**Implementation of IoT and Sensors in Agriculture: A Step Towards Smart Farming**

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**Abstract**

The projected global population growth is expected to result in a substantial rise in the demand for food over the next decade. Agriculture's existing technological capabilities are insufficient to fulfill the world's expanding need for food production. The use of resources, such as land, water, pesticides and fertilizers, is inefficient in conventional agricultural practices. With the introduction of technology, the topics of resource efficiency and productivity growth have drawn a lot of interest in the agricultural sector. The integration of Information and Communication Technologies (ICT) is the focal point of the emerging field of smart farming. The incorporation of advanced technologies, such as the Internet of Things (IoT) and cloud computing, is predicted to drive advancements and streamline the custom of robotics and Artificial Intelligence (AI) within the agriculture industry. The introduction of these novel approaches is generating apprehension among established agricultural methods, while simultaneously awarding a series of challenges. This chapter explores the methodologies and apparatus employed in the deployment of wireless sensors in the context of IoT in agriculture. Additionally, it addresses the potential challenges that arise when merging technology with conventional agricultural methods. The utilization of IoT technology within the agriculture industry has emerged as a prospective approach to mitigate the detrimental effects of climate change and water scarcity.

**Keywords:** Agriculture sustainability; AI; IoT; Precision farming; GPS; Wireless sensors

**1.1 Introduction**

The application of agricultural methods and practices has played a important role in the progress of human civilization. Agriculture plays a vital role in both sustaining human development and offering individual’s possibilities for livelihood and work. In the Indian context, it is observed that approximately 58% of the populations depend on agriculture as their primary means of sustenance. This demonstrates that agriculture also holds significant significance in the economic development of any nation. The consumption of food is an essential requirement for human survival and the world population has experienced significant growth throughout history. It is expected that by the time 2050, around 70% of the worldwide population would be residing in urban regions, as the total global population is estimated to reach 10 billion (**Dautov *et al*., 2018**). In order to accommodate the expanding population, there is a need to increase food production by 70%. The conventional practise of agriculture is characterized by a limited integration of technology, which stands in contrast to the increasingly prevalent utilization of technological advancements in the business sector. This integration aims to facilitate the introduction and integration of digital connectivity among farmers. Technological advancements have played a crucial role in enhancing conventional farming practices. Therefore, it is imperative to enhance the efficiency and calibre of agricultural yields, while simultaneously mitigating the expenses associated with production. One emerging technology that warrants attention is the Internet of Things (IoT). IoT refers to a conceptual framework wherein several objects or entities are interconnected over the internet to collaboratively execute a designated function through intercommunication. The utilization of IoT technology in the agricultural sector is sometimes noted to as smart farming or smart agriculture (**Elijah *et al.*, 2018**). Smart farming has emerged as a prominent approach for enhancing agricultural productivity, quality and quantity while minimizing costs and damages. It has the potential to facilitate the efficient utilization of resources, thereby earning the designation of "sustainable farming”. The proliferation of IoT devices can be attributed to the global expansion of interconnected systems and organizations.

**1.2 Benefits of IoT in agriculture**

The implementation of IoT technology in comparison to conventional farming practices. The subsequent section enumerates the benefits and advantages associated with smart farming based on the IoT. By implementing meticulous surveillance of soil conditions, agricultural operations and environmental factors, it is possible to maximize the utilization of sources such as water, fertilizers, pesticides and other inputs. Moreover, the utilization of intelligence techniques like as neural networks and deep learning can facilitate the optimal utilization of these resources. By effectively employing available resources, it is possible to decrease the manufacturing costs. The implementation of the IoT enables efficient monitoring of agricultural areas. This measure has the potential to aid in the prevention of interruptions by wild animals within the field (**Ahmed *et al*., 2018**). This practise aids in the mitigation of crop damage. By effectively monitoring the field characteristics, it is possible to enhance the production of the field, hence leading to higher profitability for farmers. The need of IoT technology in the agricultural sector proves to be advantageous for the promotion of sustainable farming methods and assumes a significant role in safeguarding the environment.

**1.3 Technologies used in smart farming**

Some popularly employed techniques in smart farming are discussed under the following heads:

**1.3.1 Global Positioning System (GPS**)

GPS is a position, navigation and timing-based satellite which provide exact and live information to the users. GPS effectively and precisely captures data pertaining to leeway, longitude and elevation. GPS satellites emit signals that promotes GPS receivers to calculate their real-time location and maintain a continuous position while in motion. The provision of precise information of location presents farmers with the potential to ascertain the specific coordinates of field data, encompassing occurrences of pests, soil composition, weed presence and other impairments. The system enables the identification of different field locations, followed by the application of appropriate inputs (such as seed, fertilizer, herbicide, pesticide and water) to specific fields (**Roopaei *et al.,* 2017**).

**1.3.2 Sensor technologies**

Sensor technologies encompass a diverse range of methodologies and apparatuses employed for the purpose of detecting and quantifying physical or chemical attributes within the surrounding environment. Various technologies, including as photoelectricity, electromagnetism, conduction and ultrasonography, are utilized to estimation of soil texture and structure, nutrient levels, flora, moisture, vapour, air, temperature and other relevant data. Remote sensing data possesses the capacity to differentiate between several categories of crops, categorize pests and weeds, detect regions of strain in soil and plant conditions and monitor drought conditions. The vigor of plants is influenced by a multitude of elements, including but not limited to soil moistness, nutrient availability, light exposure humidity, precipitation levels and leaf coloration. The plants are subject to monitoring through the maintenance of optimal temperature and light intensity, as well as the implementation of water and energy conservation measures via micro-irrigation (**Wang *et al.,* 2020**). Various sensors are employed for the purpose of detecting multiple factors. When the sensor detects a deviation beyond a predetermined threshold, it executes the necessary operations until the parameter reverts back to its optimal state. Prominent properties of sensors that render them suited for agricultural applications encompass consistency, recall capacity, movability, resilience, exposure and computational efficiency. Wireless sensors that are presently accessible play a crucial function in the acquisition of data pertaining to agricultural conditions and the provision of additional pertinent information. The aforementioned sensors are autonomous in nature and possess the capability to be included into sophisticated agricultural equipment and heavy machinery, depending on specific requirements of the application (**Ramachandran *et al.,* 2022**).

**1.3.3 Variable Rate Technology (VRT)**

VRT and grid soil sampling are two methodologies commonly employed in agricultural research and practice. VRT describes the use of technology to apply inputs, such insecticides or fertilizers, at varied rates according to the demands of different sections of a field. The objective of this strategy is to maximize the allocation of resources and improve crop yield through the utilization of VRT in agricultural practices. These technologies are employed to predict and adjust the application rate of inputs. This task is achieved by employing a pre-existing map generated from Geographic Information Systems (GIS) in order to compute the suitable quantities and positions for input placement, guaranteeing utmost accuracy and timing. Grid soil sampling is a systematic approach to collecting soil samples from a pre-established grid pattern, with the aim of generating a comprehensive map that accurately reflects different soil properties. The maps indicated above serve as the foundational structure for VRT and are afterwards utilized as input for a variable-rate applicator (**Chamara *et al.,* 2022**). The computer and GPS receive play a crucial role in monitoring and controlling the adjustments made to the quantity of fertilizer product during distribution, considering many map elements. The utilization of emerging technologies, such as VRT, along with its corresponding practices, such as grid soil sampling, has promise for improving soil fertility management and facilitating the assessment of nutrient and yield spatial distribution. Grid sampling is a method that entails the acquisition of samples from certain sections that have been broken into smaller units, known as cells, by overlaying grid lines onto the field. Merged samples are employed in order to effectively represent a broader geographical area by strategically picking smaller sub-regions that coincide with the intersections of grid lines. The spatial representation of values received from soil tests by grid sampling is achieved by employing interpolation techniques. These techniques estimate values at areas where testing was not conducted, using the data collected from sampled sites (**Singh *et al.,* 2022**). The necessity to strengthen nutrient management practices arises from the field-specific variability of phosphorus and potassium, which requires the implementation of customized fertilization procedures. The process entails the implementation of standardized applications of fertilizers and manure with the aim of promoting precision agriculture.

**1.3.4 Geographic Information System (GIS)**

A computerized instrument employed for the acquisition, retention, examination and visualization of geographical information. GIS consists of a collection of computer hardware and software elements planned to support the organization, storage, retrieval, analysis and visualization of spatial and attribute data related to maps, features and geographic information. These systems are employed for the purpose of conducting statistical analysis and implementing spatial techniques. The GIS database provides extensive data on several facets of agricultural fields, encompassing soil classifications, nutrient concentrations, topographic features, irrigation technique. Moreover, it enables the examination of the interconnectedness among many elements that impact the growth of crops within designated agricultural regions. In addition to its primary functions of data storage and display, GIS are utilized in the evaluation of current and alternative management strategies through the integration and manipulation of many data layers, facilitating informed decision-making processes. The topic of interest is cropping management, which refers to the practises and techniques employed in the cultivation and maintenance of crops (**Zamora-Izquierdo *et al*., 2019**).

**1.3.5 Crop management**

Satellite imagery offers valuable insights into the diverse soil conditions and crop performances influenced by the topographical characteristics within agricultural fields. Hence, farmers possess the capability to closely monitor the many production elements, namely seeds, fertilizers and pesticides, which play a crucial role in enhancing crop output and overall efficiency. Satellite photos supplied real-time information, notably in the red and near-infrared combinations known as vegetation indices, which are used to monitor the amount of green plants. The Normalized Difference Vegetation Index (NDVI) is widely recognized as a prominent indicator for evaluating vegetation health and crop output. This is primarily attributed to its strong correlation with the Leaf Area Index (LAI) and photosynthetic activity of green vegetation. The methods employed for crop monitoring rely on the analysis of indicators produced from remote sensing data, which involves comparing the current state of crops to that of previous or typical growing seasons (**Paul *et al*., 2022**).

**1.3.6 Soil and crop sensors**

It is a crucial component of precision agriculture as it offers valuable data on soil qualities, productiveness and aquatic status. Therefore, novel devices have been developed including desirable characteristics that distinguish them from existing sensor technologies. These devices offer valuable insights that may be leveraged to enhance crop development conditions, combat both biotic and abiotic challenges and ultimately augment crop harvests. Soil Organic Matter (SOM), Nitrogen (N), Phosphorous (P) and Potassium (K) are widely recognized as crucial elements for optimal crop productivity (**Abbasi *et al*., 2022**). The sensors that rely on Near Infra-Red (NIR) reflectance are capable of quantifying the spatial distribution of nitrogen content in both the surface and subsurface layers of soil. The prediction of soil organic matter (SOM) is achieved by evaluating the spectral reflectance of soil in both the Infra-Red (IR) and visible wavelength areas, with a focus on identifying the best wavelengths. The levels of nitrogen and phosphorus in the soil are estimated by the utilization of NIR spectrophotometry methodology. The soil's apparent Electrical Conductivity sensors gather continuous data on the surface of the field due to the sensitivity of EC to variations in soil texture and soil salinity. Soil insects and pests can be detected by the utilization of several sensing technologies, including optoelectronic, acoustic, impedance sensors and nano structured biosensors (**Lavanya *et al*., 2020**).

**1.3.7 Evaluation of rate controllers**

Rate controllers are specifically engineered to regulate the rate at which inputs are delivered. This is achieved by continuously observing the velocity of vehicles across the area and adjusting the flow rate of material in real-time to match the desired rate. Rate controllers are frequently employed as independent systems.

**1.4 Application of precision irrigation techniques**

In recent times, advancements in irrigation systems have brought forth the introduction of irrigation machines that focus on motion control, GPS-based controllers, sensor technologies and wireless communication. These technologies are utilized to monitor soil and climatic conditions, as well as assess irrigation parameters such as flow and pressure. The ultimate goal of these developments is to achieve improved water utilization efficiency for crops. These technologies demonstrate considerable promise; yet, additional advancements are necessary prior to their eventual commercialization.

**1.4.1 Sensors**

The yield monitor is a comprehensive system composed of many sensors and components, such as a data storage device, a computer and a user interface. These elements work together to manage the integration and interaction parts of the system. The sensor continuously assesses the yield by quantifying the force exerted by the mass or volume of grain flow. The mass flow sensor operates on the basis of utilising microwave energy beams for transmission and afterwards detecting the energy reflected upon impact. Yield monitors utilize GPS receivers to generate yield map by utilizing location-specific yield data (**Gagliardi *et al.,* 2021**). These monitors are often installed on harvesters and are connected to a mobile application that displays real-time harvest data. Additionally, the data collected by the yield monitor is automatically sent to a web-based platform. The application possesses the capability to produce and distribute yield maps of superior quality to agronomists, while farmers have the ability to export additional data pertaining to farm management for the purpose of study. In the context of horticulture crops, the accurate assessment of both the amount and quality of produce is crucial. Fruit growth is widely recognized as a significant criterion during the progression of the crop. The utilization of colour photographs serves the purpose of monitoring fruit conditions in order to estimate the maturation of the fruit, make informed decisions regarding the optimal time for harvesting and effectively target the appropriate market segment (**Pathmudi *et al*., 2023**).

**1.4.2 Satellite images**

Satellite imagery presents itself as a viable method for the contemporaneous assessment of crop productivity across extensive regions. To illustrate, the use of Sentinel-1A satellite photos has been instrumental in the mapping of rice production and crop strength in Myanmar. The agricultural yield assessment scheme was developed by integrating software and hardware components. Crop yield estimation is accomplished by means of a mobile application that utilizes a Bluetooth jumction android application and a yield estimator software programme. This estimation process involves the utilization of mathematical calculations within the mobile application. The utilization of satellite-derived spectral signatures for agricultural yield projections demonstrates a comparable level of reliability to that of real yield measurements (**Raj *et al*., 2021**).

**1.5 Applications of IoT in agriculture**

IoT has been widely utilized in several agricultural domains. The application of IoT in the agricultural part can be categorized into six basic categories. The subsequent section gives a concise overview of the aforementioned six categories defined in **Figure 1.**

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**Figure 1 Application of IoT in agriculture sector**

**1.5.1 Irrigation management system**

The irrigation management system is a technological solution designed to optimize the allocation and utilization of water resources in agricultural settings. The sustainable utilization of resources is a significant contemporary challenge. Water plays a main role in the cultivation of crops within the agricultural sector. The ongoing development of an IoT enabled smart irrigation system seeks to optimize the efficiency and efficacy of irrigation management. These technologies enable the optimizing of water consumption in agricultural fields. The main focus of smart irrigation systems centers around the domains of real time monitoring, control and weather forecasting prediction.

**1.5.2 Pest and disease control**

The subject of discourse is the administration and alleviation of pests and diseases in diverse settings. The prudent utilization of insecticides and fertilizers plays a important role in augmenting the overall quality and yield of agricultural crops. Furthermore, they play a role in decreasing agricultural costs. To achieve this goal, it is important to engage in ongoing surveillance of the crops and detection of illnesses, which presents a formidable challenge within the framework of conventional agricultural methods. IoT possesses the capacity to present a feasible resolution for tackling this matter. According to **Tzounis *et al.,* (2017**), by implementing a robust system for monitoring data processing and associated activities, it becomes feasible to consistently evaluate the health status of a plant and, when deemed appropriate, take well-informed measures to minimize or pre-empt the occurrence of diseases.

**1.5.3 Animal movement monitoring**

Several academic research’s has indicated that the movement patterns of the animals in these fields cause continuous deterioration of the agricultural environment. To address this problem, a commonly employed strategy entails the deployment of puppets in agricultural environments to mimic human presence in the fields. Nevertheless, it is important to acknowledge that this specific methodology does not offer a certain assurance of attaining the intended results. The application of IoT technology for aim of intelligent monitoring has the potential to provide an efficient resolution to tackle this problem. The implementation of IoT technology facilitates the surveillance and control of animal locomotion within a specified area (**Paraforos *et al*., 2019**).

**1.5.4 Water quality monitoring**

Monitoring of water quality is an essential component of both environmental management and the preservation of public health. The process entails the methodical gathering and examination of water samples in order to evaluate the physical, chemical and biological attributes. The possible impact of water quality on crop health and output is an additional topic that warrants attention. The quality of water is influenced by a range of characteristics, such as temperature, pH, conductivity and quantities of dissolved oxygen. The emergence of an IoT-based system for the monitoring of water quality is being considered as a potential solution to tackle this problem. According to **Gao *et al*., (2019),** these devices have the capacity to remotely monitor and control the physical and chemical characteristics of water, if necessary.

**1.5.5 Greenhouse condition monitoring**

The monitoring of greenhouse conditions encompasses various parameters, including temperature, humidity, pH levels and other related variables, which collectively impact the overall health and growth of crops, in addition to water and pest management. The adverse effects of greenhouse gases on climatic conditions have a direct impact on the agricultural productivity and overall well-being of crops. Therefore, it is crucial to ensure a consistent monitoring of greenhouse gases.

**1.6 Precision farming using Unmanned Aerial Vehicles (UAVs)**

In the present era, there is a growing trend of incorporating unmanned aerial vehicles (UAVs) and drones into agricultural practises. UAVs and drones possess the capacity to enhance precision farming methodologies, hence bolstering crop output. UAVs and drones provide significant support in the domain of advanced weather monitoring, field analysis, real-time data interpretation and associated applications (**Pramanik *et al*., 2022**).

**1.6.1 Site-Specific Nutrient Management (SSNM)**

Site-Specific Nutrient Management is a strategic methodology that seeks to maximize the utilization of nutrients within agricultural systems by tailoring its application to the unique requirements and circumstances of each site. Fertilizer is a chemical compound that can be classified as either natural or synthetic and its primary function is to provide necessary nutrients for plant growth and soil fertility maintenance. The insufficiency of nutrients and the overuse of fertilizers have detrimental effects on soil quality, plant wellbeing and the surrounding ecosystem. The practice of site-specific soil nutrient fertilization in the context of smart agriculture involves accurately determining the optimal amount of nutrients needed for a specific location. This approach aims to minimize the unfavorable impacts associated with excessive fertilizer application on both the soil and the surrounding environment. The measurements of soil nutrients at specific sites are subject to various factors, including soil types, crop types, yield objectives, exchange capacity, utilization efficiency, fertilizer type and meteorological conditions. The fertilization technique based on the IoT is used to predict the spatial patterns of nutrient distribution (**Jayaraman *et al*., 2016**). The Normalized Difference Vegetation Index (NDVI) was derived using satellite imagery in order to assess many aspects of crop health and vitality, including nutrient status, vegetation vigour, plant density and soil nutrient levels. Emerging technologies like GPS, geo mapping, VRT and autonomous vehicles play a important role in facilitating IoT-enabled smart fertilization (**Yalew *et al*., 2016**).

**1.7 Role of IoT in advanced farming practices**

The implementation of novel techniques utilizing sensor and IoT technologies has demonstrated enhanced crop output compared to traditional agricultural practices. The utilization of advanced sensor-based technologies within regulated conditions significantly contributes to the improvement of both the quantity and quality of agricultural produce.

**1.7.1 Greenhouse farming and protected cultivation**

The practice of cultivating plants within a regulated environment experienced a surge in popularity throughout the 19th Century, establishing itself as one of the earliest forms of intelligent agriculture. The aforementioned practices saw a heightened rate of acceleration throughout the 20th Century, particularly in nations that encountered adverse meteorological circumstances. Cultivating crops in controlled indoor environments mitigates the impact of external environmental factors. Consequently, the cultivation of crops that were formerly limited to specific environmental conditions has been expanded to encompass any time and location through the utilization of devices and communication instrument. The efficacy of production in a regulated environment is contingent upon several elements, including the design and composition of shed structures for mitigating wind impacts, the implementation of aeration systems, the precision of monitoring metrics and the utilization of a decision support system, among others. One of the primary difficulties encountered in greenhouse operations pertains to the accurate monitoring of environmental factors (**Dholu *et al*., 2018**). Consequently, several measurement points are necessary to anticipate and regulate the diverse parameters essential for controlling and maintaining the local climate. IoT-enabled greenhouse, sensors are employed to quantitatively assess and oversee the inside characteristics, including humidity, temperature, light intensity and atmospheric pressure. The implementation of smart greenhouse technology has facilitated the automation of agricultural tasks, eliminating the need for manual inspection. Additionally, it serves as a protective barrier against various environmental hazards such as hailstorms, winds, ultraviolet radiation, as well as insect and pest infestations, safeguarding the cultivated plants (**Ashifuddin Mondal *et al*., 2018**).

**1.7.2 Hydroponics**

It is a specialised field within the broader domain of hydro-culture, which involves the cultivation of plants without the use of traditional soil, with the aim of enhancing the advantages of greenhouse farming. Hydroponic irrigation systems provide the controlled delivery of dissolved nutrients to crop roots using a water-based solution, ensuring a well-balanced application rate. Currently, the existing systems and sensors have the capability to detect a diverse array of factors and conduct data analysis at pre-established intervals. Accurate measurement and conscientious monitoring of nutrient composition in a solution are useful for optimal plant growth and the fulfillment of its nutritional requirements. The wireless-sensor-based prototype has successfully provided a real-time solution for soilless agriculture by monitoring the concentration of various nutrients and water levels (**Araby *et al*., 2019**). The integration of an automated smart hydroponics system with IoT encompasses three primary components: input data, cloud server and output data.

**1.7.3 Vertical Farming (VF)**

It is an agricultural approach that aims to address the detrimental effects of industrial-based farming practices on soil quality, which is depleted at a rate that exceeds natural regeneration. The significant pace of erosion and the utilization of freshwater resources for agricultural purposes have resulted in a decline in the availability of cultivable land and an increasing strain on existing water reservoirs. VF presents a promising prospect for maintaining plants within a meticulously regulated environment, resulting in notable reductions in resource utilization while simultaneously enhancing yield at diverse intervals. Furthermore, the land area required for cultivation is contingent upon the number of stacks employed. VF has been found to be more efficient in terms of achieving higher crop yields and lowering water usage when compared to conventional farming methods (**Goap *et al.,* 2018**).

**1.8 Barriers to implementing smart farming technologies**

The process of technology adoption is influenced by various elements that exhibit a certain degree of variety. The integration of technology into agricultural systems has resulted in enhanced precision, improved productivity and alleviated temporal constraints. While the implementation of smart farming techniques has been shown to enhance agricultural output, it is important to acknowledge that some challenges persist in the adoption of these technologies (**Nawandar *et al*., 2019**). The use of devices and technologies necessitates a substantial financial investment, hence posing affordability challenges for farmers as they explore options beyond traditional methods. Some of the challenges faced in implementing smart farming technology are stated below:

**1.8.1 Insufficient financial resources**

In the event that farmers have lower financial resources than the projected crop yields due to unforeseen circumstances such as drought, flood, pests and diseases. The provision of enough loans by financial supporters could alleviate the financial burden.

**1.8.2 Lack of technical knowledge**

The educational attainment of farmers is a significant obstacle in the successful adoption and implementation of technologies inside emerging nations. The requisite knowledge comprises both educational and technical proficiencies necessary for effectively managing the tools. The acquisition of higher levels of education enhances farmers' cognitive abilities to effectively analyze information and subsequently utilize smart farming technologies, hence enabling their integration of computer systems into agricultural practices.

**1.8.3 Insufficient integration of systems**

The advancement of smart agricultural technology necessitates additional development in the integration of production, property management and decision-making tools, as it pertains to the integration across systems. Efforts to bridge the divide between agriculture and information science disciplines are crucial for effective communication between academics and transdisciplinary groups. The creation of an information system has placed a greater emphasis on enhancing user effectiveness. The foundation for enhanced decision-making relies on the prompt accessibility of high-quality data; therefore, it is imperative to integrate data in order to develop information and knowledge.

**1.8.4 Poor internet connection**

The implementation of smart agricultural practices requires a continuous and instantaneous connection to the internet in order to facilitate the utilization of relevant information. Furthermore, the effective functioning of several operational control systems, encompassing fertilizers, pesticides and seed volume, need a reliable and robust internet connection to yield desirable results. In light of the proliferation of mobile phones, rural producers have been afforded the opportunity to avail themselves of mobile internet services. Nevertheless, it is important to note that the quality of signal and input speed in these areas remains constrained.

**1.9 Conclusion**

There is a pressing need for the development of more intelligent and effective approaches to crop production in order to tackle the challenges posed by the diminishing availability of arable land and the escalating global food requirements resulting from population growth. It is imperative for individuals to possess a comprehensive understanding of food security within the context of sustainable agriculture. The proliferation of novel technology aimed at enhancing agricultural productivity and fostering the acceptance of farming as a viable occupation among enterprising youth. This chapter highlights the significance of various technologies employed in agriculture, with a particular focus on the IoT, in enhancing the intelligence and efficiency of farming practises to meet future demands. Scholars and engineers are guided by the recognition of the existing issues encountered by the sector as well as the potential chances that lie ahead. Therefore, it is crucial to recognize the significance of each parcel of agricultural land in improving crop yield through the implementation of sustainable IoT sensors and communication technology.

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