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A REVIEW ON IOT FOR AGRICULTURAL APPLICATIONS

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ABSTRACT

Agriculture is done in every country by manually from ages. Agriculture is the main source of food in society, providing nearly 80% of the total consumed food. It generates employment both for rural agricultural and non-agricultural labour, import and export activities over the international business. Agriculture also helps in balancing the ecosystem. The world is moving towards new technology and applications; therefore it makes sense to follow up with agriculture. An essential component of smart agriculture is the Internet of Things. IoT sensors have the ability to provide data on agricultural lands. IoT in agriculture refers to smart devices and sensors that they would monitor soil moisture, climate monitoring, temperature, crop health, nutrient content, precision farming, pH balance and other parameters in real time. By using the information from different sensors, farmers can make better decisions, such as the best time to plant or harvest and become more efficient, which results in increased yield production with lesser costs for long-term sustainability. The linkage of agricultural equipment by farmers like tractors, water pumps and drones helping farmers to manage their farms better. Further, IoT technologies make remote farm monitoring and management by farmers quite easier. The IoT has a critical future in agriculture because of the long-term gains in increased yields, reduced waste, and more efficient use of natural resources.

The Term paper mainly focus on the following topics:

- Basics of IoT
- Applications of IoT
- IoT for Agricultural applications
- Implementation of IoT for Agricultural applications (challenges & opportunities)

Keywords:
IoT, sensors, automated irrigation system, climate monitoring system, crop health, precision farming, long-term sustainability.

I. Introduction

The integration of cloud computing and IoT technologies like sensors in agriculture is covered in the study. With respect to trends, opportunities, and challenges in smart agriculture focused around India, traditional practices prevail. Techniques in precision farming and water management-otherwise used by migrants returning during the pandemic-can enhance agricultural productivity and efficiency.

Crop yield enhancement, resource waste reduction, wireless and manual control, and a mobile app are all features of an IoT-based smart agricultural robotic system that can increase profitability while causing the least amount of environmental harm.

The Internet has made possible the integration of the real and virtual worlds through IoT applications in agriculture. Connected it also solved the food security problems that grew with the people, and finally improved productivity in agriculture efficiency. Key issues in using wireless sensor networks for smart agriculture revolve around security, and data governance.

This paper also includes reviews of agricultural automation cases applying IoT and analysis of the limitations. Water content, soil quality, radiation, among others. Smart farming contributes to precision by better management of farm works and prompt decision making based on acquired data And also attempts to compare various communications technologies for IoT in agriculture and discusses security and privacy challenges in IoT agriculture.

Agriculture 4.0, underpinning IoT's role in the development of modern agriculture techniques and their ability to enhance crop production and profitability. It also enumerates various technological and application-wide trends in agriculture, including smart agriculture and AI.

1.IoT and agriculture

When IoT is combined with smart sensors and artificial intelligence, it holds a lot of potential in collecting and analyzing real-time data on crop quality, productivity, water levels, and soil health at a given site. Traditionally, agriculture has been displaced by the smart farming which boasts yield with higher values. IoT-based techniques perform well in analysis for soil fertility, health, erosion, and application of fertilisers as well as general quality of crop. Moreover, they have significant importance in smart irrigation, seed quality observation, and crop development monitoring at different stages. Data obtained through IoT and remote sensing might be used by precision farming in forestry and agriculture. Including smart sensors, techniques such as infrared thermography could give detailed information on the topography of agricultural land. In pre- and post-monitoring situations, IoT devices and soil moisture sensors assist.

Fig 1 IoT and agriculture**lications of IoT in agriculture:**

II. Literature

Below are the major applications of IoT in agriculture:

✓ Crop Monitoring and Disease Detection
✓ Smart Irrigation System
✓ Livestock Monitoring
✓ Greenhouse Automation
✓ Soil Health Monitoring
✓ Weather Forecasting and Monitoring
✓ Supply Chain and Inventory Management
✓ Automated Farm Equipment
✓ Unmanned Aerial Vehicles (UAVs)
✓ Smart Pest Management
✓ Farm Infrastructure Monitoring from a far distance
✓ Water Management and Conservation
✓ Field Mapping and Geolocation

2.1 Crop Monitoring and Disease Detection

With the introduction of IoT in agriculture, there has been a transition from centuries-old traditional qualitative crop monitoring-practice dependent on experience-to an accurate and highly quantitative data-driven practice. Farmers can also benefit by providing them with the resources to monitor crop health and growth, pest invasions, and risks of disease in real-time. The IoT sensor plays a very important role in this to recording the data for various environmental conditions such as temperature, humidity, soil moistures and nutrient levels etc. continuously. Generally, these sensors are connected in a network having the objective of sending data to cloud systems for real-time monitoring & data gathering.

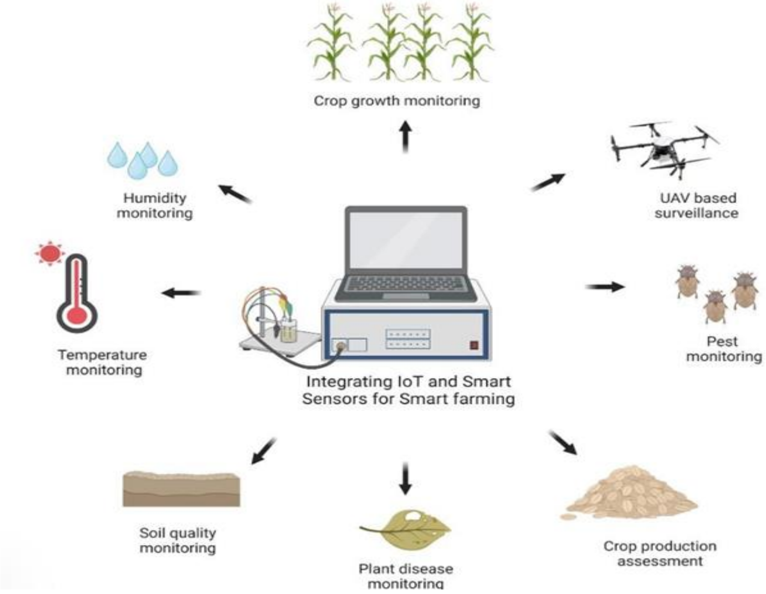


Fig 2 IoT and smart sensors integration results in precision farming, where accurate information regarding all environmental factors for assessment of soil quality detection of diseases and pests taking place in plants, UAV survey, and crop production prediction.

The data collected from such IoT systems can be used for changing patterns of advanced data analytics, primarily machine learning, which provide information regarding the health of crops, number of possible yields and ways that selected crops may grow. These inputs assist in taking informed decisions regarding the most critical aspects of crop management– irrigation, fertilizer and pest management, as well as harvesting schedules. That means they are in a position to optimize resources, reduce costs, and enhance quality and quantity of the produce.

IoT is all set to transform modern farming practices by offering the possibilities of real-time, high-precision crop health observation. An IoT-based system uses wide networks of sensors placed throughout the field to monitor how critical environmental factors, ranging from soil moisture and temperature, humidity, and nutrient levels, are differing. These sensors continuously gather data and transmit it to cloud-based platforms for analysis. It employs machine learning algorithms and advanced data analytics in processing the data in order to evaluate general crop health, identify pre-symptomatic diseases and infestations by pests, and predict outcomes for yield. It detects the disease stress, nutrient deficiencies, or adverse weather events and can help the farmer take timely action through adjustments in irrigation, fertilizers, or the use of pest control measures. These proactive measures reduce crop damages enormously and reduce the usage of pesticides in farming hence making farming sustainable. IoT-enabled systems can alert the farmer of any abnormal condition or outbreak, giving him the time to take actions to prevent actual outbreaks of diseases. With accurate data-driven insights provided by IoT technology, the crop is efficiently managed, resulting in optimum productivity and healthier crops free of disease.

2.2 Smart Irrigation System:

The Smart Irrigation System in agriculture makes a better use of irrigation water. Smart irrigation systems are fundamentally different from traditional irrigation methods that relied on fixed schedules or manual assessment for actual real-time data regarding soil moisture, weather conditions, and plant water requirements. Monitoring soil moistures and environmental conditions from the fields via sensors placed in the field is transmitted to a centralized platform or cloud. It can then automatically change its irrigation schedules according to the received data, hence ensuring that crops get the right measure of water at the appropriate time as well as reduces wasting water.

The gains of the smart irrigation system are awesome, especially in regions where water is a precious commodity. Such types of systems help save water, produce higher yields of crops, and use less energy through accurate irrigation according to real-time requirements. Data analytics, thus integrated with the system, can predict patterns of usage of water, pick up problems such as leaks, or over-irrigation, and provide insights for optimization of irrigation practices. The smart irrigation systems can be controlled through an application on a mobile phone or computer software from anywhere in the world, which is efficient but highly convenient.

2.3 Livestock Monitoring:

Livestock monitoring is the application of technology as well as data-driven applications regarding the tracking of health, behaviour, or productivity of farm animals. Advances in sensor technology and wearables, locating GPS devices, constitute new ways to continuously monitor key vital information about body temperature, movement patterns, feed intake, and reproductive status of farm animals. They could detect early warning signs of illness or distress, thus hastening intervention with a possibility of risk reduction for disease outbreaks.

Livestock monitoring improves the health and welfare of animals besides making the practice more sustainable by optimizing the usage of resources. For example, close tracking of feed consumption minimizes waste because the right nutrition for animals leads to improved growth rates and increases the quality of the produced meat or milk. Just as feed, pasture use is made easier by monitor systems since the animals can be allowed to roam freely with grazing without overloading land.

Livestock monitoring improves the health and welfare of animals as well as makes farming more sustainable by optimizing the usage of resources. Specifically, close tracking of feed consumption minimizes waste as the right nutrition for the animals leads to improved growth rates and an increase in the quality of meat or milk produced. Similar to feed, pasture use becomes easier with monitor systems since the animals can be set loose to graze without overloading the land.

2.4 Greenhouse Automation

Greenhouse automation in agriculture is the use of advanced technologies and systems to control and monitor a host of environmental variables within a greenhouse. Automation can help optimise plant growth, enhance yields, and reduce labor costs. Such greenhouses are controlled through automated systems that regulate temperature, humidity, light levels, irrigation, and CO2 concentration in order to create ideal external conditions for the continuous development of plants despite adverse external weather. Greenhouse automation integrates sensors, actuators, and controllers to ensure that a plant receives the precise conditions needed at its various growth stages.

One of the elements within the greenhouses automation system is climate control, which monitors and manages variables such as ventilation, shading, heating, and cooling systems. The variables are adjusted according to live data received from soil moisture sensors measuring the internal conditions of the plants. Automated irrigation systems are also essential in conserving water through the measurement of soil moisture by the sensors. This automatically stops the water supply so it does not over-irrigate.

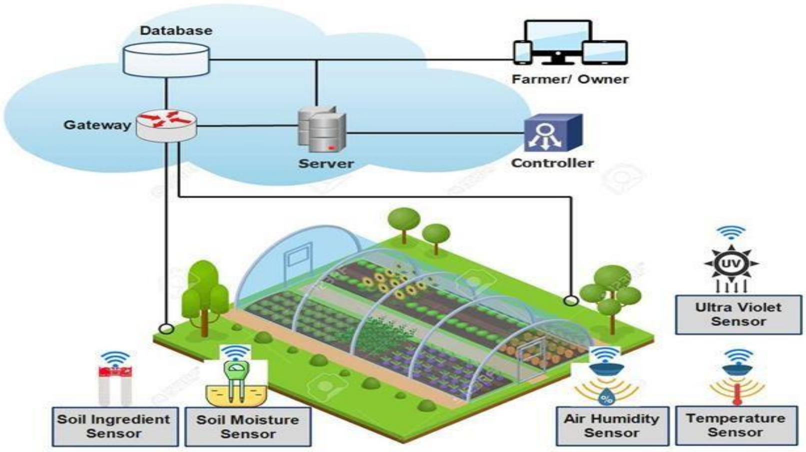


Fig 3 Internet of Things application for tracking greenhouse agricultural conditions.

2.5 Soil Health Monitoring:

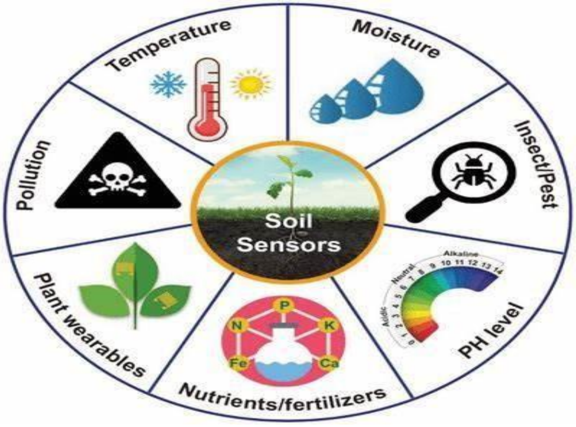


Fig 4 Smart agriculture monitor soil health

Soil health monitoring in agriculture: high tech and high touch technologies to assess and manage the soil status for optimal plant growth, productivity, environmental sustainability Soil health is essential for sustainable agricultural systems to maintain nutrient cycling, water storage and biodiversity over the long term. Some of the parameters that are monitored include Soil pH, Organic matter, Nutritional levels, Moisture, Temperature, and Microbial Activity. If farmers monitor such indicators regularly, they will be able to pick on the deteriorative state of the soil in terms of nutrient deficiencies, erosion, or compaction long before it impacts negatively on crop performance.

Today, our soil health monitoring is based on a mix of in-field sensors, remote sensing technologies and laboratory soil tests providing real-time data and the clearest detail. Sensors can be installed in the soil to learn more about moisture levels or nutrient availability, while satellite imagery and drones can understand soil texture, moisture, and vegetation health over extensive regions. The farm management software can incorporate this data and offer insights that allow farmers to customize fertilizer application, irrigation and rotation based on the condition of soil.

Soil health approach enables farmers to minimize the use of chemical inputs (synthetic fertilizers and pesticides) hence makes farming eco-friendly and minimizes pollution. Healthy soils are also stronger towards climate change-induced extreme weather events such as floods or droughts, increasingly a need with increased numbers and intensities of these events. Monitoring of the soil health is fundamental for cultivating agricultural lands without harmful effects on the ecosystem and the safety of food, demanding more work towards the utilization of agriculture resources sustainably for the future generations.

2.6 Automated Farm Equipment

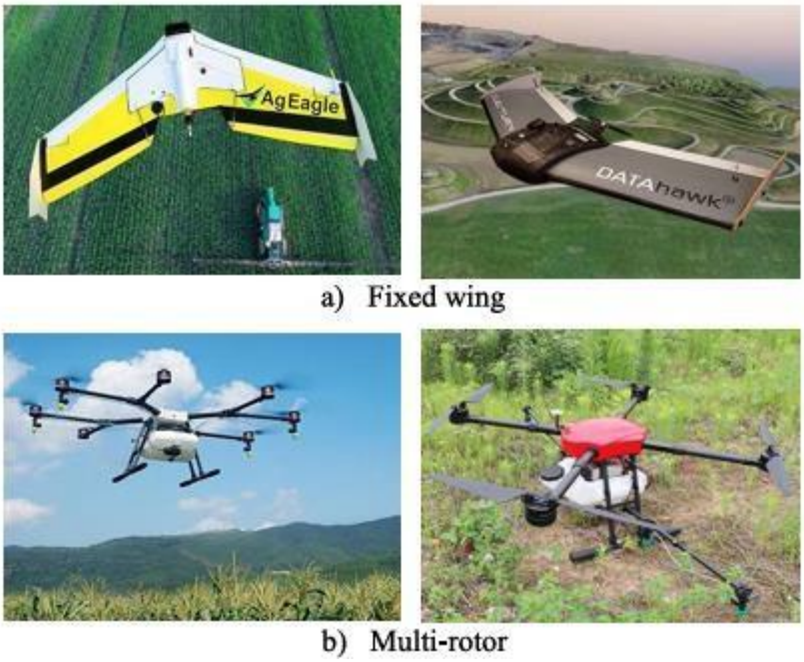
Modern agriculture grew and merged with itself into robotics, artificial intelligence, and data-driven technologies to achieve more productive yields without undoing sustainability in the search for more efficient yields. The machines in question have replaced labor-intense roles associated with planting, harvesting, tilling, and irrigation by making those transitions efficiently. Examples of the known tractors and harvesters mounting with GPS and AI makes optimization of the soil condition, crop health, among other environmental variables to optimize the performances. For example, tillage, sowing seeds, and applying fertilizers are done by self-driving tractors; therefore, requiring at least a minimum from the operators while making them focus on other key responsibilities. Drones would be sensor-equipped so they could monitor crop health and detect pests and deliver pesticides or fertilizers precisely where needed in order to minimize waste and environmental impacts. The machine harvester would be able to assess and mechanically harvest crops when they are mature to ensure that the harvest operation is more efficient and there is no crop destruction by human labor.

In general, the obvious benefits of mechanized farming machinery are the time-saving, low labor cost, high yield, and minimal consumption of resources. Yet, there are still concerns: high costs to implement, maintenance, and ensuring farmers learn to operate new technologies. Indeed, there are substantial concerns regarding the safety of data and loss of work in traditional agriculture; however, these are concerns that should be seriously addressed given these technologies do evolve. Mechanization in farming is undoubtedly part of the way a growing global population can better meet these increasing demands.

2.7 Unmanned Aerial Vehicles (UAVs)

Unmanned aerial vehicles, or drones, are quickly becoming essential in a wide range of sectors, including logistics, agriculture, and environmental monitoring. Drones are able to obtain overhead photographs that were previously thought to be very difficult to record and may readily deliver quick information. Drones are increasingly being used in precision agriculture, irrigation control, and in the analysis and monitoring of soil and crops. Their ability to sense crop condition, detect the presence of pests, and measure nutrient availability will further lead to better-informed decisions and more productive agriculture as well as increased efficiency in resource use. Drones could also spray fertilizers and pesticides with precision where they are needed to minimize waste of chemicals and other deleterious environmental impacts.

Besides tracking wildlife, researchers can use UAVs to monitor the areas where a great deal of deforestation is ongoing. They can assess the environmental impacts generated by global warming. Access to remote areas during disaster time is highly essential - surveying flooded regions, damage assessment after wildfire, or emergency supplies deployment. Logistics include the facilitation of last-mile delivery through drones, which would cut down timelines in transporting goods in urban setups. Some of the benefits UAVs offer include speed, accuracy, and the ability to conduct operations in hazardous or difficult environments without the loss of mankind. However, the UAV technology remains beleaguered by several challenges such as restrictions from regulatory bodies, privacy concerns, short lifespan, and competent operators. In the near future, high leaps in autonomy, battery capacity, and sensor accuracy will continue to expand UAV applications into new industries; those that will be harnessed will depend on the most advanced technology-driven industries today.



a) Fixed wing
b) Multi-rotor

Fig 5 Types of agricultural drones.

2.8 Field Mapping and Geolocation

Field mapping and geolocation are some of the very essential technologies that have flourished in agriculture today, helping in more than unprecedented control over farms by farmers. They make use of GPS, GIS, and even satellite pictures to create highly detailed maps of agricultural fields, information regarding soil type, crop health, and nutrient levels. Farm mapping can provide the farmer with an insight into variations within the fields-for example, parts with inferior qualities of soils, poor drainage facilities, and dissimilar nutrient needs-with consequent interventions. This may be followed by improved decision-making, planting patterns, and effective resource use such as precise fertilizer and pesticide application and irrigation.

The geolocation technology improves on the field mapping by providing the accurate coordinates of all points in any filed, which enhances site-specific farming. Such spatial data allows precision agriculture practices to be implemented wherein different parts of a field are cultivated independently according to their specific needs. For example, geolocation assists in navigation systems for autonomous machinery such as tractors and drones, carrying out work with exact precision as much as possible, avoiding overlap, and minimising waste.

The major benefit of field mapping and geolocation lies in the higher yields, lower input costs, and lesser environmental damages by virtuous farming. The challenges are good, up-to-date information as well as the cost for technology and a learning curve when dealing with high-tech mapping tools. Setting all these aside, the core of the future in agriculture will be field mapping and geolocation where farmers maximize their productivity while conserving resources and protecting the environment.

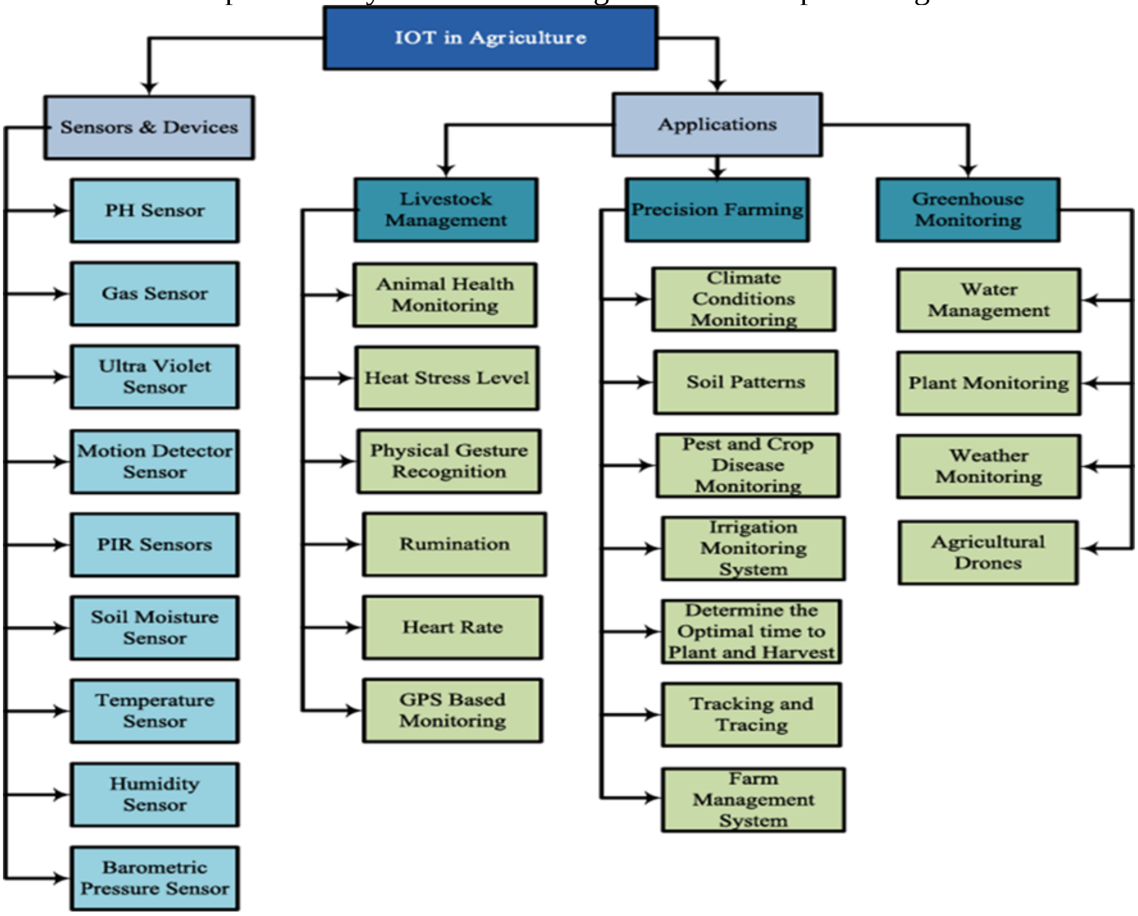


Fig 6 IoT-based smart agriculture framework, showing various sensors and devices used for applications like livestock management, precision farming, and greenhouse monitoring

3. Challenges & Limitations:

3.1 Data and Network Challenges:

which emanate from the huge volumes of data that IoT produces and the sometimes necessary or required network connectivity, present the first set of challenges that must be overcome when introducing IoT in agriculture. Sensors and devices deployed at every point in the fields continuously feed data about soil conditions, weather, and health conditions of the livestock and other aspects, hence resulting in vast amounts of information to be stored, processed, and analyzed effectively. In such a scenario, real-time data processing is critical to making on-the-fly decisions, but the more than often laggard rural infrastructure only presents more complexity in achieving this task. Furthermore, network stability remains a thorny issue for most agricultural regions with very limited or completely unreliable internet access. This makes data and system transmission interference difficult, further reducing the impact of an IoT-based solution. Such challenges create demands for investments in data management technologies and developing resilient, rurally-focused network solutions that should support the growing digital transformation of agriculture.

3.2 Security and Privacy:

IoT devices and networks in agriculture pose a serious cybersecurity threat and are vulnerable to data breaches, unauthorized access, and malicious disruption, with sensitive information about crop yield, livestock health, and operational strategies potentially put at risk. Protecting data privacy is, therefore very important to ensure that agricultural data is accessible only to authorized persons, according to farmers and organizations, who were worried about misuse or exploitation without such consent. All these point toward more robust security frameworks, the education of users on digital safety, and IoT devices developed with standardized security features baked into them.

3.3 Integration of Technologies:

Really, integration with other advanced technologies, such as AI, machine learning, and cloud computing, poses some increased challenges to agriculture. The challenge, in this context, lies in the seamless connectivity and interoperability between all these individual technologies, some of which are designed using different protocols or standards. Standardization, therefore, is complex. Moreover, it is complicated by diversity in types of devices and communication protocols within IoT systems. Such lack of uniformity in forms may, therefore, delay the effective deployment and scaling of integrated solutions, hence denying the benefits of such technologies for the agricultural operations.

3.4 Energy Efficiency:

In remote farming areas, the biggest challenge to power IoT devices can be the lack of reliable sources of energy. The infrastructure for constant power is usually not in such remote farming areas, causing a problem about how the IoT will operate over long stretches of time. This happens to be precisely why it is critical in agriculture-where constant monitoring and data collection have been effortlessly streamlined. To assist these technologies in maintaining distant farming conditions, alternate energy sources like solar power or low-energy IoT devices are required.

3.5 Policy and Regulation:

The absence of standard policies in IoT as a global phenomenon makes it hard to implement them widely in the region, particularly agriculture. Policies vary, and such differences can be an issue for farmers as well as technology providers, because various regions have different regulations and standards. Problem statement: Other unsettled issues in data ownership and usage rights are left outstanding, including who owns the ream of data produced by IoT devices and how it can be allowed to be used. These regulatory and legal uncertainties prevent IoT technology development and deployment in agriculture and applications that gain clearer policies protecting stakeholders with proper equitable benefits.

3.6 Harsh Environments: The lack of standardized international regulations pertaining to the Internet of Things (IoT) in the agricultural sector complicates its extensive implementation, given that diverse regions are governed by differing regulations and standards. This heterogeneity engenders difficulties for both agriculturists and technology providers in achieving compatibility and regulatory compliance. Additionally, there are still many unanswered problems about data ownership and usage rights, which raise important concerns about who owns the huge amounts of data produced by IoT devices and what uses are acceptable. These regulatory and legal ambiguities serve as impediments to the advancement and acceptance of IoT technologies within agriculture, necessitating the formulation of clearer policies to safeguard stakeholders and ensure equitable advantages.

3.7 Hardware Challenges: IoT devices are deployed in several harsh environments with strong conditions of rain, extreme temperatures, and humidity. Thereby, strong hardware solutions are mandatory for the devices. The design must be made from sustainable, weather-proof materials and built to function reasonably under fluctuating temperatures. Once again, power efficiency is important as many IoT devices in agriculture are put in place in rural areas where little energy source exists. Necessary to such devices would be low-power hardware solutions, such as energy-efficient sensors and components in order to guarantee longevity and reliability with minimal need for frequent maintenance or battery replacement.

3.8 Cost and Accessibility:

The initial development costs incurred by IoT solutions would be quite costly for small-scale farmers and hence limit their ability to adopt these new technologies. Furthermore, poor nations' access to cutting-edge IoT technologies differs greatly from developed nations 'The majority of agricultural practitioners within the region are deficient in the requisite resources and infrastructure to proficiently deploy Internet of Things (IoT) technology. Most farmers in the region lack the resources and infrastructure required to effectively employ IoT technology.. The stakeholders who stand to gain the most from increased productivity and efficiency are primarily impacted by this disparity, which severely impedes the broad adoption of IoT technologies in agriculture. To address and lessen these issues, put into practice affordable solutions and provide increased access to technology resources for areas that currently lack such innovations This imbalance significantly hinders the broad adoption of IoT in agriculture, namely for those who stand to benefit the most from increased agricultural efficiency and productivity. Low-cost solutions and better access to technology in areas where none now exists are needed to remove these barriers.

4. Wireless Sensors in Smart Farming

Wireless sensors form an important constituent in smart farming. They comprise an excellent system to obtain information related to crop conditions and other vital parameters. These sensors are incorporated into various agricultural tools and equipment. The use of wireless sensors is, therefore, found to be fundamental for precision agriculture. Some of the major sensor types along with their working principles, purposes, and benefits are discussed in detail below.

4.1 Acoustic Sensors

Acoustic sensors are versatile tools applied in soil cultivation, weeding, and fruit harvesting. Their strong advantage is cost-effectiveness combined with rapid response, especially in portable devices. The sensors work on noise level changes when interacting with materials such as soil particles. Applications include pest monitoring where sound patterns help to detect infestations and seed classification based on sound absorption spectra.

4.2 FPGAs-Based Sensors

The FPGA-based sensors are reconfigurable but have small sizes, high costs, and high power consumption. These attributes have kept them in their infancy regarding application in agriculture. They are not ideal for continuous monitoring because of their high power requirements. However,

4.3 Ultrasonic Ranging Sensors

These sensors are valued for being cheap, flexible, and easy. These can be employed in tank monitoring, spray distance control, collision avoidance, and crop canopy evaluation. They support the cameras in weed monitoring concerning the measurement of plant height and details where weeds grow.

4.4 Optoelectronic Sensors

Optoelectronic sensors have been possible to detect various plant species, hence are now useful for the detection of weeds, herbicides, and other unwanted vegetation, especially in the wide-row crops. Coupled with location information, these sensors make it possible to map weed distribution and resolution. Spectra of reflection can separate between vegetation and soil and hence are applicable to detailed farm management.

4.5 Airflow Sensors

Air permeability soil moisture content and structure measurements are provided by soil airflow sensors, which can determine compaction and type. They can be fixed or mobile and provide information on the soil conditions by measuring the pressure necessary to push air through into the ground. It is in these findings that soils are essentially able to identify their characteristics: compaction and moisture levels, in managing the soils.

4.6 Electrochemical Sensors

Electrochemical sensors are primarily used to assess soil nutrient levels and pH, providing a faster and more affordable alternative to traditional chemical soil analyses. These sensors measure macro and micro-nutrients, salinity, and pH levels, enabling precise fertilizer application and improving crop yield predictions.

4.7 Electromagnetic Sensors

Electromagnetic sensors measure soil electrical conductivity and transient electromagnetic responses. These sensors evaluate the ability of the soil to conduct or store electrical charges, providing data on residual nitrates, organic matter, and variable rate applications. They are available in both contact and non-contact modes to gather accurate soil information.

4.8 Mechanical Sensors

Mechanical sensors measure soil compaction in terms of the resistance the soil presents to the penetration by a tool. Such information, obtained from strain gauges or load cells, may be used to compute variable compaction levels. Such information helps in making decisions relating to soil tillage and compaction management.

4.9 Mass Flow Sensors

Mass flow sensors are very important in yield monitoring since they tell about the grain flow during harvesting. Mass flow sensors are used for many years now in crop yield measurement and are core elements of systems and thus those associated with John Deere tractors. Most are applied together with grain moisture sensors and data analysis software to give complete information about yield .

4.10Eddy Covariance-Based Sensors

These sensors measure gas exchange among carbon dioxide, water vapor, and methane between the soil and the atmospheric surface. These sensors are highly accurate and more favored than other alternatives such as closed chambers because they can provide a continuum of data over large areas of interest. They help in tracking greenhouse gas fluxes in agricultural ecosystems.

4.11Soft Water Level-Based (SWLB) Sensors

SWLB sensors can measure hydrologic parameters that include water levels, rainfall, and stream flows in an agricultural catchment. These can result in adjustable time-step data acquisition, thus managing irrigation and water resources more effectively.

4.12Light Detection and Ranging (LiDAR)

Its applications in agriculture include land mapping, soil type determination, and erosion monitoring. It is applied for detailed 3D maps of farm landscapes and goes along with GPS to give a more precise output. Other practical uses of LiDAR include crop biomass estimation and yield forecasting, hence an indispensable tool for precision farming.

CONCLUSION:

Key Findings of the Paper: The study offers a detailed explanation of the application of Internet of Things in agriculture, with few key points a finding is made. Increased Agricultural Productivity: The study notices that researches are being performed worldwide about IoT technologies to increase agricultural productivity. These technologies add more solutions to existing ones and provides innovative solutions to a range of challenges that agriculture is facing such as water scarcity and cost control conversion in agriculture: describing the smart agricultural methods, tools, and use. It discusses a few benefits and drawbacks of IoT in the agricultural industry and some parts of IoT.

Current Issues and Innovation: The current progress of IoT application in agriculture, communication protocol, devices, and sensors, has covered. Notable, the paper discusses security needs as well as other issues related to IoT in smart farming so that full understanding can be achieved of the consequences of the discussed technologies. Government and Organisational support: As the study come out, most organizations have begun investing in developing innovative techniques for farm management systems and governments have also begun to promote IoT efforts in agricultural sectors. This is a clear trend towards modernizing traditional farming using technology.

Importance of Education and Knowledge: The main challenge of adaptation of IoT technology in rural areas is unawareness of the technology among the farmers. It would require strong educational activities to help farmers understand and make effective usage of IoT solutions that may generate higher income and production.

Using IoT in agriculture is going to change the nature of farming significantly; hence, their future prospects are going to change the tradition of farming into more sustainable and effective ones. It is rich in information for researchers, practitioners, and policymakers in agricultural technologies.

It is further stated that within these, the critical technologies to be used are cloud computing, communication networks, wireless sensors, and UAVs (unmanned aerial vehicles), which would finally lead to the improvement of agriculture. Considering the sustainability requirements stated thereafter, these make agriculture more intelligent and capable of fulfilling the future demands.

The conclusion articulates that for the farmland to be as productive as it can be to be utilized for crop production, all land needs to be optimized and through IoT-based sensors and communication technologies is not only advantageous but much needed. Besides detailing the challenges and prospects the agriculture sector confronts ahead, the brief also proceeds to analyze current research and IoT architectures and platforms.

Thesefindings, altogether, point towards an IoT revolution in agriculture but with the management of challenges that need to be overcome for adoption

REFERENCES

[1]Mouha, R. A. & Anhui Polytechnic University. (2021). Internet of Things (IoT) [Journal- article]. *Journal of Data Analysis and Information Processing*, *9*, 77–101. https://doi.org/10.4236/jdaip.2021.92006

[2]Tzounis, A., Katsoulas, N., Bartzanas, T., & Kittas, C. (2017). Internet of Things in agriculture, recent advances and future challenges. *Biosystems Engineering*, *164*, 31–48. https://doi.org/10.1016/j.biosystemseng.2017.09.007

[3]Rajak, P., Ganguly, A., Adhikary, S., & Bhattacharya, S. (2023). Internet of Things and smart sensors in agriculture: Scopes and challenges. *Journal of Agriculture and Food Research*, *14*, 100776. https://doi.org/10.1016/j.jafr.2023.100776

[4]Villa-Henriksen, A., Edwards, G. T., Pesonen, L. A., Green, O., & Sørensen, C. a. G. (2020). Internet of Things in arable farming: Implementation, applications, challenges and potential. *Biosystems Engineering*, *191*, 60–84. https://doi.org/10.1016/j.biosystemseng.2019.12.013

[5]Vangala, A., Das, A. K., Kumar, N., & Alazab, M. (2020b). Smart Secure Sensing for IoT- Based Agriculture: Blockchain Perspective. *IEEE Sensors Journal*, *21*(16), 17591–17607. https://doi.org/10.1109/jsen.2020.3012294

[6]Morchid, A., Alami, R. E., Raezah, A. A., & Sabbar, Y. (2023). Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges. *Ain Shams Engineering Journal*, *15*(3), 102509. https://doi.org/10.1016/j.asej.2023.10250

[7]Raj, M., Gupta, S., Chamola, V., Elhence, A., Garg, T., Atiquzzaman, M., & Niyato, D. (2021). A survey on the role of Internet of Things for adopting and promoting Agriculture 4.0. *Journal of Network and Computer Applications*, *187*, 103107. https://doi.org/10.1016/j.jnca.2021.103107

[8]Naseer, A., Shmoon, M., Shakeel, T., Rehman, S. U., Ahmad, A., & Gruhn, V. (2024). A Systematic Literature Review of the IoT in Agriculture - Global Adoption, Innovations, Security Privacy Challenges. *IEEE Access*, *12*, 60986–61021. https://doi.org/10.1109/access.2024.3394617

[9]Ramson, S. J., Vishnu, S., & Shanmugam, M. (2020). Applications of Internet of Things (IoT) – an

overview. *IEEE*. https://doi.org/10.1109/icdcs48716.2020.243556

[10] Attia, T. M. (2019). *Challenges and Opportunities in the Future Applications of IoT Technology*. https://hdl.handle.net/10419/201752

[11] Farooq, M. S., Riaz, S., Abid, A., Abid, K., & Naeem, M. A. (2019). A survey on the Role of IoT in agriculture for the implementation of smart Farming. IEEE Access, 7, 156237–156271. https://doi.org/10.1109/access.2019.2949703

[12] Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., & Aggoune, E. M. (2019). Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk. IEEE Access, 7, 129551–129583. https://doi.org/10.1109/access.2019.2932609

[13] Quy, V. K., Van Hau, N., Van Anh, D., Quy, N. M., Ban, N. T., Lanza, S., Randazzo, G., & Muzirafuti, A. (2022). IoT-Enabled Smart Agriculture: Architecture, Applications, and Challenges. Applied Sciences, 12(7), 3396. https://doi.org/10.3390/app12073396

[14] Vadapalli, A., Peravali, S., & Dadi, V. R. (n.d.). Smart Agriculture System using IoT Technology. *Department of Instrument Technology, Andhra University*.

[15] Shaikh, F. K., Karim, S., Zeadally, S., & Nebhen, J. (2022). Recent trends in Internet- of-Things-Enabled sensor technologies for smart agriculture. IEEE Internet of Things Journal, 9(23), 23583–23598. https://doi.org/10.1109/jiot.2022.3210154

[16] Elijah, O., Rahman, T. A., Orikumhi, I., Leow, C. Y., & Hindia, M. N. (2018). An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges. IEEE Internet of Things Journal, 5(5), 3758–3773. https://doi.org/10.1109/jiot.2018.2844296

[17] Kim, W., Lee, W., & Kim, Y. (2020b). A Review of the Applications of the Internet of Things (IoT) for Agricultural Automation. Journal of Biosystems Engineering, 45(4), 385– 400. https://doi.org/10.1007/s42853-020-00078-3

[18] Naseer, A., Shmoon, M., Shakeel, T., Rehman, S. U., Ahmad, A., & Gruhn, V. (2024). A Systematic Literature Review of the IoT in Agriculture - Global Adoption, Innovations, Security Privacy Challenges. IEEE Access, 12, 60986–61021. https://doi.org/10.1109/access.2024.3394617