Smart Agriculture: Technologies, Practices and Future Direction

Abstract

The Internet of Things (IoT) has ushered in a new era of innovative agriculture research. Because IoT is still in its early stages, it must be widely tested before it can be widely deployed in many agricultural applications. In this paper, I look at different prospective IoT applications, as well as the unique concerns and constraints connected with IoT deployment for better farming. The gadgets and wireless communication technologies linked with IoT in agricultural and farming applications are thoroughly researched to focus on the unique requirements. Sensor-enabled IoT systems that deliver intelligent and smart services for smart agriculture are being investigated.

Several case studies are offered to investigate the existing IoT-based solutions implemented by various organizations, individuals, and groups depending on their deployment criteria. The difficulties in these solutions are addressed, as are the factors for improvement and the future roadmap of work with IoT. Smart farming is a trend that emphasizes the use of information and communication technology in machinery, equipment, and sensors in network-based hi-tech farm supervision cycles. Innovative technologies such as the Internet of Things (IoT) and cloud computing are expected to spur growth and kickstart the usage of robotics and artificial intelligence in agriculture. Such radical departures are upsetting established agricultural practices while also posing several obstacles. This study explores the techniques and equipment utilized in wireless sensor applications in IoT agriculture, as well as the predicted problems encountered when integrating technology with traditional farming practices. Furthermore, this technical knowledge is useful to growers during crop times ranging from planting to harvest, and applications in packing and transportation are being researched.

Keywords: agriculture practices, Internet of things, smart agriculture, Technologies

Introduction

Sustainable agriculture is a measure of the durability and sustenance of environmentally friendly food crops. Sustainable agriculture promotes farming practices and ideas that help farmers and resources last. It is economically practical, preserves soil quality, prevents soil degradation, conserves water, increases land biodiversity, and assures a natural and healthy environment. Sustainable agriculture is important for protecting natural resources, stopping biodiversity loss, and lowering greenhouse gas emissions. Sustainable agriculture farming is a means of maintaining nature without jeopardizing future generations' basic requirements, while simultaneously enhancing farming efficiency. Crop rotation, nutrient deficit control in crops, pest and disease control, recycling, and water harvesting are the primary achievements of smart farming in terms of sustainable agriculture, resulting in a safer environment overall. Living species rely on biodiversity and are contaminated by waste emissions, fertilizer and pesticide use, degraded dead plants, and so on. Greenhouse gas emissions have an impact on plants, animals, humans, and the environment, necessitating a better climate for living things. Agriculture is India's largest contributor, accounting for 18% of GDP and employing around 57% of the population. Although India's total agronomic output has increased over time, the number of growers has decreased from 71.9% in 1951 to 45.1% in 2011. According to the Economic Survey 2018, the proportion of agricultural employees in the entire employment would fall to 25.7% by 2050. In rural areas, agricultural families increasingly lose the next generation of farmers due to higher cultivation costs, low per capita output, insufficient soil management, and migrations to non-farming or higher-paying occupations. The world is currently on the edge of a digital revolution, thus now is the moment to connect the agricultural landform with wireless technology to introduce and adapt digital connectivity with farmers. Regrettably, not all regions of the Earth's surface are appropriate for agriculture due to a variety of constraints, including soil quality, topography, temperature, climate, and the fact that most significant cultivable areas are not homogeneous. Furthermore, current farmed land is fragmented due to political and fiscal factors, as well as rising urbanization, which continually puts a strain on arable land supply. Total agricultural land used for food production has recently decreased. Furthermore, each agricultural field has various important properties, such as soil type, irrigation flow, nutrient presence, and insect resistance, which are all measured independently in terms of quality and quantity for a specific crop. Crop rotation and an annual crop growth development cycle require both spatial and temporal changes to optimize crop yield in the same land. In most situations, differences in features occur within a single crop, or the same crop is planted throughout the farm, necessitating site-specific analysis for optimal yield production. To produce more from less land and manage these diverse challenges, new technology-based approaches are required. Farmers in traditional farming practices visit their fields regularly throughout the crop's life in normal farming chores to better understand crop conditions. Current sensor and communication technologies provide a detailed view of the field, allowing farmers to identify ongoing field activities without physically being in the field. Wireless sensors monitor crops with more accuracy and spot problems at an earlier stage, often easing the use of smart instruments from crop sowing to harvest. Due to accurate monitoring, the timely deployment of sensors has made the entire farming process smart and cost-effective. The various autonomous harvesters, robotic weeders, and drones have sensors attached to collect data over short intervals. However, the immensity of agriculture places high demands on technical solutions for long-term sustainability with minimal environmental impact. Sensor technology, via wireless connection, enables farmers to learn about the many demands and requirements of crops without having to visit the fields, allowing them to take remote action.

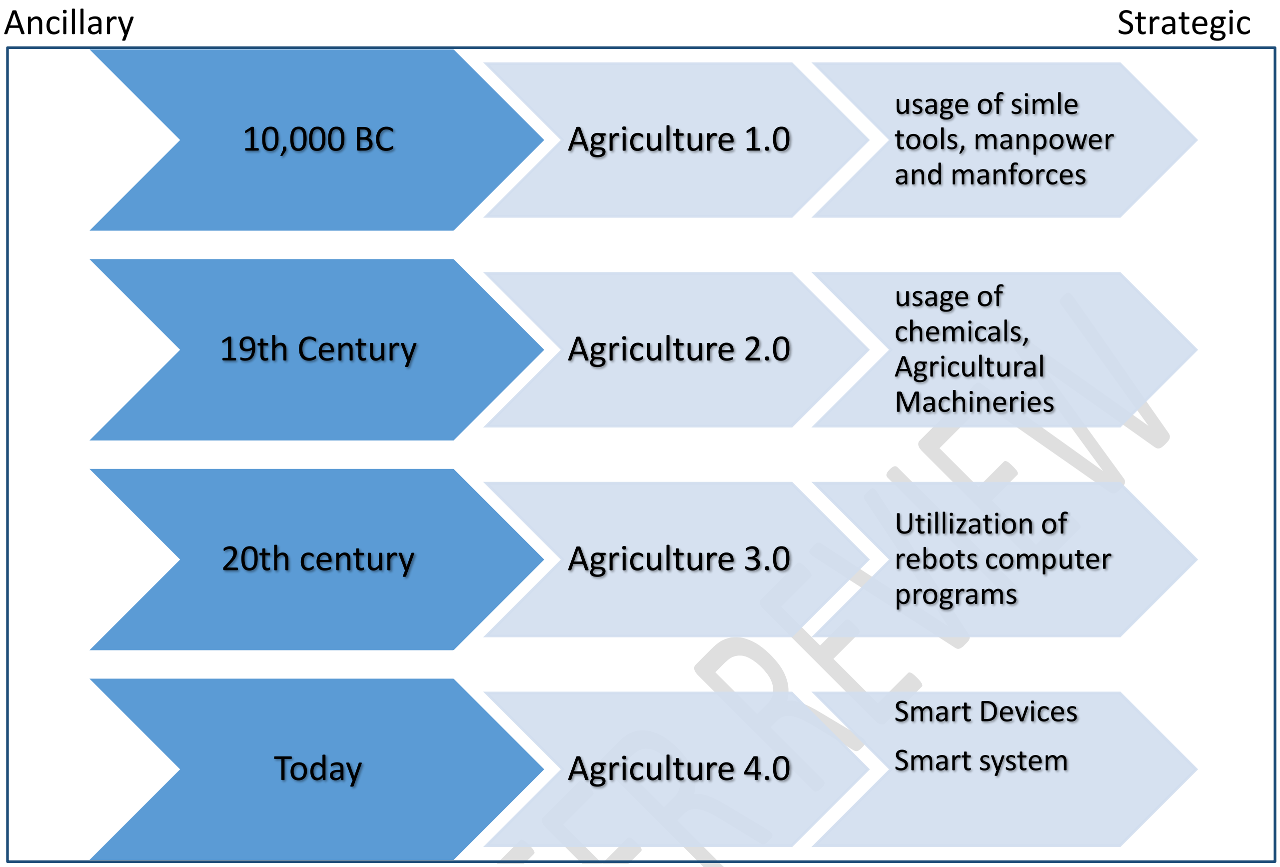

Fig 1. Agricultural decision support system framework.

Technologies Used in Smart Agriculture

Global Positioning System (GPS): GPS precisely records latitude, longitude, and elevation data. Satellites of the Global Positioning System send signals and allow. GPS receivers calculate their location in real-time and deliver continuous position updates while moving. Farmers can use precise location information to determine the exact location of field data such as insect occurrence, soil type, weeds, and other impediments. The system aids in the recognition of various field locations so that the essential inputs (seed, fertilizer, herbicide, pesticide, and water) can be applied to a specific field.

Sensor Technologies: Photoelectricity, electromagnetics, conductivity, and ultrasound are among the techniques used to evaluate soil texture and structure, nutrient content, vegetation, humidity, vapor, air, and temperature, among other things. Remote sensing data can distinguish crop varieties, classify pests and weeds, pinpoint stress in soil and plant conditions, and track drought.

Variable-Rate of Technology (VRT) and Grid Soil Sampling: In farming, variable-rate technologies (VRT) are used to anticipate the delivery rate of inputs based on a predetermined map extrapolated from GIS for the placement of variable amounts of inputs in the appropriate location and at the right time. Grid soil sampling is the gathering of soil from a systematic grid to create a map for each attribute. These maps serve as the foundation for VRT, and they are put into a variable-rate applicator. Based on map features, the computer and GPS receiver direct and control changes in the delivery volume or fertilizer product. Variable rate technology and associated practices (grid soil sampling), for example, can improve soil fertility management and examine the spatial distribution of nutrients and yields. Grid sampling collects samples from sampled portions based on a field's partition into small units, or cells, by superimposing grid lines over the field. At the intersections of grid lines, composite samples represent a complete region of each much smaller area (grid-point sampling). Interpolating algorithms are used to map soil-test values from grid sampling from non-measured sites between sampled points. Phosphorus and potassium variability is field-specific, and each field should be fertilized differently to improve nutrient management practices through uniform fertilizer and manure applications for improved precision agriculture.

Crop Management: Satellite photos give information on soil condition differences as well as crop performance as it relates to topography within the field. Farmers can precisely monitor production parameters such as seeds, fertilizers, and insecticides that are responsible for increased output and efficiency. The spatial coverage and temporal revisit frequency of satellite images provide information at a regional scale in near real-time. The association between crop spectral properties and biomass/yield trials is anticipated by vegetation spectral reflectance properties, particularly in red and near-infrared combinations (vegetation indices) to monitor green foliage. Due to the closely associated leaf area index (LAI) and photosynthetic activity of green vegetation, the normalized difference vegetation index (NDVI) is the most preferred indicator to estimate vegetation health and agricultural production among the several indices. Crop monitoring approaches rely on interpreting remote-sensing-derived indications by comparing current crop status to past or normal seasons. In certain intervals before harvest, the link between vegetation indices and biomass allows for early crop yield estimation. The more complicated functionalities available through automated field management include the automated data acquisition, processing, monitoring, decision-making, and management of farm operations, including the basic functions of crop production (yields), profits and losses, farm weather prediction, field mapping, and soil nutrients tracking.

Soil and Plant Sensors: Sensor technology, an important component of precision agriculture, gives information on soil parameters, fertility, and water status. As a result, new sensors have been developed based on desirable characteristics and established as distinct from already available sensors. Soil sensors and plant wearables analyze physical and chemical signals in the soil in real-time, such as moisture, pH, temperature, and pollutants, and offer data to optimize crop growth conditions, combat biotic and abiotic challenges, and boost crop yields. The most significant nutrients for crop productivity are soil organic matter (SOMs), nitrogen (N), phosphorous (P), and potassium (K). The sensors based on NIR reflectance measure the spatial variation of surface and beneath soil nitrogen. SOM is anticipated using ideal wavelengths determined by measuring soil spectral reflectance in the infrared and visible wavelength ranges. NIR spectrophotometry technology is used to forecast soil nitrogen and phosphorus levels. Because ECa is susceptible to variations in soil texture and salinity, soil apparent electrical conductivity (ECa) sensors collect data continuously on the field surface. Optoelectronic, acoustic, impedance, and nanostructured biosensors are used to detect soil insects/pests.

Rate Controllers: Rate controllers are intended to manage the delivery rate of inputs by monitoring the speed of vehicles across the field and adjusting the flow rate of material on a real-time basis to achieve the desired rate. Rate controllers are frequently utilized as independent systems.

Precision Irrigation in Pressurized Systems: Recent advancements in irrigation systems have introduced irrigation machines dedicated to motion control, GPS-based controllers, sensor technologies, and wireless communication to monitor soil and climatic conditions as well as an assessment of irrigation parameters, such as flow and pressure, to achieve greater crop water utilization efficiency. These technologies have considerable potential; nevertheless, further development is necessary before they can be commercialized.

Yield Monitor: Yield monitors are a collection of sensors and components that govern integration and interaction components, such as a data storage device, a computer, and a user interface. The sensor continually measures yield by assessing the force of mass or volume of grain flow. The mass flow sensor works by emitting microwave energy beams and measuring the energy that bounces back after impact. GPS receivers in yield monitors generate yield maps based on location yield data.

Software: The program performs a variety of functions, including mapping, display controller interfacing, data processing, analysis, interpretation, and so on.

➢ Role of IoT Smart Agriculture Practices

Adopting new approaches based on sensor and IoT-based technology increased crop yields more than traditional agricultural operations. The use of more sophisticated sensor-based technologies in controlled environments plays a vital role in improving production quality and quantity.

Greenhouse Farming and Protected Cultivation: Growing plants in a controlled environment became popular in the nineteenth century and is one of the oldest methods of smart farming. These practices accelerated further during the twentieth century in regions experiencing severe weather. Crops produced indoors are less impacted by environmental factors. As a result, crops grown traditionally under suitable conditions are now raised at any time and from any location thanks to the employment of sensors and communication devices. Crop production success in a controlled environment is dependent on a variety of aspects, including shed structures and materials for reducing wind effects, aeration systems, monitoring parameter accuracy, decision support systems, and so on. One of the most difficult issues in greenhouses is precise monitoring of environmental parameters; thus, numerous measurement points are required to anticipate the various parameters for managing and assuring the local climate. Sensors are utilized in an IoT-based greenhouse to measure and monitor internal characteristics including humidity, temperature, light, and pressure. The smart greenhouse has assisted farmers in automating farm work and protecting plants from hailstorms, winds, ultraviolet radiation, and insect and pest infestations. During the night, hibiscus plants are grown with the proper wavelength utilizing lights, temperature, and air humidity sensors. A study discovered a reduction in water requirements of 70-80%, and the Internet of Things provides direct contact between farmers and consumers to make farming as efficient and profitable as possible. The IoT-enabled automated system increased the productivity of greenhouse-grown rose plants by monitoring and controlling various parameters, such as humidity, mist, CO2 level, UV light intensity, pH and EC value, water nutrients solution level, temperature, and pesticide amount, using sensors for more efficient detection and diagnosis.

Hydroponics: Hydroponics, a subset of hydroculture, is the practice of growing plants without soil to maximize the benefits of greenhouse farming. As a solution, hydroponic irrigation systems offer a balanced rate of administration of dissolved nutrients in water to crop roots. At the moment, various systems and sensors detect a wide range of factors and analyze data at specified intervals. Precise measurement and monitoring of nutrient concentration in solution is critical for plant growth and taking into account its requirements. The wireless-sensor-based prototype has offered a solution for soilless agriculture and measures the concentration of multiple nutrients and water levels in real-time. An automated smart hydroponics system with IoT integration is made up of three primary components: input data, a cloud server, and output data. These analyze parameters such as pH level, water, nutrient-rich water-based solution, ambient temperature, and humidity in real-time and may be accessed from anywhere over the internet. The deep flow technique hydroponic system is a method of producing plants by inserting roots in deep water layers and assuring continuous circulation of plant nutrition solution. Sensors embedded into the Raspberry Pi collect data on plant growth variables such as pH, temperature, humidity, and water level in the hydroponic reservoir, and the data is processed and monitored automatically in real-time to ensure correct water circulation.

Vertical Farming: Industrial agricultural farming practices degrade soil quality quicker than nature can repair it. The alarming pace of erosion and usage of fresh water for agriculture has reduced arable land and increased the overburden on existing water reservoirs. Vertical farming (VF) allows plants to be kept in a perfectly regulated environment, considerably lowering resource consumption while increasing productivity at different periods; and depending on the number of stacks, only a percentage of the ground surface is required. VF is also incredibly successful at increasing yields while decreasing water consumption when compared to traditional farming. Because carbon dioxide measurement is the most crucial parameter, nondispersive infrared (NDIR) CO2 sensors are critical in tracking and managing conditions in vertical farms.

Phenotyping: Phenotyping is a new crop engineering technology that connects plant genomes to ecophysiology and agronomy. Although the improvement of genetic and molecular tools is crucial for crop breeding, quantitative measurement of crop behaviors such as disease resistance, grain weight, and so on is insufficient due to a lack of effective technology and efficient methodologies. Plant phenotyping is particularly valuable in researching the quantitative features responsible for the development, resilience to various stresses, yield quality, and quantity in this situation. IoT-based phenotyping is meant to observe crop and related trait measures, as well as provide capabilities for crop breeding and digital agriculture. Trait analysis techniques and modeling support are used to determine the correlations between genotypes, phenotypes, and growing conditions.

Current Challenges and Future Expectations: The United Nations and worldwide society established a goal to end hunger by 2030 in the 2030 Agenda for Sustainable Development. Currently, the World Health Organisation states that more than 800 million people worldwide are experiencing food insecurity. Furthermore, as the world's population grows, so does the demand for high-quality food; hence, food and cash crops have the potential to boost overall agricultural productivity. Agriculture's future is projected to be intertwined with artificial intelligence and big data services. As a result, the systems will converge into a single unit, with farm machinery and management beginning with sowing and ending with production forecasts. Few major technologies and practices are aimed at achieving long-term agricultural sustainability.

Communication: The success of IoT in agriculture is primarily dependent on device connectivity. Most telecom companies offer connectivity services, but they account for a minor portion of smart farming overall. Cellular operators provide additional services to growers and improve market facilities, particularly in rural locations. Cellular technology can succeed if service providers offer its benefits, such as flexibility, mobility, and opulence of two-way communication at a reasonable cost. In emerging countries, mobile services and smartphone technology give farmers a promising future for increasing crop yields. Because of its better facilities, efficient coverage, low power consumption, and cost economics, low power wide area technology (LPWA) is expected to play a significant role in smart farming agriculture. Cellular operators with strong IoT generate considerable returns by partnering with LPWA technology to provide smart agriculture facilities.

Wireless Sensors and IoT: Placing wireless sensors across the field offers farmers real-time information that allows them to make judgments and act to increase crop yields. Wireless sensor networks (WSNs) with GPS technology update all crop growth and terrain information. Recently, digital pictures and signal processing have added capabilities to WSN, allowing it to precisely determine crop quality and health. By evaluating crop requirements at each stage to maximize their efficacy, IoT technology may predictably streamline chores. In the future, IoT will be updated to fifth-generation (5G) cellular mobile communication technologies to supply farmers with real-time data at any time and from any location. Based on this achievement, about 29 billion IoT-based components are estimated to be in use in agriculture by the end of 2022. Furthermore, by 2050, farms are predicted to generate 4.1 million data points every day.

Drones and Unarmed Vehicles: Drones are commonly used by farmers for crop growth monitoring, spraying nutrient solutions water, and pesticides in difficult terrains and at various crop heights.

Drones have outperformed traditional gear in terms of spraying speed, area coverage, and precision. Drones are now outfitted with a variety of sensors, and 3D cameras give farmers full skills in land management. Farmers are addressing various problems with the integration of UAVs in agriculture, including the assimilation of technology and use in severe weather conditions. Aside from drones, automation in agriculture has increased production by achieving higher yields by spraying and weeding without human intervention. Traditional methods have lately gained a new degree of efficiency thanks to seeding, transplanting, and fruit harvesting/picking robots. To improve cultivation practices, UAV technology in smart agriculture delivers information on fertilization, irrigation, pesticide use, plant growth monitoring, weed management, crop disease management, and field-level phenotyping. A new 3D modeling method was utilized to monitor agricultural growth characteristics in the field to determine the height of maize and sorghum plants using UAV, and the average root mean square error (RMSE) of sorghum height with hand sampling field data was 0.33 m. The UAV and 3D models were also recovered to extract the leaf area index (LAI) in soybean plants, with the measured LAI predicted accuracy matching the handheld device (R2 = 0.92) being connected with destructive LAI measurements (R2 = 0.89). UAV-derived multi-spectral digital images are used to evaluate vegetation indices (VIs) and multi-temporal VIs to estimate grain production in wheat. In wheat crops, the indices, which include the normalized difference vegetation index (NDVI), spectral vegetation index (SVI), and green area index (GAI), are used to predict grain yield, monitor the breeding, detect plant stress caused by yellow rust disease, and quantify plant density. Pesticide use in agriculture is critical for crop yields and the environment, hence efforts have been made to create and test an algorithm to self-adjust UAV paths during chemical spraying in an agricultural field to minimize pesticide and fertilizer waste.

Vertical Farming and Hydroponics: The diminishing of arable land and rising urbanization put more strain on existing resources, causing difficulties for food production using current agricultural practices. Vertical farming (VF) overcomes land and water scarcity issues and is well-suited for implementation in neighboring cities. Hydroponics is important in reducing water requirements.Hydroponics, in conjunction with VF, expands available arable land without negatively impacting forests and other natural habitats. The existence of new technology, particularly the Internet of Things, makes the agriculture industry more profitable by reducing labor requirements and other resources while also minimizing environmental impact.

Performance Analysis Using Machine Learning: Real-time data is analyzed using data analytics and machine learning methods. Identifying the best genes in crop production is an important task that may be carried out utilizing machine learning approaches. Machine learning is used in agriculture to predict the best genes for crop development, particularly when selecting seed varieties that are highly adapted to specific climate conditions and locales. Machine learning algorithms detect products in high demand as well as those that are currently unavailable. Recent advances in machine learning and analytics enable farmers to appropriately categorize their harvests before processing and delivering them to clients. In large data systems, machine learning (ML) handles problems connected to farmer decision-making, crops, animal research, land, food supply and security, weather and climate change, and weeds. A wide range of agricultural activities can be accommodated by ML-based applications, including maize yield prediction based on a deep memory model, a binary classification model with logistic regression technique to assess rainfall intensity, and a short-term memory model to predict soil water content with data parameters of rainfall, temperature, water diversion, evaporation, and time for the next 1, 2, and 7 days with greater R2 than artificial neural networks. As a result, farmers' earnings are improving, and communities are becoming more integrated into the agricultural value chain to eliminate poverty and offer access to health care, education, and healthy food for their families.

Renewable Energy, Microgrids and Smart Grids: Smart farming necessitates a large amount of energy due to the power consumed by long-term sensor placement, GPS use, and data transfer. Using renewable energy sources in rural places has traditionally solved long-term electricity challenges. Smart grids and microgrids are components of distributed energy sources (DERs). Recent storage device advancements combine electrical and heat systems to store energy and use the heat produced. Smart grid technology, on a global scale, provides a smooth transition from traditional to smart energy systems, providing energy security. Power-strengthening systems integrated with renewable sources have improved the transport sector and increased bioenergy use in the power sector in developing countries by identifying numerous renewable energy sources using smart technologies such as energy storage devices, smart appliances, computational intelligence, and the Internet of Things.

Conclusions

Smarter and more effective agricultural production methods are required to solve the concerns of limited arable land and rising global food demand. Everyone must be aware of the importance of food security in terms of sustainable agriculture. The development of new technology for enhancing crop productivity and encouraging innovative young people to pursue farming as a legitimate vocation. This article emphasised the significance of numerous farming technologies, particularly the Internet of Things, in making agriculture smarter and more successful in fulfilling future demands. The current industry issues and future potential are noted to help researchers and engineers. As a result, every piece of farmland is critical to increasing crop yield by addressing every inch of land with sustainable IoT-based sensors and communication technology.

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