:

Global expansion of the internet has revolutionized innumerable organizations and individuals in the last 20 years. The primary advantage of this innovation was the real-time production and consumption of services. The IoT has emerged recently, offering the potential to improve user perception and capabilities by altering the work environment, while continuing to deliver similar benefits through its innovative technologies [1]. The IoT offers various solutions across multiple sectors, including retail, healthcare, security, transportation, smart homes, smart cities and agriculture. Implementing IoT in agriculture is an optimal solution, as this industry requires constant monitoring and control. The IoT is applied in agriculture across multiple levels [2]. Various surveillance categories apply to the three primary uses of IoT in agriculture: greenhouses, livestock and precision farming.

Wireless sensor networks (WSNs), which assist farmers in gathering pertinent data by utilizing detectors and a range of IoT-based sensors and devices. Cloud services help researchers and agriculturists make better decisions while handling and analyzing distant data in IoT systems. Today's environmental monitoring solutions provide enhanced management and decision-making capabilities, driven by advancements in modern technology [3]. A modified landslide risk monitoring system are available which are capable of rapid deployment in difficult conditions without human intervention. The developed system is even more intriguing because it automatically reorganizes the network's low-quality communication channels and handles node failures [4]. A suggested IoT management system has a wide range of environmental factors, including wind, soil, atmosphere and water. Additionally, IoT-based agricultural monitoring systems have been deployed through their respective platforms or technologies. The identified sub-domains include soil, air, temperature, water, disease, location, environmental conditions, pest control, fertilization and environmental monitoring [5]. Additionally, the IoT paradigm enhances real-world human contact by utilizing affordable technology devices and communication protocols. IoT also monitors several environmental factors, including temperature, hazardous radiation, air and water pollution, noise levels and more, to create comprehensive, real-time maps. Furthermore, the user receives information acquired about different environmental conditions via trigger alerts or message recommendations to authorities [5].

In recent decades, numerous studies have been presented on IoT-based agriculture. Therefore, it is essential to gather, summarize, evaluate and categorize the latest research in this area. This study aims to provide an extensive and methodical overview of the literature pertaining to IoT agriculture [6]. Overall, IoT management, compatibility and installation requirements are generally straightforward. Moreover, many researchers are recognizing the benefits of incorporating IoT into their studies, though challenges like data collection and security are becoming more prominent. The purpose of this research is to investigate or assess current agricultural monitoring apps, sensors and networking equipment that use the IoT. Then, in terms of data selection and photographic findings, we utilized the idea presented to make the research objective.

Sensor technology enhances agricultural practices by providing real-time data on soil conditions, crop health and environmental factors. This information allows farmers to optimize resource usage, leading to increased yields and reduced costs. Additionally, more precise farming techniques minimize waste and environmental impact, promoting sustainable agriculture. Overall, sensors play a crucial role in modernizing farming while benefiting both productivity and the environment. By collecting data on various environmental factors such as nutrients, soil moisture, temperature and more, farmers can make informed decisions regarding irrigation, fertilization and pest control. Smart agriculture enables continuous monitoring of crop growth and environmental conditions, allowing farmers to anticipate potential issues and respond quickly to changes. This approach promotes efficient and environmentally friendly farming methods, which is essential in light of climate change and other environmental problems [7]. The application of sensor technology in agriculture is anticipated to have a substantial influence on future food production. Every element of conventional agricultural operations has been significantly improved by the integration of cutting-edge sensors and IoT technology. Currently, smart agriculture has the potential to revolutionize farming by integrating wireless sensors and IoT technology, advancing the industry to levels once thought unimaginable [8].

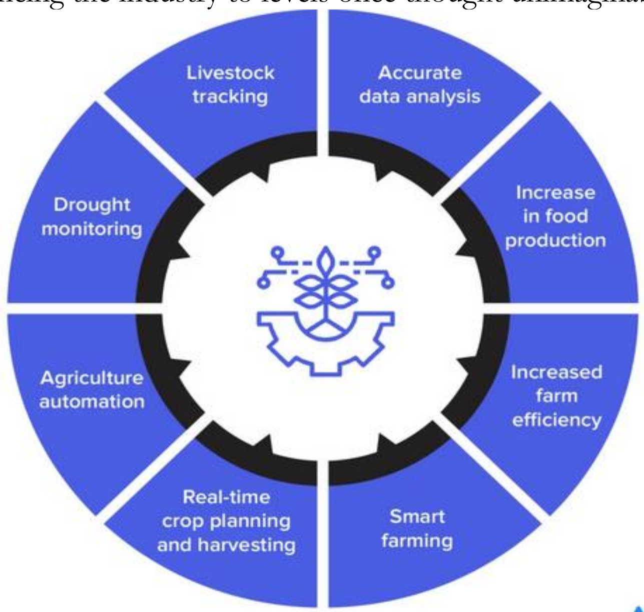

Figure 1. Impact of IoT in Agriculture
Source: https://appinventiv.com/blog/iot-in-agriculture-industry/

IoT use Cases in Agriculture:

Monitoring of Climate Conditions:

Because the traditional devices incorporate several smart farming sensors, the most widely used smart agriculture devices are weather stations. Smart farming sensors are scattered over the area and gather different kinds of environmental data before sending it to the cloud. It is feasible to map the environment, select suitable crops and take the necessary steps to increase productivity by using the measures offered (also known as precise farming) [9].

Greenhouse Automation:

Farmers typically manage the greenhouse environment through manual intervention. However, with IoT sensors, they can access precise real-time data on factors such as lighting, temperature, soil quality and humidity.

Crop Management:

Another type of IoT product utilized in agriculture and a part of precision farming are crop management devices. Similar to weather stations, these devices should be installed in the field to gather data relevant to agricultural production, such as temperature, rainfall, leaf water potential and overall crop health.

Cattle Monitoring and Management:

Similar to crop monitoring, IoT agricultural sensors can track the health and performance of farm animals. Tracking and monitoring livestock allows for the collection of data on their location, health and overall well-being.

Precision Farming:

Precision farming sometimes referred to as precision agriculture, is centered on productivity and precise, data-driven decision-making. It's also among the most popular and successful uses of IoT in farming.

Agricultural Drones:

One of the aggrotech industry's most exciting new innovations is undoubtedly the usage of agricultural drones in smart farming. Unmanned aerial vehicles, or UAVs, sometimes known as drones, are better at collecting agricultural data than satellites and airplanes. Apart from their surveillance functions, drones may do an extensive array of tasks that were conventionally performed by humans, like planting crops, eliminating pests and diseases, applying agricultural sprays, keeping an eye on crops and more [10].

Predictive Analytics for Smart Farming:

Predictive data analytics and precision farming go hand in hand. By interpreting the vast amounts of real-time data provided by IoT and smart sensor technology, farmers can use data analytics to predict crop harvest times, address disease and pest issues, estimate yield volumes and manage other related concerns. Agricultural practices, which are primarily weather-dependent, can be made more predictable and controlled with the use of data analytics techniques [11].

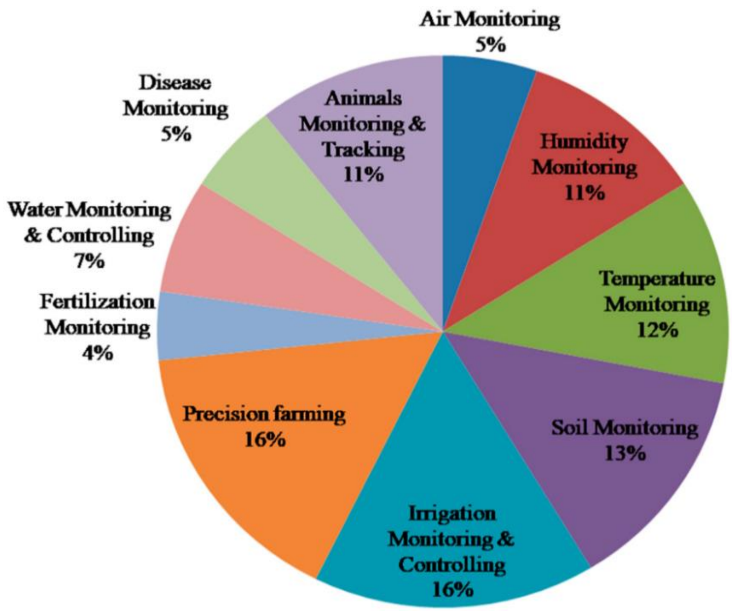

Figure 2. IoT agriculture applications

Source: https://www.mdpi.com/2079-9292/9/2/319

Research Objectives:

This research comprised the following objectives:

- Assess how the IoT applications enhance agricultural productivity, efficiency and sustainability through real-time monitoring and data-driven decision-making.
- To Identify and characterize the sensors, devices and communication protocols utilized in the present IoT applications in agriculture.
- Investigate the benefits of adopting the IoT in farming practices, including cost reduction and environmental impact, while also addressing potential challenges and barriers to implementation.
- An IoT-based framework for smart farming has been presented, which incorporates basic ideas of IoT agriculture to identify current IoT solutions targeted at smart farming.
- To Highlight the research gaps by outlining the challenges and unresolved issues.

Research Question:

- How has the frequency of approaches to IOT agriculture evolved?
- What methods are implemented to deal with problems posed by agriculture IoT issues?
- What are the areas where IoT systems are mostly applied in agriculture?

- What is the main interest of the articles which have been selected?
- In agriculture, what kinds of IoT devices especially sensors have been used?
- Describe the IOT networks as well as the applicable communication protocols that you recommend in this study.

Literature Review:

In recent years, interest in integrating the IoT with food and agricultural technologies has significantly grown, especially in developing countries. It is a transformative tool as global challenges related to food security, resource management and sustainability intensify. Since 2020, a growing body of research has highlighted the potential, challenges related to food security, resource management and sustainability intensifying and the progress of IoT in these sectors.

IoT in Precision Agriculture:

Since 2020, researchers have been interested in the investigation of the role IoT technologies play in the development of precision farming, in which the moisture, temperature and other parameters of crops are supervised via IOT sensors. Other works, for example, Kumar et al. (2021) highlight the importance of IoT in increasing yields as agriculture is not only about growing crops but optimizing them as well [12]. Abbas et al. (2022) indicate that IoT technology complemented precision farming practices which helped reduce labor, water, fertilizer and pesticides, thus more sustainable practices are supported [13]. Such advancements are essential in developing countries as there are more challenges due to the limited resources and ever-changing climate [14].

Smart Irrigation and Water Management:

Advancements in IoT-based smart irrigation systems have become one of the most important aspects of development. Ahmed et al. (2021) studied how smart irrigation can improve water efficiency through IoT systems by incorporating weather and soil moisture parameters in managing crops [15]. This has been highly beneficial in regions including Africa and South Asia where there is limited availability of water resources. Sharma et al., 2023 Research indicates that IoT-based irrigation systems can improve water efficiency by up to 30%, helping farmers combat water scarcity and reduce production costs [16].

IoT in Supply Chain and Food Security:

IoT has several applications in the post-harvest and presenting/exporting agricultural products management. Patel, Aman, et al. (2021) monitored the attenuation of temperature and moisture via monitoring systems based on IoT in perishable items caused by exposure to the external environment [17]. This is especially helpful in developing countries where there are significant post-harvest losses, as it will increase food security and reduce wastage.

Barriers to IoT Adoption:

In the studies conducted by Banerjee et al. (2022) and Li, Xiaomin, et al. (2023 the authors identified the high cost of IoT devices, limited internet access and low technical knowledge among farmers as barriers to the widespread adoption of IoT applications. They also emphasized the need for both government and private sectors to intervene by subsidizing IoT technology acquisition and providing the necessary infrastructure support [18][19].

Policy and Institutional Support:

Government-subsidized farming projects in India and Kenya, as highlighted by Williams and Singh (2021), demonstrate how small-scale farmers have gained access to IoT farming through the use of subsidized tools. Laurianto, Erick, et al, (2022) also mentioned that increased access to communication and information technology is very vital in the changing farming environment and farming practices [20]. Thus, organizations such as the African Smart Farming Alliance launched in 2021 and other programs seek to develop improved farming systems by utilizing IoT tools by farmers [21].

Sustainability and Extended Eco-Friendly Strategies:

Recent studies have also made advancements in exploring how IoT is utilized to improve the sustainability of farming practices [22]. For example, IoT applications that monitor environmental parameters can help decrease greenhouse gas emissions linked to agriculture. Additionally, IoT-enabled smart energy systems improve the efficiency of farm equipment operations, which in turn contributes to energy conservation. Moreover, Zhao, Yingding, et al (2023) highlighted that biopesticides and biocontrol methods in agriculture not only minimize environmental impact but also leverage IoT to reduce chemical usage and prevent water wastage [23].

The technology also provides solutions for precision farming, smart irrigation and supply chain management amongst others, however, challenges in terms of cost, infrastructure and education still pose a lot of challenges [24].

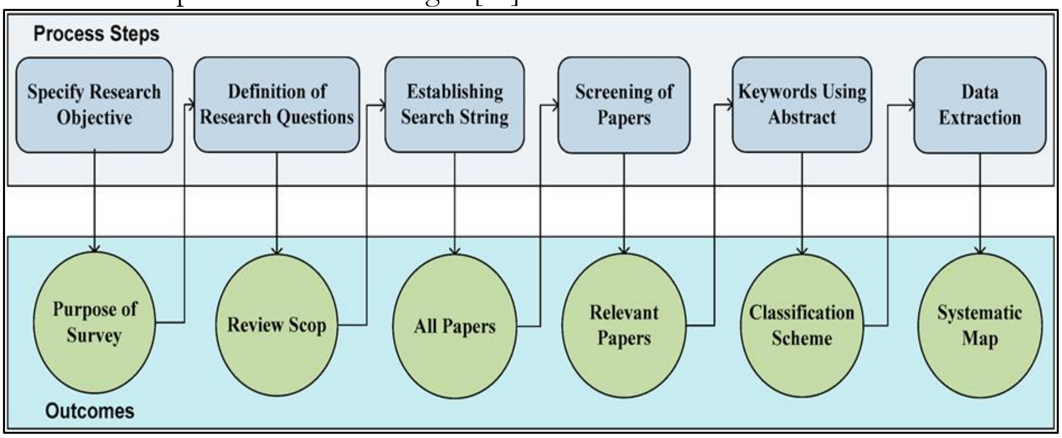

Figure 3. Process steps (Methodology SLR)
Source: https://www.mdpi.com/2079-9292/9/2/319

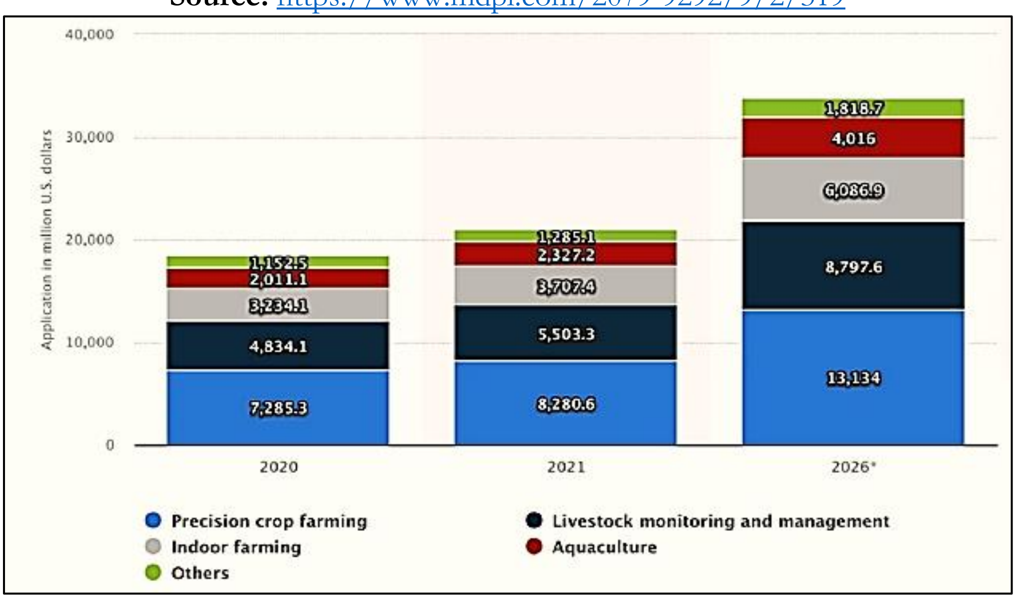

Figure 4. IoT in Agriculture Market 2020-2026
Source: https://appinventiv.com/blog/iot-in-agriculture-industry/

Research Methodology:

The research methodology deployed for this study involved a systematic literature review (SLR). This study aims to investigate and present an overview of agricultural monitoring apps, sensors/devices and connections that are currently based on the IoT. We followed the instructions of a systematic literature review (SLR) study to ensure that the research was impartial concerning the choice of data and representational conclusions.

Methodological/Implementation Detail:

The project implementation method includes the following points.

- The system is designed with two nodes per mesh and each node is made up of sensors that gather data from other sensors. These sensors are then connected to a microcontroller, which transforms the analog data into digital form and sends it to the NODE MCU ESP8266 module, which transmits it to the main controller.
- All sensors and the NODE MCU ESP8266 module are linked via a microcontroller and the NODE MCU ESP8266 transmits the sensor data collection to Thing speak. These sensors gather information based on their areas of expertise.
- The NODE MCU ESP8266 and microcontroller are connected. In this instance, the microcontroller received all sensor data and sent it to the NODE MCU ESP8266, which in turn sent it to the NODE MCU ESP8266.

Hardware/Development Setup:

Physical Earth Condition:

Soil moisture sensors gather information (moisture content) from the ground or field and transmit it to the ATMEGA 328 UNO microcontroller, which digitizes the analog data. The reason behind is that the microcontrollers can read data in digital form since they can readily understand digital form. Additionally, the controller sends all of the data to the NODE MCU ESP8266. After that, the NODE MCU ESP8266 connects to the internet and uses it to send data to the Thing Speak channel.

Measure Amount of Light:

LDR sensors measure the amount of light and send this collected data to micro-controller Arduino UNO (ATMEGA 328) which will convert analog data into digital. This digital data is sent to NODE MCU ESP8266 and then NODE MCU ESP8266 with the help of the internet sends data on the Thing Speak channel (IoT platform).

Detect Gases:

MQ-135 sensor can detect different toxic gases when the sensor detects different gases the sensor sends this collected data to the micro-controller Arduino UNO (ATMEGA 328) which will convert analog data into digital. This digital data is sent to NODE MCU ESP8266 and then NODE MCU ESP8266 with the help of the internet sends data on the Thing speak channel (IoT platform). In this channel, we can easily monitor different variable conditions of different sensors on this channel.

Temperature and Humidity Level:

DHT11 sensor collects Temperature and Humidity levels and then sends them to the controller. Then convert this analog data into digital. Then the controller sends this data to NODE MCU ESP8266 and with the help of the Internet NODE MCU ESP8266 can send data on a channel of Thing Speak.

Hardware Component to be Used:

- Arduino UNO Atmega328
- Water Pump
- Arduino Cable
- NODE MCU ESP8266 Module
- Temperature and Humidity Sensor
- Male and Female Cable
- Soil Moisture Sensor
- Breadboard Power Supply
- LCD
- Buzzer

- I2C Module
- Relay

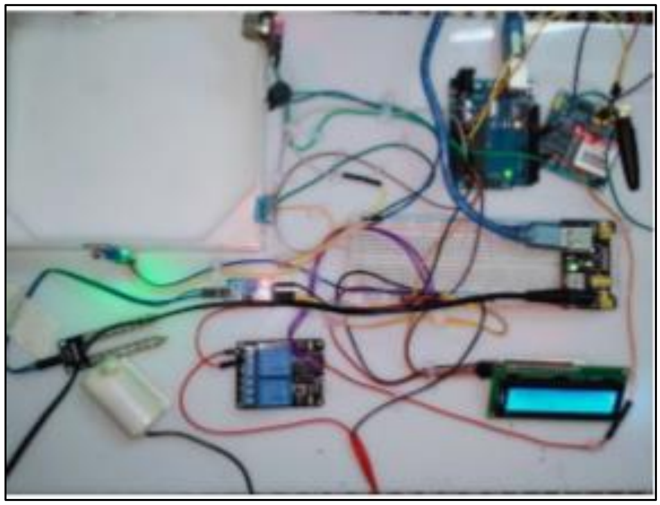

Figure 5. Hardware components

Result and Discussion:

This section contains a thorough explanation of the many IoT agricultural applications, sensors and gadgets. The results of this study have been compiled into a proposed agriculture hierarchy.

System Design and Implementation:

Smart Agriculture Monitoring System incorporates several sensors to help with various agricultural issues. These sensors are utilized based on system requirements and to maximize the capabilities of the sensors for our research objective. Using new trends, smart agriculture shifts agriculture toward new technology to increase agricultural yields. A microcontroller is connected to a variety of sensors, each of which completes a certain task. A soil moisture sensor can be used in smart agriculture to maximize the use of available natural resources and address the problem of water shortage. It employs intelligent soil moisture sensors to determine whether or not the land needs water based on its physical state. Smart Agriculture includes a gas sensor to detect different toxic gases that are dangerous and harmful to crop's health and growth.

IoT Agricultural Hierarchy:

An IoT-based agricultural hierarchy has been designed to summarize the research outcomes as in Figure 5. These include sensors/devices, country policies, communication protocols and IoT agricultural applications; these cover the majority of the findings examined in this research. The various characteristics connected to greenhouse farming, animal husbandry and precision farming are tracked, managed and observed by IoT agriculture apps. Via WSN, sensors and devices sense and track several field variables to generate useful data.

The planned hierarchy consists of four primary tasks which are IoT agricultural applications, sensors/devices, communication methods and national policies. The numerous features connected to greenhouse farming, animal husbandry and precision farming are tracked, monitored and managed by IoT agriculture applications. Applications for agriculture utilizing the IoT and its subdomains. By sensing and tracking numerous field variables via WSN, sensors and devices provide useful data.

IoT Smart Farming Agricultural Framework:

Figure 5 proposes an IoT smart farming agriculture framework with five main components: data gathering, common platform, data processing, data visualization and system administration. The network produced by numerous communications networks converges to form the data acquisition component. Wireless technologies like LoRa, Zigbee, NB-IoT and Bluetooth, or wired technologies like a Controller Area Network (CAN) can be used as the transmission medium. In the meantime, mobile communication technologies are further subdivided into sub-components of a Wide Area Network (WAN). Cellular connectivity comes in four generations; 5G was introduced in 2016 and is expected to revolutionize agriculture monitoring by enabling high-speed data transfer, network control and energy efficiency.

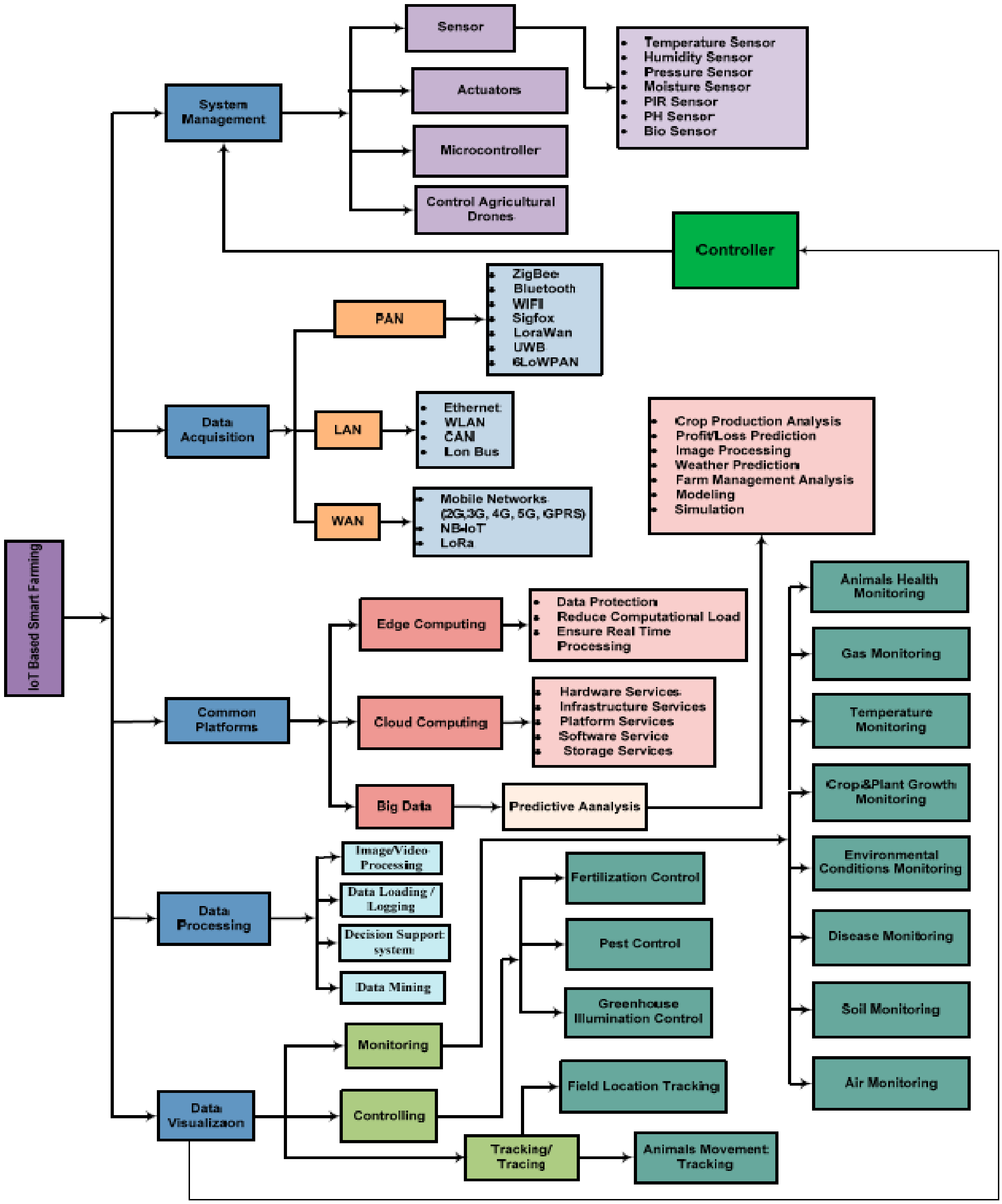

Figure 6. IoT Smart Farming Framework

In addition, the data presentation component gathers agricultural-related data and the collection of data components gives control directives to the system management. Using a variety of models and algorithms, a common platforms component handles statistical analysis, data storage and agricultural data-related decision-making for the agricultural production process. Three categories have been established for the component's subcomponents: edge computing, cloud computing and big data. Big data technologies enable predictive analysis by identifying underlying links between the data, which are discovered through information mining and other methods. Along with performing a broad range of processing operations, including statistical analysis, modeling, simulation, prediction, early warning and image processing, it also offers data support for new processes.

Platform, hardware, software and infrastructure services are all provided by cloud computing for a variety of IoT agricultural applications. The cloud platform, which also reduces storage costs for agricultural organizations, enables farmers to save photos, text, videos and other sorts of agricultural data at a minimal cost. Additionally, relying on raw agricultural data to make informed decisions based on farmers' technical skills presents a significant challenge. On the other hand, agriculture specialists can also offer recommendations and render precise decisions through quantitative analysis. Therefore, the only technology available that provides a clever and safe method of crops the cloud platform's innovative methods help farmers, but there are still some limitations that prevent them from taking advantage of low-power and internet connection technologies. Edge computing, one of the newest kinds of computing, performs calculations at the edge of the network. This technology also reduces computing burden by safeguarding agricultural data and speeding up data transmission.

This is because edge computing operations happen more often than cloud computing. Data processing includes text, image, audio and video processing, among many more processing methods. Certain functionalities may need to be added or removed based on the requirements of the system. Among the components of the IoT agriculture area that are most prominent are data visualization, tracking and controlling. Monitoring of soil, plant and crop growth, illness, ambient factors and animal health are all included in the monitoring function. Pest, fertilizer and greenhouse lighting control are just a few of the agricultural characteristics that are managed by the regulating function. Additionally, the field location and animals are tracked using the tracking/tracing sub-component. The system management component manages and controls the entire process of tracking, monitoring and managing through a controller. The system administration component includes several actuators, sensors, microcontrollers and drone controller kinds. The three categories of sensors/devices that are most commonly used are those that track the health of animals, crops and the environment. These sensors gather data on many agricultural characteristics and embedded electronics evaluate this data to create the appropriate analysis needed for smart farming.

Field Distribution for Each Sensor:

There is separate field distribution for each senor in IoT Channel. Reading value of each sensor represented in graphical form.

Table 1. Field Distribution

Sr. No.	Field No	Sensors
1	Field 1	Soil Moisture
2	Field 2	Temperature
3	Field 4	Humidity
4	Field 5	Air Quality

The Output of Different Sensors is Shown Below in figure 7. These reading shown on Laptop. But these results can Monitor easily these parameters on Cell Phone. All cell phones that support GPRS internet can display these graphical readings on Thing Speak

Issues and Challenges:

The deployment of IoT applications is fraught with numerous problems and difficulties.

Security:

IoT-based agricultural systems have distinct security challenges that must be addressed. Users have numerous challenges as a result of inadequate security, including data loss and other on-field characteristics. Issues with IoT security and privacy have been widely discussed. IoT devices in the agriculture sector are vulnerable to physical interference from things like animal and predator attacks and physical address modifications. Furthermore, it is challenging to develop intricate and advanced algorithms because of the low energy usage and memory limitations.

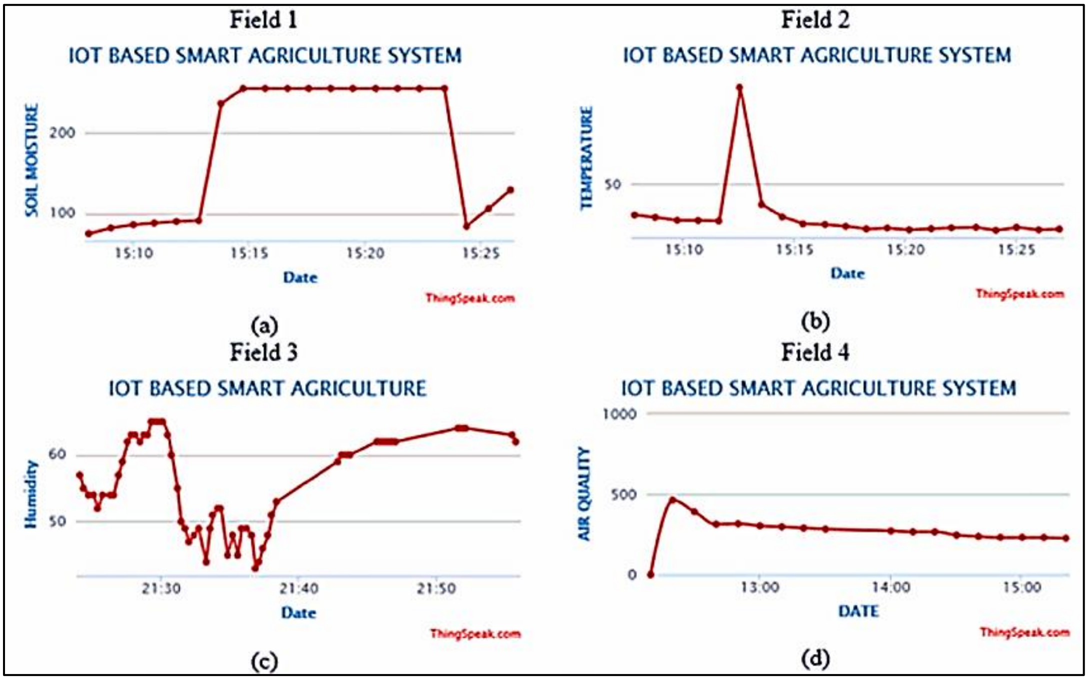

Figure 7. IoT devices applied to various fields.

Cost:

Agricultural IoT deployment brings up several financial issues, such as setup and running costs. The setup costs include hardware for gateways, IoT devices/sensors and base station infrastructure. Operational costs also include recurring membership fees for centralized data collection services, information sharing between services and IoT device administration.

Lack of Knowledge:

For farmers living in rural areas, the biggest obstacle is a lack of technological expertise. Since the majority of farmers are illiterate in developing nations, this issue is widespread. Because it costs a lot to train farmers before building IoT infrastructure, implementing IoT in agriculture is a significant barrier.

Interoperability:

Billions of IoT devices, standards and protocols are needed to guarantee compatibility. Interoperability is impacted by syntactic, organizational, technical and semantic policies. Semantic interoperability is the capacity to handle the interpretation of shared content across individuals. Data formats related to syntactical interoperability include variables separated by commas, electronically transferred data, JavaScript Object Notation (JSON) and flexible Markup Language (XML). The description of the hardware and software components, protocols and infrastructure that enable communication across IoT devices is known as technical interoperability.

To hasten the transition, they also evaluate the necessity of addressing problems including the initial high investment costs, inadequate internet access in many distant regions and concerns about data security. To get past these obstacles, cooperation between the agriculture industry and technology suppliers, as well as government policies and financial incentives, will be crucial.

Conclusions:

The use of the IoT in designing smart farming and agricultural technologies constitutes a dramatic shift currently taking place in the agriculture industry. By utilizing various IoT devices like sensors, drones and even automation systems, modern farmers can acquire actionable information concerning various elements such as soil, weather, crops or animals present on the farm. This also enhances operational decision-making, powering resource allocation efficiency and considerable enhancement in the productivity or productivity. Embracing IoT technologies in agriculture also promotes sustainability because it facilitates efficient use of water, waste reduction, less use of fertilizers as well as pesticides and general reduction of harmful effects caused by production methods. Also, considering the future, greater levels of transparency within the food supply chain are envisaged through the potential use of blockchain technology and improved predictive farming business thanks to AI-based analytics. The IoT has great promise for the agriculture sector where it equips farmers with the necessary facilities to satisfy the increasing global food requirements without compromising the efficiency of operations and the principles of environment-friendly agricultural practices. As IoT technologies continue to evolve, they will play an increasingly vital role in shaping the future of smart farming, benefiting farmers, consumers and the environment alike.

Future Recommendations:

Enhanced IoT-Driven Data Analytics:

Leverage AI and machine learning algorithms for advanced data analytics in IoT devices. By improving the ability to analyze large datasets from IoT sensors (such as crop health, weather and moisture in the soil), farms can make more informed decisions regarding irrigation, fertilization and harvesting.

Blockchain Integration for Traceability and Security:

Integrate blockchain technology with IoT systems to enhance transparency and traceability of agricultural products, from farm to consumer. This ensures food security and builds consumer trust, especially in export markets.

Energy-Efficient IoT Devices:

Develop energy-efficient, solar-powered IoT devices and sensors for use in remote or rural areas. This can significantly reduce operational costs and increase the adoption of smart farming practices in developing regions.

IoT-Driven Smart Irrigation Systems:

Design smart irrigation systems using IoT to optimize water usage, reduce waste and conserve this precious resource. This is particularly important for drought-prone areas.

Integration with Robotics and Automation:

Encourage the development of IoT-driven robotics for tasks such as planting, weeding and harvesting. These autonomous robots could work alongside IoT sensors to provide precision farming solutions.

Environmental Sustainability:

Promote research on how IoT can contribute to more environmentally sustainable farming practices. This includes reducing pesticide and fertilizer use, improving biodiversity and lowering carbon emissions.

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