Short Communication

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IoT Innovations Revolutionizing Agricultural Practices for Sustainability

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ABSTRACT

This abstract provides an overview of the dynamic landscape of Internet of Things (IoT) solutions in agriculture, illustrating their potential to revolutionize farming practices and enhance agricultural productivity. It begins by elucidating the fundamental concepts of IoT and its application in agriculture, emphasizing the integration of sensors, actuators, and connectivity technologies for real-time data collection and analysis in agricultural environments. The subsequent section delves into various IoT applications in agriculture, including precision irrigation, soil monitoring, crop health monitoring, and animal management. These applications empower farmers to make data-driven decisions, optimize resource utilization, and increase yield outcomes while minimizing environmental impact, the abstract underscores the role of IoT in promoting sustainable agricultural practices by reducing water usage, optimizing fertilizer application, and mitigating greenhouse gas emissions during agricultural production, it addresses the challenges and opportunities associated with the adoption of IoT in agriculture, such as concerns regarding data privacy, limitations in technical infrastructure, and the digital divide in rural areas. Overall, this abstract highlights the transformative potential of IoT solutions in agriculture and underscores the importance of ongoing research and collaboration to unlock the full benefits of these solutions for farmers and food systems worldwide.

Keywords: *Internet of Things, data, agriculture, sustainable, farmers*

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Introduction

Among the numerous industries that have been significantly impacted by the Industrial Internet of Things (IoT), agriculture is one of the most prominent examples. The market for connected agriculture reached 1.8 billion US dollars in 2018, and it is estimated that it will climb to 4.3 billion US dollars by 2023 at a compound annual growth rate (CAGR) of 19.3% [1]. This means that the market is expected to reach 4.3 billion US dollars. Internet of Things (IoT) technology has made it feasible to construct intelligent wearables, networked devices, automated machinery, and autonomous autos. These advancements have been made possible by the Internet of Things. The growing population of the globe, which is projected to reach 9.6 billion by the year 2050 [2], has a particularly significant influence on the agricultural industry. Internet of Things is helping to fulfill the need for new food items by addressing challenges such as severe weather conditions, climatic changes, and environmental effects. This is contributing to the fulfilment of the requirement for additional food items. The second half of the 20th century saw the introduction of mechanical technologies into agricultural activities. These inventions included harvesters and tractors, among others. As the need for food continues to rise, the agricultural industry is becoming more reliant on innovative concepts [3].

A compound annual growth rate of twenty percent is expected to be seen in the use of intelligent solutions that are driven by the internet of things in agricultural operations over the course of the next several years. From the year 2014 to the year 2024, it is anticipated that the number of linked devices in the agriculture industry would expand from 13 million to 225 million [4]. The deployment of satellite connections and the development of cellular networks are both being pursued by network operators despite the challenges that arise from the lack of trustworthy communication network infrastructure in less developed or rural areas. Both of these initiatives are being carried out concurrently. It is now possible for farmers to examine the quantity of water that is contained inside their tanks in real time, which has led to the development of more efficient irrigation methods [5]. This is made possible by the development of more advanced sensors in the agricultural industry. The Internet of Things in agriculture has become a second wave of the green revolution, which is helpful to farmers since it lowers costs and boosts yields while also improving decision-making with accurate data [6]. This is a way that farmers may benefit from the green revolution.

Application of IoT

The use of modern technology, namely the Internet of Things in agriculture, has a number of advantages, including the following:

Climate Conditions

The weather is a substantial component that has a significant role on agricultural productivity. On top of that, having an erroneous knowledge of the climate has a substantial detrimental influence, not only on the quantity of agricultural production but also on the quality of such output for agricultural purposes. On the other hand, technologies that are implemented via the Internet of Things make it possible for you to be aware of the present weather conditions in real time. The sensors that have been deployed may be found both within and outside of the agricultural fields [7]. [8] They collect data from the environment that is around them, which is then used in the process of picking the suitable crops that are able to thrive and persist in the particular climatic conditions that are there. The Internet of Things ecosystem is made up of sensors that are able to accurately monitor real-time weather factors such as temperature, humidity, and rainfall, amongst others. Each and every component of this ecosystem is made up of sensors. The ability to discover a big number of sensors that are capable of detecting all of these aspects and setting them in a way that is suitable for your smart farming requirements is something that is achievable. Not only do these sensors monitor the quality of the crops, but they also monitor the meteorological conditions that are occurring in the surrounding area. An alert will be sent in the event that any weather conditions that are deemed to be concerning are identified [9]. As a consequence of this, the need of physical presence during climatic conditions that are disruptive is decreased, which eventually results in an increase in productivity and supports farmers in reaping better benefits from agriculture [10].

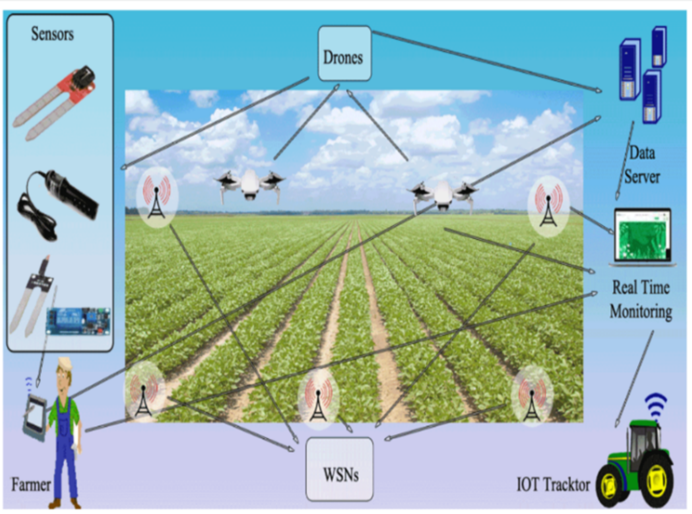

Fig 1: Source from Google Scholar: Open access

Precision farming

Precision farming, also known as precision agriculture, has revolutionized the agricultural landscape by leveraging the Internet of Things (IoT) technology. By integrating smart farming applications such as animal monitoring, vehicle tracking, field observation, and inventory monitoring, precision farming empowers farmers with accurate and controlled farming experiences [11]. Through the deployment of sensors, precision farming collects vast amounts of data, which is then analyzed to inform intelligent and responsive decision-making. This data-driven approach is integral to optimizing agricultural production. Precision farming encompasses various techniques, including the precise control of irrigation systems, efficient management of livestock, monitoring of agricultural machinery, and implementation of diverse agricultural practices. By harnessing the power of IoT and data analytics, precision farming significantly enhances both the efficiency and sustainability of agricultural processes, precision farming holds promise for addressing key challenges facing modern agriculture, such as resource optimization, environmental sustainability, and yield maximization. By enabling farmers to make informed decisions based on real-time data insights, precision farming represents a transformative force in shaping the future of agriculture. [12]. By analyzing the conditions of the soil and other elements associated to it with the aid of precision farming, you are able to increase the operational efficiency of your farming activities. This is possible because precision farming allows you to analyze how the soil is. In addition to this, you are able to assess the real-time operating conditions of the devices that are connected together in order to ascertain the quantity of water and nutrients that are present [13].

Smart Greenhouse

The Internet of Things has made it possible for weather stations to automatically adjust the temperature conditions in line with a specific set of instructions. Therefore, our greenhouses have grown more intelligent as a result of this development. As a consequence of the elimination of human involvement in greenhouses brought about by the use of Internet of Things technology, the whole process has seen an increase in precision while simultaneously seeing a decrease in expenses [14]. For instance, the use of sensors that are powered by solar energy and are connected to the Internet of Things makes it possible to develop modern greenhouses that are also economical. The gathering and transmission of real-time data is made possible by these sensors, which allows the greenhouse to be monitored in a way that is both very precise and in real time. Because of the sensors, it is possible to keep track of the amount of water that is being used in the greenhouse as well as the current condition of the greenhouse via the use of email or text message alerts. The Internet of Things makes it possible to create irrigation systems that are both intelligent and equipped with automated controls. With the aid of these sensors, it is possible to get information on all of the following: pressure, humidity, temperature, and light levels [15].

Data Analytics

The limitations of traditional database systems in accommodating the vast amounts of data generated by IoT sensors have prompted the adoption of cloud-based data storage and comprehensive IoT platforms in intelligent agriculture systems. These components are crucial for the successful implementation of activities, leading to superior outcomes [16]. In the realm of IoT, sensors serve as the primary data collection mechanism on a large scale. Through data analytics, this information is transformed into actionable insights, facilitating the examination of crop conditions, livestock health, and weather patterns [17]. Data analytics enables more informed decision-making by leveraging technological advancements. Real-time monitoring of crop conditions via IoT-connected devices provides immediate insights, while predictive analytics aids in optimizing harvesting decisions [18]. Trend analysis allows farmers to better anticipate weather patterns and plan crop harvesting accordingly. Consequently, IoT technologies have empowered farmers to increase both the quantity and quality of their produce by safeguarding crop quality and soil fertility [19]. This dual approach has enabled farmers to boost productivity while simultaneously enhancing the quality of their agricultural products.

Agriculture-related drones

Agricultural operations have been practically totally transformed as a result of technological advancements, and the introduction of agricultural drones is the disruption that is now dominating the industry. Ground and aerial drones may be used to perform a variety of functions, including but not limited to: assessing the state of the crop's health; monitoring the crop; planting the crop; spraying the crop; and doing field analysis. The use of drone technology has resulted in a huge boost and change for the agricultural sector [20]. This has been accomplished via the utilization of proper strategies and planning that are based on real-time analytics. Drones that are fitted with thermal or multispectral sensors are used to locate the areas of the crop that need modifications to the irrigation system. In the moment that the plants start to grow, sensors will start assessing their current state of health and calculating their vegetation index. With the passage of time, intelligent drones have been able to reduce the impact that they have on the surrounding environment. Because of the results, there has been a considerable reduction in the quantity of chemical that has found its way into the groundwater [21]. This is due to the fact that the outcomes have been such that there has been a large drop.

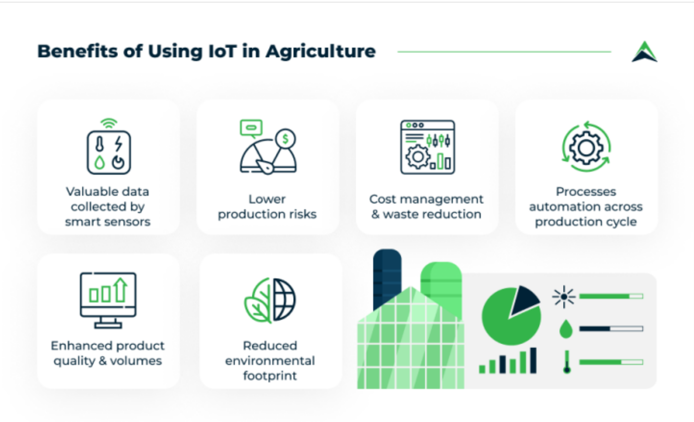

Fig 2: Source from Google Scholar: Open access

Challenges Facing the Construction of the Platform for the Internet of Things

- A single solution that is capable of being integrated with a variety of devices that are connected to the Internet of Things.
- In the field of agriculture, connection is the most prevalent obstacle that the Internet of Things must overcome. There is not a single location that has adequate internet access [22].
- The lack of understanding among customers is the second most prevalent difficulty that advanced agriculture that is based on the Internet of Things faces.
- When there are many distinct service providers, it becomes very challenging to maintain interoperability across the many Internet of Things platforms.
- The technology is scalable and can be combined with thousands of Internet of Things devices, making it suitable for huge farms [23].
- Opportunities for the Development of Intelligent Agriculture Through the Utilization of the Internet of Things With the use of sensors (light, humidity, temperature, soil moisture, and so on), as well as the automation of irrigation systems, smart farming has made it possible for farmers to reduce the amount of resources that they waste while simultaneously increasing their total productivity. Furthermore, with the aid of these sensors, farmers are able to monitor the status of the field from any area in the world from any location [24]. A comparison between the conventional approach and the Internet of Things-based Advanced Farming demonstrates that the latter is far more effective than the former. There are a variety of uses of intelligent agricultural methods, and the primary emphasis of these applications is not limited to conventional and large-scale farming. With operations, but might also be new levers to elevate other developing or common trends in agriculture like organic farming, family farming (complicated or limited areas, special livestock and/or cultures, preservation of specific or high-quality types, etc.), and boost highly transparent Farming [25]. The Internet of Things Hub, which functions as the fundamental unit in Azure, makes it possible to connect, monitor, and manage millions of devices via the use of bi-directional communications. This is made possible by the Internet of Things Hub. AMQP, MQTT, and HTTP are the protocols that it supports when it comes to talking with devices that are connected to the Internet of Things. In the case that a device does not support AMQP, MQTT, or HTTP, it is also helpful for the device to have its own protocol gateway, which is made possible by the Azure Internet of Things Protocol Gateway [26,27].

IoT problems in the agricultural sector

It is possible that a smart agricultural system that makes use of Internet of Things and big data technologies would be the industry's salvation. The integration of technology into conventional agricultural practices, on the other hand, has not been without its own set of challenges.

Interconnections A link must be established across the whole of the agricultural environment in order for an Internet of Things system to work correctly [28]. This includes fields, barns, greenhouses, and any other buildings that may be there. This constitutes a significant amount of room when it comes to dealing with it. Additionally, it should be a connection that is reliable and uninterrupted, and it should be able to withstand unfavorable weather conditions and open space settings [55,56]. In an ideal situation, it should be able to maintain these characteristics.

Regarding the Internet of Things in general, however, connectivity remains a problem that has to be addressed. For the purpose of data transmission, different systems make use of a wide range of protocols and methods. This is the reason for this phenomenon. It is hoped that efforts to govern this sector, the introduction of standards, as well as the development of 5G technology and the space-based Internet, will soon be able to overcome this issue and offer a connection to the Internet that is both quick and reliable for any space, that is, regardless of the size of the space or the circumstances that it is in [29].

Design and long-term durability

Any Internet of Things system that is used in agriculture should not only be able to manage connection, but it should also be able to handle the circumstances that are present in locations that are outside of the farm environment. In order for technologies like drones, portable sensors, Internet of Things (IoT) in smart grids, and weather monitoring stations to be able to "work in the farm," they need to have a design that is not only simple but also helpful, and they also need to have a certain degree of resilience [30]. That is not even mentioning the challenges and idiosyncrasies that are involved in the production of an Internet of Things product in general. As a side point, do you have a project that involves intelligent agriculture and needs designers and developers that are not just clever but also skillful in order to put it into practical use? You should get in contact with our team so that we can have a discussion about how to make it happen and start building a product that will transform the industry as soon as tomorrow [31].

Limited time and resources available

The fact that the deployment of intelligent technology in agriculture takes place within the context of a dynamic environment that is always changing and a shortage of time, the Internet of Things (IoT) plays a very major role in agriculture. This is the case despite the fact that the amount of time available is limited. The companies that are in charge of designing and developing the Internet of Things (IoT) for agriculture are required to take into consideration the rapid climate change and the increasing frequency of extreme weather conditions, in addition to the limited supply of land and unfavourable circumstances such as the extinction of pollinators [32,55].

The fact that these conditions have resulted in the creation of a great number of forward-thinking projects is one of the good aspects these circumstances have brought about. Deutsche Telekom, for example, has constructed connected beehives, and Square Roots, which was established by Elon Musk's younger brother Kimbal Musk, has produced urban farms that are housed in shipping containers [33]. Both of these companies are examples of innovative approaches to urban farming.

Despite the fact that the deployment of intelligent technology in agriculture takes place within the context of a dynamic environment that is always changing and a shortage of time, the Internet of Things (IoT) plays a very major role in agriculture. This is the case despite the fact that the amount of time available is limited. The companies that are in charge of designing and developing the Internet of Things (IoT) for agriculture are required to take into consideration the rapid climate change and the increasing frequency of extreme weather conditions, in addition to the limited supply of land and unfavourable circumstances such as the extinction of pollinators [32,55]. The fact that these conditions have resulted in the creation of a great number of forward-thinking projects is one of the good aspects these circumstances have brought about. Deutsche Telekom, for example, has constructed connected beehives, and Square Roots, which was established by Elon Musk's younger brother Kimbal Musk, has produced urban farms that are housed in shipping containers [33]. Both of these companies are examples of innovative approaches to urban farming.

Agricultural Technology

Utilizing Digiteum to put Internet of Things technology into effect in the agricultural sector. The realms of agricultural technology and the internet of things are areas in which our teams have a broad variety of knowledge. Throughout the course of the last several years, we have been working with clients in the agriculture business who are either just beginning their careers or have already reached the enterprise level. Over the course of this time period, we have made contributions to the development of a wide range of technologies that are capable of managing field analytics, geomapping, people, and documents [34,54]. Beginning in the year 2020, we have been working together with a startup firm based in the United States that specializes in agricultural technology and precision agriculture on a number of different research and development initiatives. The purpose of these projects is to improve operational efficiency and introduce automation to the agricultural sector. These projects involve the creation of proof-of-concepts as well as the examination of the possible uses of data science and the Internet of Things. We have given a number of automation services for the management of people during the 2019-2020 fiscal year [35] as part of our partnership with a large Canadian company that specializes in the area of agricultural technology.

Fig 3: Source from Google Scholar: Open access

Advantages in agriculture

Technologies and IoT can greatly impact agriculture in various ways. Smart agriculture sensors collect a wealth of data encompassing weather conditions, soil quality, crop growth progress, and livestock health, offering valuable insights into various facets of your agricultural operations, including overall performance, staff productivity, and equipment efficiency [36]. Optimized internal processes translate into reduced production risks. With a clear grasp of anticipated production outcomes, you can devise strategies for more efficient product distribution. Accurate predictions of crop yield ensure efficient sales and minimal wastage [37,51]. Enhanced cost management and waste reduction result from better production control. By closely monitoring crop growth and livestock health, potential risks of yield loss can be effectively minimized [38]. Business effectiveness is heightened through process automation. Smart devices facilitate the streamlining of various production cycle processes, such as irrigation, fertilization, and pest control [39,52]. Product quality improves and production volumes increase with enhanced control over the production process. Automation enables the maintenance of superior standards of crop quality and growth capacity [40,53]. Environmental impact is minimized through automation, yielding positive environmental outcomes. Smart farming technologies offer precise coverage, reducing the need for pesticides and fertilizers and consequently lowering greenhouse gas emissions [41].

The advantages of the Internet of Things in agriculture
The use of the Internet of Things in agriculture offers hitherto inaccessible levels of efficiency, reductions in resources and costs, automation, and data-driven operations. This is similar to what is seen in other sectors' applications. Within the realm of agriculture, on the other hand, these advantages do not function as enhancements; rather, they serve as remedies for the whole sector, which is struggling with a variety of hazardous issues [42].

Exceptional levels of productivity
Competition is fierce in the contemporary agriculture sector. In spite of the fact that the soil is decreasing in quality, there is a decrease in the amount of land that is accessible, and the weather is getting more unpredictable, farmers are making efforts to boost their production. As a result of the Internet of Things (IoT) in agriculture, farmers are now able to keep track of their goods and the circumstances in which they are stored in real time. It is possible for them to get insights in a short amount of time, to foresee issues before they emerge, and to make decisions based on correct knowledge on how to avoid problems from occurring. Additionally, Internet of Things (IoT) solutions in agriculture bring about automation, such as harvesting robots, watering robots, and fertilization robots that are dependent on demand [43,50].

Spreading out
As the global population approaches 9 billion, with seventy percent expected to reside in urban areas, the demand for innovative food production solutions becomes imperative. Utilizing greenhouses and hydroponic systems powered by the Internet of Things (IoT) presents a viable strategy for shortening the food supply chain and providing fresh fruits and vegetables to urban populations [44]. Advancements in closed-cycle agricultural systems have made it possible to cultivate food in diverse environments, including supermarkets, on the walls and rooftops of skyscrapers, within shipping containers, and even within individual residences. These sophisticated systems leverage IoT technology to monitor and control various parameters such as temperature, humidity, nutrient levels, and light intensity, ensuring optimal growing conditions and maximizing yield efficiency. By integrating IoT-powered agricultural solutions into urban landscapes, cities can enhance food security, reduce dependence on distant agricultural regions, and mitigate the environmental footprint associated with traditional farming practices. This paradigm shift towards localized, technology-driven food production holds the promise of creating more sustainable and resilient food systems to meet the needs of an increasingly urbanized world.

Less available resources
Indeed, maximizing resource efficiency, including water, power, and land, is a primary objective of numerous Internet of Things (IoT) solutions in agriculture. These IoT-driven farming practices rely on data collected from an array of sensors strategically positioned throughout the field. By harnessing this data, farmers can precisely manage and allocate resources to ensure that each plant receives the optimal amount necessary for healthy growth and development [45]. This data-driven approach enables farmers to implement targeted irrigation schedules, adjust nutrient levels, and optimize energy usage based on real-time environmental conditions and plant needs. By leveraging IoT technology, agricultural operations can minimize resource wastage, enhance crop yields, and promote sustainability in farming practices.

More hygienic method
The Internet of Things (IoT) is a real method that may be used to reduce the quantity of fertilizers and pesticides that are now utilized in agricultural practices. Precision farming not only helps farmers save water and energy, but it also makes farming more ecologically friendly. Precision farming is become more and more popular. A further benefit is that it significantly cuts down on the quantity of fertilizer and pesticides that are used in agricultural production. Because of the utilization of this technology, it is possible to generate a final product that is not only more organic but also more environmentally friendly in comparison to the traditional farming practices [46].

Application of the Internet of Things in renewable energy
The use of the Internet of Things in agricultural settings comes with a number of benefits, one of which is an increase in the operations' degree of agility. Real-time monitoring and prediction technologies enable farmers to promptly respond to any significant change in the weather, humidity, air quality, and the general health of each crop or soil in the field. This allows farmers to maximize their farming productivity. Since this is the case, farmers are able to make choices that are more informed than ever before. As a result of the current abilities that have been gained, agriculture professionals are now able to protect crops even when they are subjected to unfavorable weather circumstances [47].

Elevated level of product quality
Data-driven agriculture enables farmers to cultivate not only increased quantities but also superior quality products. Leveraging various technologies such as soil and crop sensors, aerial drone monitoring, and farm mapping, farmers gain a comprehensive understanding of the intricate interplay between environmental factors and crop quality. By utilizing this wealth of data, farmers can replicate ideal growing conditions and enhance the nutritional attributes of their produce through integrated systems [48,49]. This approach allows for precise management of variables such as soil moisture, nutrient levels, pest infestations, and microclimatic conditions, thereby optimizing crop health and quality. By integrating data-driven insights into their farming practices, growers can consistently produce high-quality crops with desirable characteristics, meeting consumer demands for nutritious and flavorful produce.

Conclusion

In conclusion, the use of Internet of Things (IoT) solutions in agriculture shows a great deal of potential for tackling critical difficulties that are currently being faced by the agricultural sector, while also supporting agricultural practices that are sustainable and increasing overall production. Farmers are able to have access to real-time data and insights into numerous elements of their operations by using Internet of Things technology. These aspects include the management of livestock and irrigation, as well as the health of the soil and the conditions of the crops. Taking this strategy, which is driven by data, makes it possible to make decisions that are better informed, which ultimately results in increased resource efficiency, optimal yields, and less environmental impact. In order to successfully use the Internet of Things (IoT) in agriculture, it is necessary to overcome a number of hurdles. These problems include issues around data security and privacy, as well as the need to provide accessibility for farmers who live in locations that are underserved or distant. Moving ahead, it will be vital to maintain research, innovation, and cooperation across stakeholders in order to achieve the full potential of the Internet of Things (IoT) in agriculture and to establish a food system that is more robust, efficient, and sustainable for the future.

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