Advancements and Challenges in IOT-Based Smart Agriculture: A Review

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Abstract

A vital sector of both national economy and human existence, agriculture must update antiquated methods while tackling resource shortages, most notably water. By combining the Internet of Things (IOT) with associated technologies, agriculture is becoming "Smart Agriculture," which increases sustainability and efficiency. This study investigates current developments in IOT-based smart agricultural systems, with an emphasis on novel approaches to crop management, waste management, weather control, water management, and soil monitoring. It looks at how sensors, remote sensing, and unmanned air vehicles (UAVs) work in precision agriculture. The research also covers communication strategies and the difficulties in putting IOT ideas into practice, including concerns about connection, consumption of energy, compatibility, and info safety. In order to demonstrate how the Internet of Things (IOT) has an opportunity to revolutionize the agriculture sector and support more effective and sustainable agricultural production, this paper will provide a thorough examination of current advancements and their various uses.

Keywords: *Security, wireless sensor networks, smart agriculture, Internet of Things, remote sensing, water management, emerging technologies, and wireless network protocols*

I. INTRODUCTION

Considering farmland is the primary source for nutrition and other necessities, it plays a major role in the expansion of the national economy and creates a multitude of career possibilities, making it vital to human life[1]. If the economy of a nation is to be strong for the next few years, the agriculture sector needs to expand. Still, a lot of farmers work their land with outdated techniques, which do not yield much in the form of agricultural products[2]. One of the sectors that has the most impact on national economies is the agricultural sector, which uses over sixty percent of the clean water on Earth. Owing to its enormous proportion, innovative, clever methods for the effective use of this priceless natural resource are desperately needed. Aerial imaging, computer-based information systems, and the Internet of Things (IOT) come together to develop Smart Agriculture Systems, which are crucial in streamlining agricultural activities like irrigation management[3]. Crop water need is the primary parameter in smart irrigation that has to be estimated for irrigation management.

Numerous applications of the Internet of Things (IOT) have been developed, such as linked transportation, smart unmanned aircraft, smart factories, smart cities and homes, smart gadgets, smart agriculture, and smart health systems[4]. Real- world items may communicate with one another, share information, and collaborate to make choices thanks to the Internet of Things. The Internet of Things (IOT) makes ordinary items intelligent by utilizing its underlying technologies, which include sensor networks, Internet protocols, applications, and communication technologies[5].

Creating an IOT-based agricultural system that is environmentally friendly has six major challenges: hardware, data analytics, maintenance and repair, infrastructure, connection, data security, and privacy. The selection of sensors and distance for Internet of Things devices are the most important hardware concerns[6].Consequently, a multitude of sensor categories are available for use in Internet of Things applications (e.g., pressure, temperature, chemical, proximity, humidity, water quality, gas, and so on). Frequent sensor inspections are necessary for the repair and maintenance of each IOT device, as they are quickly damaged in an agricultural setting. The range of wireless technologies (such as 4G, 5G, zigbee, wifi, LoRa, and 6LowPan) that can link sensors dispersed across a large area in agriculture is the cause of the connection problems. The infrastructure problems have to do with configuring and executing Internet of Things network design using state-of-the-art technologies like cloud computing, fog computing, virtualization of networks, and more[7].

A major obstacle to the creation of ecologically friendly Internet of Agriculture is more about protecting privacy and security than it is about having physical support[8].
Publicating the findings of a systematic literature review (SLR) in the area of IOT in agriculture is the goal of the proposed study. Many research studies have lately been published on this topic[9].

II. IoT-Powered Transformation in Agriculture: Substantial Developments in Climate, Water, Soil, Waste, and Farm Monitoring

Smart the agricultural sector, also known as precision gardening, has totally changed the farming industry by fusing traditional agricultural practices with cutting-edge technology like digitization, analysis of data, and the prevalence of the Internet of Thing.
Internet of Things-based smart agriculture systems have become more and more popular recently because of their capacity to increase output, decrease resource waste, and increase crop yields[10].

Management of Water and Irrigation:
Concerns over the finite availability of water are growing among farmers. Consequently, efficient water management is crucial. intelligent irrigation systems that are now considered a major answer and are based on IOT[11].Artificial intelligence (AI) algorithms for predicting soil moisture levels, real- time water quality monitoring, and automated control systems that adjust irrigation according to plant requirements are examples of recent advancements[12].

Management of Soil:
The preservation of healthy soil is essential to agriculture. IOT-based real-time soil monitoring makes measuring variables, including the amount of moisture, the pH, and the nutrients levels that are feasible. Soil sensors collect data, which is evaluated to yield insightful information. Combining machine learning algorithms with Internet of Things-based soil management systems is an emerging trend. Make customized recommendations for soil adaptation as well as conception[13].

Weather Control:
The weather is vital to agriculture, and IOT has enhanced the accuracy and accessibility of weather monitoring. Realtime information on temperature, humidity, wind speed, and rainfall is provided by IOT-based weather stations that are equipped with a number of sensors[14].Farmers can access this information through internet platforms and mobile apps, allowing them to make informed decisions about planting, harvesting, and controlling pests[15].
Accurate recently, meteorological data and analytics have been in tandem to evaluate climate risks and forecast weather patterns. This enables farmers to adapt to changing weather conditions trends and lower crop loss rates.

Waste management:
Reducing agricultural waste has positive effects on the economy and ecology. Farmers can employ smart agriculture technologies powered by the Internet of Things to maximize resource utilization and reduce waste. Recently, industrial waste has been tracked and postharvest storage conditions have been monitored using IOT sensors. Additionally, systems for clever recycling and sorting have designed to deal with agricultural waste in an efficient manner[16].

Crop Management:

IOT-based crop management systems, which employ sensors to track pest infestations, crop health, and development, are being pioneered by smart agriculture.A new finding is the use of multispectral cameras on drones to capture high-resolution images of crops[16].

Advancements in several areas of agricultural management have led to ongoing changes in IOT- based smart agriculture systems. Farmers may now use IOT technology to make data-driven choices, boost resource economy and adopt sustainable agricultural practices techniques related to crop, waste, weather, nutrients, water, and soil oversight[17].

III. IOT Sensors and Data Sources in Smart Agriculture

1) sensors

A vital role is played by sensors placed in a variety of locations, including agricultural fields, natural settings and regulated areas like greenhouses, in the real-time measurement and transmission of data related to particular characteristics of interest. These characteristics include soil moisture content, weather data from weather stations, plant health indicators (such the Normalized Vegetation Index (NDVI), which is obtained from sensors that measure plant reflectance), and several metrics related to water quality, like conductivity and pH. Furthermore,
sensors that keep track of nutrient levels such as those of potassium, phosphorus, nitrates, etc. have been essential to precision farming. In general, sensors and associated data allow for exact control over the application of pesticides and fertilizers, as well as the optimization of irrigation schedules, the safe and effective reuse of treated wastewater, the determination of the best times to harvest crops, and the creation of optimum growing conditions for agricultural products[19].

In addition, to ensure the safety of drinking water in residential, agricultural, and commercial settings, routine water quality monitoring is essential. In laboratories, traditional techniques like qualitative analysis have been widely used to detect water characteristics and calculate the water quality index. Comparing ancient approaches to modern instrumental analytical techniques, however, reveals that these procedures are costly, time-consuming, and labour intensive[20]. To address these issues, research is now focused on creating specialized sensors that will improve measurement accuracy and enable real-time measurements of relevant data. These sensors show great potential for agricultural applications like irrigation with treated wastewater, providing a useful substitute for the drawn-out procedures of typical laboratory studies[21].

But while sensor technologies advance quickly, they also present a number of new issues, most of which have to do with the sustainability of long-term sensor networks, particularly when those networks are operating in hostile settings without a constant electrical power source. Since sensors run on batteries, measurements and data transmission at short intervals deplete their energy reserves, endangering the network's ability to function as well as the accuracy of the data gathered and the viability of intelligent applications. In these kinds of settings, it is now essential to create low-power sensor technologies and investigate energy-harvesting strategies[22].

2) Aerial vehicles without a crew

By combining revolutionary innovations includes digitalization, data visualization, and the widespread use of the Internet of Things with conventional agricultural techniques, the smart agriculture sector also referred to as accuracy gardening—has completely transformed the agriculture industry as a whole.
This allows for the remarkably accurate forecasting of agricultural patterns. In the agriculture industry, this datadriven strategy enhances farming operations' accuracy and efficiency, enabling informed decision- making and resource management[23].

In particular, UAVs have been successfully used to create exact Digital Elevation Models (DEMs) and Ortho mosaic maps of agricultural fields, allowing for a very accurate and up-to-date perspective of the whole agricultural region. Furthermore, by using their sophisticated imaging capabilities to reveal complex patterns of stress, illness, and nutritional shortages that may affect plants, UAVs are invaluable in the evaluation of crop health[24]. Additionally, UAVs play a critical role in giving farmers important information on disease outbreaks and insect infestations in their agricultural lands.

Additionally, there has been a growing interest in science on the application of robotic swarms for various agricultural tasks. With the advent of tiny robots that resemble nature and work in swarms, the field of precision agriculture is changing. These biomimicry-inspired robots mimic the actions of real- world creatures and cooperate in synchronized swarms to improve farming operations including pollination, selective harvesting, and disease detection with unmatched accuracy[25]. Their size allows them to access hard-to-reach areas, minimizing crop damage and maximizing efficiency. Because of this, the use of small robots in conjunction with UGVs has the potential to completely transform current agricultural methods, improving crop quality, productivity, and sustainability while lowering the need for chemical inputs and manual labour[26].

3) Observing the Earth and using Remote Sensing

Earth observation (EO) science integrates a range of measuring techniques to evaluate the dynamic processes of our globe, providing a complete understanding of our world. These methods include in-situ data collecting, aerial surveys, and ground- based measurements[27].

As a subset of Earth observation, remote sensing focuses on gathering data via the analysis of photos taken by satellites or unmanned aerial vehicles . Simultaneously, developments in remote sensing technologies and computational capacities have transformed data provisioning, improving both spatial and temporal resolution and covering a wider range

of spectral domains for the efficient and economical monitoring of parameters such as soil , crops , and water quality. In parallel, there has been a greater emphasis on using reflected light from the sun to learn more about the state of the plants. Crucial details on vegetation production may be obtained from another source of important information in the optical and near-infrared spectrum: the fluorescence that leaves on plants due to the presence of chlorophyll[28].

Measurement of the natural electromagnetic radiation that Earth's surface objects produce or reflect is known as passive remote sensing, and it is used for activities like environmental monitoring and land cover categorization. Using sensors that record information at various wavelengths, multispectral remote sensing is essential for tracking crop health, spotting nutrient shortages, and evaluating soil characteristics. Precision agriculture relies heavily on active remote sensing, especially with radar equipment, which allows for mapping topography, measuring soil moisture, and identifying crop growth stages. Improved material identification capabilities are provided by hyperspectral remote sensing, which supports applications such as accurate crop disease diagnosis, thorough soil nutrient analysis, and identification of certain plant species. Agricultural fields are monitored for temperature fluctuations using thermal infrared remote sensing[29]. It aids in determining irrigation requirements, evaluating crop stress, and maximizing water use.

Managing large data, resolving cloud cover restrictions, and refining machine learning algorithms to solve accuracy and quality issues are examples of ongoing problems. Additionally, the introduction of new spectral sub- bands into the electromagnetic spectrum allows for a more thorough characterization of particular earthly features and phenomena[30]. These sub-bands make it easier to observe and analyze particular parameters, such as crop yield estimation, vegetation health, and soil moisture and nutrient content.

IV. IOT based smart agriculture often uses application layer protocols and communication protocols.

The Internet of Things (IOT) network uses a variety of protocols to transfer data, and these protocols play a crucial role in determining how devices interact with one another during data transfer. These protocols are a collection of logical rules and syntax that govern how the machine's network exchanges data. Choosing the right data transmission technology is important since it may greatly increase an IoT network's capacity for data transmission and efficiency[31]. This is demonstrated by strategically placing sensors and sinks.

By preventing various sensors from sharing the same data, this approach guarantees two crucial aspects: security and privacy. Energy conservation is also necessary, as it is a top concern for Internet of Things applications.

1) SENSE LAYER PROTOCOLS FOR IOT IN AGRICULTURE

The IEEE 802.15.4 standard, which is well-known for its ease of use, affordability, and low power consumption, is commonly used for perception layer protocols. This standard was created especially for Internet of Things devices with limited bandwidth and allows wireless communication at a much lower data rate Perception layer protocols are widely used by agriculture systems to rapidly and consistently get data from field sensors.

• **Bluetooth:** Utilizing radio transmissions at ultra- high frequencies (UHF) to facilitate communication across short distances, Bluetooth is a type of wireless communication.
Agricultural IOT equipment may communicate wirelessly thanks to Bluetooth. Using the 2.4 GHz radio band, Bluetooth enables connections between devices up to 100 meters distant. Due of its limited range, Bluetooth is more suitable for local communication within the farm or a specific area[32].

•**RFID (Radio-Frequency Identification):** RFID technology assigns a unique identifying number to each object in the data it captures. In the context of agriculture IOT, RFID tags may be used to track and keep an eye on a range of assets, such as goods, animals, and agricultural machinery. RFID technology is very helpful in two areas: environmental monitoring and real-time asset tracking[33].

• **Infrared:** A cheap and low-cost method for wirelessly transmitting tiny quantities of data is
infrared communication. It may be found in IOT and farm products like cameras and thermometers that track temperature and environmental variables. Many remote controls and basic electronics use infrared technology, and protocols like RCC and NEC are used to transfer data. It works well for close-quarters, short-range communication[34].

Conclusion: In summary, Bluetooth is used for short- range communication, RFID is used for asset tracking and environmental monitoring, and infrared is used for basic data transfer in the perception layer protocols of the agricultural Internet of things.

2) **PROTOCOLS FOR NETWORK LAYERS IN AGRICULTURE IOT**

The network layer of the Internet of Things in agriculture includes key components such access point networks, gateways, and routing devices that manage IP addresses and other networking functions. At this level, several protocols are used, such as WiFi and Zigbee, which are quickly taking the lead in the agricultural Internet of things. Moreover, 6LoWPAN and LoRaWAN are used to facilitate communication with wireless sensor networks.

• **WiFi:** WiFi has a data transmission speed range of 1 Mb/s to 7 Gb/s and can communicate over a distance of 20 to 100 meters. WiFi is now widely utilized in IoT-based agricultural systems to link and monitor a variety of assets, including irrigation systems, weather stations, and agricultural machinery, as it securely and effectively connects distant monitoring and control devices[35].

• **Zigbee:** An established protocol for data transmission amongst agricultural equipment is called Zigbee. The 2.4 GHz frequency band is used by Zigbee, which has a greater communication range than Bluetooth. It makes use of a mesh network topology and consists of processing gateways, network routers, and end devices[36]. the Zigbee has a number of benefits. including high network speed, quick transmission costs, and low energy use.

•**Sigfox:** Sigfox has is a low-power devices wide- area networking protocol that allows Internet of Things equipment to communicate across vast distances. It works
well for Internet of Things (IoT)
applications in agriculture that need an affordable, energyeffective link.

Sigfox technology may be used for smart drip irrigation system deployment, asset tracking, and environmental condition monitoring[37].

• **LoRaWAN:** Optimal for Internet of Things applications, LoRaWAN is a low-power, long-range wireless network based on long-range chirp spread spectrum (CSS) modulation. It is used in many different industries, including as smart cities, metering, logistics, agriculture, and more. Effective and dependable communication is made possible by LoRaWAN, addressing major issues including energy management, protecting natural resources, and averting disasters[38].

Conclusion: These network communication technologies offer a wide range of options for Internet of Things infrastructure in agriculture, accommodating different power requirements, connection needs, and geographic locations[39].

V. Challenges

- **Challenges with Connectivity:**

Concern: constant transmission as well as receiving of data is essential to IOT devices. In many rural and remote areas, there may be little or no network infrastructure, which makes it hard to have consistent connectivity. **Impact:** Limited connectivity might cause data to be lost or delayed, which may interfere with decision- making and real-time monitoring.
Solutions: Satellite internet and low-power devices widearea networks (LPWAN) are two examples of enhancements in rural internet networks that can boost connection[40]. To further help with this problem, offline storage of data that synchronizes when a connection exists should be included.

- **Privacy and Data Security: Issue:** Location, parameters of the environment, and maybe also user specifics are among the many sensitive data points that Internet of Things devices gather. **Effect:** Improper access to data or data breaches may result in data modification, intellectual property theft, or a loss of confidence.

Responses: To safeguard data, use strong encryption techniques, frequent software upgrades, and effective authentication procedures. Additionally crucial are regular security assessments and adherence to information security laws[41].

- **Interoperability and Integration:**

Issue: multiple producers' devices frequently use multiple connection protocols and standards in IoT ecosystems
Impact: Inefficiencies and a disjointed user experience may result from challenges in merging these separate systems.
Solutions: You could improve interoperability by standardizing communication protocols and using open standards. IoT interface solutions and other platform that provide collaboration can also aid in bridging gaps amongst various systems[42].

- **Exorbitant starting costs**

Problem: The cost of sensors, connection infrastructures and data analytics platforms may all add up to a significant initial investment in IoT technology.
Impact: Ridiculous expenses can be a serious obstacle, particularly for tiny farms or those operating in underdeveloped nations. **Solutions:** One way to reduce upfront expenses is to look into government grants, subsidies, or sharing costs schemes[43]. Additionally, structures that are scalable and adaptable enable incremental growth and investments.

- **Energy Use:**

Problem: Obtaining a steady power source for IoT devices might be difficult in isolated or off-grid areas. **Impact:** Device functioning and data transfer may be hampered by energy-related problems. **Solutions:** Sustainable electrical power may be obtained by utilizing solar energy, energy-efficient appliances, or alternative forms of energy. Low-power design concepts and energy collecting machines can help lower total energy needs[44

VI. Conclusion

An in-depth and methodical examination of connected to IoT systems for farming is given in this review paper, including technological breakthroughs, advances in the sector, equipment long-term viability usage, communicating guidelines, research needs, important problems related to privacy and security, as well as remedies that are unique to the Internet of Things in agriculture and cutting-edge Usage of machine learning and its approaches in intelligent agriculture. ZigBee, wireless internet, SigFox, and LoRaWAN are just a few of the wellknown network protocols that are covered in-depth in this paper on the architecture of IoT WSN interaction with networks communications in the SA domain. These protocols have shown to be very helpful in IoT- WSNs SA usage, including as energy-saving techniques, early-stage insects and agricultural illness management, nutrient efficiency and control, systems for irrigation, and soil- moisture tracking.

The study emphasizes how crucial it is to carry out ongoing studies and research in order to get over these challenges and successfully use IoT technology. By concentrating on those fields, the agriculture sector may increase durability and production, which will eventually help the world's efforts to accomplish sustainability as well as nutritional safety targets.

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