Leveraging Internet of Things (IoT) for Sustainable Agriculture: A Comprehensive Review and Future Perspectives

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Abstract: The agricultural sector is undergoing a revolutionary upheaval with the advent of the Internet of Things (IoT), which presents new opportunities to enhance efficiency, sustainability, and productivity. Information and communication technology is enabling smart farming, which is revolutionizing conventional agricultural methods. Modern technology, Internet of Things (IoT), clubbed with cloud computing, produces a confluence that propels growth and introduces robotics and artificial intelligence to agriculture. Still, there are drawbacks to these revolutionary departures. This study offers a thorough analysis of IoT applications in agriculture as they stand today, emphasizing their profound influence on numerous facets of crop production, livestock management, and general farm operations. The report also discusses problems, possible fixes, and future possibilities for this rapidly evolving field's application and research.

Keywords: Agriculture, Precision Farming, Internet of Things Livestock Management, Smart Farming, IoT Challenges, Future Perspectives.

1 Introduction

The resilience and sustainability of food grains produced in an environmentally responsible manner are measured by sustainable agriculture. Encouragement of agricultural methods and techniques that support the sustainability of farmers and resources is made possible by sustainable agriculture. In addition to being economically viable, it guarantees a natural and healthy environment, preserves soil quality, lessens soil degradation, conserves water, and increases land biodiversity [1]. Reducing greenhouse gas emissions, stopping the loss of biodiversity, and protecting natural resources are all made possible by sustainable agriculture. Increasing farming productivity while pro-

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tecting the environment and meeting the requirements of future generations are the aims of sustainable agriculture. Crop rotation, controlling crop nutrient shortages, controlling pests and diseases, water collecting, recycling, are the foundations of smart farming which in turn create a safe environment.

In addition to being harmed by pesticides and fertilizers, decaying dead plants, waste emissions, and other factors, living things rely on biodiversity. A better home for living things is necessary since greenhouse gas emissions affect people, animals, plants, and the environment. India's main industry is agriculture, with an 18% GDP contribution and 57% of the population residing in rural areas [2].

According to the 2018 Economic Survey, in 2050, the percentage of workers in agriculture will make up just 25.7% of the workforce overall. A growing number of rural families are losing their next generation of farmers as a result of issues like rising cultivation costs, low yield per person, inadequate soil management, and migration to higher-paying or non-farming jobs. With the world about to experience a digital revolution, now is the perfect moment to introduce and facilitate digital communication with farmers through the use of wireless technology to connect the agricultural landform.

Furthermore, the supply of arable land is continuously under strain due to the fragmentation of current farmed land caused by fiscal and political factors as well as the rate of urbanization. The overall amount of agricultural area utilized to produce food has decreased recently. A field's unique characteristics also include its type of soil, irrigation pattern, availability of nutrients, and insect resistance, all of which are quantified and evaluated independently for a certain crop. Two strategies to maximize agricultural productivity in the same region are crop rotation and annual crops; both need temporal and geographic adjustments [3].

Most of the time, a single crop will have different features from one another, or the same crop may be planted throughout the farm, necessitating site-specific analysis to produce the highest yields. To solve these different problems and produce more on less land, new technology-based methods are required. Throughout the crop's life, producers engage in normal agricultural tasks that need frequent field visits to gain a better understanding of the crop's conditions. Farmers can monitor on-going field operations from a precise field view provided by today's sensor and communication technology without physically being there [4].

2 Smart Agriculture

The use of contemporary technology in farming includes, but not limited to, cloud computing, artificial intelligence, big data analysis, internet of things, and remote sensing. Agricultural activities have been substantially increased by the implementation of new technologies, primarily through the creation of low-cost sensor and network platforms. By using less energy and water and limiting adverse effects on the environment, these initiatives seek to maximize industrial efficiency.

Extrapolative overviews of current agricultural conditions are made possible by big data in smart farming, which empowers farmers to take wise decisions. To assist in making the best decisions, real-time programming is created using artificial intelligence and integrated with Internet of Things devices. Smart farming enables us to remotely monitor plants and promotes precision agriculture through the use of advanced, sophisticated technologies. Technology's transformation of manual agricultural methods into automated machinery leads to a modernization in agriculture. Farming operations were altered by modern agricultural technology, and the Internet of Things has revolutionized traditional farming processes [5].

Smart farming is a modern technical strategy that optimizes farm work force necessities and boosts output quantity and quality. It makes application of ICT (information and communication technologies). To determine the demands of farmers and choose appropriate solutions for their issues, The IOT, Sensors, drones, GPS, actuators, precision equipment, robotics, and data handling are examples of contemporary ICT technologies in use. These developments boost crop productivity and decision-making timeliness and accuracy. To boost agricultural productivity, a number of poor nations and international organizations have suggested smart farming technologies.

The Most Recent technology applied to Smart Farming is GPS which accurately records elevation, and coordinates. The Global Positioning System's satellites emit signals that allow GPS receivers to provide continuous positions even while they are in motion and to determine their current location in real time. Thanks to the precise location data, farmers may locate specific field data [6].

Remote sensing data can be used to measure drought, identify different crop kinds. Temperature, humidity, soil pattern monitoring, airflow sensor, location, CO_2, pressure, light, and moisture sensors are commonly used with sensing technologies. Computational efficiency, portability, durability, memory, coverage, and reliability are the features of sensors. For information collecting and crop condition monitoring, the wireless sensors that are presently available on the bazaar are indispensable. These sensors are stand-alone varieties that, depending on the needs of the application, can be integrated with heavy machinery and sophisticated agricultural instruments.

Soil is collected from a methodical grid to create a map for each characteristic, which is known as grid soil sampling. These maps are imported into a variable-rate application and serve as the foundation for Variable rate technology (VRT). The computer and navigation system direct and regulate adjustments to the fertilizer product distribution quantity or amount based on information from the map. In addition to improving soil fertility management, variable rate technology and related methods (grid soil sample) can be used to map out the regional distribution of yields and nutrients. To generate maps and examine features and geography for numerical and three-dimensional methodologies, the Geographic Information System (GIS) consists of hardware and software that makes data storage, compilation, retrieval, characteristics study, and location data easier. In addition to storing and presenting data, the GIS is used to evaluate management strategies, both current and alternative, by combining and modifying data layers to aid in decision-making [7].

Data on soil changes and crop performance impacted by field topography can be obtained from satellite imagery. At the regional level, the information is provided almost instantly thanks to the satellite pictures' temporal revisit frequency and spatial coverage. The normalized difference vegetation index (NDVI) is used gauge to assess agricultural productivity and vegetation health due to its significant correlation with the leaf area index (LAI) and photosynthesis of vegetation. The interpretation of indications obtained from remote sensing by contrasting the current crop state with that of prior or typical seasons is the basis of crop monitoring techniques. In some cases, crop production can be estimated ahead of harvest time thanks to the correlation between biomass and vegetation indices.

A crucial element of precision agriculture is sensor technology, which provides information on soil properties, water condition, and fertility. As a result, new sensors have been created that differ from those that are currently on the market and are based on desirable properties. Plant wearables and soil sensors monitor temperature, pH, moisture content, and contaminants, among other physical and chemical signals in the soil, in real time. Their data helps farmers overcome biotic and abiotic obstacles, enhance crop development conditions, and increase yields [8].

The elements nitrogen (N), potassium (K), phosphorus (P), and soil organic matter (SOMs) are the most vital for crop output.SOM is determined based on ideal wavelengths by measuring the reflectance characteristics of the soil in the visible and infrared wavelength ranges. NIR spectrophotometry technology is used to forecast the amount of phosphorus and nitrogen in the soil. Since soil apparent electrical conductivity (ECa) is sensitive to variations in salinity and texture, data is continuously gathered on the field surface by the soil ECa sensors. Nanostructured biosensors, acoustic, optoelectronic, and impedance sensors are used to detect soil insects and pests. The list of sensors and their applications were given in the following table1.

TABLE 1. SENSORS AND APPLICATIONS.

S. No	Sensors	Applications
1	Acoustic sensors	Fruit harvesting, seed variety classification, pest monitoring, and pest detection.
2	Airflow sensors	Measuring the structure, moisture content, and air permeability of soil in a mobile or stationary manner.
3	Eddy covariance-based sensors	Measuring the flow of gases such as methane, CO2, and water vapor. monitoring the trace gas fluxes and surface atmosphere in different agricultural environments.
4	Electrochemical sensors	To evaluate the pH and nutrient content of soil.
5	Electromagnetic sensors	Logging soil's organic matter, electrical conductivity, residual nitrates, and electromagnetic reactions.
6	Sensors based on field programmable gate arrays (FAAA)	Monitoring the watering, humidity, and transpiration of plants in real time.
7	Lidar, or light detection and ranging	Surveying the land, identifying the type of soil, creating 3D models of farms, tracking

		soil erosion and loss, and forecasting production.
8	mass flow detectors	Monitoring of yield using a combine harvester's grain flow as a basis.
9	Mechanical sensors	Compaction of the soil or mechanical resistance
10	Optical sensors	Soil moisture, color, mineral content, composition, Organic matter in the soil and so forth. Fruit maturation is monitored by optical sensors based on fluorescence. using microwave scattering and optical sensors to describe orchard canopies.
11	Optoelectronic sensors	Sort plants differently to find weeds in crops grown in wide rows.
12	Level-based sensors based on soft water (SWLB)	Utilized in catchments for time-step acquisitions and the characterization of hydrological characteristics (water level and flow).
13	Telematics sensors	Evaluating the farm's operations, machine and machine operating activities, and travel routes.
14	Ultrasonic ranging sensors	Spray distance measurement, consistent spray coverage, object detection, crop canopy monitoring, tank monitoring, and weed detection.
15	Remote sensing	Mapping of land use/ cover, Crop evaluation, yield forecasting, degradation, pest and plant identification, etc.

Precision Irrigation in Pressurized Systems

Recent improvements in irrigation schemes have led to the introduction of irrigation devices with motion control, wireless connection, sensor technology, and GPS-based controls in an effort to increase the water utilisation efficiency by crop. These devices assess irrigation parameters including flow and pressure in addition to monitoring soil and climate variables. These technologies have a lot of promise, but further development is needed before they can be made widely accessible. Yield observers are composed of devices and additional components that control integration and interaction, like a computer, data storing device, and user interface. The mass flow sensor's purpose was to gauge the energy that bounces back after being hit by microwave energy beams. Yield maps are created by GPS receivers in yield monitors using location yield data [9].

3 Internet of Things

The Internet of Things (IoT), a new technology that enables remote device connections, makes smart farming conceivable. Applications currently in use offer insights on the impact of IoT and its as-yet-unobserved habits. The Internet of Things (IoT) is expected to play a significant role in agriculture as technology advances in a number of areas. IoT technology observes vegetation and creatures by remotely retrieving data from transportable phones and other sensors. Thanks to sensors and technologies, farmers can forecast production levels and assess the weather. The Internet of Things is more helpful than ever in assessing agricultural water requirements, harvesting water, monitoring and controlling flow volume, estimating supply time, and promoting water conservation [10].

Sensors and cloud communication through the gateway allow for remote condition and water delivery monitoring based on plant and soil requirements. The monitoring platform is interactive, affordable, and easy to use. It provides aggregated data from various sources on crop pests and diseases, conventional farming practices, tools, and other related topics for sustainable farming. Users can easily obtain data through interactive agriculture on a variety of platforms, including computers and mobile phones.

4 Applications of IOT in Agriculture

The integration of wireless sensors and the Internet of Things in smart farming solves a number of issues that traditional agriculture encounters, including land suitability, drought monitoring, irrigation, insect management, and yield optimization. The next several applications will change agriculture and increase productivity by utilizing state-of-the-art technologies at different stages. Plant Monitoring and Soil Mapping Based on GPS position and field-specific data, soil analysis determines the field's estimated nutritional status. Based on nutrient shortages at various crop stages, important decisions are subsequently made. The fertility level of the soil is determined by a number of elements, including topography, type and texture, cropping plan, fertilizer application, irrigation, and others.

Remote sensing methods that can collect information on soil moisture content are frequently useful for allowing prediction models to be built based on the physical properties of the soil. By 2030, desertification will entirely engulf 168 countries, according to the UN Convention to Combat Desertification (UNCCD), and over half of the world's population would reside in areas with severe water scarcity. It must be delivered to areas with enough water, given the current limitations and the increasing demand for agricultural and other operations. Drip and sprinkler irrigation are two more efficient and regulated watering techniques that help protect water supplies.

Site-Particular Nutrient Control: Fertilizer is a chemical compound that can be manufactured or natural that gives soil fertility and plant development nutrients. Soil, plant health, and the ecosystem are all negatively impacted by both inadequate and excessive fertilizer application. The normalized difference vegetation index (NDVI) was developed to track crop health, crop nutrient status, plant density, and soil nutrient levels using satellite data [11].

Modern technologies like GPS, geotagging, variable rate technology (VRT) and self-driving cars considerably facilitate IoT-based smart fertilization. Other than these, fertigation and chemigation—the application of pesticides and soil amendments containing water-soluble fertilizers—are thought to be efficient management techniques for enhancing fertilization efficiency, controlling crop diseases and pests. The Food and agriculture Organization (FAO) determined that 20–40% of the global crop output loss occurs each year due to pests and diseases alone and that using pesticides and other agrochemicals can help lower these losses.

Fig 1: Role of IoT in agriculture (https://www.deepseadev.com)

The majority of them eventually contaminate environmental systems and endanger the health of people and animals. Robots, wireless sensors, and drones are examples of IoT-based products that often have more success than traditional pest control techniques because they can precisely identify and manage crop foes through real-time monitoring, modelling, and disease forecasting. Keeping an eye on and projecting yields, the moisture content, quality, and yield of the produce are all met by the yield monitoring system.

5 IOT in Advanced Practices of Farming

The yield of crops was higher when the new, sensor- and IoT-based agricultural techniques were implemented than when traditional agricultural methods were used. One of the main keys to increasing produce quality and quantity is to deploy advanced sensor-based technologies in controlled situations. Protected cultivation and greenhouse farming. In nations that experienced severe weather, these methods spread much more throughout the 20th century. Crops grown indoors are less vulnerable to environmental factors.

Thus, through the use of sensors and communication equipment, crops that were once cultivated traditionally in favorable conditions are now raised whenever and wherever they are needed. Aeration systems, shed structures, materials to reduce wind effects, decision support systems, precise monitoring parameters, and other elements are all necessary for the success of crop production in controlled environments.

Growing plants without soil is known as hydroponics, a branch of hydroculture that enhances the advantages of green-house farming. As of right now, a variety of parameters can be detected by the systems and sensors that are now accessible and data analysis is done on a set schedule. Precise measurement and continuous observation of the concentration of nutrients in solution are necessary for plants to develop and fulfil their requirements.

A real-time solution for soilless agriculture has been provided by the wireless-sensor-based prototype, which can monitor water levels and the content of various nutrients. Three essential parts make up mechanized smart hydroponics system with Internet of Things integration: input data, output data and cloud server. To ensure adequate water circulation, the data is automatically analyzed and tracked in real time. Industrial farming practices are degrading soil quality faster than nature can repair it. Because of the alarming rate of erosion and the use of fresh water for agriculture, the amount of arable land has declined and the strain on existing water reservoirs has increased.

Vertical farming (VF) reduces resource use and increases production on demand by allowing plants to be maintained in a strictly controlled environment. VF is quite operational, and it also delivers more yields while using less water than traditional farming. Non-dispersive infrared (NDIR) carbon dioxide (CO_2) sensors are crucial for environmental monitoring and management in vertical farms since the measurement of carbon dioxide is the most significant factor. Using phenotypes: A new method of crop engineering that connects plant genetics to agronomy and eco-physiology is called phenotyping [12].

In these conditions, plant phenotyping proves to be highly beneficial in analyzing the quantitative characteristics that control growth, stress tolerance. Monitoring the crop and related trait measurements, as well as offering resources for digital agriculture and crop breeding, are the objectives of IoT-based phenotyping. With the aid of modeling and trait analysis techniques, the relationships between genotypes, phenotypes, and their growth environments are established.

6 Barriers and Challenges

Adoption of technology is a process that involves a certain amount of affective variability. The use of technology in farming operations has reduced time constraints and increased precision and efficiency.

The Price of Technology: Current technologies reduce the need for labour and do tasks very quickly and accurately. As such, it is expected that in the not too distant future, machines will most likely take the place of human labour.

Insufficient Funds: Financial backers might provide farmers enough credit if they did not receive the expected harvest, perhaps as a result of unanticipated calamities like drought, flood, pests, and diseases harming the crops.

Farmers' Level of Literacy: The level of education attained by farmers is one of the main barriers to the adoption of new technology in developing countries. To operate the tools, one must possess both technical and educational expertise. Due to their improved capacity for information interpretation and decision-making with smart agricultural technologies, farmers can use computers more easily

Infrastructure for Telecommunications: Most farming is done in rural locations, where arable land works better for farming than contaminated soil. Unfortunately, due to insufficient telecommunications infrastructure, data transfer is erratic, especially when utilizing mobile phones. Smart farming requires real-time internet connection, cloud server to utilize information. Furthermore, in order for different operation control systems to function, like those for seed quantities, fertilizer, and pesticides, a strong internet connection is necessary [13].

Information Administration: Farmers are having trouble managing and organizing the sensor-derived data. Farmers do not know how to use the data that the weather stations are producing or how to transform it into a format that is more readily available. Its intricate processes cause inaccurate calculations in addition to acceptability and usability problems [14].

Present-day difficulties: The Sustainable Development Goals of 2030 is to end hunger by that year. The World Health Organization reports that food shortages are affecting over 800 million people worldwide. Moreover, the demand for wholesome food rises along with the global population, which means both food and cash crops could raise crop yield overall. The issues agriculture is expected to encounter in 2050 are numerous. The three main goals are to feed 10 billion people, restrict land expansion, and lower greenhouse gas emissions. In addition to causing communities to shrink and populations to age, the decline in rural populations brought about by urbanization necessitates that younger producers take on greater responsibilities.

Many problems beset the agricultural sector in developing countries: poor animal husbandry, inadequate soil testing, inefficient irrigation systems, erroneous weather forecasts, inappropriate crop choices, etc. 50% of people in developing countries are now working in agriculture, despite the fact that technology advancements have proven beneficial in industrialized nations in both quantitative and qualitative ways [15].

7 Conclusions

Among other things, IoT technologies make it possible to gather data on soil fertility, temperature, humidity, and climate, which makes it possible to effectively monitor crops from a distance. Farmers may now monitor the condition of their crop from anywhere at any time, thanks to these technological advancements. Wireless sensor networks, on the other hand, enable automation of various tasks and management of farm conditions. For instance, wireless cameras are used in a few of the experiments examined in this paper to provide real-time crop status information. Drones have been used in other studies to assist with precision agriculture activities, and farmers have been kept informed on the state of their cultivation through the use of smartphones. Among the most amazing technologies that are combined with IoT to offer agricultural solutions are mobile applications, cloud computing, middleware systems, wireless sensor networks. IoT technologies are already crucial to the solution of many issues in the agricultural setting. To ascertain the principal Internet of Things (IoT) applications in agricultural, the IoT-based equipment and software employed in agriculture, and the benefits provided by this type of technology, we conducted a literature review in this work. While the subjects covered in this paper are crucial for everyone working in agriculture, it is also vital to note that additional study on environmental issues needs to be examined in order to attain sustainable food production.

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