**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. The current technical capabilities of agriculture are not enough to meet the growing global need for food production. In conventional agriculture, resources including land, water, fertilizers, and pesticides are used inefficiently. With the introduction of technology, the topics of resource efficiency and productivity growth have drawn a lot of interest in the agricultural sector. In the emerging area of smart farming, information and communication technologies (ICT) integration is the central theme. Advanced technologies like cloud computing and the Internet of Things (IoT) are expected to revolutionize and simplify robotics and artificial intelligence (AI) practices in the agricultural sector. The introduction of these novel approaches is generating apprehension among established agricultural methods, while simultaneously awarding a series of challenges. In the context of the Internet of Things in agriculture, this chapter examines the techniques and equipment used in the deployment of wireless sensors. Additionally, it addresses the potential challenges that arise when merging technology with conventional agricultural methods. One potential strategy to lessen the negative consequences of climate change and water shortages is the application of IoT technology in the agriculture sector.

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

**1.1 Introduction**

The development of agricultural techniques and procedures has been crucial to the advancement of human civilization. Agriculture is essential to maintaining human growth as well as providing opportunities for employment and subsistence for individuals. It is noted that in the Indian setting, 58% of the population works mostly on agriculture for their support. 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. By the year 2050, around 70% of the world's population is predicted to live in cities, with an estimated 10 billion people on earth (**Dautov *et al*., 2018**). Around 70% increase in food production is required to meet the demands of the growing population. 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 most effective use of these resources may be facilitated by the application of intelligence techniques like deep learning and neural networks. 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 for Internet of Things (IoT) technology in agriculture is beneficial for promoting sustainable farming practices and plays a major role in protecting 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 carry out signals that encourage GPS receivers to track their exact location in real time and hold that position while moving. 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. Numerous methods are used to estimate soil texture and structure, nutrient levels, flora, moisture, vapour, air, temperature, and other relevant information. These technologies include photoelectricity, electromagnetism, conduction, and ultrasonography. Data from remote sensing has the ability to differentiate between various crop types, identify weeds and pests, identify areas of stress in plant and soil conditions, and track 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**). Considering into thought several map components, the computer and GPS receiver are essential for tracking and managing the modifications made to the amount of fertilizer product during distribution. 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. Real-time data was provided via satellite images, particularly in the red and near-infrared ranges known as vegetation indices, which track the quantity of greenery. The Normalized Difference Vegetation Index (NDVI) is widely recognized as a prominent indicator for evaluating vegetation health and crop output. Its significant association with the Leaf Area Index (LAI) and photosynthetic activity of green plants is mainly responsible for this. 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 tools provide informative information that may be used to improve agricultural growth conditions, address biotic and abiotic obstacles, and eventually increase crop yields. For maximum crop yield, nitrogen (N), phosphorus (P), potassium (K), and soil organic matter (SOM) are universally acknowledged as essential components (**Abbasi *et al*., 2022**). The Near Infra-Red (NIR) reflectance-based sensors can measure the nitrogen content's spatial distribution in the soil's surface and subsurface layers. 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. As EC is sensitive to changes in both soil texture and soil salinity, sensors measuring the apparent electrical conductivity of the soil continuously collect data on the field's surface. 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**

The purpose of rate controllers is to control the rate at which inputs are supplied. This is accomplished by tracking the movement of cars around the region and modifying the material flow rate in real-time to meet the intended pace. Rate controllers are often used as stand-alone units.

**1.4 Application of precision irrigation techniques**

The development of irrigation machines that prioritize motion control, GPS-based controllers, sensor technologies, and wireless communication is a result of recent improvements in irrigation systems. These technologies are used to measure irrigation parameters including flow and pressure, as well as to monitor soil and meteorological conditions. 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 multi-sensory, multi-component system that includes a computer, a user interface, and a data storage device. 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 works by transmitting energy using microwave beams and then measuring the energy reflected upon hit. Yield monitors use location-specific yield data and GPS receivers to create yield maps (**Gagliardi *et al.,* 2021**). These monitors are often installed on harvesters and are connected to a mobile application that displays real-time harvest data. Furthermore, a web-based application receives the yield monitor's collected data automatically. 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 generally acknowledged as an important factor in the crop's development. 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. A smartphone application that combines an Android application for Bluetooth pairing with an estimating software package is used to estimate crop yields. 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 extensively applied in several kinds of agricultural fields. 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. In the agricultural industry, water is essential to the growth of crops. 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. Enhancing the overall quality and production of agricultural crops is largely dependent on the careful application of fertilizers and pesticides. 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**

Water quality monitoring is a crucial part of environmental management and public health maintenance. The procedure comprises collecting and analyzing water samples in a scientific manner to assess their physical, chemical, and biological characteristics. We also need to pay attention to the potential effects of water quality on crop health and yield. The quality of water is influenced by a range of characteristics, such as temperature, pH, conductivity and quantities of dissolved oxygen. One possible way to address this issue is the development of an Internet of Things (IoT) system for water quality monitoring. These gadgets can, as needed, remotely monitor and regulate the chemical and physical properties of water (**Gao *et al.*, 2019**).

**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. Numerous factors, such as soil types, crop kinds, production targets, exchange capacity, usage efficiency, fertilizer type, and climatic circumstances, affect the measurements of soil nutrients at particular sites. The fertilization technique based on the IoT is used to predict the spatial patterns of nutrient distribution (**Jayaraman *et al*., 2016**). Using satellite data, the Normalized Difference Vegetation Index (NDVI) was developed to evaluate a variety of crop health and vitality factors, such as nutrient status, vegetation energy, 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 design and construction of shed structures to reduce wind effects, the use of aeration systems, the accuracy of metrics monitored, and the application of decision support systems are some of the factors that determine how effective production is in a regulated setting. One of the primary difficulties encountered in greenhouse operations pertains to the accurate monitoring of environmental factors (**Dholu *et al*., 2018**). As a result, several monitoring sites are required to predict and control the various factors that are crucial for regulating and preserving the local climate. Sensors are used in an Internet of Things (IoT) greenhouse to monitor and measure its internal parameters, including as temperature, humidity, light intensity, and air 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 subfield of hydro-culture, a larger discipline that focuses on growing plants without using conventional soil in order to maximize the benefits 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. As of right now, the sensors and technologies in place are able to identify a wide range of variables and perform data analysis on a predetermined schedule. For a plant to develop as best it can and meet its nutritional needs, precise measurement and diligent monitoring of the nutrients in a solution are helpful. By tracking the concentration of different nutrients and water levels, the wireless-sensor-based prototype has effectively offered a real-time solution for soilless agriculture (**Araby *et al*., 2019**). Three main elements are involved in the IoT integration of an automated smart hydroponics system: input data, cloud server, and output data.

**1.7.3 Vertical Farming (VF)**

It's an agricultural strategy aimed at addressing the damaging impacts of modern farming methods on soil quality, which is decreasing more than it can be replaced naturally. 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. It is essential to recognize that certain challenges still exist in the adoption of these technologies, even if it has been demonstrated that the use of smart farming techniques increases agricultural productivity (**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**

The challenges faced by a decreasing amount of cultivated land and the increasing global food demand due to population expansion mean that it is imperative that more smart and efficient agricultural production techniques be developed. It is essential that people have an extensive understanding of food security in relation to 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. In order to fulfill future demands, this chapter highlights the importance of various technologies used in agriculture, with an emphasis on the Internet of Things, in order to improve the intelligence and efficiency of farming practices. The awareness of the challenges the industry is currently facing and the opportunities that might arise in the future serves as a guide for academics and engineers. 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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