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A Comprehensive Review on IoT-Based Smart Agriculture Systems

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Abstract: The rapid growth in global population has significantly increased the demand for efficient and sustainable agricultural practices. Traditional farming approaches often suffer from limitations such as inefficient water usage, lack of real-time monitoring, and heavy reliance on manual labor. The Internet of Things (IoT) has emerged as a transformative technology capable of addressing these challenges by enabling smart and automated agricultural systems [1], [2].
This paper presents a comprehensive review of IoT-based smart agriculture systems. It examines various components including sensors, communication technologies, cloud platforms, and smart irrigation mechanisms. The study also evaluates multiple research contributions to highlight improvements in productivity, resource utilization, and decision-making processes. Furthermore, key challenges such as infrastructure cost, network reliability, and system maintenance are discussed. Finally, future research directions involving artificial intelligence, machine learning, and predictive analytics are explored to enhance precision farming.

Keywords: IoT, Smart Agriculture, Precision Farming, Sensor Networks, Smart Irrigation

I. INTRODUCTION

Agriculture is one of the most critical sectors supporting human survival and economic growth. Smart agriculture uses IoT devices for monitoring and automation [2]. However, traditional farming methods are often inefficient due to limited access to real-time data and dependence on manual observation. Farmers frequently face challenges such as unpredictable weather conditions, water scarcity, and soil degradation.
In recent years, technological advancements have introduced new possibilities for improving agricultural practices. Precision farming improves productivity and resource management [4], [10]. IoT enables the interconnection of physical devices and systems, allowing real-time data collection and analysis. This technology supports automation and enhances decision-making processes.
Smart agriculture systems utilize IoT to monitor environmental parameters such as soil moisture, temperature, humidity, and crop health. Wireless sensor networks are widely used in agricultural monitoring systems [5], [6]. These systems help farmers optimize resource usage, reduce costs, and improve productivity.

II. LITERATURE REVIEW

Ayaz et al. discussed IoT-based communication technologies for smart farming [2]. A wide range of studies have been conducted to explore IoT applications in agriculture. These studies focus on improving efficiency, reducing resource wastage, and enabling precision farming.

Garcia et al. proposed smart irrigation techniques using IoT sensors [3]. Many researchers have proposed IoT-based monitoring systems that use wireless sensor networks (WSNs). Wolfert et al. explained the importance of big data in smart farming systems [8]. These systems collect real-time data from agricultural fields and provide valuable insights for decision-making.

Smart irrigation systems are among the most widely implemented IoT applications. These systems automatically regulate water supply based on soil moisture levels, significantly reducing water wastage and improving efficiency.
Communication technologies such as Wi-Fi, ZigBee, LoRa, and NB-IoT play a crucial role in data transmission. Low-power communication technologies are particularly suitable for large agricultural environments.

Khanna and Kaur reviewed precision agriculture applications based on IoT [10]. Cloud computing is commonly used to store and process agricultural data. Farmers can access real-time information through mobile applications, enabling remote monitoring.
Recent research integrates IoT with artificial intelligence, allowing predictive analysis such as crop disease detection and yield forecasting.

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TABLE I
COMPARISON OF EXISTING STUDIES

Study Type	Technology	Advantage	Limitation
IEEE	Smart Irrigation	Water saving	Cost
Springer	IoT + Cloud	Remote monitoring	Network dependency
Elsevier	WSN	Real-time data	Maintenance

III. IoT ARCHITECTURE

IoT-based agriculture systems consist of multiple layers:
The device layer consists of sensors and actuators for collecting field information [2], [4]. The architecture of an IoT-based smart agriculture system is designed to enable efficient data collection, communication, processing, and decision-making. These systems are generally divided into multiple layers, where each layer performs a specific function to ensure smooth operation of agricultural activities. The integration of these layers helps farmers monitor field conditions in real time and automate several farming processes.

A. Device Layer (Sensors and Actuators)

The device layer forms the foundation of the IoT agriculture system. It consists of different types of sensors and actuators installed across agricultural fields. Sensors are responsible for collecting environmental and soil-related data such as soil moisture, temperature, humidity, water level, pH value, and light intensity. These sensors continuously monitor field conditions and generate real-time information.
Actuators perform physical actions based on the data received from sensors. For example, when soil moisture levels fall below a predefined threshold, the actuator can automatically activate a water pump or irrigation system. This automation reduces manual effort and improves farming efficiency.

B. Network Layer (Communication Protocols)

The network layer is responsible for transmitting data collected by sensors to centralized systems such as cloud servers or monitoring applications. Communication technologies including Wi-Fi, ZigBee, LoRa, Bluetooth, and cellular networks are commonly used in smart agriculture systems.
Communication protocols such as Wi-Fi and LoRa support reliable data transmission [1], [14]. The selection of communication protocol depends on factors such as range, power consumption, and data transmission speed. Low-power communication technologies such as LoRa are highly suitable for agricultural environments because they support long-distance communication with minimal energy consumption.
This layer ensures reliable communication between field devices and monitoring platforms, enabling farmers to access information remotely.

C. Cloud Layer (Data Processing and Storage)

The cloud layer is responsible for storing, processing, and analyzing the data collected from agricultural fields. Large volumes of sensor data are transferred to cloud platforms where advanced data analytics techniques are applied to generate meaningful insights.
Cloud computing enables remote monitoring and data analysis in agriculture [7]. Cloud computing enables farmers to access agricultural information from anywhere using internet-connected devices. It also supports historical data storage, allowing comparison of previous and current farming conditions. In some systems, machine learning algorithms are integrated within the cloud layer to predict crop diseases, weather conditions, and irrigation requirements.
The cloud layer plays an important role in improving decision-making and increasing overall agricultural productivity.

D. Application Layer (User Interface)

The application layer acts as the interaction point between the farmer and the IoT system. This layer includes mobile applications, web dashboards, and monitoring software that display real-time agricultural information in a user-friendly format.
Through these applications, farmers can monitor soil conditions, weather data, irrigation status, and crop health remotely. The application layer may also provide notifications and alerts when abnormal conditions are detected, such as low soil moisture or sudden temperature changes.
This layer improves accessibility and enables farmers to make timely decisions for better farm management and resource utilization.

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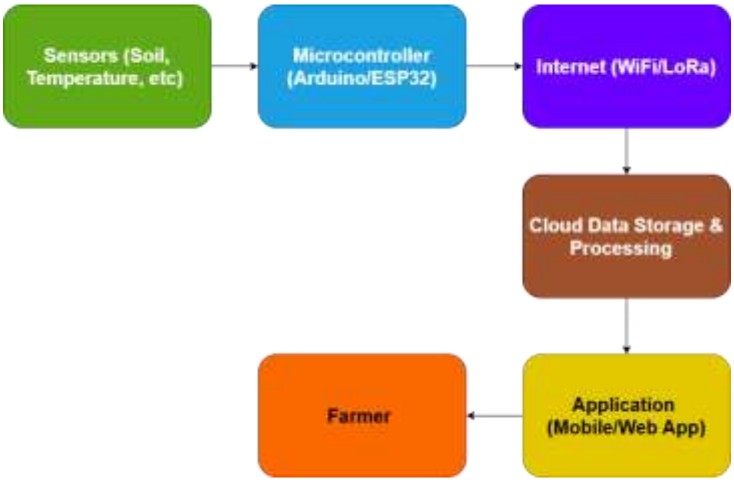

Fig. 1: IoT Architecture in Agriculture

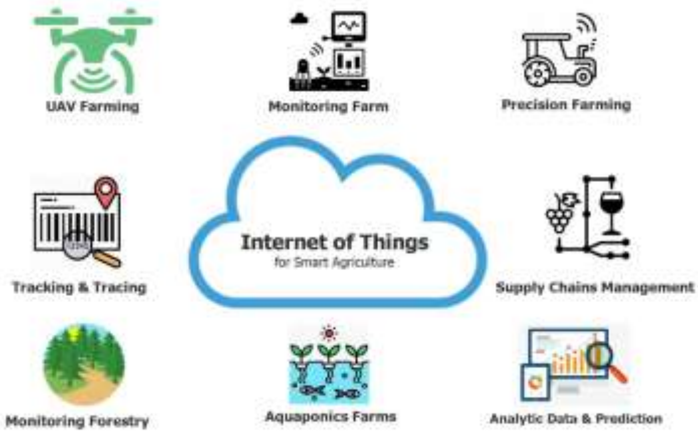

Fig. 2: IoT Applications

IV. APPLICATIONS

The implementation of the Internet of Things (IoT) in agriculture has introduced several innovative applications that improve farming efficiency, reduce resource wastage, and support better decision-making. Smart agriculture systems use connected devices, sensors, and automated technologies to monitor and manage agricultural activities in real time. Some of the major applications of IoT in agriculture are discussed below.

A. Smart Irrigation

Smart irrigation is one of the most important applications of IoT in agriculture. IoT-based irrigation systems help reduce water wastage and improve efficiency [3], [6]. Traditional irrigation methods often result in excessive water consumption due to manual control and lack of monitoring. IoT-based irrigation systems solve this issue by using soil moisture sensors and automated water control mechanisms.

These systems continuously monitor soil conditions and determine the exact amount of water required by crops. When the soil moisture level decreases below a specified value, the system automatically activates the irrigation pump. Once the required moisture level is achieved, the water supply is stopped automatically.

Smart irrigation not only conserves water but also improves crop growth and reduces human effort. Farmers can monitor and control irrigation systems remotely through mobile applications or web platforms.

B. Crop Monitoring

Crop monitoring systems help farmers observe the condition and growth of crops using IoT sensors and smart devices. Crop monitoring systems continuously observe environmental conditions and crop health [5], [10]. Different environmental parameters such as temperature, humidity, soil quality, and light intensity are continuously monitored.

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The collected information enables farmers to identify problems at an early stage, including crop diseases, nutrient deficiencies, or unfavorable environmental conditions. In some advanced systems, cameras and image-processing technologies are also used for detecting plant health issues.
Real-time crop monitoring improves agricultural productivity by helping farmers make timely decisions related to fertilization, irrigation, and pest management.

C. Livestock Monitoring
IoT technology is also widely used in livestock management. Smart monitoring devices such as wearable sensors and GPS trackers are attached to animals to monitor their location, movement, body temperature, and overall health condition. Sensor-based livestock monitoring improves animal safety and health tracking [2]. These systems help farmers identify abnormal animal behavior, illness, or health-related issues at an early stage. Continuous monitoring improves animal safety, reduces losses, and supports efficient livestock management.
In large farms, IoT-based livestock monitoring reduces manual supervision and increases operational efficiency.

D. Weather Monitoring
Weather conditions play a significant role in agricultural productivity. IoT-based weather monitoring systems collect real-time environmental information such as rainfall, temperature, humidity, wind speed, and atmospheric pressure.
Weather monitoring systems provide real-time environmental information for farmers [7], [8]. This information helps farmers plan farming activities more effectively. For example, weather data can assist in determining the best time for irrigation, pesticide application, and harvesting.
Accurate weather monitoring reduces risks caused by sudden climate changes and helps farmers improve crop management strategies.
Overall, IoT applications in agriculture contribute to efficient resource utilization, automation of farming activities, and improved productivity. These technologies are transforming traditional farming methods into modern smart agriculture systems.

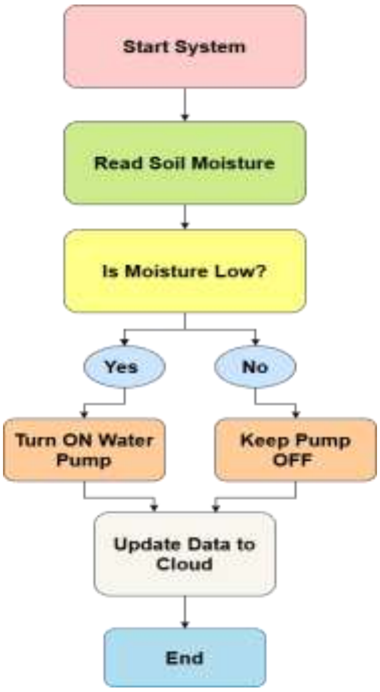

Fig. 3: Smart Irrigation System Flowchart

V. ADVANTAGES

The use of the Internet of Things (IoT) in agriculture has introduced significant improvements in farming practices. Smart agriculture systems help farmers monitor field conditions, automate operations, and manage resources more efficiently. The major advantages of IoT in agriculture are explained below.

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A. Real-Time Monitoring

One of the primary benefits of IoT in agriculture is the ability to monitor agricultural conditions in real time. Sensors installed in the field continuously collect information related to soil moisture, temperature, humidity, water level, and crop condition.

Real-time monitoring improves agricultural productivity and crop quality [2], [4]. The collected data is transmitted to cloud platforms or mobile applications, allowing farmers to observe field conditions from any location. Real-time monitoring helps farmers quickly identify problems such as water shortages, temperature fluctuations, or disease risks before they become severe.

This continuous observation improves farm management and supports timely decision-making.

B. Efficient Water Usage

Water management is a major challenge in modern agriculture. Traditional irrigation methods often waste a large amount of water due to manual operation and lack of accurate monitoring.

IoT systems support efficient water management and automation in farming [3], [10]. IoT-based smart irrigation systems help solve this problem by supplying water only when required. Soil moisture sensors measure the water content present in the soil and automatically control irrigation systems according to crop needs.

This approach reduces unnecessary water consumption and improves irrigation efficiency. Efficient water usage is especially important in regions facing water scarcity and irregular rainfall conditions.

C. Reduced Labour Cost

Traditional farming activities usually require continuous manual supervision and physical labor. Monitoring crops, operating irrigation systems, and checking environmental conditions can consume a significant amount of time and effort.

IoT technology automates many of these tasks through sensors, controllers, and smart devices. Automated irrigation systems, livestock monitoring, and environmental monitoring reduce the need for constant human involvement.

As a result, farmers can manage large agricultural areas more efficiently while reducing labor costs and operational expenses.

D. Increased Productivity

IoT systems contribute to higher agricultural productivity by improving farming accuracy and efficiency. Continuous monitoring enables farmers to maintain suitable environmental conditions for crop growth.

Automated systems ensure that crops receive proper irrigation, temperature control, and nutrient management. Early detection of diseases or unfavorable conditions also prevents crop damage and reduces production losses.

These improvements help farmers achieve better crop quality and higher yields compared to traditional farming methods.

E. Data-Driven Decisions

IoT-based agriculture systems generate a large amount of useful data related to farming operations. This data can be analyzed to identify patterns, predict future conditions, and improve agricultural planning.

Data-driven farming techniques help farmers make accurate decisions [8]. Farmers can use historical and real-time data to make informed decisions regarding irrigation schedules, fertilizer application, pest control, and harvesting time.

Data-driven farming reduces uncertainty and increases the overall effectiveness of agricultural management practices. It also supports the development of precision agriculture techniques for sustainable farming.

Overall, IoT technology provides several advantages that improve efficiency, reduce resource wastage, and support modern agricultural development. These benefits make IoT an important technology for the future of smart farming systems.

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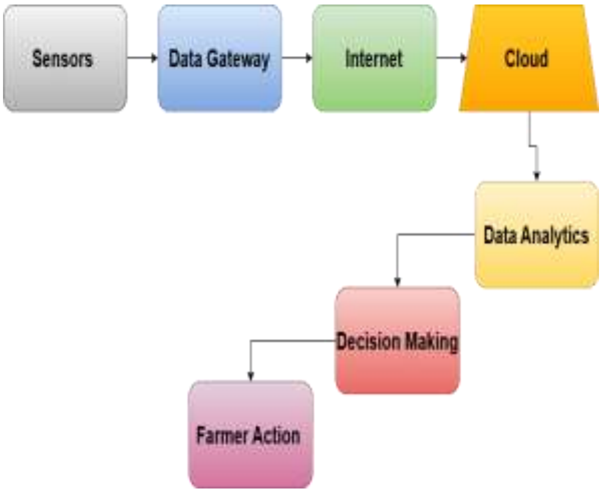

Fig. 4: IoT Data Flow in Agriculture

VI. CHALLENGES

Although the Internet of Things (IoT) provides many benefits in modern agriculture, its implementation also faces several practical and technical challenges. These issues can affect the performance, reliability, and adoption of smart agriculture systems, especially in rural and developing regions. Some of the major challenges are discussed below.

A. High Initial Cost

High implementation cost remains a major limitation in smart agriculture systems [1]. One of the biggest challenges in adopting IoT-based agriculture systems is the high installation and setup cost. Smart farming requires different hardware components such as sensors, controllers, communication devices, cloud platforms, and automated irrigation systems.

The cost of purchasing, installing, and maintaining these technologies can be expensive for small-scale farmers. In addition, advanced systems may require software subscriptions, internet services, and technical support, which further increase overall expenses.

Due to financial limitations, many farmers are unable to adopt smart agriculture technologies on a large scale.

B. Internet Connectivity Issues

Reliable internet connectivity is essential for IoT systems because data collected from sensors must be transmitted to cloud platforms or monitoring applications. However, many agricultural areas are located in remote or rural regions where network coverage is limited or unstable.

Poor internet connectivity affects data transmission in rural areas [7]. Poor internet connectivity can interrupt communication between devices and reduce the effectiveness of real-time monitoring systems. Delayed or lost data transmission may affect automated decision-making processes such as irrigation control and environmental monitoring.

Therefore, lack of proper communication infrastructure remains a major obstacle in implementing IoT systems in agriculture.

C. Sensor Maintenance

Sensors are the core components of IoT-based agriculture systems, but they require regular maintenance to function accurately. Agricultural environments often expose sensors to dust, mud, water, extreme temperatures, and humidity.

These environmental conditions can damage sensors or reduce their accuracy over time. Inaccurate sensor readings may result in incorrect decisions related to irrigation, fertilization, or crop monitoring.

Farmers may also face difficulties in replacing damaged sensors or performing technical maintenance due to lack of technical knowledge and support.

D. Data Security Risks

IoT systems continuously collect and transmit large amounts of agricultural data through internet-connected networks. This creates concerns related to data privacy and cybersecurity.

Security and privacy concerns are important challenges in IoT environments [14]. Unauthorized access, hacking, or malware attacks can compromise sensitive farming information and disrupt system operations. For example, attackers may manipulate irrigation systems or access confidential agricultural data stored on cloud servers.

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To reduce such risks, strong security mechanisms such as encryption, authentication, and secure communication protocols are required. However, implementing advanced security measures can increase system complexity and cost. Overall, despite the advantages of IoT in agriculture, these challenges must be addressed to ensure reliable, secure, and cost-effective smart farming systems. Continuous technological advancements and improved infrastructure are expected to reduce these limitations in the future.

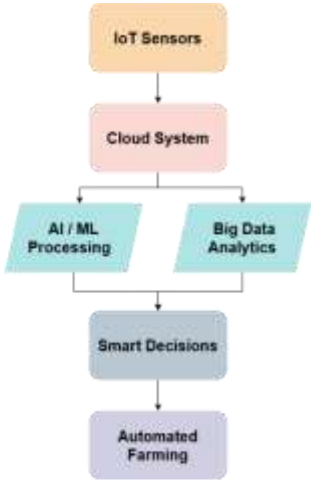

Fig. 5: Future Smart Farming Model

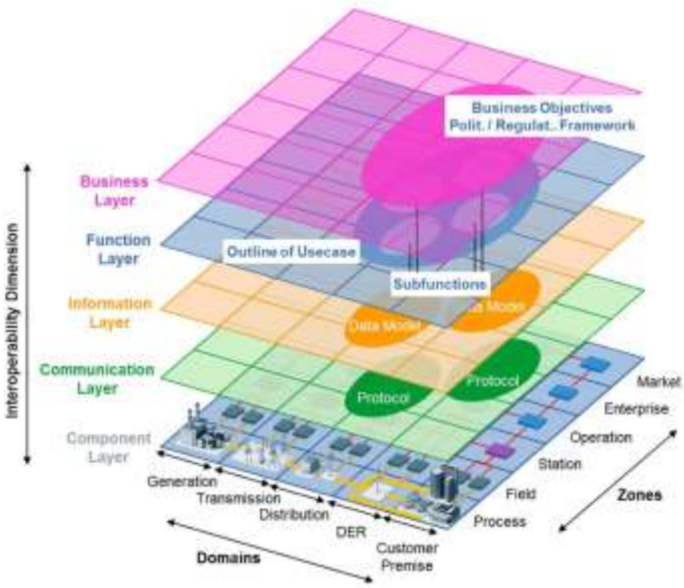

Fig. 6: Dimension, Domains and Zones

VII. FUTURE SCOPE

The future of Internet of Things (IoT) in agriculture is highly promising due to continuous advancements in digital technologies and automation systems. As modern farming increasingly depends on data-driven solutions, IoT is expected to play a major role in improving agricultural productivity, sustainability, and efficiency. Several emerging technologies are likely to enhance the capabilities of smart agriculture systems in the coming years.

A. AI-Based Smart Farming

Artificial intelligence and predictive analytics are expected to improve smart farming systems [15]. Artificial Intelligence (AI) is expected to significantly improve the performance of IoT-based agriculture systems. AI algorithms can analyze large volumes of agricultural data collected from sensors, cameras, and weather monitoring systems.

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By using machine learning techniques, smart farming systems can identify crop diseases, detect nutrient deficiencies, and recommend suitable farming actions automatically. AI can also optimize irrigation schedules, fertilizer usage, and pest management based on environmental conditions.
The integration of AI with IoT will help farmers make faster and more accurate decisions, leading to improved crop quality and higher productivity.

B. Drone Monitoring

Drones are becoming an important technology in modern agriculture because they provide fast and accurate field monitoring. Agricultural drones equipped with cameras and sensors can capture aerial images of crops and farmland.
Drone-based monitoring may enhance crop management and field analysis [10]. These drones help farmers monitor crop health, detect diseases, identify water stress, and observe field conditions over large agricultural areas. Compared to manual inspection, drone monitoring saves time and reduces labor requirements.
In the future, drones may also be used for automatic pesticide spraying, fertilizer distribution, and seed planting, making agricultural operations more efficient and precise.

C. Predictive Analytics

Predictive analytics refers to the use of historical and real-time data to forecast future agricultural conditions and events. IoT systems generate a large amount of valuable farming data that can be analyzed to identify patterns and trends.
Predictive models can help farmers estimate crop yield, predict weather changes, and detect possible disease outbreaks before they occur. This allows farmers to take preventive measures and minimize production losses.
The use of predictive analytics will improve agricultural planning and support more efficient resource management in smart farming systems.

D. Fully Automated Farms

Fully automated farms could reduce human effort and improve efficiency [2], [7]. The development of fully automated farming systems is considered one of the major future goals of smart agriculture. In such systems, most agricultural operations will be performed automatically using IoT devices, robots, AI systems, and automated machinery.
Tasks such as irrigation, crop monitoring, fertilization, harvesting, and livestock management can be controlled with minimal human involvement. Automated systems will improve operational efficiency, reduce labor dependency, and increase farming accuracy.
As technology continues to evolve, fully automated farms may become more practical and affordable for large-scale agricultural production.
Overall, the future scope of IoT in agriculture is extensive and continuously expanding. The combination of IoT with advanced technologies such as artificial intelligence, drones, and predictive analytics is expected to transform traditional farming into a highly intelligent and automated system.

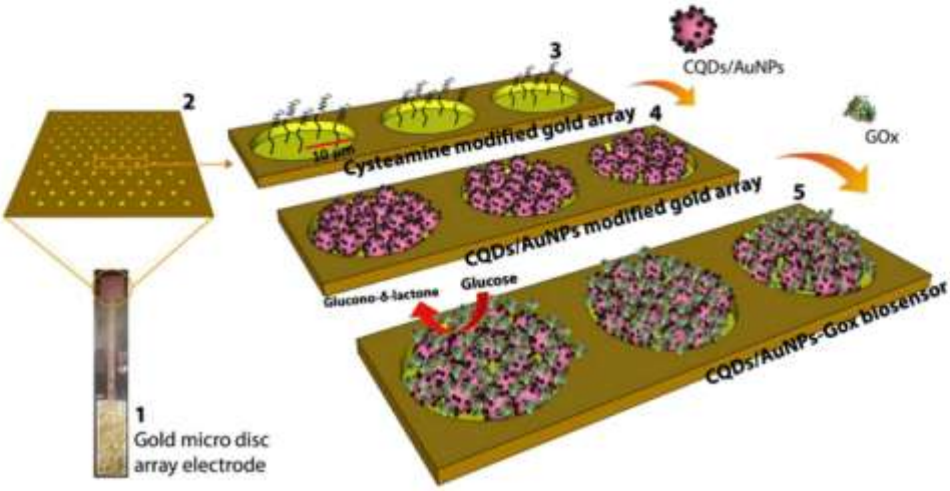

Fig. 7: Monitoring of Crops

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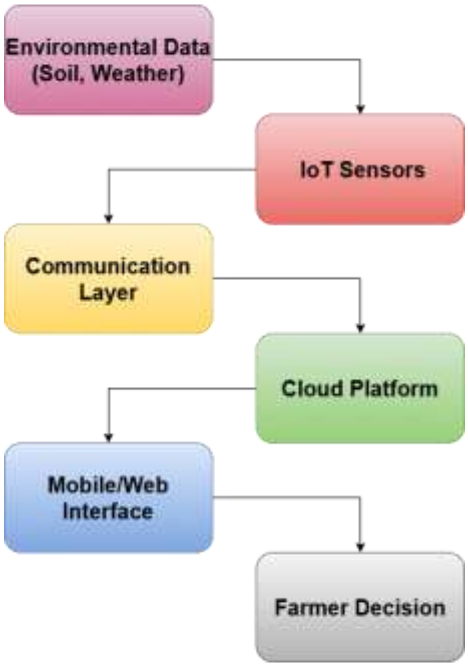

Fig. 8: Overall Smart Agriculture System

VIII. CONCLUSION

IoT-based agriculture systems improve resource management and agricultural productivity [1], [2]. The implementation of the Internet of Things (IoT) in agriculture has introduced a modern approach to improving farming efficiency, productivity, and resource management. IoT-based smart agriculture systems enable continuous monitoring of environmental conditions, automated irrigation, and real-time data collection, allowing farmers to make accurate and timely decisions.

This review paper examined various applications of IoT in agriculture, including smart irrigation, crop monitoring, livestock management, and weather monitoring systems. Future advancements are expected to enhance the adoption of smart farming technologies [15]. The study also discussed the architecture of IoT-based farming systems and highlighted the advantages of automation, efficient water usage, reduced labor requirements, and data-driven agricultural management.

Although IoT offers several benefits, certain challenges such as high implementation cost, internet connectivity limitations, sensor maintenance, and data security concerns still affect large-scale adoption. However, continuous technological advancements and ongoing research are expected to overcome these limitations in the future.

Furthermore, emerging technologies such as artificial intelligence, drone monitoring, predictive analytics, and fully automated farming systems are likely to enhance the capabilities of smart agriculture. These developments will contribute to sustainable farming practices and improved agricultural productivity.

In conclusion, IoT has the potential to transform traditional farming methods into intelligent and efficient smart agriculture systems, supporting the future growth and sustainability of the agricultural sector.

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