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A Review of the Historical and Prospective Applications of Predictive Analytics in Precision Agriculture

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ABSTRACT

Precision agriculture (PA) has gained popularity because it can solve the agricultural industry's problems while reducing its environmental impact. This paper examines precision agriculture's predictive analytics history and possible applications. The report underlines the rising global demand for food and the need for sustainable agriculture. The restrictions and environmental concerns of conventional agriculture have driven precision agriculture adoption. This study analyses the development of precision agricultural technologies from wireless sensor networks (WSN) to the Internet of Things. This article covers the numerous IoT challenges in agriculture. Internet security, power constraints, and storage limits are covered in detail. This study shows that precision agriculture relies on the Internet of Things (IoT). Sensors, communication devices, and embedded systems collect and evaluate crucial agricultural data. This article evaluates LoRa, Bluetooth, and Zigbee in agricultural settings. This research also examines data analytics in agriculture, explaining the concept and emphasising the importance of big data. This article discusses big data in agriculture, covering large data sets, quick data collection, different data kinds, data correctness and dependability, and data value extraction. Machine learning (ML), deep learning (DL), and data mining are essential for predictive analytics, which predicts future outcomes based on previous data. This research shows that precision agriculture can meet global food demand and environmental concerns. In order to exploit precision agriculture, IoT and big data issues must be addressed

Keywords:

Precision agriculture; WSN; IoT; Bluetooth; Zigbee; LoRa; Big data; Predictive analytics

1. Introduction

Agriculture is a crucial global industry that balances environmental and economic aspects. It can be categorized into traditional and modern agriculture. Traditional agriculture was used to sustain food chains before advanced technologies, but the increasing human population has put pressure on

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the agricultural system. Modern agriculture is defined as a modern enterprise utilizing informative and biological technologies to increase the global economy and integrate industry, trade, and agriculture, while traditional agriculture is seen as having limited access to domestic markets and low technology levels [1].

Event though, agriculture trends interpenetrate into industrial and modernized technologies and keep risen but it is not environmentally friendly and cause the lost in the biodiversity. Soil erosion, contaminated of ground water, water-logging, salinity and excessive use of pesticide are drawback of modern agriculture. These drawbacks can lead to global warming in which the nutrient in the soil loss in result of release of soil carbon from particular organic materials which is the effect from soil erosion process. After all, the excessive use of pesticide can lead to health problem in human since many pesticides that being use are non- biodegradable. These systems provide real-time data on the effects of agricultural practices, allowing for quick modifications and adjustments to improve crop health and production quality. By continuously monitoring environmental conditions, soil moisture levels, and crop growth, farmers can make informed decisions regarding irrigation schedules, fertilizer application, and pest control measures [2].

Precision agriculture (PA) is a prospective solution to the ecological challenges inherent in modern agricultural practices, as it optimises the administration of pesticides and fertilisers through the use of sophisticated technologies. This innovative method, as highlighted in source [3], not only ensures crop yields remain comparable to those obtained through modern agricultural techniques but also addresses environmental concerns through the prudent management of chemical inputs. Farmers can mitigate the negative effects of excessive pesticide use and nutrient imbalances while still meeting the demand for food production by adopting precision agriculture.

According to the source [4], Internet of Things (IoT) technology performs a crucial and transformative function in the context of precision agriculture. Three integral components constitute the IoT ecosystem: hardware, middleware, and data visualisation. The hardware consists of an assortment of sensors, communication devices, and embedded systems deployed strategically across farms and conservatories. These sensors gather information on vital parameters such as soil moisture, pH levels, weather conditions, temperature variations, and nutrient compositions.

This information is then transmitted to the middleware, which processes and stores it. Data analysis and computation duties are managed by embedded systems, which include technologies such as the Raspberry Pi, Waspmote, and Arduino. Farmers gain a comprehensive understanding of their crop's health, growth trajectory, and environmental conditions as a result.

IoT technology emerges as part of PA, consisting of hardware, middleware, and data visualization. Hardware includes sensors, communication protocol devices, and embedded devices, while middleware stores, processes, and analyses data. Table 1 show different types of communication protocols used in IoT. These protocols have different frequency range and distance range. Therefore, it is important to identify scalability of distance and its applications. For greater distance, LoRa and IEEE 802.1.4 protocols can be used for the bigger farm. This enables accuracy collecting data trough sensors nodes leading to good data interpretation.

Table 1
Comparison of Communication Module [5]

Technology	Frequency	Data rate	Range	Power usage	Cost
2G/3G	Cellular Bands	10 mbps	Several miles	High	high
Bluetooth/BLE	2.4GHz	1,2, 3 mbps	~ 300 feet	Low	Low
802.15.4	Sub GHZ/ 2.4 GHz	40, 250 kbps	> 100 square miles	Low	Low
Lora	Sub GHz	< 50 kbps	1 -3 miles	Low	Medium
LTE Cat 0/1	Cellular Bands	1 -10 mbps	Several miles	Medium	High
NB-IoT	Cellular Bands	1 mbps	Several miles	Medium	High
Sigfox	Sub GHz	< 1kbps	Several miles	Low	Medium
Weightless	Sub GHz	0.1 -24 mbps	Several miles	Low	Low
Wi-Fi	Sub GHz, 2.4 GHz, 5GHz	0.1 -54 mbps	< 300 feet	Medium	Low
WirelessHART	2.4 GHz	250 kbps	~ 300 feet	Medium	Medium
Zigbee	2.4 GHz	250 kbps	~ 300 feet	Low	Medium
Z-Wave	Sub GHz	40 kbps	~ 100 feet	Low	Medium

2. IoT in Precision Agriculture: Concept and Overview

The concept of precision agriculture (PA) involves incorporating diverse information and communication technologies (ICTs) to optimize agricultural processes and data administration throughout the production cycle of vegetation and animals. This strategy employs scientific methods to boost productivity and efficiency. ICTs enable the exploitation of numerous data sources, including field-related information such as topography, soil characteristics, and productivity, as well as data from satellite images, climate records, yield maps, historical data, and external sources [6].

The primary objective of integrating PA and IoT is to maximize the utilization of resources such as water, energy, pesticides, and fertilizers. Thus, agricultural production can be increased while minimizing environmental impact, effort, and cost. This pursuit enables producers to achieve enhanced productivity, sustainability, economic advantages, and environmental conservation [7,8]. Diverse technological innovations have been developed for this purpose, including machinery and robots for routine tasks, drones for field monitoring, remote sensing and sensors, highly accurate positioning systems such as geo-mapping, automatic information systems, variable rate technology (VRT), and data storage solutions such as big data and the cloud. These technologies make monitoring and managing agricultural processes easier [9,10].

In the realm of the Internet of Things which includes smart cities [11-13], smart homes [14-16], connected cars [17], and military and government applications [18,19], the integration of new devices consisting of sensors and actuators through various forms of communication is rapidly expanding. The data from these devices is aggregated by IoT gateways [20], transmitted via the Internet, and ultimately processed and stored in systems such as databases and servers. The data can then be accessed and analysed. One of the essential elements for implementing IoT in agriculture is architecture and protocols which consists of three architectural layers: perception, network, and application. The sensors are the devices used to collect and monitor data from a variety of agricultural variables e.g. nutrients, soil moisture and weather in order to identify the factors that influence agricultural productivity. There are numerous types of sensors, such as optical, location, electrochemical, mechanical, and ventilation [21]. Typically, this type of sensor can measure data such as air temperature, precipitation, soil temperature and moisture at a specific depth, leaf dampness, wind speed, chlorophyll, wind direction, relative temperature and humidity, atmospheric pressure, and solar radiation. Ultimately, power efficiency [22], memory capacity [23], computational efficiencies [24], portability [25], durability [26], coverage [27], dependability [28], and price [29] are the most important criteria for IoT devices in agriculture.

Implementation of IoT in the smart vineyard system in Lebanon demonstrates the actual implementation of a wired device designed to monitor the growth and climatic change of grapes in wine-producing regions. Waspmote plug and sense of smart agriculture IoT devices are installed at the farm to measure soil moisture, humidity, and other variables. The vineyard could conduct predictive analytics for future wine production include cost and less production. Despite of increasing technology in agriculture, IoT attract more attention researcher either in industry or scholar to research and develop more in details of benefit and architecture IoT in PA. Nonetheless, there are challenges and limitation of future prospect in IoT include for agriculture application.

Along with an increase in the number of connected devices and applications, the IoT still has security flaws, which is the most important metric. For a system to be complete, a million connected devices and billions of sensors must be secure and have dependable connectivity. Since the IoT landscape is expansive and expanding, the likelihood of an assault on any IoT device increases, as some IoT devices are located in untrusted areas and assailants e.g. open farm can gain access to and control the device.

3. Data Analytics in Agriculture: Concept and Overview

Rapid advancements in IoT [30], remote sensing [31], and cloud computation [32] are largely responsible for the emergence of smart farming [33]. In comparison to precision agriculture (PA), smart farming predicts the future of fundamental management tasks in terms of circumstances and awareness status resulting from real-time events. Smart farming employs information and data technology to optimize the complex farming system, whereas precision agriculture employs digital techniques to optimize and monitor agricultural production processes [34]. In order to address the challenges in agriculture in terms of sustainability, production, environmental impact, and food security, smart farming entails a number of essential components. The complexity and unpredictability of the agricultural ecosystem, for example, necessitate an in-depth understanding, which can be attained through continuous monitoring and measurement of various aspects of the physical environment [36]. This is one of the solutions to the smart farming and sustainable agriculture challenges [35]. In the meantime, big data in agriculture necessitates a substantial investment in infrastructure, particularly for data storage and processing [32], which must occur in real time for applications such as crop surveillance and weather forecasting. Even though big data is prevalent in many fields, the exploration of big data in agriculture is relatively new [37]. As a result, researchers in [38] identified and elaborates on five key components of big data in agriculture:

i. Volume (V1): The amount of information gathered for analysis.
ii. Velocity (V2): The ability to identify pertinent and useful data within a predetermined timeframe.
iii. Variety (V3): multisource of videos, images, remote, and field based on sensing data collected at various dates and times and having varying formats.
iv. Veracity (V4): The capability, dependability, and quality of the data in terms of accuracy, authenticity, and security.
v. Valorisations (V5): The capacity to replicate innovation, knowledge, and esteem.

In the context of agricultural research, analysis entails the examination of a variety of agricultural sector issues. Low (L), medium (M), and high (H) are all levels of severity rather than V1, V2, and V3 which used to categorize the importance of these issues. The complexities associated with V4 and V5 are disregarded for the sake of simplicity. Exhaustive overview of significant data pertinent to big data is provided [40]. Based on the three defined levels, this summary suggests that numerous studies emphasize crucial aspects such as food availability, security, land management, and animal-related concerns. In order to obtain a comprehensive understanding of the complete process of big data analysis in agriculture, researchers must focus on two primary aspects: data science expertise and analytical skills [41]. This involves employing both qualitative and quantitative techniques to assess and predict outcomes.

To obtain a comprehensive understanding of the data science, predictive analytics and big data (DPB) domain, researchers must have a firm background in logistics and supply chain management (SCM). This is essential because economic and data analytics are inextricably linked, as they mutually inform business and farm management decision-making processes. From an economic standpoint, agriculture resembles the healthcare industry in that both are comprised of a series of interconnected yet distinct markets. The incorporation of big data and data analytics has a significant effect not only on processes and operations, but also on strategies across and within a variety of domains. [39] stated that the future of smart Farming may be in two severe events:

i. Closed, propriety system where farmers are constituent of food supply chain and become businessmen.
ii. Open- collaborative systems where farmers and businessmen are collaborating as business partner in term of advanced technology and food production side.

In the field of predictive analytics, it is essential to comprehend the success-driving factors and to employ mathematical models. This involves using past instances of success and failure to develop formulas for predicting future outcomes. Predictive analytics has evolved to integrate sophisticated techniques such as Machine Learning (ML), Deep Learning (DL), and Data Mining to manage the complexities of large data. One study [42] proposes a Big Data framework for machine learning that incorporates diverse structures and processing phases to address Big Data challenges. In contrast, another author [43] highlights the limitations of traditional machine learning when applied to IoT technologies. Due to its superior training and prediction abilities, Deep Learning (DL) emerges as a viable solution. DL decreases manual feature engineering and improves precision. The investigation explores DL architecture, real-time applications, integrations, and frameworks. With supervised and unsupervised learning, the layered architecture of DL excels at capturing complex data hierarchies. Table 2 shows that summarize of papers that use others several techniques in Data Mining to analyse data in predictive analytic.

Table 2
Summarize of Technique Used in Data Mining for Agricultural Applications

No.	Technique used	Ref
1.	Clustering (Grouping similar data points based on traits)	[44,45]
2.	Regression analysis (Understanding relationships between variables)	[46,47]
3.	Choice modelling (Predicting choices made by consumers or farmers)	[48,49]
4.	Neural Network (Machine learning model for prediction)	[50,51]
5.	Network / link analysis (Analysing relationships in a network)	[52,53]
6.	Decision tree (Visual representation of decision outcomes)	[54-56]

Even though the benefit of BD is big and important, there are remains of several challenge that must be fulfil in order to leverage the potential of BD. These challenges not only occur in analysis of method and model but also exist in current data processing system. Example of challenge in BD is in term of privacy, ethical consideration to mining data, building solution for large and multifaceted data and understanding the notion of BD [57]. Another challenge in realising BD exploitation is high cost [58]. Overall challenge in BD comprises of three major challenge which is data challenge, process challenge, and management challenge [59]. Data challenge is all about the data itself. It is including of volume, velocity and variety veracity in term of data. While for process challenge, is all about challenge of technique to process the data in term of data mining and data acquisition.

5. Conclusions

In conclusion, this thorough examination has shown the historical progression and potential uses of predictive analytics in the field of precision agriculture. The technologies have played a pivotal role in facilitating precision farming through the provision of up-to-date data and valuable insights. The primary results of this research underscore the significance of the Internet of Things (IoT) in the realm of precision agriculture. In this context, the utilisation of sensors, middleware, and machine learning algorithms plays a crucial role in enhancing and optimising various agricultural procedures. The field of machine learning can accurately forecast the most advantageous seasons for harvesting, resulting in enhanced agricultural output and financial gains for farmers. Nevertheless, it is essential to recognise the obstacles and limits linked to the use of Internet of Things (IoT) technology in the agricultural sector. These problems include issues such as security vulnerabilities, limitations in power supply, and constraints in data storage capacity. The resolution of these concerns will be of utmost importance in effectively using the capabilities of precision agriculture to address the increasing worldwide need for food production while mitigating adverse environmental consequences. In summary, the amalgamation of predictive analytics and Internet of Things (IoT) technology presents auspicious resolutions to the intricate predicaments encountered in contemporary agriculture. The integration of these technologies will be crucial in attaining sustainable and effective farming practices in the future as the agricultural sector undergoes ongoing transformation.

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