REVIEW ARTICLE

The integration of Internet of Things (IoT) in precision agriculture

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Precision Agriculture (PA) is a type of agricultural technology that is widely used in the field of agriculture. The Internet of Things (IoT) is one of the most widely used technologies for precision agriculture. However, the application of IoT in precision agriculture has not been fully explored. In this article, a comprehensive review of the current innovative means of utilizing the internet of things in PA practices was carried out. The paper provides a concise review of current applications of the internet and communication technologies in PA. In addition, the paper discusses the design architecture of communicating systems and communication system technologies. The results of the carried-out technical review are as follows: (a) A detailed study of the features of the utilized sensors, agricultural fields and crop changes and the design of communication systems are the key outcomes of the technical review; (b) Using big data for IoT applications in precision farming allows the aggregation and management of a large volume of data captured from a wide variety of different sources; (c) The effective use of big data can have broad and potentially transformative effects for making progress in how to apply IoT for precision agricultural; (d) The current state of the art of integrating Internet of Things (IoT) with precision agriculture is mainly based on the concept of the web of things.

Key Words: *Internet of things; Precision agriculture, Communication system; Web of things*

INTRODUCTION

The integration of the IoT with current applications and future technologies has a noteworthy impact on the economy, society and environment. Consequently, IoT is increasingly found in various sectors and domains, agricultural production being one of its beneficiaries. The current flow of research and development, investment opportunities and the rapid growth of the market highlight the overall potential of smart agricultural solutions. The paper provides a concise review of the current applications of IoT in precision agriculture. We further provide readers with different use case scenarios by describing each step of the research pipeline in precision agriculture, such as monitoring and control including cloud computing, alert systems and other web-based artifacts. We conclude that the IoT has already provided valuable conclusions in the field by performing intelligent data analysis of greenhouses with vertical farming and aeroponics. In the near future, we expect each farmer to take advantage of IoT technology by using some of the agricultural platforms available by connecting their traditional tools and microservices [1,2].

In the field of precision agriculture, the role of scientists and researchers is to increase yield and agricultural management using their knowledge in the field of electronics, software and sensors. PA is an overall term for site-specific crop management, which includes making the right crop input at the right place and the right time, taking into consideration individual field and crop conditions. With a proactive stance to modifying practices to best meet the crop requirements using the available resources and not necessarily maximizing yields, PA contributes to sustainable agricultural development. The design, development and integration of new technologies uniquely customized to the specific conditions of agricultural production make PA a dynamic, interdisciplinary field that uniquely combines biophysical and socioeconomic concepts and methodologies. In present-day agricultural practices, the IoT concept is widely used to achieve a more modern and effective agriculture [3,4].

LITERATURE REVIEW

IoT technologies in precision agriculture

Sensors, networks, Unmanned Aerial Vehicles (UAV), tractors and other smart machines are considered to be the most important elements of the IoT technology-assisted smart farming process. The IoT in smart farming feature of the novel agricultural approach aims for eco-friendly, profitable, productive and well-timed harvests automatically. In this way, it helps the hardware, software and Information Technology (IT) engineering teams as well as farming engineers and agricultural experts to frame smart farming techniques. They also would like to accomplish their smart systems by exploiting their machinery, media server and cloud to monitor farm regions automatically [5,6].

In the agriculture sector, there is a growing demand for the use of technology to enhance production, reduce labor, efficiently utilize resources and decrease adverse environmental impacts. There are several technology solutions deployed for solving agriculture-specific technical problems. A blend of agriculture and technology makes farming smart or intelligent and it is termed as precision agriculture. Precision agriculture involves the use of extensive data about weather, farm conditions and other variables, data acquisition tools, IoT and Artificial Intelligence (AI) software to process this data to monitor and manage crop growth. The goal of precision agriculture research is to define a Decision Support System (DSS) for the entire farm management process so as to optimize returns on inputs while taking into consideration environmental, economic and social sustainability. The integrated use of several smart gadgets and technologies like sensors and actuators, GPS, robotics, AI and IoT with the drones make the system intelligent. The IoT-based setup for precision agriculture is called smart farming [7].

Sensors and actuators: Sensors and actuators are the core of precision farming as the whole idea is based on measurements and management of field variability. There are three main types of sensors applied in precision farming: crop sensors, soil sensors and weather sensors. Crop sensors are utilized for measuring the color and reflectance of leaf vegetation. On the other hand, soil sensors are used for the measurement of soil properties, such as the content of moisture, temperature, texture and salinity. Conversely, weather sensors provide the measurement of environmental data. Additionally, actuators also have a key role in precision farming as they are being used for precision seeding, irrigation and fertilization [8].

Wireless communication technologies: Simple gateway and sensors facilitate load balancing across the system and energy management to extend class battery life. Moreover, this platform is supported with existing cellular infrastructure. It is a national network operator for public-based IoT to provide connection services for IoT devices nationwide. There are various types of Low Power Wide Area Network (LPWAN) technology. They use distinct

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connectivity, bandwidth type, range, service and data transport quality. The diagram offers a low-power long-range communications solution to extend and simplify wireless connectivity for smart cities, smart agriculture and other remote monitoring systems. Sub-1 GHz design centers are attracting great interest. The standard argues to reduce development barriers for suppliers of system-on-chip sensors and gateways, resulting in high compatibility and an extensive selection of diverse communication-informative interest. The performance of traditional sub-1 GHz systems excels in link budget and data rates. However, the excessive link budget is a deterrent because it consumes more power and supports a very short range. The long-range and low-power requirements for IoT devices make these constraints very different. Wireless intelligent networks for sliding window scenarios are used to improve system performance while avoiding overlapping transactions from multiple devices. These are fundamental in large aggregation applications, such as asset tracking, street lighting and condition monitoring [9].

The communication with the devices is more challenging. The devices related to the IoT may involve terrestrial, satellite or hybrid systems. Unlike terrestrial systems, satellite communication can provide resources for a long-range, one-to-many communication model, customized for sparse and remote locations. However, the propagation delay is a key concern for terrestrial devices which require timely interaction such as monitoring and controlling. Many of the supporting technologies and system tools have been progressing over years. Thus, development related to the IoT is inclined with evolution rather than creation. One of the requirements for telemetry in rural and outdoor environments is long-range communications. This kind of communication offers some advantages in different practical activities. LPWAN is a type of wireless network designed for long-range communication with small data streams required by IoT devices.

Data collection and analysis in precision agriculture

The term "actual" refers not only to the timing but also to the precision of the information produced and to the decision support criteria adopted by the decision makers. The online monitoring and the offline data mining are mechanisms strongly linked to each other, which have to be integrated into the information system to provide demonstrations of the current and future state and related research, along with detailed explanations on significant trends. This information is organized in the shape of an active map, providing the evaluated and foreseen status of an activity before during and after the occurrence at different resolution scales.

Precision agriculture is divided into three management levels. Management level 1 deals with the activities aiming to describe the state of the cultivated plants or observed characteristics of samples. All relevant characteristics or parameters describing the physical condition are collected and can then be used to verify the supposed plant behavior according to the models or reference conditions. This data can be exploited by real-time centers, which adjust any actions, e.g. operating parameters for the agricultural machines, fertilizers and plant protective agents to the actual requirements and therefore optimize the process. They are designed to evaluate an actual situation but also the future development of a given activity, irrespective of it being related to the control of machines and procedures or to the forecast of plant and animal conditions at different scales.

Remote sensing technologies: Trimble GreenSeeker is a passive sensor that provides real-time yield estimates. The optical sensor is suspended directly over the row crop to be monitored. Light output is used to determine uniformity for a single row, and crop density is recorded in overall uniformity. The Global Positioning System (GPS) signal is used to determine the speed of travel while the sensor is activated. Data is computed and displayed in a map chart with the GPS data. The GreenSeeker operates down to three inches above the canopy of row crops such as cotton, corn, sugarcane and wheat. Grazing research has used a GreenSeeker monitor to establish and compare the overall relative forage quantity of grazed and ungrazed ranges.

CropScan is a passive crop-infrared sensor that measures the amount of light reflected by the leaves, then converts it to a Leaf Area Index (LAI) measurement. The LAI measurements can be used to control ripening and check the overall plant health. The reflectance-based measurements are obtained in the near-infrared and visible spectrums. CropCircle is also a passive sensor tool that can calculate the leaf area index of a crop stand. It measures red and near-infrared reflectance at four spectral bands to derive the LAI measurements [10].

Remote sensing technologies have an important role in precision agriculture as they direct the use of resources according to the variability in the field. The images, taken by sensors, show the spatial variability of the factors affecting crop yield and give farmers the necessary spatial information for decision-making. It is a low-cost solution to provide timely status. There are two types of remote sensing: Passive sensors and active sensors. Passive sensors measure the solar radiation reflected or emitted by objects.

Big data analytics: The whole basis for IoT is to connect everyday devices to a network with the ability to send and receive data. Most people are considering mundane things like watches, washing machines, dishwashers and the like but the same hypothesis can also be applied to fields of crops, irrigation equipment, soil nutrients, weather, crop pests, crop diseases and humidity. Furthermore, interconnections can also be made to crop forecasting, transportation, weather forecasting, energy usage, mobile operations and many others. This is where the connected environment is going. Smart agricultural industries embedded software into the controllers that do everything from monitor soil weight to provide the perfect environment for root growth and associated needs. This is picture recognition and logistics of the highest level.

This refers to large amounts of data from precision agriculture, which can come from various sources such as satellites, GPS and mapping systems, sensors and telematics, environmental factors such as weather forecasts or historical weather data and wide expertise from service/equipment providers, growers, toxicologists, entomologists and plant pathologists etc. Often, data is multilayered and can be very complex. Big data analytics are crucial to this topic mainly in the following areas of scientific research for generating new ideas, knowledge discovery, finding innovative patterns and building decision support systems. Crop modelling decision support, pest management, decision support, decision support for irrigation and soil management, yield variability and decision support have all taken or are taking advantage of big data for forwarding enhanced solutions.

IoT applications in crop monitoring and management

One of the principal areas that can leverage the use of IoT is precision agriculture. Precision agriculture is an agro-industrial management model where producers can identify in the field, monitor and apply crop inputs in real time for improved productivity. Among the products that this technology can supply are reduced use of chemical inputs such as pesticides, improved control over irrigation applied to land and greenhouse products, soil evaluation with consequent application of nutrients, reduction of physical damage in post-harvest, higher productivity and improved early prediction of crop productions, which optimizes logistics of storage and transport. The benefits of implementing precision agriculture for producers can include improving the quantity and consistency of products, optimizing the application of inputs, reducing environmental impact, respecting the existing legislation and thus mitigating risks, making economic and efficient decisions [7,11].

By generating pertinent agricultural information from a variety of resources (sensors, drones, satellites, georeferenced reports, among others) within a complex and dynamic reality, data analysis can be simplified. Moreover, the possible interactions of this collected data can contribute to agricultural control and management by reducing the ecological and economic threats on crop production. Advances in information and communication technologies have contributed strongly to the creation of the term Internet of Things (IoT), a set of physical objects that can exchange information and messages *via* the internet. The IoT is portrayed by systems connecting devices and objects that are uniquely identifiable on the network.

Soil moisture monitoring: There is a library of countless papers detailing the great number of soil moisture measuring devices enhancing precision agriculture. The importance of this figure lies in the fields in the research area, showing that engineers have to pay much more attention to R4, i.e., correct device utilization. The amount of water in the soil is presented in a large range, besides technological area better than a half a century available for artificial (irrigation) support to the plants. The amount of water determines the chemical and biological reactions as well. Large portions of the Earth are semi-arid or arid lands and areas with scarcity of water belonging to 70% of the world's population are widespread. These two key figures highlight the fact that the importance and the attention of managing water does not stop at the "normal" agricultural lands but should be definitely and attentively considered in large areas of the World. On the other hand, in humidity areas, water might be toxic as well if present in very high excess. Satisfying the requirements of the plants is not a simple task at all.

We detailed the importance of soil moisture to the crop and how it is traditionally and in modern agriculture monitored. Then, we discussed the technology choices of soil monitoring in precision agriculture in the light of soil's electrical characteristics using five different future scenarios for in-field soil moisture monitoring. The great importance of soil moisture for plants is widely known. Soil moisture, described in percentage or volume units and measured by the volumetric is the most critical environmental parameter for most plant species. The plant itself causes several processes within the plant for example, photosynthesis and nutrient transportation. If it is not present at the distance required by the crop, one of the immobile nutrients can become limiting. Plants have no possibility of getting the needed moisture. The closeness of the water within the plant fluctuating around 95%. Due to rapid moisture loss, plants can collapse in a very short period under unfavorable, for example, dry and hot, conditions [11].

Pest and disease detection: Currently, pest and disease detection is primarily based on the scouting methodology, where trained agricultural personnel move throughout the plants, visually checking for diseases and pests at a set frequency, depth and method. This traditional physical methodology creates problems such as high work costs, pathogen transmission between plants or other fields, inaccuracy, inconsistency and delay in detection. In line with this, biological methods have been developed, based on the deployment of beneficial insects on a set frequency, but their success is highly dependent on the density and type of beneficial insects in the field. Early detection is the key in both cases. This is the focus of hypsometric plant sensing. However, there are a few pests and diseases for which remote sensing is difficult, such as the apple maggot. In line with that, pest modeling includes pest life stage models, which use biological sub-models that predict the stage of the pest based on initial pest life-stage inputs. Typically, the proximal inputs to these models are thermal sums, measured in degree days based on daily mean temperatures in the environment. More recently, these pest models have been applied in IoT-based precision agriculture systems to assist farmers in deciding which time is most opportune to apply commercial pheromones and matrics, e.g. the entomopathogenic fungus *Metarhizium brunneum*, in the case of *Drosophila suzukii* pest control [12,13].

Pest and disease detection is one of the categories with the highest potential benefits of the implementation of internet of things sensors in precision agriculture. This category is highly relevant for the European Union (EU), where the reduction in the quantity of Crop Protection Agents (CPAs) as well as the partial replacement of existing CPAs are important issues and are defended in the 2020 European Green Deal. Pest and disease detection is directly related to reducing the use of CPAs, by automatically detecting the first stages and triggering the deployment of beneficial insects or other methods for controlling these issues without using CPAs. In addition, rapid and automatic detection is also related to early disease or pest control with CPAs, which normally requires resolved symptoms.

IoT applications in livestock monitoring

In the last few years, many studies have shown that the precision of animal production can be improved by the use of IoT technologies. The main argument in livestock management is to bring the right tools for support in critical decisions regarding farm management in all areas, enabling animals to express their maximum genetic potential, ensuring animal welfare and increasing the sustainability of the production system. By monitoring animals individually (e.g. feeding, reproduction and health), an increase in efficiency of farms is expected. The requests for products derived from livestock are increasingly specific, so precision supplementation is indispensable. The forage availability measurement is also significant for ranchers who carry out rotational management. Within this branch of IoT, there is a technological trend that uses "sensors to talk to plants". Water is also an important factor to consider in the management of livestock. Scientists have defined different ways to monitor water stress. In addition, it is necessary to reinforce that excessive water supply is as dangerous as insufficiency. Dairy cows and bulls remember the seasonal quality of food, so the availability of grass throughout the year must be guaranteed.

DISCUSSION

Challenges and opportunities in implementing IoT in precision agriculture

It is important for professional scientists to integrate a large number of things in precision agriculture to shape our future of smart farming. In an engineering point of view, this means establishing highly integrated and intelligent communication and sensory systems in agricultural fields, to achieve more focused and quantitative data than human-based observations. The proliferation of precision agriculture brings together the concept of the Internet of Things (IoT) and agriculture, specifically for information delivery, analysis and support for precision agriculture technologies. The technical research costs for most agricultural studies related to IoT also seldomly meet the sophisticated demands of agricultural researchers. The opinions of how IoT may contribute to precision agriculture also vary. Important scientific challenges arise from combining different types of sensory data over time and using it to provide advice to a farmer in an operational setting. The first question that should be asked in this context is what is the environment, specifically agriculture, that an IoT for agglomerating various sensing items involves. This question requires more than a look at the enabling technologies.

Precision agriculture requires the acquisition of data with various sensing technologies. To fulfill the need for more specific data, the number of sensors is extended through the principles of IoT to form Internet of Things specific to Agriculture (IoTA). In this article, a detailed review of current state-of-the-art means of utilizing IoT in PA practices was carried out. An investigation into the features of the utilized sensors, agricultural fields and crop changes, the design architecture of communicating systems and communication system technologies are the key outcomes of the carried-out technical review. Although those are not all that is needed to integrate IoT in PA practices, eight steps, in the format of a flowchart, were developed to guide professional scientists working on implementing IoT in PA practices. According to the carried-out review, these steps should be tailored considering PA demands and the available resources. The identification of not only the communication systems encompassing IoT sensors, but also transmitting transmitted data, is required for PA applications to be improved.

Data security and privacy concerns: In large-scale precision agriculture practices, several agricultural sensors need to be cascaded and deployed on farmland and these sensors can communicate wirelessly to form the edge network of a large-scale precision agriculture internet of things system with agricultural production equipment for field *in-situ* monitoring and the collected data is transmitted to the decision-support expert agricultural management system through base stations or gateways. The IoT system aggregates the rich, real-time data of the remote planning and execution processes in the extended edge network and connects service procedures for direct or indirect interoperability *via* a back-end service procedure bus to support high-level decision making, high-quality mission operation and personalized, proactive agricultural management.

In agricultural practice, a variety of new technologies have been a breakthrough and the application of precision agriculture has achieved remarkable results. The continuous evolution of the IoT has also made our lives full of wisdom, but during the integration of the internet of things in the application of precision agriculture, we also need to pay attention to data security and privacy protection. This paper mainly integrates low-latency, low-power and low-cost wireless communication technology for energy-constrained devices such as sensors and actuators. We build long-range, large-scale IoT systems to meet the needs of large-scale data collection and data interactions in precision agriculture.

Interoperability issues: The intertwining of ubiquity, intelligence and connectivity, which are enabled by wireless sensor networks, embedded systems and Internet technologies, is the key point to create the IoT. Effectively, small-scale households or individuals can build sensor networks to enable the connection to everyday objects. However, most sensor nodes are involved in sensor network activities to achieve a specific goal, without sharing their sensing data with other users. The services to be developed are strictly dependent on the sensors and their locations, which in culturally different locations, population densities and pacing, leads to services that waste infrastructure, power and invaluable time. It is, in fact, a complicating

IoT issue. Interoperability in the IoT context means enabling the interaction and cooperation of heterogeneous devices and services in a transparent or invisible way, in such a manner that the user is unaware of their presence. It is a key concept for creating an open working environment for devices and services in the IoT, allowing the development of advanced applications with new and rich functionalities previously unimagined. In particular, interoperability issues of IoT devices employed in precision agriculture can be identified as either technological myths about IoT being solved or current problems-situations that are real, but the technology is currently dealing with.

Future trends and innovations in IoT for precision agriculture

Using big data applications in IoT-assisted precision agriculture allows the aggregation and management of a large volume of data types captured from a wide variety of different sources. The effective use of big data for IoT applications in precision agriculture will involve improvements in information technology and communication technology to manage the capture and sharing at appropriate spatial granularity, cost and scale. Appropriately structured data sets can guide smart data analytics to provide direction and decision assistance for its sensor informatics users. Common access to these data can also have economic benefits, such as better risk-based pricing that insurance companies can apply to provide their growing market for agricultural weather insurance. The effective use of big data can have broad and potentially transformative effects for making progress in how to apply IoT in precision agriculture. Smart data capture and sharing can enable savings over the entire food production and processing chain. The early identification of supply and demand imbalances can enable price smoothing over regular and irregular fluctuations in market conditions. In the long run, participants in the food production and processing chain can benefit from forward contracts that reduce the risk for their primary product pricing changes under volatile market conditions [14,15].

Future direction of IoT for precision agriculture involves adapting IoT for precision agriculture, using big data to guide IoT applications and adopting interlinked governance for resolving concerns raised with the implementation of IoT for precision agriculture. Agriculturists are the most affected stakeholders by the adoption and use of IoT for precision agriculture applications. They are also the ones who use and generate the data that enable the development of related applications. To achieve integration and formulation with IoT applications and precision agriculture has the potential to change the consumer-to-farmer relationship in a way that places agricultural producers at the center of an agri-food innovation system. This will require improved information flow and coordination, establishing a feedback loop [16].

CONCLUSION

In conclusion, the integration of internet of things with precision agriculture is transforming agricultural practices by enhancing data collection and analysis, leading to more efficient and sustainable farming. The review highlights how IoT technologies, including sensors and big data analytics are instrumental in optimizing crop and livestock management, improving resource use and reducing environmental impact. Despite advancements, challenges such as data security, interoperability and the need for effective communication systems remain. Future innovations are expected to refine these technologies further, making precision agriculture more accessible and impactful. Ultimately, internet of things role in precision agriculture promises significant improvements in agricultural productivity and sustainability.

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