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IoT Technology in Smart Agriculture

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Abstract – In recent years, IoT technology has been increasingly used in the agriculture sector, making it smarter with its usage. This study examines the application areas of IoT technology in the agriculture sector, the advantages it provides, and the necessary equipment for these applications. IoT technology provides advantages in improving efficiency, reducing production costs, increasing product quality, ensuring sustainability, and facilitating resource management in the agriculture sector. There are various applications in agriculture, such as smart greenhouse systems, soil moisture and temperature sensors, automation of farming machinery, animal tracking and health monitoring, plant disease and pest monitoring, grain storage monitoring, data analysis, and artificial intelligence. The necessary equipment for IoT applications includes sensors, actuators, wireless networks, data storage and processing devices, cameras and imaging systems, and GPS devices, allowing farmers to collect real-time data on weather conditions, soil moisture levels, plant diseases, and pests in their fields. This study explains the advantages and application areas of IoT technologies in the agriculture sector, demonstrating to researchers and farmers how to use them to increase efficiency and ensure sustainability in the agriculture sector. Additionally, the study identifies the necessary resources for the implementation of these technologies, including the required equipment for IoT applications. Therefore, this study can be beneficial in the decision-making process of researches and industry leaders who follow innovative applications and technologies in the agriculture sector.

Keywords – IoT, Smart Agriculture, Precision Farming, Sensor Networks, Machine Learning.

I. INTRODUCTION

In today's world, the agricultural sector has been rapidly transforming into a more efficient and sustainable industry, thanks to the development of cutting-edge technologies. One of the most significant technologies is the Internet of Things (IoT), which consists of smart devices and sensor networks. The use of these technologies in the agricultural sector is known as smart agriculture, and it has led to the development of numerous innovative applications [1].

Smart agriculture is a newly introduced concept, and most farmers and agricultural experts are still becoming familiar with it. Smart agriculture involves the use of intelligent technologies such as automated machines, sensors, actuators, drones, and security cameras to manage and operate agricultural lands and livestock. The goal is to increase the quality and quantity of agricultural products while considering cost and energy usage [2].

Smart agriculture aims to increase productivity, use resources more efficiently, and optimize agricultural operations through the integration of advanced technologies into the agricultural sector. Therefore, many countries are promoting smart agriculture applications [3]. Smart agriculture aims to increase productivity, use resources more efficiently, and optimize farming operations through the integration of advanced technologies into the agricultural sector. Many countries are encouraging the adoption of smart farming practices. For example, in the United States, the federal government provides financial support for smart agriculture projects and allocates funds for digitization in the agricultural sector. Similarly, the European Union promotes the use of smart

agriculture technologies among member countries under the Common Agricultural Policy. In addition, the Indian government uses smart farming technologies to provide crop insurance to farmers through a program called "Pradhan Mantri Fasal Bima Yojana." Many smart agriculture initiatives are also supported in China, such as the "Zhongguancun Smart Agriculture" program. In Turkey, the Ministry of Agriculture and Forestry provides incentives for farmers to increase their production by using agricultural technologies and software under the "Smart Agriculture" program. These incentives include tax exemptions for smart agriculture devices, support for smart irrigation systems, and training programs.

Smart agriculture, also known as precision farming, utilizes various cutting-edge technologies to increase productivity, optimize resources, and reduce waste in the agricultural sector. Internet of Things (IoT) is one of the most important technologies used in smart agriculture. IoT technology is applied in various areas of agriculture, such as smart irrigation systems, which can save water and provide more accurate water supply to plants. Additionally, data collected by sensors can be used to better control the growth process of crops and determine the optimal harvest time. IoT technology can also be used in agricultural machinery to monitor their maintenance and operational status, which can prevent malfunctions and reduce downtime [4].

The use of IoT technology in smart agriculture provides many advantages such as increasing agricultural productivity, reducing costs, developing environmentally friendly farming practices, and ensuring food safety [5]. As a result, the use of IoT technologies in the agriculture sector is increasing day by day.

Machine learning has gained significant importance in recent years, particularly in the agricultural sector, just like in many other areas. IoT devices used in smart farming applications are employed together with machine learning algorithms to process and analyze the data they collect. The use of these algorithms enables many agricultural processes to become automated and enhances productivity. Additionally, the use of these technologies also contributes to the development of sustainable agricultural practices [6]. Machine learning algorithms analyze environmental conditions and farming practices, suggesting the most suitable solutions. For example, machine learning algorithms can determine the most appropriate crop cultivation methods and irrigation amounts for farmers, resulting in more efficient use of water resources. Moreover, the use of machine learning can increase soil fertility, allowing for production with less fertilizer use. All of these factors demonstrate the importance of using IoT and machine learning technologies in the agricultural sector.

In this study, we have explored the usage and applications of IoT technology in the field of smart agriculture, along with the benefits it provides. This study will serve as a useful resource for researchers and practitioners who are interested in exploring the potential of IoT technologies and machine learning approaches in the agricultural sector in more detail.

II. COMPONENTS FOR IOT APPLICATIONS IN THE SMART AGRICULTURE

In the agricultural sector, IoT applications require various components including hardware such as sensors, data collection devices, communication devices, and storage devices, as well as cloud computing infrastructure, wireless network devices, smart devices, and software [7]. Figure 1 presents an architecture consisting of smart farming components.

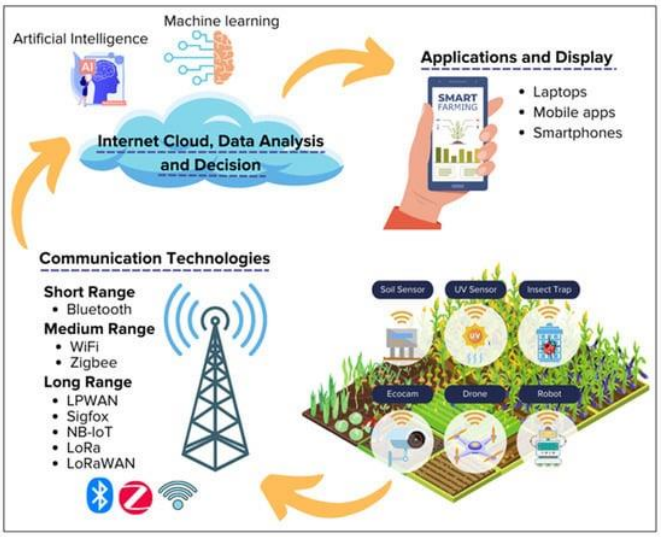

Fig. 1 An example architecture consisting of smart agriculture components [7]

Sensors such as soil moisture and temperature sensors, weather and rainfall sensors, plant growth monitoring sensors, animal behavior tracking sensors, and more can be used in collecting agricultural data. Sensors can be utilized to gather

information about soil moisture and temperature status, weather conditions, plant growth, water levels, animal movements, and many other variables. While data collection devices are used to process and transmit collected data, data communication devices are used to transmit data wirelessly from the sensors. Data storage devices, on the other hand, are used to store and analyze the collected data [8].

Actuators are mechanical or electrical devices used to perform a specific movement in a system. In IoT applications for the agricultural sector, actuators are used to control or perform specific tasks. For example, in irrigation systems, actuators can be used to control water flow. They can also be used in agricultural machinery, such as tractors, where actuators can be used to lift or lower different farming equipment. Actuators can be integrated with IoT systems for more efficient and intelligent operation in agricultural applications [9].

Wireless networks play an important role in IoT applications in the agricultural sector. These networks are used for collecting, processing, and transmitting data from sensors and other IoT devices. Wireless networks can be designed to cover long distances in wide areas such as farms or fields. Technologies such as Wi-Fi, Bluetooth, ZigBee, LoRa, and Sigfox can be used to create these networks. Wi-Fi provides high bandwidth and fast data transfer, but it has limited range. ZigBee is a network designed for low-power consumption and low-cost devices. LoRa and Sigfox are low-power consumption networks designed to cover long distances. Wireless networks help IoT applications in the agricultural sector work efficiently. By enabling communication among agricultural devices, a smart and efficient farming process can be achieved [10].

Data storage and processing devices are commonly used in cloud-based services to store data collected from sensors. The data is then analyzed by cloud-based software and the results are presented to users. Storage devices include hard disk drives, redundant storage devices, network-attached storage devices, and cloud storage services. Data processing devices are used to process and analyze the collected data. These devices are specially designed to provide the high processing power required to analyze large amounts of data. Data processing devices include specialized processors, high-performance computers, and cloud-based computing services. By analyzing the data, these devices can assist farmers in early detection of plant diseases, determining harvest time, and reducing irrigation needs, among other things [11].

Cameras and imaging systems are used in IoT applications in the agriculture sector to provide important information about plant diseases, pests, and plant growth. These devices are used to detect changes in leaf color, plant growth, signs of disease, and the presence of pests. Additionally, camera and imaging systems can also measure pre-harvest predictions, product quantities, and quality. These devices help to make accurate and quick decisions in agricultural activities, and increase efficiency [12].

GPS devices are widely used in IoT applications in the agricultural sector. These devices can be attached to farming machines or animals used in fields and farms. GPS devices help to efficiently work in agricultural lands by marking certain points in the fields. They assist in properly aligning farming machines and timely completion of tasks on the agricultural land. Additionally, GPS devices can also measure data such as soil pH levels, soil moisture, and temperature in agricultural lands. These data can aid in determining which types of crops can be grown in the soil. Overall, GPS devices are essential tools for precision agriculture, enabling farmers to make data-driven decisions and maximize productivity [13].

Cloud computing infrastructure enables agricultural businesses to store and process large amounts of data. Wireless network devices help spread data over a wider area, while smart devices enable agricultural businesses to monitor, analyze, and manage data [14].

Software components are used to analyze collected data and provide information to business owners to make better decisions. These components may include automation software, data analysis software, machine learning algorithms, server software, mobile applications, and web interfaces. Automation software can help with tasks such as scheduling and resource allocation, while data analysis software can help identify trends and patterns in data. Machine learning algorithms can help make predictions and optimize processes. Server software can handle the processing and storage of data, while mobile applications and web interfaces can provide easy access to data and tools for analysis. Together, these software components

can help businesses in the agricultural sector make more informed decisions and improve efficiency [15].

III. Advantages of IoT technologies in the agricultural sector

IoT technologies provide numerous advantages in the agricultural sector. Firstly, these technologies make farming activities more efficient and effective, allowing agricultural producers to increase their productivity and obtain more products using fewer resources. Moreover, IoT technologies enable agricultural businesses to manage their operations more intelligently and make better decisions by accurately analyzing data. Additionally, IoT technologies allow agricultural businesses to use natural resources more sustainably. By using these technologies, natural resources such as water, soil, and energy can be used more efficiently, reducing their consumption and enabling agriculture businesses to operate in a more eco-friendly and sustainable manner. IoT technologies also contribute to improving the quality of agricultural production. Producers can increase the quality and safety of their products, providing consumers with healthier and safer food products. In conclusion, IoT technologies provide many benefits in the agricultural sector, improving productivity, enabling sustainable use of natural resources, and improving product quality. IoT can be used in various areas of agriculture, such as soil management, crop growth, water management, product tracking, and supply chain management. The use of IoT technology in the agricultural sector offers many advantages, including:

- **Increase efficiency:** By monitoring plant growth, soil moisture, weather conditions, and other factors, IoT sensors provide farmers with a more efficient production management. IoT applications are an important tool to increase efficiency in the agricultural sector. In agriculture, IoT sensors and devices can measure soil moisture, temperature, humidity, plant growth rate, and many other parameters. This data allows farmers to make more accurate decisions, enabling them to use resources more efficiently. For example, measuring soil moisture can optimize water usage and lead to water savings. Additionally, sensors can help prevent unnecessary expenses and enable more efficient resource usage by controlling factors such as fertilizer and water amounts [16].
- **Reducing Production Costs:** The IoT technology automates farmers' production processes, reducing labor costs. Additionally, data analysis helps farmers to use their resources more efficiently. The use of IoT technology in the agriculture sector can help reduce production costs. The technology can increase efficiency and reduce labor costs. For instance, by using automatic irrigation systems, the timing and quantity of irrigation can be adjusted more accurately, helping to conserve water resources and reduce irrigation costs. Additionally, by using IoT sensors to measure factors such as soil moisture, temperature, and other factors, fertilizer and other input costs can be better managed, helping to reduce production costs and increase profits [17].
- **Improving product quality:** IoT sensors provide detailed information about plant growth and health, helping farmers improve the quality of their products. In addition, early detection of diseases or pests enables farmers to solve problems that require intervention more quickly. IoT offers many opportunities to improve product quality in the agricultural sector. For example, sensors can be used to monitor plant growth, optimize irrigation and fertilization systems, and help farmers select the right time to harvest and the right products to harvest. Additionally, thanks to IoT technology, it is possible to monitor temperature, humidity, and other factors during storage and transportation of products. This helps to preserve product quality and prevent product loss. Furthermore, IoT allows for faster detection and resolution of production errors. This improves product quality and enables farmers to provide better products to satisfy their customers [16].
- **Easily managing resources:** IoT technology facilitates the management of agricultural resources, helping farmers optimize their use of water and fertilizer. This results in more efficient use of natural resources. Devices such as soil moisture sensors and weather sensors track soil and weather conditions, optimizing resource usage in irrigation and fertilization

processes with timely application. Additionally, IoT devices assist in monitoring machinery and other resources used in the production process, thereby increasing efficiency. This enables the sustainable management of agricultural resources [18].

- **Assists in the control of diseases and pests:** IoT offers various methods for controlling plant diseases and pests. For instance, smart sensors help with the early detection of plant diseases and pests, allowing for prompt identification and necessary measures to be taken. Additionally, IoT enables the collection of data related to the spread and control of plant diseases. This data can be used to understand the causes and effects of plant diseases and to develop new solutions for prevention. For example, drones equipped with sensors and artificial intelligence technologies can be used in an agricultural operation to reduce damage caused by plant diseases. Drones can monitor the spread of plant diseases and determine the boundaries of damage caused by them. As a result, damage caused by diseases can be minimized and plant productivity can be increased [15].
- **Enables sustainable production:** Through the use of IoT technology, farmers can make production more sustainable by using natural resources more efficiently, promoting environmentally friendly agricultural practices. The use of this technology facilitates the transition to a sustainable agricultural production model. By ensuring the efficient use of resources, it increases farmers' productivity while also conserving natural resources. For example, IoT sensors measure soil moisture, temperature, and other parameters, allowing farmers to apply irrigation and fertilization more accurately. This prevents unnecessary watering and fertilization, promoting the efficient use of water and other resources. Additionally, IoT technology enables the early diagnosis of plant diseases and pests, allowing farmers to combat them naturally without the need for chemical interventions. This contributes to the conservation of natural resources and increases the sustainability of production [19].

IV. IoT Applications In Agriculture

Smart agriculture applications are becoming increasingly popular, and there are many different examples available. These applications are designed to help manage soil, water, plants, and animals efficiently. IoT solutions make smart farming applications more efficient, sustainable, and profitable. Soil moisture and temperature sensors, agricultural machinery automation, animal tracking and health, plant disease and pest monitoring, grain storage monitoring, smart greenhouse, and data analysis and artificial intelligence applications are examples of IoT technologies used in smart farming applications, which are detailed in this section.

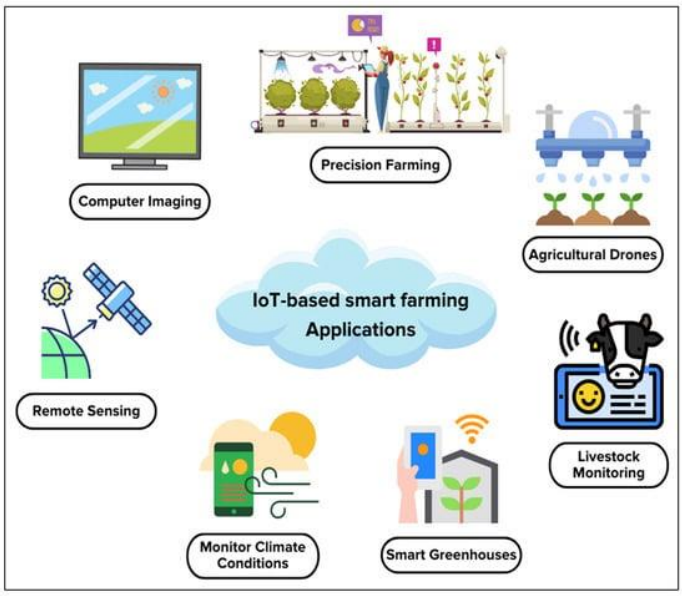

Fig. 2 Examples of IoT applications in smart agriculture [7]

A. *Soil Moisture and Temperature Sensors*

Soil moisture and temperature sensors provide data to optimize plant growth by measuring the moisture and temperature levels in the soil. These sensors are an important component of smart agriculture applications. Soil moisture sensors are used to measure the moisture content of the soil to control water consumption and optimize plant growth. Soil temperature sensors, on the other hand, measure changes in soil temperature and help determine whether the soil temperature is ideal for plant growth. When used in conjunction with IoT technology, the data obtained from these sensors can be processed through cloud-based analysis to provide recommendations to farmers for optimizing plant growth [16].

B. *Agricultural Machinery Automation*

IoT technology can automate and optimize agricultural machinery such as tractors, harvesters, and irrigation systems. Agriculture machinery automation is an IoT application used to reduce the labor force in the agricultural sector and increase productivity. These applications enable farmers to automate their work and reduce the need for continuous physical presence in the field. Agriculture machinery automation helps to control and manage the movements of agricultural machinery using sensors, actuators, and other IoT devices. This enables agricultural machinery to work more efficiently, complete agricultural operations faster, and reduce errors. Furthermore, agriculture machinery automation allows farmers to perform their work at a lower cost, thereby contributing to increased agricultural production [20].

C. *Tracking and Health Monitoring of Livestock*

Livestock tracking and health monitoring can be achieved using various sensors to track their location, monitor their activities, measure their health status, and control other factors. This application of IoT technology has a significant impact on the agricultural sector. Its use plays an important role in tracking, controlling, and monitoring the health of livestock. In particular, smart tags used for tracking cattle allow data to be collected on their location, movements, milk yields, and health status. This data can be tracked by farmers and veterinarians to ensure that the animals grow healthily and produce more milk. Additionally, IoT technology allows the monitoring of livestock body temperatures through the use of body temperature sensors, which track temperature changes and enable early detection of diseases. Furthermore, heating and cooling systems in farms can also be automated using IoT technology to increase animal comfort. All of these applications ensure that livestock grow healthily while saving farmers time and costs [21].

D. *Monitoring Plant Diseases and Pests*

Plant diseases and pests can be monitored using sensors and cameras. This involves collecting data by monitoring the development of plants to detect diseases and pests and taking measures against them. Plant diseases and pests are a significant problem in the agriculture sector. The impacts of these problems can lead to high amounts of crop loss and, therefore, financial losses. Therefore, monitoring plant diseases and pests is one of the most crucial components of smart agriculture technologies. IoT technology provides farmers with vital information on plant health by using sensors and imaging systems to identify plant diseases and pests. This enables farmers to take timely action to protect their crops. Additionally, monitoring plant diseases and pests can contribute to more sustainable agricultural practices by reducing the use of chemical pesticides [22].

E. *Grain Storage Monitoring*

Temperature and humidity sensors in grain storage areas can help monitor storage conditions to preserve the quality of the product. Grain storage monitoring is an IoT application that enables grain producers to monitor their harvested grains during the storage process. This application uses sensors that continuously measure the moisture, temperature, carbon dioxide, and oxygen levels of the grain during storage. This allows for the early detection and prevention of spoilage, mold, moisture, and temperature issues that may arise during storage. This application provides agricultural producers with better control over the grain storage process and improves the quality of their products [23].

F. *Smart Greenhouse*

Smart greenhouses use IoT technology to provide optimized environmental conditions for plant cultivation. This technology continuously monitors and controls various parameters such as temperature, humidity, light, and carbon dioxide levels in the greenhouse environment through sensors, and automatically adjusts them to optimize plant growth. Smart greenhouse technology increases product efficiency by optimizing environmental conditions for plant cultivation, while reducing energy consumption and preserving natural resources. It also provides early warning systems for plant diseases and pests, improving productivity and product quality. Smart greenhouse technology enables continuous production of many plant species year-round, resulting in higher product yields than traditional farming methods.

Additionally, monitoring the greenhouse environment through sensors provides real-time data to producers, helping them make more efficient and profitable production decisions [24].

G. *Data Analysis and Artificial Intelligence Applications*

The use of IoT in agriculture is an important tool for increasing agricultural productivity and creating a more sustainable agricultural structure. However, processing and analyzing the data collected by IoT is also of great importance. At this point, data analysis and artificial intelligence applications can be utilized to enable more effective use of agricultural data. Data analysis is the process of organizing and making sense of the data collected by IoT sensors. This data can encompass many factors, such as plant growth, soil fertility, climate change, and water management. Through data analysis, agricultural experts can make informed decisions and make improvements in agricultural processes. Artificial intelligence can help with faster and more accurate processing of agricultural data. AI algorithms can analyze agricultural data and generate predictions and forecasts. This allows agricultural experts to perform processes such as early detection of diseases more quickly and effectively. Additionally, AI algorithms can help automate agricultural processes. Therefore, data analysis and artificial intelligence applications are important tools that help the more effective use of IoT technologies in the agriculture sector [25].

V. CONCLUSION

The agriculture sector is an increasingly important industry that needs to become more sustainable. Therefore, the use of innovative technologies such as IoT in the agriculture sector can contribute to both increasing productivity and creating a more sustainable agriculture structure by using natural resources more efficiently.

IoT technology can be used in many areas of the agriculture sector. Smart greenhouses can provide optimized environmental conditions for crop cultivation, which can increase crop productivity while reducing energy consumption. The use of IoT sensors in farming equipment can make agriculture processes more efficient. Additionally, IoT technology can be used in processes such as transportation and storage of agricultural products.

However, the use of IoT technology is not limited to collecting and analyzing data. Data analysis and artificial intelligence applications are important tools that can help utilize agricultural data more effectively. Through data analysis, agricultural experts can make informed decisions and improve agricultural processes by making data meaningful. Artificial intelligence algorithms can help process agricultural data faster and more accurately.

In conclusion, the use of IoT technology and related technologies can increase productivity, help use natural resources more efficiently, and contribute to creating a more sustainable agriculture structure. The use of these technologies presents an important opportunity to overcome the challenges faced by the agriculture sector.

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