A Detailed Survey of IoT Based Smart Agriculture System

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Abstract: *The integration of Internet of Things (IoT) technology in agriculture has revolutionized traditional farming methods, leading to the emergence of smart agriculture practices. This paper provides a comprehensive review of IoT sensors for smart agriculture, exploring the diverse ecosystem of IoT applications in the agricultural sector. Various IoT-supported technologies utilized in agriculture are discussed, highlighting their roles in enhancing productivity, efficiency, and sustainability. Additionally, a summary of different IoT-based methods employed in agriculture is provided, elucidating their contributions to precision farming and resource optimization. The benefits of IoT in agriculture are underscored, encompassing improved decision-making, reduced resource wastage, and increased yields. However, alongside these benefits, several hardware and software challenges of implementing IoT in agriculture are examined, including issues related to connectivity, interoperability, data security, and scalability. Overall, this paper offers insights into the transformative potential of IoT in agriculture while acknowledging the complexities and hurdles that accompany its adoption.*

Keywords: IoT, Agriculture, Sensors, smart farming, security.

Introduction

As the world is trending into new technologies and implementations it is a necessary goal to trend up in agriculture also. Many researches are done in the field of agriculture. Most projects signify the use of wireless sensor network collect data from different sensors deployed at various nodes and send it through the wireless protocol. The collected data provide the information about the various environmental factors. Monitoring the environmental factors is not the complete solution to increase the yield of crops. There are number of other factors that decrease the productivity to a greater extent. Hence automation must be implemented in agriculture to overcome these problems. So, in order to provide solution to all such problems, it is necessary to develop an integrated system which will take care of all factors affecting the productivity in every stage. But complete automation in agriculture is not achieved due to various issues. Though it is implemented in the research level it is not given to the farmers as a product to get benefitted

from the resources. Internet of Things (IoT) refers to the implementable Machine-to-Machine (M2M) communications which is a crucial component of recent growth in the digital market. IoT is a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network [30].
An IoT system is comprised of a number of functional blocks to facilitate various utilities to the system such as, sensing, identification, actuation, communication, and management [2]. Figure 1 presents these functional blocks as described below.

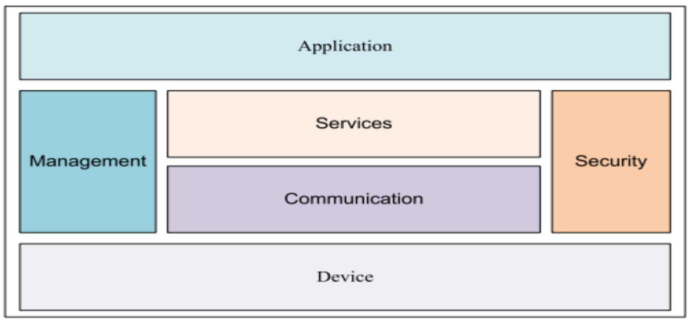


Fig. 1: Functional blocks of IoT.

II. IoT Sensors for Smart Agriculture

A sensor is indeed a device that monitors several parameters, such as pressure, light, moisture level, and so on. Most of the time, the sensor output is an electrical signal, which is sent to a micro-controller for the further analysis on a network. The development of simple to advanced sensors represents a transformation in the way we gather information, conduct analysis, and connect diverse structures in order to attain new ideas we may never before have conceived of. Figure 2 illustrates the components and basic structure of a sensor node used for performing smart agriculture.

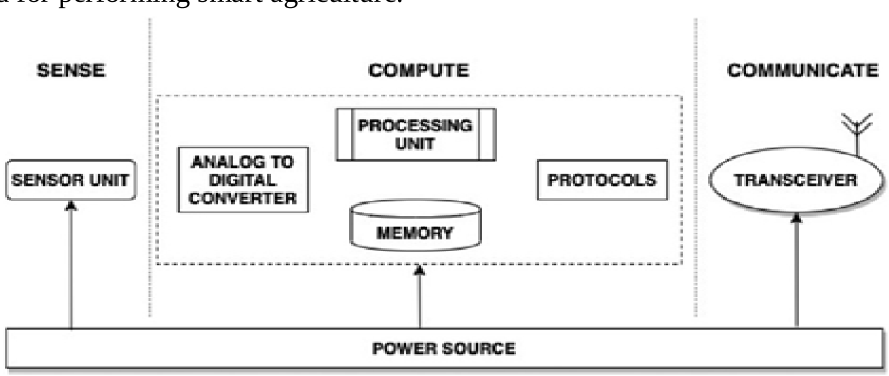


Fig. 2: Components of sensor node.

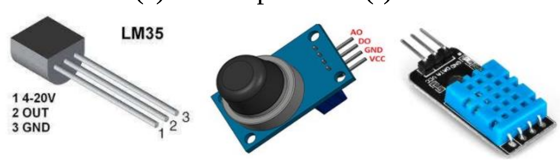
ISSN: 2581-3404 (Online) IF: 5.68 (SJIF)
IJIRTM, Volume-8, Issue-2, April-2024.

An intelligent sensor node comprise of three components namely: Sense, Compute, and Communicate. The sensing component is responsible for capturing the real-world parameters such as moisture, temperature, etc. The computational component pre-processes the captured parameter value and the communication component makes sure that the gateway sensor nodes are able to communicate with gateway nodes and can share the information among them. A variety of sensors are available for measuring and calculating the specifications of a farming field. Various sensors are depicted in figure 3.

PH sensors are being used to track the precise quantity of nutrition in soil, which is important for the stable germination of seeds and crops PIR (Passive Infrared) sensor: A motion detector is integrated into the PIR sensor, which tracks the direction of an individual's movements in the field. UV sensor monitors the intensity of ultraviolet radiation for optimal crop production [11]. Weed seeker is a self-confined unit that is usually fitted with opto electronic components for the purpose of weed identification and spraying. Wind speed indicates the speed of the wind at the surface. It is often important to observe occurrences in a field, such as changes in wind direction.

(a) PH sensors (b) PIR Sensor (c) UV sensor

(d) Weed seeker (e) Wind speed (f) Soil Moisture Sensor



(g) Temperature Sensor (h) Gas sensor (i) Humidity sensor

(j) Motion detector sensor (k) GPS Sensor (l) Photodiode Sensor

Fig. 3: Sensors Used in Smart Farming.

Water content/Soil moisture sensors for measuring water content are used in a broad variety of research fields. The proportion of the quantity of water available in the test soil to the overall amount of the test soil denotes the soil water content. Temperature sensor monitors the temperature changes in the soil that have an impact on the absorption of nutrients and moisture. Gas sensor determines the precise concentration of poisonous gases in farmland, livestock and hydroponics by monitoring infrared radiations [8]. Humidity sensor captures humidity that has a detrimental effect on plant leaf growth, and photosynthesis. Motion detector sensor is often used to locate the position of animals and fields; however, it detects the motion of an unexpected entity in the farm and sends warnings to the farmer, allowing for prompt intervention and crop loss prevention [10]. GPS (Global positioning system) provides the precise positioning of farm, or livestock with respect to latitude, longitude and altitude. Photodiode helps in identifying the soil properties such as organic matter and moisture content using light. It can be used by γ ray attenuation for measuring the soil-water content [11].

III. IoT Ecosystem for Agriculture

The Internet of Things (IoT) has found its application in several areas, such as connected industry, smart city [1], [2], smart-home [3] smart-energy, connected car [4], smart-agriculture [5], connected building and campus [6], health care [7], logistics [8], among other domains. IoT aims to integrate the physical world with the virtual world by using the Internet as the medium to communicate and exchange information [9]. IoT ecosystem for agriculture is shown in figure 4. IoT has been defined as a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. A key area of interest in this paper is the application of IoT in agriculture. The world population is estimated to be about 9.7 billion in 2050, as such there will be great demand for food. This coupled with the diminishing natural resources, arable land, unpredictable weather conditions make food security a major concern for most countries. The world is turning to the use of IoT combined with data analytics (DA) to meet them world's food demands in the coming years [10]. It is predicted that IoT device installations in the agriculture sector will increase from 30 million in 2015 to 75 million by 2020. The use of IoT and DA will enable smart agriculture which is expected to deliver high operational efficiency and high yield [11], [12]. Over the years, wireless sensor networks (WSNs) has been deployed for smart agriculture and food production with a focus on environmental monitoring, precision agriculture, machine and process control automation and traceability [13]–[18]. The capability of WSN to self-organize, self-configure, self-diagnosis, and self-heal has made it a good choice for smart agriculture and the food industry. The WSN is a system that comprise of radio frequency (RF) transceivers, sensors, microcontrollers and power sources [13]. However, with the emergency of IoT there has been a paradigm shift from the use of WSN for smart agriculture to IoT as the major driver of smart agriculture. The IoT integrates several technologies that already exist, such as WSN, RF identification, cloud computing, middleware systems and end-user applications [9].

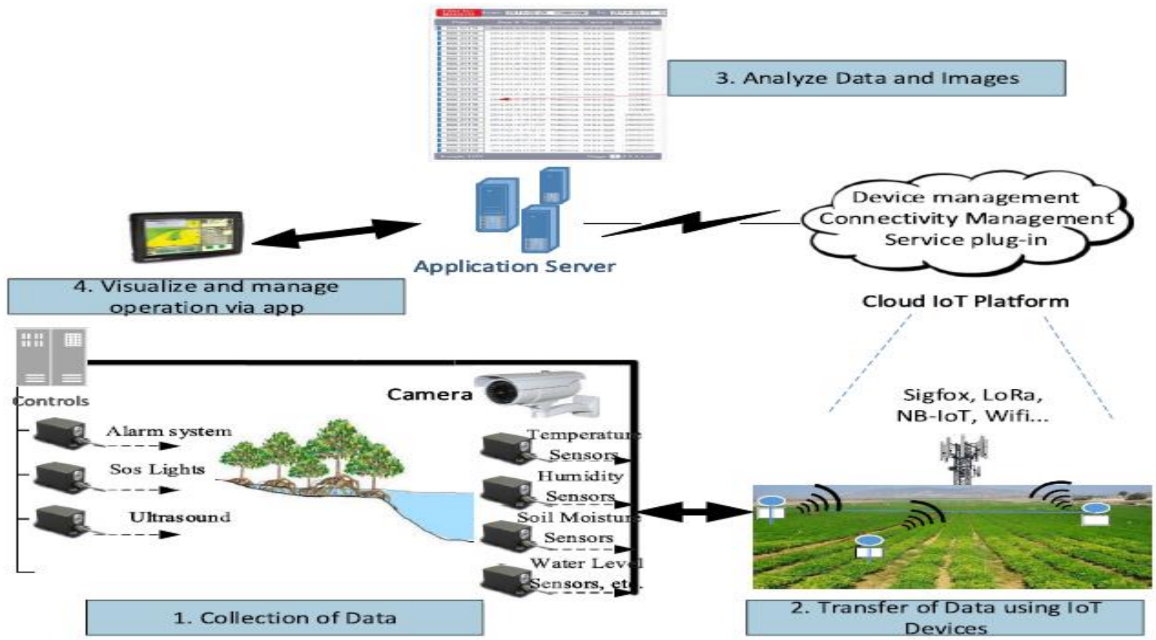


Fig. 4: Illustration of IoT ecosystem for agriculture.

IV. IoT Supported Technologies Used In Agriculture

In this section, we have discussed the details of the IoT technologies such as, hardware platforms, and wireless communication technologies used in various agricultural applications. Different IoT cloud service providers, which are being popular in the current market for use in these applications, are also studied. A number of different IoT supported hardware platforms do exist for use in the agricultural domains. Communication Protocols form the backbone of IoT systems and enable network connectivity and coupling to applications. Communication protocols allow devices to exchange data over the network. The protocols define the data exchange formats, data encoding, addressing schemes for devices and routing of packets from source to destination. Other functions of the protocols include sequence control, flow control, and retransmission of lost packets.

802.11-WiFi- IEEE 802.11 is a collection of Wireless Local Area Network (WLAN) communication standards. For example, 802.11a operates in the 5 GHz band, 802.11b and 802.11g operate in the 2.4 GHz band, 802.11n operates in the 2.4/5 GHz bands, 802.11ac operates in the 5 GHz band and 802.11ad operates in the 60 GHz band.

802.16–WiMax- IEEE 802.16 is a collection of wireless broadband standards. WiMAX (Worldwide Interoperability for Microwave Access) standards provide data rates from 1.5 Mb/s to 1 Gb/s.

802.15.4–LR-WPAN- IEEE 802.15.4 is a collection of Low-Rate Wireless Personal Area Networks (LR-WPAN) standards. These standards form the basis of specifications for high level communications protocols such as ZigBee. LR-WPAN standards provide data rates from 40 Kb/s to 250 Kb/s.
2G/3G/4G–mobile communication- There are different generations of mobile communication standards including second generation (2G including GSM and CDMA), third generation (3Gincluding UMTS ad CDMA2000) and fourth generation (4G-including LTE).
802.15.1-BlueTooth- Bluetooth (http://www.bluetooth.org) is based on the IEEE 802.15.1 standard. It is a low power, low cost wireless communication technology suitable for data transmission between mobile devices over a short range (8–10 m). The Bluetooth standard defines a personal area network (PAN) communication.
LoRaWAN R1.0–LoRa- LoRaWAN (https://www.lora-alliance.org) is a recently developed long range communication protocol designed by the LoRa™ Alliance which is an open and non-profit association. It defines Low Power Wide Area Networks (LPWAN) standard to enable IoT. Mainly its aim is to guarantee interoperability between various operators in one open global standard. LoRaWAN data rates range from 0.3 kb/s to 50 kb/s. LoRa operates in 868 and 900 MHz ISM bandsCloud solutions- IoT cloud solutions pave the facilities like real time data capture, visualization, data analytics, decision making, device management etc. tasks through remote cloud servers implying pay-as-you. Various cloud service providers are becoming gradually popular in the agriculture cum farming market.

V. Summary of Various IoT Based Methods Used In Agriculture

From the above table it is clear that the literature survey explores a diverse range of technologies and methodologies in the field of precision agriculture, emphasizing the integration of modern technologies to enhance farming practices. Researchers have employed various tools, including Arduino, Cloud Computing, IoT, Data Mining, and Machine Learning, to address key challenges in agriculture and provide practical solutions. The findings across the studies reveal a common theme of leveraging technology for efficient soil analysis, crop recommendation, automated processes, and predictive modeling. The studies by Shubham Prabhu et al. highlight the significance of real-time data in assisting farmers for precise decision-making, achieving over 99% accuracy in soil analysis. S. Sundaresan et al. focus on reducing manual labor and conserving energy through automated crop recommendations and watering systems. Komal Abhang et al. introduce an efficient automated soil testing method, overcoming the drawbacks of manual processes. Shruti Mishra et al. delve into crop yield prediction using Data Mining techniques, emphasizing the importance of accurate classifiers for optimal results. Ritesh Kumar Singh et al. provide a comprehensive review of emerging technologies, proposing an IoT solution architecture, AgriFusion, to meet the challenges of precision agriculture. The work by M. Balasubramaniyan and C. Navaneethan surveys various technologies in agriculture related to IoT, addressing the need for security for farmers. N. Aggarwal and D. Singh emphasize the revolutionary impact of IoT on traditional agriculture, making farming more profitable through the prediction of environmental factors. Johnathon Shook et al. introduce a sophisticated LSTM-based model for soybean yield prediction, outperforming other machine learning models. Aghila Rajagopal et al. propose an AI system predicting market value based on various factors, offering benefits such as balanced crop production and economic growth. R. Reshma et al. focus on soil classification and crop suitability prediction using Decision tree and SVM, with the potential to aid soil analysts and increase crop production. Dinesh Sharma and Geetam Singh Tomar review soil parameter measurement using WSN, emphasizing the need for energy-efficient protocols. Ersin Elbasi et al. highlight the transformative potential of machine learning in agriculture, achieving high classification accuracy for informed decision-making. Table 1 shows the summary of IoT Based methods in Agriculture.

In conclusion, the literature survey underscores the growing adoption of advanced technologies in agriculture, aiming to address challenges, increase efficiency, and promote sustainable farming practices. The studies collectively contribute to the evolving landscape of precision agriculture, providing valuable insights and practical solutions for the agricultural community.

Table 1: Summary of IoT Based methods in Agriculture.

Reference	Authors	Key Focus	Technology Used	Main Findings/Results
[1]	Shubham Prabhu et al.	Soil analysis based on Temperature and Soil Moisture using Arduino and Cloud Computing	Arduino, Cloud Computing, IoT	High efficiency and accuracy in fetching live data, assisting farmers in increasing agriculture yield.
[2]	S. Sundaresan et al.	Crop recommendation, automatic watering, and fertilizer recommendation based on local climate and soil characteristics	Not specified	Reduction in manual labor, energy conservation, increased crop output, success in mentioned systems.
[4]	Komal Abhang et al.	Automated soil testing for pH, nutrient values determination, crop, and fertilizer prediction	Handheld device, pH testing	Real-time results, efficient automated soil testing, prediction of suitable crops and fertilizers.
[5]	Shruti Mishra et al.	Crop yield prediction using Data Mining techniques	Data Mining (J48, LWL, LAD Tree, IBK classifiers), WEKA tool	Comparison of classifiers, IBK achieved highest accuracy, results based on dataset and classifier nature.
[6]	Ritesh Kumar Singh et al.	Review of emerging technologies in Precision Agriculture	IoT, ML, AI, big data, SDN, nanotechnology, blockchains, UAVs	Proposed AgriFusion IoT solution architecture, identified challenges, exponential growth in PA adoption.
[7]	M. Balasubramaniy	Survey of technologies, applications, and models	IoT, machine learning algorithms	Explored various aspects of agriculture in IoT, identified

	an and C. Navaneethan	in agriculture-related to IoT		challenges in security for farmers.
[8]	N. Aggarwal and D. Singh	Impact of IoT on agriculture, prediction of temperature, rainfall, humidity, fertilizer needs	IoT & AI technologies	Revolutionizing traditional agriculture, making farming profitable, prediction of environmental factors.
[9]	Johnathon Shook et al.	LSTM-based model for genotype response prediction in soybeans	LSTM, Pedigree relatedness measures, weather parameters	Outperformed other models in yield prediction, introduced temporal attention mechanism for interpretability.
[11]	Aghila Rajagopal et al.	AI system for predicting market value based on soil, rainfall, and crop production	Recurrent Cuckoo Search optimization, Discrete DBN-VGGNet classifier	Benefits include right crop yield, balanced production, and economic growth.
[12]	R. Reshma et al.	Soil classification, crop suitability prediction using Decision tree and SVM	Data mining techniques, Decision tree, Support Vector Machine	Proposed system for soil analysis, classification, and crop suitability prediction.
[13]	Shubham Prabhu et al.	Analysis of soil based on temperature and soil moisture using Arduino and Cloud Computing	Arduino, Cloud Computing, IoT	High efficiency and accuracy in fetching live data, assistance to farmers in increasing agriculture yield.
[14]	Dinesh Sharma and Geetam Singh Tomar	Review of soil parameter measurement using WSN and energy-efficient protocols	WSN, temperature, humidity, pH sensors	Presented comparison of WSN techniques, identified challenges, emphasized the need for energy-efficient WSN.
[15]	Ersin Elbasi et al.	Integration of machine learning algorithms in modern agriculture	Machine learning algorithms, IoT sensor data	Increased crop yields, reduced waste, highlighted challenges and opportunities in machine learning for agriculture.
[16]	Yu Xie et al.	Investigation of N transformation in soils along aridity gradient	Soil pH, N transformation rates	Soil pH crucial for N transformation, no significant variation in N_2O emissions along aridity gradient.

VI. Benefits of IoT in Agriculture

There are several benefits that can be derived from the use of IoT in agriculture. Some of the benefits have been mentioned and summarize as follows and shown in figure 5.

Fig. 5: IoT in agriculture.

Community Farming- The use of IoT can help promote community farming especially in the rural areas. The IoT can be leveraged to promote services that allow the community to have a common data storage, share data and information, increase interaction between the farmers and agriculture experts [10].
Safety Control and Fraud Prevention- The challenge in the agriculture sector is not just limited to sufficient production but also the ability to ensure safe and nutritious food supply. There have been several reports in food fraud which includes adulteration, counterfeit, artificial enhancement [10].
Competitive Advantages- The increase in demand for food and the use of innovative technology is expected to make the agriculture sector very competitive. Also, the enabling of data driven agriculture using IoT will open new direction in trading, monitoring, and marketing. The ability to lower costs, reduce wastage in application of farm inputs, such as fertilizer and pesticides increase productivity.
Wealth Creation and Distributions- The deployment of IoT will provide new business models, where the single farmers can avoid the exploitation of "middle men" and can be in direct relationship with the consumers [10] leading to higher profit.
Cost Reduction and Wastage- One of the perceived advantages of IoT is the ability to monitor remotely devices and equipment [16]. The application of IoT in agriculture will help to save time and money in inspecting large fields compared to personnel physically, inspecting the field either via use of vehicles or walking. **Operational Efficiency-** The operational efficiency not only relates to farmers but to decision makers related to agriculture sector, such as government and nongovernmental agencies. Data gathered from agriculture surveillance schemes via IoT can serve as a guide in agriculture interventions. Such interventions can be prevention of spread of diseases, veld fire outbreaks, compensation schemes and

resource allocations. **Awareness-** IoT is expected to drive low cost applications and access to wireless network services in the agriculture sector. To this end, information on markets, prices, services can be accessed via mobile apps. Also, government services and regulatory standard regarding different farm produce can be made readily available. In addition, consumers who are interested in organic products and fresh products can easily locate farmers or be alerted when fresh products are available.

Asset Management- IoT will enable real time monitoring of farm assets and machinery against theft, replacement of parts, and for timely routine maintenance.

VII. H/W & S/W Challenges of IoT in Agriculture

When it comes to IoT in agriculture, several challenges arise. Firstly, the equipment residing at the perception layer has to be exposed directly to harsh environmental phenomena, like high solar radiation, extreme temperatures, rain or high humidity, strong winds, vibrations and other dangers capable of destroying the electronic circuits. The end-devices will have to stay active and function reliably for long periods relying on the limited power resources of batteries. Therefore, appropriate programming tools and low-power capabilities are mandatory, since the frequent battery replacement or reset of the stations (in case of a program failure), for example in a large scale open field deployment, is not easy. Power harvesting can be a solution to some extent, however, the power consumption has still to be within the power budget of small power harvesting modules (e.g. solar panels, wind turbines etc.). Furthermore, the large number of interconnected (in an internet-like manner) devices produces an incredibly large amount of data, which will soon be beyond the resource capacities of small-scale server infrastructures to handle.

Organisational challenges & interoperability- When it comes to logistics for the food and agricultural sector, this infrastructure aims to facilitate the exchange of information and the transportation of goods, optimising the production process and the supply chain networks globally. IoT is gradually transforming business processes by providing more accurate and real-time visibility to the flow of materials and products (Lee & Lee, 2015). Cloud Computing provides high quality services, hardware-agnostic application development tools and sufficient storage and computational resources to store and process the data produced at the edge of the network.

Networking challenges- The characteristics of the environment do not only impose challenges to the hardware, but also to the network layer. Wireless communication is the most common in agricultural deployments, due to the lack of wiring costs. Environment is known to be one of the major factors which lead to low wireless link quality, through the multi-path propagation effects and its contribution to background noise. Therefore, data have to be transferred using robust and reliable technologies, according to the requirements and challenges of the rural environment.

Security challenges- The transfer to an interconnected internet of “smart things” must ensure the security, authenticity, confidentiality and privacy of the stakeholders involved in this network. In other words, IoT must be secure against external attacks, in the perception layer, secure the aggregation of data in the network layer and offer specific guarantees that only authorised entities can access and modify data in the application layer. Security in IoT is summarised in three requirements: authentication, confidentiality and access control. In the perception layer the most common security issues include information acquisition security and physical security of the hardware. The latter one is quite important in the case of agriculture, since the devices can be deployed in open fields and function without surveillance for long periods. Due to the distributed nature of IoT and the fact that its devicesmay be deployed in diverse environments, a single security protocol is, usually, not enough (Li, 2012).

Stack challenges- Middleware is another part of IoT presenting specific requirements for increased security, since it stands between the network and application layers and is responsible both for data processing and communication interface between these two layers. Security in the middleware layer requires confidentiality and security of data storage. Wireless medium is challenging, when it comes to security in transmissions, even for more sophisticated hardware than the platforms met in IoT deployments. Therefore, the IoT architecture can easily be exposed to risks, such as denial of service attacks, unauthorised access, man-in-the-middle attacks, and virus injections which target and affect confidentiality and data integrity.

Potential value of IoT in agriculture- Internet of Things is rapidly evolving and many novel applications and services are emerging from it. A great amount of research is being conducting towards the integration of various heterogeneous systems, the security assurance at various levels of IoT and the analytics, which will give a better insight into the "Big Data" in order to optimise various business processes. National policy of governments around the world for increased production rate of fresh-cut vegetables and meat, at lower price, with higher quality standards, as well as, the consumers' demand for transparency in the production cycle and the environmental footprint of the products they buy, provide IoT a huge field for development and diffusion. Much of the added-value of IoT comes from the flexibility and the optimisation and precision that it introduces into the production processes of industry and production units of all types. Therefore, it is not so risky to forecast that agricultural sector processes at all levels will drastically change in the very near future.

VIII. Conclusions

In conclusion, the proliferation of IoT technology in agriculture holds immense promise for addressing the evolving challenges faced by the farming industry. By harnessing IoT sensors and associated technologies, farmers can attain greater levels of precision, efficiency, and sustainability in their operations. The diverse array of IoT applications discussed in this paper showcases the versatility and adaptability of this technology in meeting the specific needs of agriculture, ranging from soil monitoring to livestock management. Despite the undeniable benefits, the successful implementation of IoT in agriculture is contingent upon overcoming various hardware and software challenges. Addressing issues such as connectivity gaps, data privacy concerns, and technological interoperability will be pivotal in unlocking the full potential of IoT-driven smart agriculture. Moreover, collaboration among stakeholders, including farmers, technology developers, policymakers, and researchers, is essential for fostering an ecosystem conducive to IoT innovation in agriculture. Looking ahead, continued advancements in IoT infrastructure, coupled with targeted efforts to address challenges, are poised to catalyze the transition towards a more efficient, sustainable, and resilient agricultural sector.

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