Smart Agriculture: Technologies, Practices, and Future Directions

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 communications technology (ICT) 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 encompasses a set of practices and principles aimed at ensuring the long-term viability of environmentally friendly food crop production. It promotes farming methods that not only prove economically practical but also serve as custodians of soil quality, preventing degradation, conserving water, enhancing land biodiversity, and securing a natural and healthy environment. Sustainable agriculture plays a pivotal role in safeguarding natural resources, curbing biodiversity loss, and mitigating greenhouse gas emissions. It offers a way to harmonize the preservation of nature with the fulfillment of basic needs for future generations, while simultaneously improving agricultural efficiency. Key achievements in the realm of smart farming, which align with the principles of sustainable agriculture, include crop rotation, the judicious management of nutrient deficits in crops, effective pest and disease control measures, recycling practices, and efficient water harvesting techniques. These advancements contribute to creating a safer and more environmentally sound agricultural landscape. Biodiversity, a cornerstone of ecological health, is vital to the survival of living species. Unfortunately, agricultural activities often bring about biodiversity loss due to waste emissions, the use of fertilizers and pesticides, the degradation of organic matter, and other factors. Furthermore, greenhouse gas emissions have far-reaching consequences, affecting plants, animals, humans,

UNDER PEER REVIEW

and the environment, highlighting the urgent need for climate-conscious practices. In the context of India, agriculture plays a pivotal role as the largest contributor to the country's GDP, accounting for approximately 18% and employing around 57% of the population. However, the proportion of agricultural laborers in the overall workforce is on a declining trend. Factors such as rising cultivation costs, low per capita output, inadequate soil management, and the attraction of non-farming or higher-paying jobs in urban areas contribute to this decline. The rural exodus of the younger generation from farming families is a significant concern, with consequences for the future of agriculture in the country. As the world stands on the cusp of a digital revolution, there is an opportune moment to integrate wireless technology into the agricultural landscape, thereby facilitating digital connectivity with farmers. Nevertheless, not all regions of the world's surface are suitable for agriculture, constrained by factors like soil quality, topography, temperature, climate, and the unequal distribution of arable land. Moreover, the fragmentation of cultivated land due to political, economic, and urbanization factors exacerbates the pressure on arable land supply. Total agricultural land used for food production has recently decreased. Furthermore, each piece of agricultural land possesses distinct characteristics, such as soil type, irrigation capacity, nutrient content, and pest resistance, all of which need to be measured individually in terms of quality and quantity for a specific crop. To overcome these multifaceted challenges, innovative technology-based approaches are imperative. Traditional farming practices require farmers to make regular visits to their fields to monitor crop conditions. Modern sensor and communication technologies, however, provide a comprehensive view of the field, enabling remote monitoring of field activities. Wireless sensors offer a high degree of precision and allow the early detection of problems, streamlining the entire farming process from sowing to harvesting. Autonomous harvesters, robotic weeders, and drones equipped with sensors collect data at frequent intervals. Nonetheless, the vastness of agriculture imposes rigorous demands on technological solutions to ensure long-term sustainability with minimal environmental impact. Wireless sensor technology enables farmers to understand the multifaceted needs and requirements of crops without being physically present in the fields, enabling remote decision-making and action.

UNDER PEER REVIEW

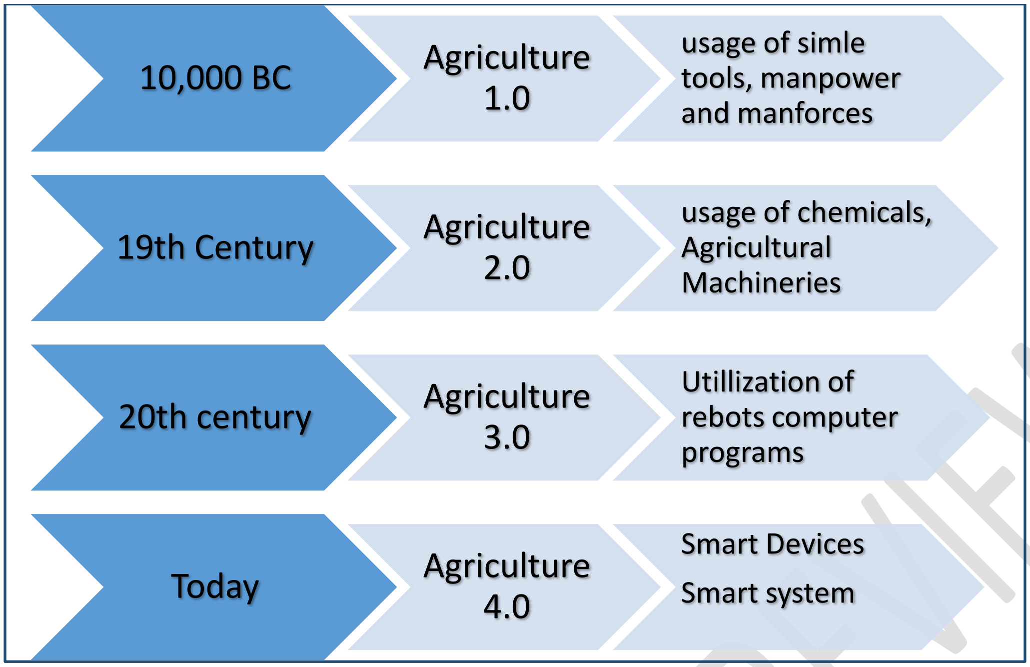

Fig 1. Agricultural decision support system framework.????

UNDER PEER REVIEW

Technologies Used in Smart Agriculture Validate with citations all the next parts

- **Precision Agriculture Technologies Global Positioning System (GPS):** GPS is a technology that accurately records latitude, longitude, and elevation data. Satellites of the Global Positioning System transmit signals, enabling GPS receivers to calculate their real-time location while in motion. For farmers, GPS technology is invaluable, allowing them to pinpoint the exact location of field data, such as insect occurrences, soil types, weed distributions, and other obstacles. This precise information facilitates targeted applications of essential inputs like seeds, fertilizers, herbicides, pesticides, and water to specific field areas. Sensor Technologies: Various sensor technologies, including photoelectricity, electromagnetics, conductivity, and ultrasound, are employed to assess soil characteristics, nutrient content, vegetation, humidity, vapor, air, temperature, and more. These sensors offer insights into crop varieties, pest and weed identification, soil and plant stress detection, and drought monitoring. The data collected through remote sensing aids farmers in making informed decisions about resource allocation and crop management. Variable-Rate Technology (VRT) and Grid Soil Sampling: Variable-rate technologies (VRT) utilize geographic information system (GIS) maps to adjust the application rates of inputs based on specific field conditions. Grid soil sampling involves systematically collecting soil samples from a grid pattern to create attribute maps. These maps serve as the foundation for VRT, allowing precise control of input delivery based on the field's variability. Implementing VRT and grid soil sampling can enhance soil fertility management and optimize nutrient distribution for improved precision agriculture. Crop Management: Crop management in precision agriculture relies on satellite imagery to assess soil conditions and crop performance concerning topography within fields. This technology enables farmers to monitor critical factors such as seed placement, fertilizer application, and pest control. Satellite images provide regional-scale, near real-time information. Spectral reflectance properties, especially in the red and near-infrared wavelengths, are used to monitor vegetation health and estimate crop yield. The normalized difference vegetation index (NDVI) is a preferred indicator due to its correlation with leaf area index and photosynthetic activity. Soil and Plant Sensors: Sensor technology is essential in precision agriculture, providing real-time data on soil parameters, fertility, and water status. These sensors monitor variables such as moisture, pH, temperature, and pollutants, offering valuable insights into optimizing crop growth conditions and addressing biotic and abiotic challenges. Key nutrients like soil organic matter, nitrogen, phosphorus, and potassium are assessed using various sensor technologies, such as near-infrared reflectance (NIR) and electrical conductivity (ECa) sensors. Rate Controllers: Rate controllers play a crucial role in managing input delivery by monitoring vehicle speed across fields and adjusting material flow rates in real-time to achieve desired application rates. These controllers operate independently and ensure precise input management. Precision Irrigation in Pressurized Systems: Advancements in irrigation systems have introduced motion-controlled machines, GPS-based controllers, sensor technologies, and wireless communication to enhance crop water utilization efficiency. These technologies monitor soil and climatic conditions, providing insights into irrigation parameters, such as flow and pressure. While promising, further development is required before widespread commercialization. Yield Monitor: Yield monitors, equipped with sensors and integrated components, continuously measure crop yield by assessing mass or volume flow. Mass flow sensors use microwave energy to gauge the energy reflected after impact. GPS receivers generate yield maps based on location-specific yield data. Software: Precision agriculture software performs a wide range of functions, including mapping, display controller interfacing, data processing, analysis, and interpretation, enabling farmers to make informed decisions based on collected dataRole of IoTSmart 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.

Advanced Agricultural Technologies for Future Farming

Greenhouse Farming and Protected Cultivation: Controlled environment agriculture, including greenhouse farming, has a long history dating back to the nineteenth century and gained significant traction during the twentieth century, particularly in regions with challenging weather conditions. Growing crops in controlled environments significantly reduces the impact of environmental factors on crop production. Thanks to advancements in sensor technologies and communication devices, traditional crops can now be grown year-round and in diverse locations. Success in controlled environments depends on factors such as infrastructure design, wind protection, aeration systems, precise monitoring, and decision support systems. The challenge lies in accurately monitoring environmental parameters, necessitating the use of numerous sensors to ensure optimal local climate management. Internet of Things (IoT)-enabled smart

UNDER PEER REVIEW

greenhouses have automated farming operations and protected plants from various environmental threats, leading to impressive results such as substantial water savings. Furthermore, IoT facilitates direct communication between farmers and consumers, promoting efficient and profitable farming. Hydroponics: Hydroponics, a subset of hydroculture, involves growing plants without soil, maximizing the benefits of controlled environments such as greenhouses. Hydroponic systems ensure a balanced and efficient delivery of dissolved nutrients to plant roots through water. Current systems employ various sensors to detect and analyze a wide range of factors, including nutrient concentration. Real-time measurement and monitoring of nutrient levels are crucial for optimizing plant growth. Wireless-sensor-based prototypes have emerged, enabling soilless agriculture and providing real-time data on multiple parameters. Smart hydroponics systems, integrated with IoT, consist of three main components: input data, a cloud server, and output data. These systems monitor parameters like pH levels, nutrient-rich water solutions, ambient temperature, and humidity in real-time, accessible from anywhere via the internet. Vertical Farming: The rapid degradation of soil quality and increased urbanization pose challenges for traditional agriculture. Vertical farming (VF) offers a solution by providing a highly controlled environment that minimizes resource consumption and maximizes productivity. VF is particularly efficient in conserving water compared to traditional farming practices. Monitoring carbon dioxide levels is crucial for the success of vertical farms. Non-dispersive infrared (NDIR) CO2 sensors play a vital role in managing VF conditions and ensuring optimal crop growth. Phenotyping: Phenotyping is an emerging technology in crop engineering that connects plant genomes with ecophysiology and agronomy. While genetic and molecular tools are vital for crop breeding, quantitative measurement of crop traits, such as disease resistance and grain weight, remains a challenge due to the lack of efficient technology and methodologies. IoT-based phenotyping aims to monitor and measure crop traits and provide valuable insights for crop breeding and digital agriculture. This technology is instrumental in understanding the quantitative features responsible for crop development, stress resilience, yield quality, and quantity. Current Challenges and Future Expectations: Addressing global food security remains a paramount goal, as more than 800 million people worldwide experience food insecurity. Meeting the demands of a growing population necessitates advancements in agriculture, with a focus on artificial intelligence, big data, and the convergence of systems. Smart farming relies on robust communication networks, with the potential for low-power wide area technology (LPWA) to play a significant role in rural areas. Wireless sensors and IoT empower farmers with real-time data for decision-making, with an estimated 29 billion IoT-based components in agriculture by 2022. Drones and unmanned vehicles have transformed agriculture by providing precise monitoring, spraying, and automation. Vertical farming and hydroponics address land and water scarcity issues, offering sustainable alternatives. Machine learning and analytics enable data-driven farming, while renewable energy, microgrids, and smart grids support the energy needs of advanced agriculture. To ensure a sustainable future, every inch of farmland must be optimized with IoT-based sensors and communication technology.

UNDER PEER REVIEW

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UNDER REVIEW