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Internet of Things (IoT's) in Agriculture: Unexplored Opportunities in Cross – Platform

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Abstract

Through precision agriculture, IoT has taken it to the real-time observation and optimization of resources; moreover, the improved productivity within that particular area. Although with numerous developments in the respective areas, most of the agricultural IoT systems lack integration from cross-platform, giving a fragmentation effect on the data and very limited inter- device interoperability between them of different manufacturers. Cross-platform IoT integration in the area of agriculture is also examined here to discuss what seamless data exchange, strong decision-support systems, and even improved automation can gain in agriculture. This study shall review case studies and analyses of technical details to study the existing challenges in areas of standardization, security, and scalability. Its findings show that a singular platform for IoT devices in agriculture can transform agricultural systems, including better resource utilizations, automation, and transparency in the supply chain. Therefore, most probably, cross- platform IoT could overcome such integration barriers and create a more sustainable, connected, and intelligent agricultural ecosystem.

Keywords: Internet of Things (IoT), Precision agriculture, Cross-platform integration, Data interoperability, Agricultural automation, IoT standardization, Sustainable farming, Decision support systems (DSS), Smart farming technology, Agricultural data security

Introduction

IoT has completely altered several industries of the present time, one of the worst-hit areas being agriculture [1]. Climate change, a growing population, and lack of resources are some of the

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challenges the world faces in food production; technology is slowly turning out to be an enabling factor that helps overcome such challenges. In this respect, precision agriculture, or in other words, usage of data and advanced technologies in order to enhance crops and animal production, has appeared to be one of the convincing tools the world can rely on in their struggle to satisfy food needs in a sustainable manner [2]. Precisive agriculture allows farmers to make better use of resources, minimize waste, and increase yields. In agriculture, IoT systems mostly exist in silos, barely communicating with other platforms, and this brings about fragmentation of data. This means lack of a complete view hampers farmers to make fully informed decisions and hence reduces overall effectiveness of IoT in agriculture.

IoT technology has brought a new revolution in agriculture by enabling real-time monitoring and control over critical variables like soil moisture [3], crop health, temperature, and humidity. With the aid of sensors, drones, and automated machinery, for example, data gathering could be realized even over the most extensive agricultural landscapes and then processed for analysis to guide decision-making. Precision agriculture reaps from such data to boost efficiency while cutting costs, hence increasing output. One of the major issues that persist in agriculture is cross- platform integration. The various producers of IoT devices employ different forms of communication protocols and are, therefore, not compatible with each other. All this fragmentation makes the integration of data from various sources not that smooth; hence, it does not allow the system to show its full potential in creating an operational picture. And that's where cross-platform integration- that is, the ability of seamless interaction and communication

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between devices by different providers-really makes a big difference in lifting IoT capabilities in agriculture [4].

There are, however, various challenges that have to be overcome before true cross-platform integration is realized in precision agriculture. For example, data from different devices, while being collected without standardization, cannot be merged into a single platform. The consequence of this is that farmers have information scattered all over the place, and this makes it difficult for them to understand the conditions in the farm. Eventually, IoT's great potential for agriculture can never be fully transformative if all farmers have around them are bits of data incapable of integration [5]. Additionally, their setup and maintenance are very expensive. In practice, this might prove prohibitively expensive for farmers, especially in small-scale farms in developing nations. Therefore, for IoT to find its full potential in agriculture, solutions must first become affordable and accessible. This must also be based on open standards whereby devices communicate with ease irrespective of their manufacturer.

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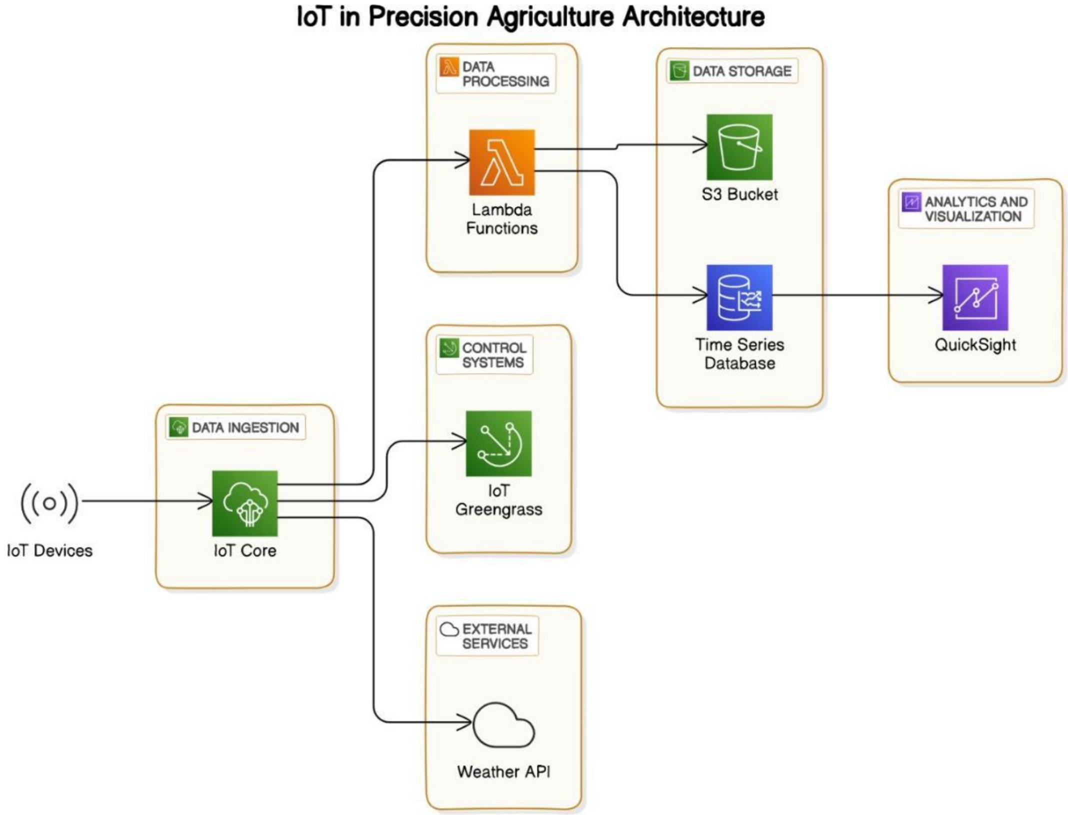

Fig. 1 IOT Precision in Agriculture

The benefits of cross-platform integration in IoT for agriculture could be availed along various dimensions. For example, data interoperability would allow farmers to see and analyze data from different IoT devices regardless of make or communication protocol. A unified view of farm conditions finally allows better decision-making, which in turn enables efficient usage of resources. Such integration with the data from weather stations, for example, would lead to better irrigation techniques. It would supply the crop with just the quantity of water it needs, basing it on current soil and weather conditions. Similarly, the DSS improvement could also be facilitated directly by integration, whereby data from the diverse IoT devices could be synthesized into acentral platform for better predictions over yield outcomes, disease prevention, and optimized

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planting schedules. In fact, such comprehensive aggregation could even automate a few processes like irrigation adjustments in real-time or deploying drones for pest control, thus freeing up more labor and resulting in enhanced efficiency [15].

IoT-powered automation and robotics are another domain in which cross-platform IoT integration will significantly improve agriculture . As farms continue to adopt robots and autonomous machines to lower their labor costs or increase efficiency greatly, this integration allows such machines to talk to each other. For example, it enables autonomous tractors to host IoT-enabled drones for real-time feedback on crop conditions [13], thus enabling the tractor to make changes in operation. This level of coordination among various automated systems would heighten the level of precision in farming and completely optimize farming production.

The potential to integrate IoT data with blockchain technology is an exciting approach, especially towards the attainment of transparency in the agricultural supply chain. IoT data can enhance the traceability features of blockchain as consumers trace food products from farm to table. The verification of origin, quality, and sustainability information of agricultural products will increase consumer benefits, giving credence to food supply chains [10]. Integration would play to the benefit of farmers, manufacturers, and consumers alike by supporting a transparent, accountable agricultural process [7].

Several projects are exploiting the potential of cross-platform IoT integration in real-world agriculture. IoF2020, for instance, is a European project that aims to stimulate interoperable IoT systems with the intent of their exploitation for increasing productivity. IoF

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2020 develops uniform protocols that will reinforce collaboration across different IoT platforms with the aim of demonstrating how interoperability might come to support sustainable agricultural practice while optimizing farm management. Cross-platform integration may also become very critical for the developing world, as financial constraints make small-scale farmers unable to afford advanced IoT systems. Efforts such as Digital Green are aimed at making IoT solutions for this group of farmers affordable by making technology accessible and adaptable to their needs.

Not to be underestimated are a number of technical challenges that still act as a barrier to the smooth integration of IoT in agriculture [6]. Besides, the missing general standards of devices and platforms in IoT have many issues regarding compatibility. Without such standards, all of those platforms stay in their ivory tower, further causing a situation where not only is interoperability not achieved but also agricultural data remains fragmented. Security concerns are very important, taking into consideration the fact that IoT data in agriculture is sensitive and needs to be transmitted securely to avoid unauthorized access. It also requires scalability due to the fact that integrated IoT solutions must be adaptable to farms of different sizes. Each agricultural operation is unique in its own right, with varying needs and resources. Any cross- platform IoT solution should be able to scale up or down through various scales and complexities. In the future, the adoption of open standards may even enable true data sharing across platforms in the form of seamlessly connected devices from different manufacturers. Advancements in the field of AI and ML promise further enhancements in the possibilities of IoT [8]. Thesetechnologies, through predictive analytics, might empower an

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IoT system to analyze huge volumes of agricultural data on its own, drawing out trends and making proactive adjustments sans human interference. For instance, AI-powered algorithms can predict crop diseases based on history [12] and present conditions and send timely alerts to farmers so that necessary remedies can be deployed. This is where IoT, AI, and ML come together in a forceful combination to further precision agriculture, cut human errors, and make farming more productive[11].

While IoT has already taken huge steps in agriculture, there is still some way to go, especially with regard to cross-platform integration. Indeed, with further development within the agricultural sector, cross-platform integration may just be IoT's future role in farming: making it more connected and efficient. Such cross-platform integrations of IoT enable farmers to look at overall operations, which, in turn, spur smarter decision-making, increased productivity, and more sustainable practices. However, tapping into these gains does presuppose concerted efforts to overcome some rather technical challenges: standardization, security, and scalability.

What is important is collaboration among technology providers, policymakers, and farmers in developing IoT systems that are accessible, adaptive, and scalable. Cross-platform IoT integration in the process of building a single digital agricultural landscape could turn out to be just what precision agriculture needs to trigger full optimization for a truly sustainable farming future which would be able to meet the challenges of a continuously growing global population. [14]

Role of IoT in Precision Agriculture

They absolutely changed the complexion of farming by offering, at proper times, much-needed information about critical variables

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regarding moisture in soil, temperature, humidity, and health status of crop. These include sensor networks and drones and some form of automated machinery wherein a farmer can monitor control agricultural operations from anywhere on the world. The productive capability can be increased, reduction of consumed resources, along with minimization of operations. Mostly all the prevailing systems though work in isolative silos with self-soliciting proprietary platforms and proprietary protocols in place.

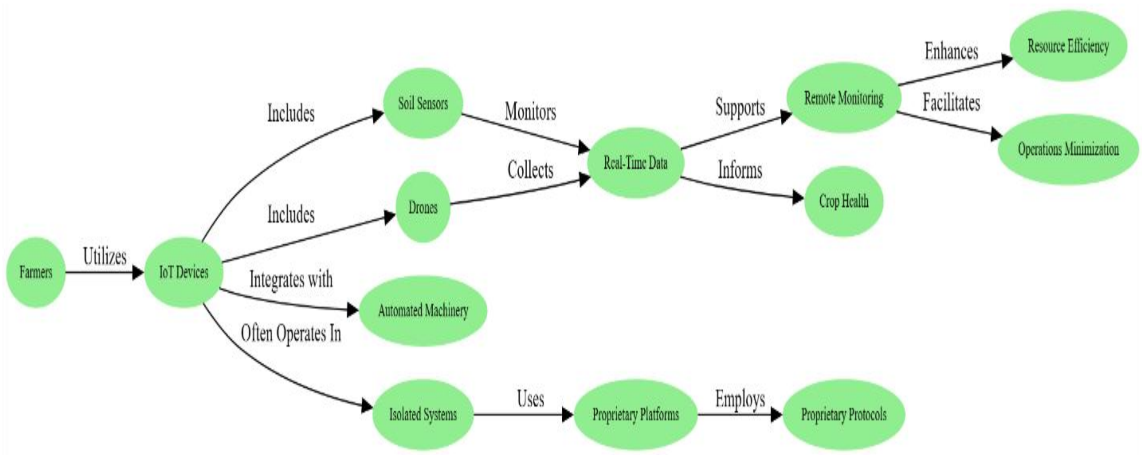

Fig. 2 Precision Hierarchy

Challenges in Cross-Platform IoT Integration

This technology, with all the above advantages realizable, suffers at its helm with interoperability; different IoTs platforms of devices cannot readily communicate not to mention exchanging information about how the interconnection amongst its constituent parts of the farm look like because there isn't much standardization. Eventually, farmers will find that they cannot have a thorough understanding of everything going around within a farm in the real time but becomes one of the collection systems merely working in an isolated but not fully interoperable fashion. It can be solved with cross-platform integration to ensure smooth data transfer and

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provide a unified interface for working with different types of IoT devices.

Overview of Precision Agriculture

This section will go through precision agriculture, its applications, and the usefulness of advancing in information and communication technology (ICT) on the way to transform agricultural industry, the benefits of using IoT technologies to make precision algorithm more efficient.

The precision agriculture is a methodology of modern times that will help managing the farming and cultivation through ICT to revolutionize production quality and the efficiency of it. This emerge of ICT includes the whole farming process chain to be optimized, from observing animal health and plants, and development for observing the overall environment, employing fertilizers, maintaining water fertilization, and plantation of sensors on tractors to collect necessary data on soil moisture and development of crops by implementing the use of technologies like drones and GPS (Global Positioning System). After this whole process is completed, information analysis services analyze the information to convey farming practices, this will result in improvements to overall efficiency.

The precision agriculture applies modern ICT to advance production yield, enhancement, and quality can greatly be advantageous after adding IoT in farming. Crop farms like olive tree farms, farmers are equipped to monitor production and quality of their yields, and collect data like heat, storms, potential of leaf water, and overall plant health through IoT. This advancement will help us make yields protected from pests and diseases.

Animal Farms will use IoT to signify the health and growth of

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the creatures which will result in getting the required data like creature's health, welfare, and location-at-the-time. Such as a horse ranch stallion stable, sensors and tags will collect data on horses like their temperature, activities, daily routines, and herd information. This will help to figure out which horses are sick and these horses will be separated from the rest of the herd. It will reduce contamination and labor costs by implementing the use of camera drones for getting real-time tracking of livestock. By implementing of the IoT-based model will decide a significant impact on the advancement of farming operations in horse stable management and olive trees. In olive tree farming, an IoT-modeling system will help to monitor and manipulate irrigation, plantation, and pests. The system will collect data on soil moisturization, and other environmentatl factors.It will help us to maintain an optimal schedule and plantation rates. It will lead to a more efficient way of watering and well-being of plants which will be cheaper, and have a higher ratio of crop yields.

Overall, the implantation of the IoT system on Precision Agriculture will help farmers to collect data on plants and make decisions based on that specific data that will thrive the grow of plants and its accuracy will be far higher than without this system. It will automate tasks that are basic and necessary. It will result in an optimization of of resource usage which will lead to increased efficiency and have a significant impact on economy in areas of olive trees and animal farming.

IoT in Agricluture

A great number of researches are present on the IoT in Agriculture. Most of them are about sensor and wireless sensor networks others are about specialized application e.g. monitoring and greenhouse

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system. Some studies also work upon the solutions of problem like Weather analysis, disease detection and pest control. In sustainable farming environment, Artificial intelligence is efficiently used in this field and people are very familiar to IoT and technology. To improve climate factors [26, 27].

IoT integration in protected agriculture had, therefore, facilitated efficient climate control in adjustments according to environmental parameters. Moreover, the deployment of smart farming techniques-IoT-based monitoring and management-is a continuous approach toward sustainable agriculture. Further, the pace at which advancements in IoT technology happen-even the prospect of a transition toward 6G-IoT-is the pathway toward the next revolution in farming: Agriculture 5.0. IoT networks' conditions, like LoRa, for tropical farming, are focused on other research: signal strength and quality in data transmission.

IoT-driven solutions have become vital in smart farming to help farmers optimize crop management through precision farming and real-time monitoring. IoT sensors are presumed to be very beneficial in yield prediction, irrigation management, and nitrogen use efficiency to improve farm productivity. IoT innovations have helped in automated irrigation and methods of precision farming, ultimately helping in the easy conservation of water and resources.

Recently, there has been an increased interest in learning about the general adoption of IoT in agriculture and its technical and practical problems. Papers related to IoT for agriculture address several strategies regarding how these adoption barriers can be overcome and take into account solutions that span different layers of IoT systems. Other studies point out the potential of data transmission underground to support IoT infrastructure in farming.

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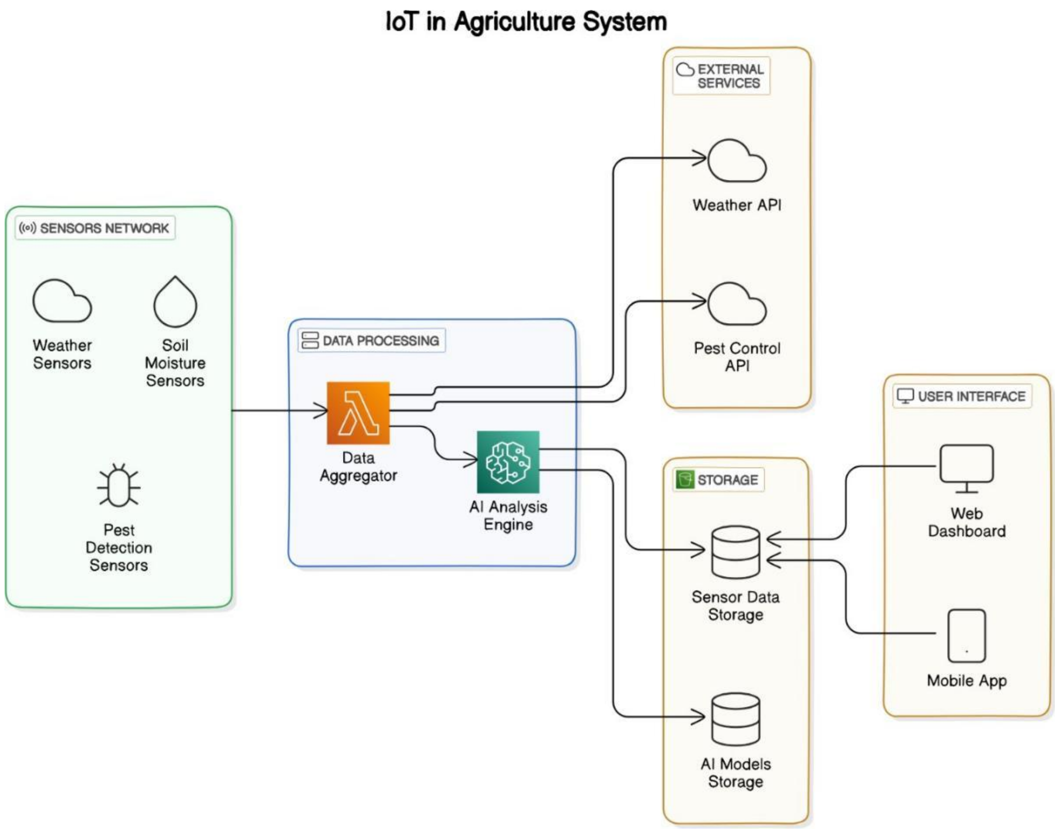

Fig. 3 IOT based Agriculture System

Also, IoT is bringing revolution to agriculture one way or another by developing ways of sustainable and efficient agriculture using sensors, controllers, and wireless networks. Further, based on different approaches like drip irrigation, greenhouse monitoring, and smart farming, there is a huge scope for IoT in the pursuit of sustainable agriculture. However, much of the current research remains focused on IoT alone, without exploring how IoT could work in tandem with other emerging technologies like AI to create even more robust farming solutions.

IoT Farming System

This section describes the suggested Internet of Things (IoT)-based intelligent farming tracking system intended to lower the possibility of rice fields bolting as a result of environmental conditions. We can

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develop cost-effective smart agricultural solutions thanks to the development of cloud computing and communication technologies. Temperature-humidity, soil moisture, wind speed, tank water level, and motion detection are the five sensor types used in the suggested monitoring system (see Fig. 1). Farmers receive notifications via a website to take the appropriate action once the raw data is transferred to a cloud server for analysis.

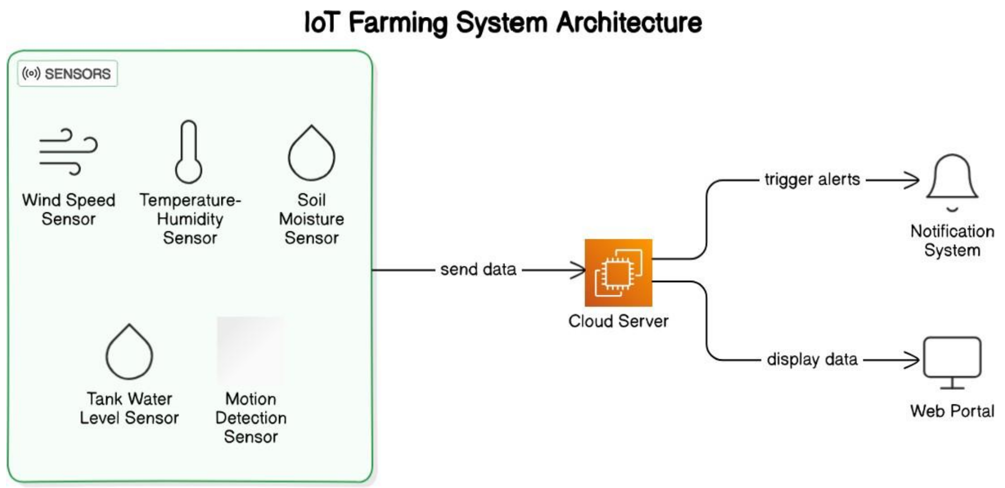

Fig. 4 IOT Farming System

Arduino is an open-source platform for electronics construction and programming. It can manage specialized electrical equipment through the Internet and send and receive data to and from a variety of devices. The DHT11 sensor (Fig. 1A) uses an optical signal to display temperature and humidity data independently [23]. Built into the open-source NodeMCU board, the ESP8266 WiFi chip is used to link the system to the Internet [24]. Because it functions as a full System on Chip (SoC) with an integrated TCP/IP protocol stack, this module is recommended because it enables any microcontroller to establish a WiFi network connection.

The ESP8266 can share WiFi tasks with another processor or

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operate as a stand-alone program. By sensing variations in capacitance, the capacitive soil moisture sensor determines soil moisture and can be configured to automatically water plants or notify farmers of plant conditions [25]. By using two pyroelectric sensors to measure heat energy, the passive infrared (PIR) sensors are able to detect motion [26]. The sensor will cut off if there is a significant change in the signal, which signals the presence of an unauthorized individual.

Furthermore, the HC-SR04 Ultrasonic sensor can measure distances up to 13 feet and detects objects using sound waves without touching them [27]. By indicating when to refill the tank, it aids in controlling the water level. The electrical water pump begins filling the tank when it detects a distance of 10 cm from the water level. Although it needs a voltage range of 7 to 24 volts DC [28], the Adafruit Anemometer sensor (Fig. 1E) monitors wind speed and operates efficiently with 5V from the Arduino Uno Microcontroller. To improve efficiency, the lithium- ion battery voltage is raised from 3.7V to 7.5V using a solar system. The exact sensors and microcontrollers utilized in this system are depicted in Fig. 1F [29].

Traditional farming frequently uses little to no technology and mainly depends on farmers' knowledge. This restricts the ability to analyze data and comprehend how environmental conditions impact the growth and health of rice. In order to overcome these obstacles and improve agricultural productivity, our project intends to create an intelligent farming monitoring system based on the Internet of Things. Since there aren't any indigenous technological solutions to address these problems at the moment, our goal is to integrate improved rice growing methods with contemporary technology.

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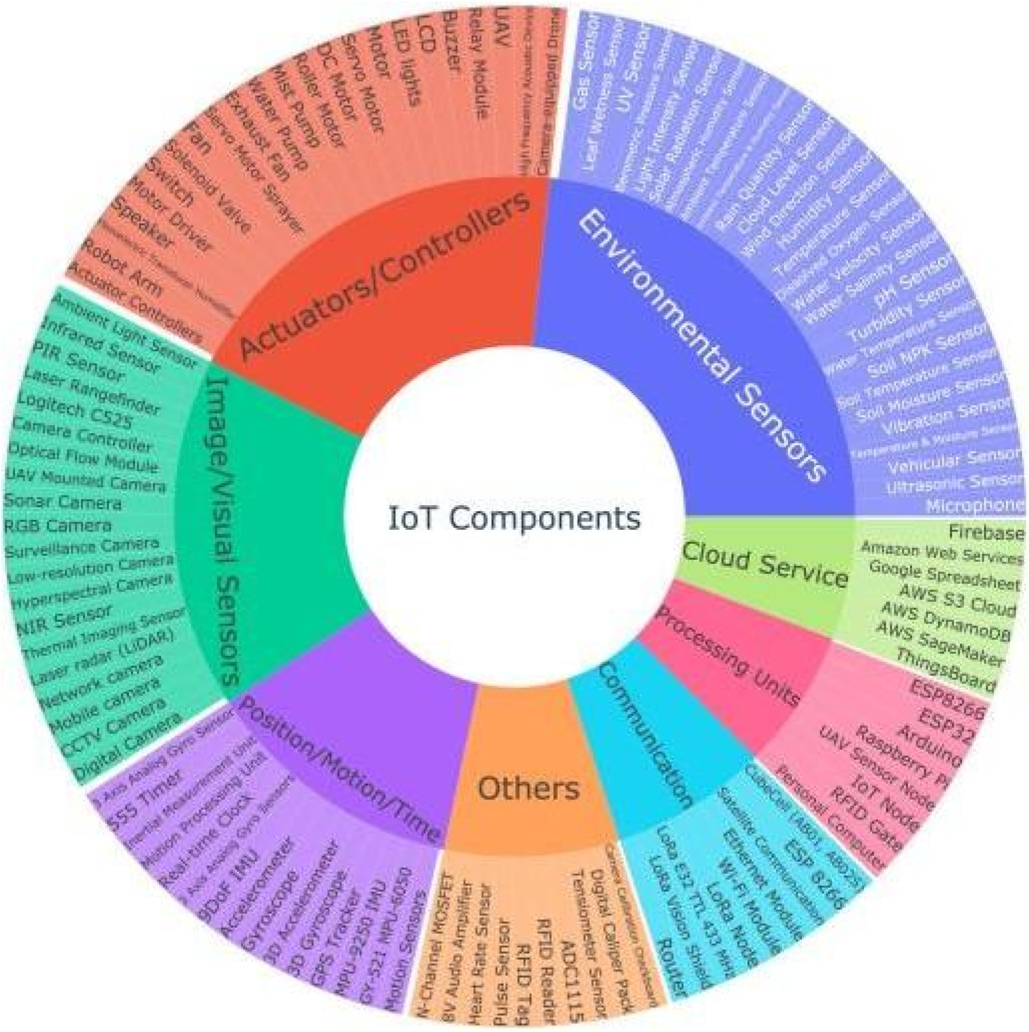

Fig 5. IoT Components fount in sysnthesis [16]

IoT-based farming has the ability to improve rice yield and quality while lowering the danger of bolting by overcoming the constraints of traditional farming. The aforementioned sensors serve as the foundation for the system's architecture and are positioned in rice fields to gather crucial data. After that, the data is transferred to a cloud server for analysis, which aids in farmers' decision-making.

Five sensors are included in the intelligent farming system: motion detection, wind speed, water level, soil moisture, and

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temperature-humidity. Any trespassing by people, animals, or birds on the farm is detected by the motion detection sensor (see Fig. 3). To enable output reading, each of these sensors is linked to the Arduino Uno microcontroller as a separate subsystem (subsystem 1). By connecting the Arduino's TX pin to the NodeMCU's RX pin (Fig. 4), the two microcontrollers have a common ground (GND) and the Arduino may communicate sensor data to the NodeMCU (subsystem 2) via the RX port.

A PC or laptop can be used by farmers to access the data that is kept on the cloud server. The data is visualized using a clever PHP software application that also sends out notifications in the event that there are any notable environmental changes that can affect the quality of the rice.

This project's IoT platform solves the problems mentioned in the introduction by storing data on a public IP-based website using SQL.

The XAMPP package, which includes the MariaDB, PHP, and Perl languages for simple installation, is used to set up the database for the IoT platform. For security purposes, a specific public IP address (160.20.147.239) is used to arrange the database and the IoT platform design. A comprehensive picture of the entire system and its operations.

Technologies for Smart and Precision Agriculture

In the sector of farming we focus on the IoT (Internet of things) that contain Clouding Computer, geometrics, sensor technology Image Processor, Radio Frequency Identification (RFID) , Wireless System Manager (WSM) etc. Wireless sensor and Image sensor helps us to detect quickly the place is suitable for fields and food production or not. Image processor check the current state of field and also detect

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how much food this year field produce. RFID is used to identify objects or track vehicle. In the developed countries food traceability is very usual. WSM is a software use to manage tasks and it is a wireless controlling system.[4]

Irrigation activity will detect automatically through sensor. Block level is allowed for accurate reporting in the aggregation data. Application of fertilizer and seeding become more accurate because of it. It will track location, injury, movement. It also helps to detect any theft and also innovate and update the mechanization of crop harvesting. IoT will also help for high quality products and provide information for efficient use of resources and also maintain the environment of earth. An IoT solution in agriculture can be design to get help for future.

Agriculturalist can gather data for each and every block. The second step will be match for each one block watering, spraying of fungicides and herbicide. New Generation not only step in technology but also having interact with digital agriculture. Therefore, in food production more data analytics and data representation play an effective role.[2]

Unexplored Opportunities in Cross-Platform Integration

Probably, the greatest opportunities for cross-platform IoT integration in agriculture lie in data interoperability. The farmers would have access to multiple IoT devices, no matter what the manufacturer or protocol is. This will lead to better knowledge of the farm conditions and allow for more informed decision-making. For instance, integration of weather data from one platform with soil sensors from another would be optimized for irrigation strategies.

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Enhanced Decision Support Systems (DSS)

Integrating the DSS across the different platforms will enhance aggregation of data across various sources. With a single platform, soil sensors, weather stations, drones, and machinery can come together. In this context, prediction of crop yield, outbreaks of diseases, and optimum planting times by farmers can be enhanced. This vast pool of data can also be used to automate processes for adjusting the irrigation schedule based on the real-time moisture level of the soil or deployment of drones for targeted pesticide application.

Automation and Robotics

More dependence on automation is being put on the future of precision agriculture, where robots and self-driving machinery are playing a leading role in reducing manual labor and increasing efficiency [22].Further integration of cross-platform IoT will further enhance these technologies since it enables communication between multiple automated systems. For example, self-driving tractors can be combined with IoT-capable drones to monitor crop health in real time; based on the feedback received from the drone, the tractor can then alter its operation.

Block-chain and Supply Chain Transparency

Cross-platform integration can also be taken outside the farm with further transparency in agricultural supply chain. In this way, an entire product life cycle right from the farm to table would be traceable by combining IoT data with blockchain technology[17]. This will not only help increase food safety but also trust among consumers as verified information for origin, quality, and sustainability is provided for agricultural products.[18]

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Case Studies

Cross-Platform IoT Integration in Europe

A few Europe-based initiatives are starting to look into integrating IoT across different platforms with the aim of precision agriculture. For instance, Internet of Food & Farm proposes developing interoperable IoT for increasing farm productivity. They would achieve this by making standards and promoting collaboration between these various IoT platforms to foster an integrated agricultural IoT landscape.[16]

Integrating IoT in Developing Countries

In developing countries, small-scale farmers often lack the financial resources to invest in advanced IoT systems. However, cross-platform integration could lower the entry barriers by allowing farmers to adopt affordable IoT devices that are compatible with more extensive systems. Projects like Digital Green are working on integrating low-cost IoT solutions for smallholder farmers, enabling them to leverage IoT technology without being tied to expensive, proprietary platforms.

Technical Challenges

While the benefits of cross-platform IoT integration are clearly visible, there are huge technical challenges to work over. These include:

1.**Lack of Standardized Framework:** The absence of any universal standards to use for IoT devices and platforms is a serious constraint in compatibility.[19]

2.**Data Security:** In this, the cross-platform system should ensure protection of data transfers, which are primarily related to sensitive agriculture data[21].

3.**Scalability:** The second challenge is ensuring that cross-

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platform solutions can scale from small farms to large industrial operations.

4.**Cost:** integrated IoT development and maintenance could be expensive and most cattle farm setups notably small ones may not afford. [20].

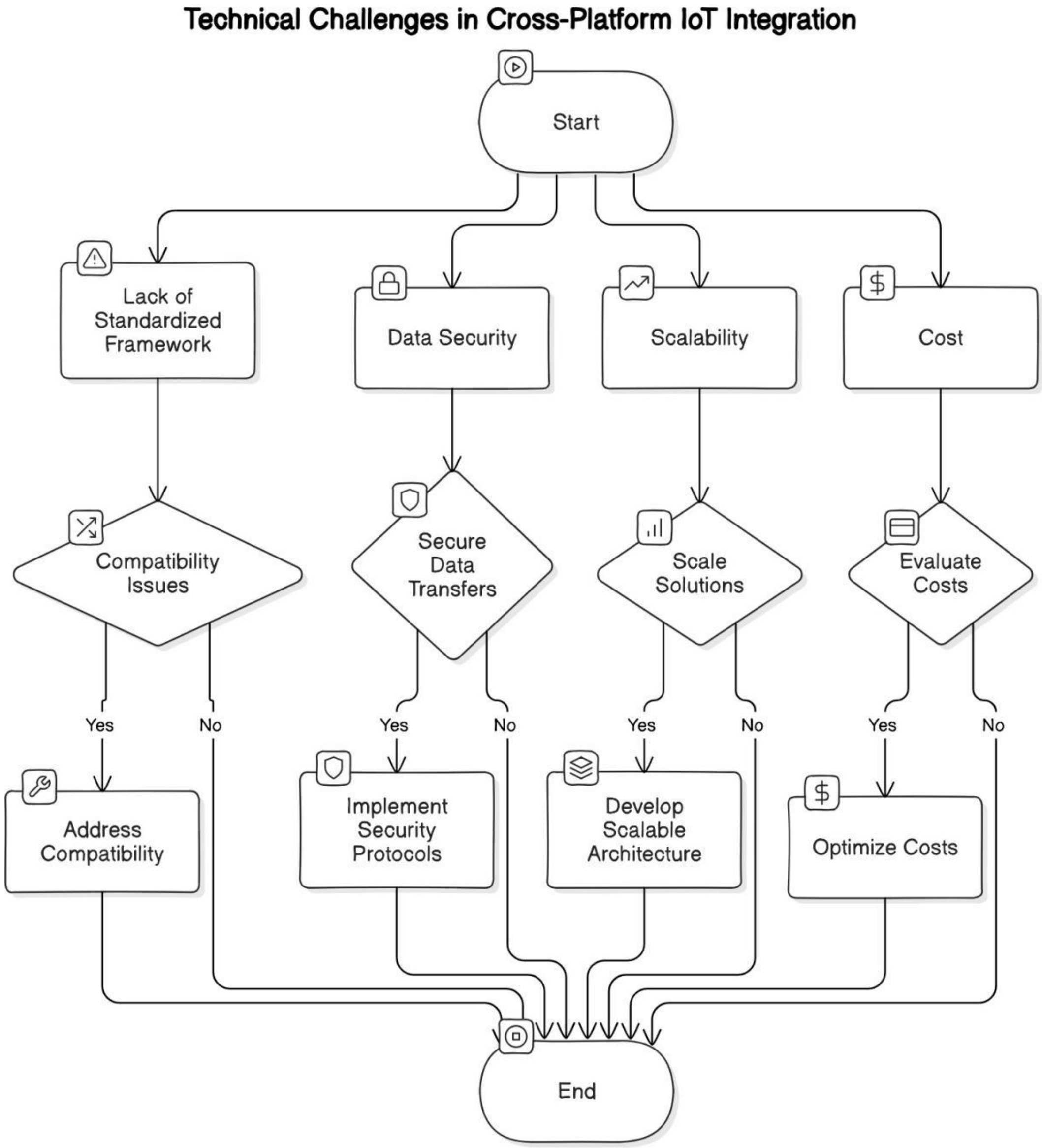

Fig. 7: Future Trends

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Therefore, the future of precision agriculture lies in the full realization of cross-platform IoT integration. As companies and governments more and more wake up to the need for interoperability, the developments of open standards and protocols that could allow free flowing of data from one platform to the other can be expected. Moreover, advancements in AI and ML will increase the capability of IoT devices toward providing predictive analytics and smarter automation systems.

Future research may focus on more modular sensor designs that enable standardized interfaces and have the capability for plug-and-play functionality, which enables fast and efficient integration and therefore scales well. Non-invasive and non-destructive technologies have major benefits in agricultural scenarios with regard to remote sensing, and also in animal welfare monitoring[30][31].

Future research directions include the development of adaptive control algorithms based on environmental feedback and predictive modeling of natural processes. The long-term environmental and ecological impacts of MCC interventions are very important and should be adequately studied to ensure the sustainability of agricultural practices [32].

Another challenge that is faced with developing IoT-based systems is that they require a long operation period to collect massive data [33]. However, this collection of data is essential for the performance of ML in the future. Among the challenges that should be given further attention is the system complexity and long processing time faced in IoT development [33].

For IoT and AI/ML solution scalability on PA, areas for further

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research are scalable models able to integrate properly with currently in-place practices, also being interoperable, paving the way towards broad acceptability. Focus of the future research, thus should be on scaling, as well as interoperability-based framework for IoT as well as AI/ML solutions.

The potential space of inter-domain integration can bring exciting innovations for agriculture-also appears to be quite promising future space for the said topic [35].

Conclusion

With the integration of cross-platform IoT, there is vast unexplored opportunity in precision agriculture that comes with a better understanding of farming operations by breaking the silos between different IoT systems, thus helping to achieve efficiency, sustainability, and profitability. In this regard, the seamless exchange of data would enable more holistic decisions to be made. Nevertheless, to unlock the full potential of this technology, solving the technical challenges of standardization, security, and scalability will be fundamental. Therefore, with the advancement of agriculture, cross-platform integration of IoT systems will be the key to future farming.

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