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The Impact of using Wireless Sensors Technology Methods on Precision Agriculture: A Review

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Abstract: Nowadays, most farmers all over the world are suffering from crop loss and irregular growth which caused due to some environmental changes or other reasons such as; climate change, soil composition, cropping techniques, weeds, and illnesses. For this purpose, precision agriculture plays a vital role as a farming method that employs data to ensure that crops grow in the best possible conditions. Therefore, Growers can track their crop's state by monitoring key point indicators, which can assist them to detect if their crops are suffering from water stress, nitrogen stress, or disease development. Mainly, precision agriculture depends on utilizing wireless sensors which used to obtain accurate information about farmers' cultivation land by measuring various parameters of the land and then applying these parameters to earn more money from agriculture. This paper will discuss and survey the advantages of precision agriculture over traditional agriculture, and describes the numerous sensors used by precision agriculture to detect various land factors such as moisture, temperature, and soil salinity, which is the most significant aspect of farming. The major contributions of this paper are it can help researchers to define existing problems, methods and techniques in precision agriculture and choose the proper one that cope with their research problems or helping them to discover new research domains.

Keywords: Precision Agriculture (PA), Wireless Sensor Network(WSN), Big Data, Unmanned aerial vehicles, LORA, WUSN-PLM.

1 Introduction

The sudden change in weather conditions and environmental factors, such as humidity and temperature, are crucial factors that farmers who use traditional agriculture suffer. These factors lead to the rapid progression of plants illness and therefore crop loss or low-interest rates in farming activities in general which will impact later on the total economic growth of the countries. As a result, it is essential for growers to track their crop's state by monitoring key point indicators, which can assist them detect if their crops are suffering from water stress, nitrogen stress, or other disease development such as microorganism diseases which includes "eyespot," "Pseudomonas Syringae," "Phomalingam," "LeptosphaeriaMaculans," "Alternaria-Dligst," and "Phytophthora". Additionally, growers need to be more flexible to adapt according to any environmental changes and make needed adjustments to regular farming activities for boosting plant growth when environmental or weather conditions change[55,1,15,20].

The challenges and problems previously discussed make traditional agriculture impediment for farmers to increase their crop yields or growth rate, and therefore this makes traditional agriculture gradually giving way to precision agriculture to overcome these issues. Overall, precision agriculture is a farming method that employs data to ensure that crops grow in the best possible conditions and helps growers to track their crop's state. Moreover, precision agriculture enables farmers to obtain precise information about their cultivation land by employing wireless sensors which measures different parameters of the land and based on them farming activities are done according to those parameters, this is will lead increase product growth rate and crop gain. Additionally, precision agriculture allows farmers to monitor crop loss, irregular crop growth, change in weather conditions and change in environmental conditions, and this helps to cut production costs by reducing waste, generate higher-quality goods with fewer resources and higher profit rate. To sum-up, the information gathered and factors measured by precision

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agriculture can significantly use to assess performance, improve productivity rather than past seasons, overcome common problems farmers suffer from and increase total crop yield[36].

Mainly, precision agriculture depends on employing Wireless Sensor Network (WSN) to gather information needed to guide farmers. Wireless Sensor Network (WSN) is a cutting-edge technology that is gaining traction in the modern world because to its low-power wireless communication, low-cost performance, low-power detector nodes, and self-healing capabilities. The use of Wireless Sensing Element Networks (WSNs) in agriculture is becoming quickly adopted under the banner of precision farming. Nowadays, agriculture begins with technological farming machines such as tractors and grain mixers that must be cost-effective and beneficial to farmers, and this gives farmers advantages to boost their crop yields. Agriculture fields are connected to the Internet of Things via sensing element networks, allowing agronomists and farmers to make connections regardless of their location. Farmers may make better judgments with the support of this technique, which includes historical data on lands and crops. This paper describes techniques and methods of using wireless sensor network (WSN) applications in precision agriculture[48,43,8,39,14].

Indeed, before applying precision agriculture, some notes need to be considered from different perspective. From the *management* perspective, precision farming distinguishes itself from traditional agriculture by its level of management. So, instead of managing whole fields as a single unit, management is customized for small areas within fields. This increased level of management emphasizes the need for sound agronomic practices. Before considering the jump to precision agriculture management, a good farm management system must already be in place. These farm management systems must include internally data acquisition and analysis and decision support system. From *economics* perspective, precision agriculture must consider economic and environmental benefits, as well as the practical questions of field-level management and the needed alliances to provide the infrastructure for technologies such as changes in costs or changes in revenues. From *environmental* perspective, precision agriculture merges the new technologies borne of the information age with a mature agricultural industry. It is an integrated crop management system that attempts to match the kind and number of inputs with the actual crop needs for small areas within a farm field. This goal is not new, but new technologies now available allow the concept of precision agriculture to be realized in a practical production setting, precision agriculture must ensure the following; decrease input losses and target nutrients to increase uptake efficiency[16].

The rest of the paper is organized as follows. Section 2 presents the open Issues and Challenges. Section 3 highlights the precision agriculture techniques and methods. Section 4 describes the precision agriculture applications. Section 5 concludes the paper.

Fig. 1: An irrigation sprinkler powered by a solar pump under precision farming

2 The need for precision agriculture.

Sustainable precision agriculture is this century's most valuable innovation in farm management that is based on using Information and Communication Technologies (ICTs). This is the most recent innovative technology based on sustainable agriculture and healthy food production and it consists of profitability and increasing production, economic efficiency, and the reduction of side effects on the environment. Additionally, precision agriculture identifies, analyses and manages variability in fields by conducting crop production practices at the right place and time and in the right way, for optimum profitability, sustainability and protection of the land resource. The overall benefits of precision agriculture can be summarized as follows:

- **Increase agriculture productivity.** Real life experiments prove that precision agriculture increase the farming productivity which correspondingly has a significant impact in the total economic growth. Besides, the great cost reduction happened due effective land use and farming resources.
- **Prevents soil degradation**. Soil degradation in agriculture results in a soil erosion which causes loss of topsoil and terrain deformation which has an impact on crop growth. For example, In India in 2015, based on a first approximation analysis of existing soil loss data, the average soil erosion rate was approximately 16.4 ton, leading in an annual total soil loss of 5.3 billion tons throughout the country. Soil degradation is considered as a serious problem need to be avoided. Indeed, precision agriculture prevents the soil degradation by monitoring the quality and health of the soil over the time, reports any strange

change that will cause soil erosion, and therefore this saves the crop growth over the time[44,19,35].

–**Efficient use of water resources.** Experiments prove that precision farming leads to an efficient water management in agriculture. Mainly, precision agriculture depends on irrigation scheduling activities and efficient technologies such as drip irrigation, this is will lead to reduce water consumption by 30 to 70 percent and achieve yields increase by 30 to 200 percent for several types of crops. Figure 1 presents smart techniques for irrigation which lead to an efficient water management[5,40,42].

–**Reduction of chemical application in crop production.** In general, farmers focus on reducing the cost of production and aim to increase profit. In [10], the authors studied the reduction of pesticides applied to soybean and maize crops in several stages of the production cycle using a site-specific spraying application based on real-time sensors in the Brazilian Cerrado region. The sprayers were equipped with a precision spraying control system based on a real-time sensor. The precision spraying system based on real-time sensors reduced the volume of pesticides (including herbicides, insecticides, and fungicides) applied to soybean and maize crops. There was a more significant reduction in the volume of pesticides applied post-emergence of the crops in the initial stages of soybean and maize when the crops had less leaf area or less foliage coverage between the rows. The cost reduction achieved using this technology was 2.3 times lower than the cost associated with pesticide application over the entire area using a conventional sprayer. Overall, precision agriculture implies a drastic reduction of adverse environmental effects arising from agricultural activities, also the reduction of pesticide use is one of the critical drivers to preserving the environment, human health, crop quality and crop growth[32,34,24,23].

3 Open Issues and Challenges

This section highlights the existing challenges and issues in the traditional agriculture from farmers side. on the other side, this section describes the challenges on methods used to apply precision agriculture.

Physically: from farmer's side, Recently, growers suffer from environmental variations like climate change, soil composition, cropping techniques, weeds, water stress, nitrogen stress, and disease development which cause rapid progression of plant illnesses, crop loss and erratic crop growth. On the other side, growers suffer from climate changes such as humidity and change soil temperature which cause several plant diseases like; "eyespot," "Pseudomonas Syringae," "Phomalingam," "LeptosphaeriaMaculans," "Alternaria-Dligst," and "Phytophthora", these diseases play a big role in how quickly a plant infection spreads and total crop loss[36].

Technically : from Application side, The major technical limitations and challenges can be summarized as follows:

–Collecting and analyzing environmental data is an expensive and complicated endeavor.

–Several current wireless sensor network (WSN) solutions use protocols like 802.15.4 b (LR-WPANs) and 802.11x (WLAN), however, they have limited transmission range, and complex communication stacks, and data management, and consume a lot of power.

–Early investigators experienced challenges with complexity of deployment, network connectivity and battery life. While systems can be deployed with a wire-based system that provides power and facilitates data transfer over a stable wired connection, they are inconvenient because large amounts of wire are needed to connect the sensor nodes. The wire must also be concealed in a manner that does not limit accessibility and is protected from machinery and environmental degradation. Damaged wires will disable some or all of the sensor network and will require user intervention to troubleshoot and restore functionality.

–The resources required to implement and maintain sensor networks are too high to justify the investment.

–Many current services have issues with data ownership and residency.

4 Precision agriculture: Techniques and Methods

4.1 LORA

The LoRa is defined as a wireless modulation system that is based on Chirp Spread Spectrum (CSS). It uses chirping pulses to encode information on radio waves, similar to how dolphins and bats communicate. Besides, the improved LoRa transmission is resistant to interference and has a long range of reception. Practically, LoRa modulation and Chirp Spread Spectrum technology are straightforward to grasp. LoRa is well suited to applications that send little amounts of data at low rates. When compared to WiFi, Bluetooth, or ZigBee, data can be carried over a greater distance. Therefore, these characteristics make LoRa an excellent choice for low-power sensors and actuators. On the other side, LoRa may operate in license-free sub-GHz bands like 915MHz, 868MHz, and 433MHz, for example. Also, it can operate at 2.4GHz to provide faster data rates than sub-GHz bands, although this comes at the expense of the band[9,22,28].

The application of LORA protocol is named Lorawan, LoRaWAN is a LoRa modification-based layer media access control (MAC) protocol. It's a software layer that governs how LoRa devices are used, such as when transmitting and formatting messages. The LoRa Alliance created and maintains the LoRaWAN protocol. In January 2015, the first LoRaWAN specification was published[6].

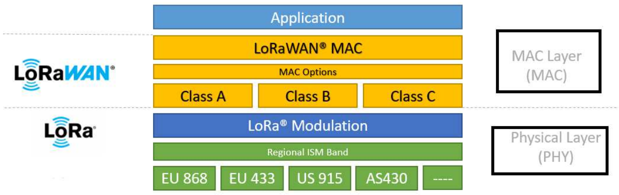

Fig. 2: LoRa & LoRaWAN Layers

Figure 2 describes LoRa and LoRaWAN methods.

It is worth saying that the LoRa is a specialized wireless spectrum modulation technology, while LoRaWAN is an open standard that enables IoT devices to use LoRa for communication[52,7,49].

The following points highlighted the advantages of using LoRa and LoRaWAN methods:

- LoRa eliminates the need for complex and energy intensive routing and synchronization protocols, allowing for sensor nodes to communicate directly with the data collection point.
- LoRa is most suitable for implementations that do not require large amounts of data transferred over short periods of time because it uses low data rate.
- LoRA allows developers to utilize low-cost, open-source solutions leading to high scalability. Specifically for cost sensitive, agricultural applications this is suitable as an installation may only require hundreds of nodes.
- With LoRa developers can implement low-cost, local data storage and visualization tools, allowing a grower to maintain control of data privacy and ownership.
- As many agricultural locations lack internet connectivity, LoRa devices can be run decoupled from the internet, offering maximum flexibility that focuses on medium access and network congestion.
- While LoRa allows physical point-to-point communications, LoRaWAN offers a complete network topology, focused at scalability towards hundreds of thousands of devices connecting to the Internet. With LoRaWAN, the topology requires a gateway that encapsulates network dataframes as well as providing cloud-based network services for storage and analysis, and this makes LoRaWAN most suitable for controlling percsion agricultural applications .

4.2 WUSN-PLM: Wireless Underground Sensor Networks Path Loss Model

Recently, the Wireless Underground Sensor Network (WUSN) is a well-known Internet of Things domain of interest (IOT). The WUSN has a variety of uses, including military tracking, health care, environmental monitoring, human rescues following natural disasters, and intelligent agriculture[4,2]. The sensor nodes are generally buried under the earth in agriculture-related applications, and communication between nodes is done by electromagnetic (EM) waves. The data acquired by nodes is transported up to a Base Station (BS) placed above the ground surface through Wireless Underground Communications. However, because the earth is denser than air when a terrestrial sensor node is buried, its communication range is hardly reduced. Unlike classic wireless technologies which operate at a high frequency (often 2.4 GHz) like WiFi, Bluetooth, or ZigBee, in WUSN, such signals are quickly muted when they cross the ground. WUSN accepts low-frequency transceivers to have an acceptable communication range under the earth (433MHz). Furthermore, depending on the soil qualities, wave behavior may alter, affecting the sensor communication range. The soil dielectric, which is influenced by soil moisture (percentage), is the most critical characteristic for underground signal attenuation. Because the soil qualities may differ at different spots across the field, the wave signal attenuation should vary accordingly. The wireless subterranean signals must then be accurately forecasted based on in situ soil properties[30,3,31].

The advantages of using WUSN-PLM model in precision agriculture lies on the WUSN-PLM model considers the underground parts (topsoil and subsoil) because in agriculture the topsoil region or the subsoil can be plowed before planting seeds or young plants. Furthermore, since the traditional WSN nodes have several constraints due to their limited resources, a path loss model adapted to their constraints with low computation and memory needs is planned. To evaluate and validate the WUSN PLM, and intensive experimentations have been conducted in a real environment with two different pairs of wireless transceivers (nRF905 and LoRa SX1278). The resulting comparison has shown that the proposed WUSN-PLM outperforms the other approaches with the overall highest amount of Good Prediction GP.[53,11]

4.3 Unmanned aerial vehicles

Unmanned aerial vehicles (UAVs), are becoming more common in agricultural and livestock for monitoring, spraying, and tracking, as well as image and sensory data collection. Recently, advances in UAV technology have dramatically lowered costs. Indeed, the UAVs technology

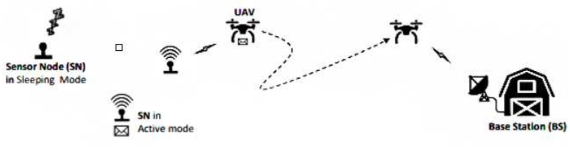

Fig. 3: UAV System Elements

has transformed other fields like; terrain mapping, search and rescue, security, filmmaking, and delivery[54,25,50,12]. The proposed technique for re-configuring the sensor nodes (SNs) intends to match the UAV flight's activation and hibernation times. It allows SNs to communicate for the shortest time possible, lowering their battery consumption and extending their lifetime. Besides, the UAVs employ time-slots as a point of reference for state management. In precision agriculture, the use of monitoring sensors is becoming more common. To save battery power, these sensor nodes (SNs) usually cycle between periods of active and hibernation. There is a need to coordinate the UAV path with the activation period of each SN while using unmanned aerial vehicles (UAVs) to gather data from SNs scattered across a broad agricultural area[41,45,18,29]. As illustrated in Figure 3, the scenario considered in this work is composed of SNs, UAVs, and a BS, while we consider the following characteristics for each element: Sensor nodes (SNs) are homogeneous, have fixed locations, and are known by the UAVs. We assume that they are composed of a set of sensors, processors, memory for sensory data storage, and also a Global Positioning System (GPS) interface. Besides that, we consider that SNs have a limited lifetime due to the capacity restrictions of their batteries. Thus, SNs must alternate their states between periods of activation and hibernation. We assume that there is no direct communication between SNs due to the distance between them and the limited communication capacity. Therefore, they depend on the UAV to collect data stored in memory and deliver it to the BS. Unmanned aerial vehicles (UAVs) have high mobility, are homogeneous, multi-rotor, and have ad hoc communication systems [26] for UAV-UAV, UAV-SN, and UAV-BS communication types. Besides gathering data from the SNs, they can exchange information with each other by copying its local database, about the scenario, directly to the new UAV on Return to the Home procedure, and transfer the sensory data to the BS. The base station (BS) has a fixed location known by the UAVs, and it is the final destination of the information generated by the SNs. It is primarily responsible for the post-processing of the sensory data delivered by the UAVs[13,27,21,47,26].

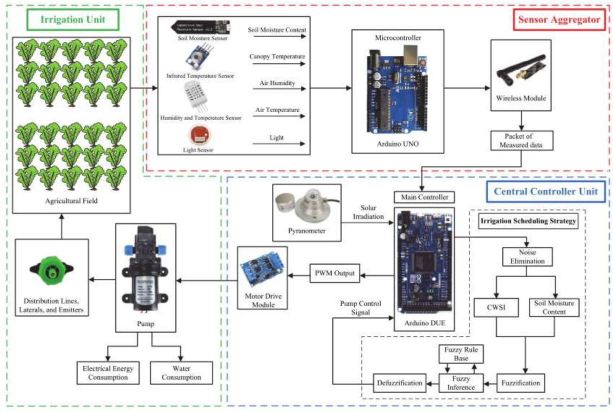

Fig. 4: Structure of the proposed intelligent irrigation scheduling system

4.4 An Intelligent Irrigation Scheduling System Using Low-Cost Wireless Sensor Network Toward Sustainable and Precision Agriculture

Agricultural irrigation developments play a vital role in improving crop yields and managing efficiently water use and resources. On the other side, traditional irrigation consumes excessive amounts of water and consumes high electrical energy to schedule irrigation. In [17], authors proposed a fuzzy-based intelligent irrigation scheduling system using a low-cost wireless sensor network (WSN) which takes crop and soil water variabilities into account to adaptively schedule irrigations. Besides, the theoretical crop water stress index (CWSI) is calculated to indicate plant water status using canopy temperature, solar irradiation, and vapor pressure deficit. Furthermore, the soil moisture content obtained by a capacitive soil moisture sensor is used as a determination of water status in soil. These two variables are thus incorporated to improve the precision of the irrigation scheduling system. System performance tests have done to validate and compare it with existing conventional irrigation systems, results reported that this system leads to a decrease in water use by 59.61% and electrical energy consumption by 67.35%, while the crop yield increases by 22.58%. Moreover, results confirm that the proposed irrigation scheduling system is effective in terms of precision irrigation scheduling and efficient regarding water use and energy consumption. Finally, the cost analysis is performed to confirm the economic benefit of the proposed irrigation scheduling system.

Figure 4 illustrates the proposed irrigation scheduling system which consists of three main parts, (1) sensor aggregator, (2) central controller unit, and (3)irrigation unit.

Figure 5 describes the prototype of the proposed irrigation scheduling system. The central controller unit is

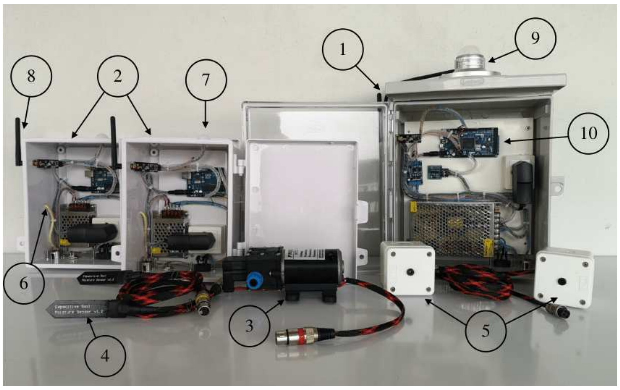

Fig. 5: Prototype of the proposed intelligent irrigation scheduling system.

shown in number 1. The sensor aggregators are shown in number 2, while the irrigation unit is shown in number 3. In the sensor aggregator, the dielectric-based capacitance soil moisture sensor is used because of its capability is shown in number 4. To calculate CWSI, the infrared temperature sensor is used and embedded in the water-proof plastic container as shown in number 5. Furthermore, the air temperature and humidity sensor are necessarily used to calculate CWSI, as installed in number 6. The light sensor is also used to detect the sunlight and used to automatically turn off during the nighttime, as shown in number 7. The wireless module is installed to send the measurement data to the central controller unit, as shown in number 8. In the central controller unit, the pyranometer is installed to measure the solar irradiation, as shown in number 9. The structure of the central controller unit is made as shown in number 10 of Fig. 2.

5 Precision agriculture: Applications

The *Cropio* application is a satellite crop health management and vegetation control platform that facilitates remote monitoring of agricultural land and enables its users to efficiently plan and carry out agricultural operations. The Cropio provides real-time updates on current field and crop conditions, determines vegetation levels and pinpoints problem areas, delivers precise weather forecasts and an actual overview of the soft commodity market. Also Cropio can be described as a satellite field management system that facilitates remote monitoring of agricultural land. The System provides real-time updates on current field and crop conditions, determines vegetation levels and identifies problem areas, delivers precise weather forecasts. Mainly, Cropio application designed for managing agricultural companies. It gives the access to main information about fields, satellite images, status of agricultural works, current weather data, and field status reports. Once synced, application could work offline, without Internet access. Also, Cropio application gives ability for agronomists to create reports for their fields (with photos and text notes) that could be synced with Cropio site. To sum up, Cropio main service functions: (1) real-time vegetation monitoring, (2) field zoning and problem area identification, (3) fertiliser and seed distribution mapping, (4) reporting and notification system, (5) data-bank and historical information, (6) integration with GPS monitoring system, monitoring of agriculture operations, (7) productivity estimate, and (8) weather forecast and information[37,38].

The *Adapt-N* application provides proven, advanced and trusted agricultural modeling of soil, water, crops and fertilizer. It analyses soil, weather, crop, and field management data to offer a field-specific, always-on nitrogen prescription that has been proved to improve financial and environmental performance. Adapt-N uses a combination of soil, weather, crop, and field management models to simulate the nitrogen cycle, including nitrogen fixation, nitrification, and denitrification. Adapt-N, a software tool for agronomists that combines data around soil types and weather with crop modeling and field management to provide farmers with detailed fertilizer prescriptions, to avoid overuse and wastage. Its Adapt-N and N-Insight products provide nitrogen management solutions in partnership with agricultural retailers, agricultural technology companies, and farmers. The Adapt-N tool is a user friendly, web-based nitrogen (N) recommendation tool for corn crops. The tool provides precise N fertilizer recommendations that account for the effects of seasonal conditions using high-resolution climate data, a dynamic computer model, and field-specific information on crop and soil management[46,51].

The *Climate FieldView* application, allows making data-driven decisions to maximize your return on every acre. We're your data partner to collect and analyze field data, measure performance, monitor nitrogen, and build tailored seeding prescriptions. Sign up today and put the power of data in the palm of your hand[33].

CropZilla is software tool designed for farm resource planning and operations. By using this tool farmers are able to design and plan their farming activities such as planting, growing season and harvest by testing resource allocation in multiple operating scenarios. This tool enables farmers to make intelligent decisions to improve their operational efficiencies and ultimately profitability. CropZilla is available as cloud SaaS with subscription fees calculated based on acreage.

6 Conclusion

The precision agriculture is a recent direction that help farmers to overcome issues and challenges they face in frequent manner. These issues include; environmental variations like climate change, soil composition, cropping techniques, weeds, water stress, nitrogen stress, and disease development which cause rapid progression of plant illnesses, crop loss and erratic crop growth. Indeed, this paper discusses the methods used that help applying precision agriculture; these methods include Lora, WUSN-PLM and Unmanned aerial vehicles and how these methods fix the issues that farmers suffer from. Finally, precision agriculture is a must for farmers to increase crop growth and avoid problems raised by traditional agriculture.

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