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A Literature Survey on Internet-of-Things (IoT)-Based Smart Agriculture

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ABSTRACT

In today's world, despite people may have the perception regarding the agricultural process, the reality is that today's agriculture industry is data-centered, precise, and smarter than ever. The rapid emergence of the Internet-of-Things (IoT) based technologies redesigned almost every industry including ''smart agriculture'' which moved the industry from statistical to quantitative approaches. This paper focuses on the potential of IoT in agriculture process, as well as the challenges expected to be faced while technology integration with the traditional farming practices. In agriculture applications, IoT devices and communication techniques associated with wireless sensors encountered are analyzed in detail. What are sensors available for specific agriculture application, like soil preparation, crop status, irrigation, insect and pest detection are listed. How this wireless sensor technology helping the growers throughout the various crop stages, from sowing until harvesting, packing and transportation is explained.

Key Words: Food quality and quantity, Internet-of-Things (IoT), smart agriculture, advanced agriculture practices, urban farming, agriculture robots, automation, future food expectation.

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I. INTRODUCTION

To improve the agricultural yield with fewer resources and labor efforts, substantial innovations have been made throughout human history. Nevertheless, the high population rate never let the demand and supply match during all these times. According to the forecasted figures, in 2050, the world population is expected to touch 9.8 billion, an increase of approximately 25% from the current figure. Almost the entire mentioned rise of population is forecasted to occur among the developing countries . On the other side, the trend of urbanization is forecasted to continue at an accelerated pace, with about 70% of the world's population predicted to be urban until 2050 (currently 49%). Furthermore, income levels will be multiples of what they are now, which will drive the food demand further, especially in developing countries. As a result, these nations will be more careful about their diet and food quality; hence, consumer preferences can move from wheat and grains to legumes and, later, to meat. In order to feed this larger population, food production should double by 2050. Particularly, the current figure of 2.1 billion tons of annual cereal production should touch approximately 3 billion tons, and the annual meat production should increase by more than 200 million tons to fulfill the demand of 470 million tons.

Considering the standard farming procedures, farmers need to visit the agriculture sites frequently throughout the crop life to have a better idea about the crop conditions. For this, the need of smart agriculture arises, as 70% of farming time is spent monitoring and understanding the crop states instead of doing actual field work. Considering the vastness of the agriculture industry, it incredibly demands for technological and precise solutions with the aim of sustainability while leaving minimum environmental impact. Recent sensing and communication technologies provide a true remote ''eye in the field'' ability in which farmers can observe happenings in the field without being in the field. Wireless sensors are facilitating the monitoring of crops constantly with higher accuracy and are able to, most importantly, detect early stages of unwanted state. This is the major reason behind modern agriculture involving the usage of smart tools and kits, from sowing to crop harvesting and even during storage and transportation. Timely reporting using a range of sensors makes the entire operation not only smart but also cost effective due to its precise monitoring capabilities. Variety of autonomous tractors, harvesters, robotic welders, drones, and satellites currently complement agriculture equipment. Sensors can be installed and start collecting data in a short time, which is then available online for further analyses nearly immediately. Sensor technology offers crop specific and site specific agriculture, as it supports accurate and precise data collection from every site.

Researchers and engineers around the globe are proposing different methods and architectures and based on that suggesting a variety of equipment to monitor and fetch the information regarding crop status during different stages, considering numerous crop and field types. Focusing on the market demand, many leading manufactures are providing a range of sensors, unmanned aerial vehicles (UAVs), robots, communication devices, and other heavy machinery to deliver the sensed data.

Figure-1: Major hurdles in technology implementation for smart agriculture.

II. MAJOR APPLICATIONS

By implementing the latest sensing and IoT technologies in agriculture practices, every aspect of traditional farming methods can be fundamentally changed. Currently, seamless integration of wireless sensors and the IoT in smart agriculture can raise agriculture to levels which were previously unimaginable. By following the practices of smart agriculture, IoT can help to improve the solutions of many traditional farming issues, like drought response, yield optimization, land suitability, irrigation, and pest control.

Figure-2: General hierarchy of possible applications, services and sensors for smart agriculture.

2.1 Soil Sampling and Mapping

Soil is the ‘‘stomach’’ of plants, and its sampling is the first step of examination to obtain field-specific information, which is then further used to make various critical decisions at different stages. The main objective of soil analysis is to determine the nutrient status of a field so that measures can be taken accordingly when nutrient deficiencies are found. Comprehensive soil tests are recommended on and weather consents, it may be done in Fall or Winter. The factors that are critical to analyze the soil nutrient levels include soil type, cropping history, fertilizer application, irrigation level, topography, etc. These factors give insight regarding the chemical, physical, and biological statuses of a soil to identify the limiting factors such that the crops can be dealt accordingly. Soil mapping opens the door to sowing different crop varieties in a specific field to better match soil properties accordingly, like seed suitability, time to sow, and even the planting depth, as some are deep-rooted and others less.

2.2 Irrigation

About 97% of Earth’s water is salt-water held by oceans and seas, and only the remaining 3% is fresh water—more than two-third of which is frozen in the forms of glaciers and polar ice caps. Only 0.5% of the unfrozen fresh water is above the ground or in the air, as the rest lies underground. In short, humanity relies on this 0.5% to fulfill all its requirements and to maintain the ecosystem, as enough fresh water must be kept in rivers, lakes, and other similar reservoirs to sustain it.

The current situation of irrigation methods is expected to be changed by adopting the emerging IoT technologies. A significant increase in crop efficiency is expected with the use of IoT based techniques, such as crop water stress index (CWSI)-based irrigation management.

2.3 Fertilizer

A fertilizer is a natural or chemical substance that can provide important nutrients for the growth and fertility of plants. Plants mainly need three key macronutrients: nitrogen (N) for leaf growth; phosphorus (P) for root, flowers, and fruit development; potassium (K) for stem growth and water movement [38]. Any sort of nutrients deficiency or applying them improperly can be seriously harmful for the plant health. More importantly, excessive use of fertilizer not only results in financial losses but also creates harmful impacts to the soil and environment by depleting the soil quality, poisoning ground water, and contributing to global climate changes.

Fertilization under smart agriculture helps to precisely estimate the required dose of nutrients, ultimately minimize their negative effects on the environment. Fertilization requires site-specific soil nutrient level measurements based on various factors, such as crop type, soil type, soil absorption capability, product yield, fertility type and utilization rate, weather condition, etc. New IoT-based fertilizing approaches help to estimate the spatial patterns of nutrients requirements with a higher accuracy and minimum labor requirements.

2.4 Crop Disease and Pest Management

To control vast production losses in farming, pesticides and other agrochemicals became an important component of the agriculture industry during the last century. It is estimated that, in each year, around half a million tons of pesticide are used in the US alone, while more than two-million tons are used globally. Most of these pesticides are harmful to human and animal health, leaving severe, even irreversible, impact to the environment, ultimately causing significant contamination to entire ecosystems. Recent IoT based intelligent devices, such as wireless sensors, robots and drones are allowing the growers to slash pesticide uses significantly by precisely spotting crop enemies. Compared to traditional calendar or prescription based pest control procedures, modern IoT-based pest management provides real-time monitoring, modeling, disease forecasting, hence proving more effective.

2.5 Yield Monitoring , Forecasting , And Harvesting

Yield monitoring is the mechanism used to analyze various aspects corresponding to agricultural yield, like grain mass flow, moisture content, and harvested grain quantity. It helps to accurately assess by recording the crop yield and moisture level to estimate, how well the crop performed and what to do next. Yield monitoring is considered an essential part of precision farming not only at the time of harvest but even before that, as monitoring the yield quality plays a crucial role. Crop forecasting is an art to predict the yield and production (tons/ha) before the harvest takes place. This forecasting helps the farmer for near-future planning and decision making. Furthermore, analyzing the yield quality and its maturity is another critical factor which enables the determination of the right time for harvesting. This monitoring covers various development stages and uses fruit conditions like its color, size, etc., for this purpose. Predicting the right harvesting time not only helps to maximize the crop quality and production but also provides an opportunity to adjust the management strategy.

Furthermore, analyzing the yield quality and its maturity is another critical factor which enables the determination of the right time for harvesting. This monitoring covers various development stages and uses fruit conditions like its color, size, etc., for this purpose. Predicting the right harvesting time not only helps to maximize the crop quality and production but also provides an opportunity to adjust the management strategy. Although, harvesting is the last stage of this process, proper scheduling can make a clear difference. To obtain the real benefits from crops, farmers need to know when these crops are actually ready to harvest. Figure 5 represents a snapshot of a farm area network (FAN) that can portrait the whole farm to the farmer in real time.

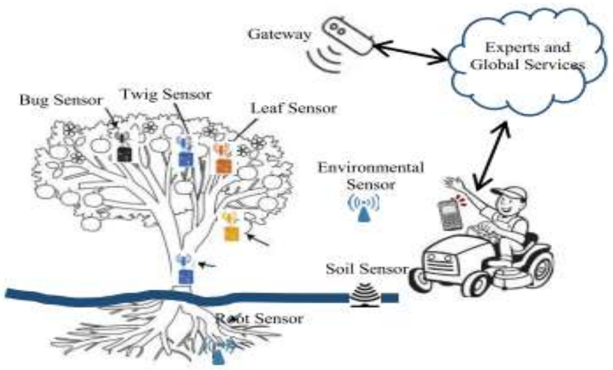

Figure-3: An IoT based farm area network (FAN).

III. ADVANCED AGRICULTURAL PRACTICES

Adopting the novel methods to enhance the quality and quantity of food is not something new, as humans have been doing this for centuries. Initially, we tried to enhance the crop production by focusing on seed variety, fertilizers, and pesticides. Soon it was realized that these conventional ways were not adequate enough to fit this demand gap. However, several studies highlight their serious effects on human health, including infertility, disruption in immune system, accelerated aging, faulty insulin regulations, etc. All these and many other similar technologies did not receive much popularity and acceptance in society because people prefer bio and organic food. In this regards, massive research has been conducted for decades in which sensors and IoT-based technologies are helping to improve conventional agriculture processes to enhance yield production without, or with minimum, effect on its originality.

3.1 Greenhouse Farming

Crops grown indoors are very less affected by environment; most importantly, they are not limited to receiving light only during the daytime. As a result, the crops that traditionally could only be grown under suitable conditions or in certain parts of the world are now being growing anytime and anywhere. This was the actual time in which sensors and communication devices started to support various agriculture applications genuinely. The success and production of various crops under such controlled environment depend on many factors, like accuracy of monitoring parameters, structure of shed, covering material to control wind effects, ventilation system, decision support system, etc. A detailed analysis is provided in, where all these factors, their impacts, and how wireless sensors can help for all this are considered.

3.2 Vertical Farming

The current trends in agricultural practices based on industrial farming are damaging the soil quality far faster than nature can rebuild it. Overall, it is estimated that erosion rates from cultivated fields is 10 to 40 times greater than the soil formation rates. Considering the reduction of arable land issues, it could be a disaster for food production in the near future with current agriculture practices. Further, as we mentioned, 70% of fresh water is only used for agriculture purpose, which can increase the burden on existing limited water reservoirs. Vertical Farming (VF) is an answer to meet the challenges of land and water shortages. VF in the form of urban agriculture offers an opportunity to stack the plants in a more controlled environment resulting in, most importantly, significant reduction in resource consumption.

3.3 Hydroponic

In order to enhance the benefits of greenhouse farming, agriculture experts moved forward another step and provided the idea of hydroponic, a subset of hydro culture in which plants are grown without soil. Hydroponic is based on an irrigation system in which balanced nutrients are dissolved in water and crop roots stay in that solution; in some cases, roots can be supported by medium like perlite or gravel. When combining hydroponics with VF, a farm of 100 sq. meters can produce the crop equivalent to 1 acre of traditional farm, most importantly upto 95% less water and fertilizers utilization and without pesticides/herbicides. Currently, available systems and sensors are not only used to monitor a range of parameters and take readings at predefined intervals but, also, the measurements are stored so that can be used to analyze and diagnostic purpose later on. Under this application, the precision of nutrient measurements is crucial, as such, a highly reliable wireless control system for tomato hydroponics is proposed in which they focused on various communication standards that are least effected by plants' presence and their growth. The monitoring of solution contents and their precision is most critical under this method; for this purpose, many systems are offered to check the presence of contents considering the plant demands.

3.4 Phenotyping

There are few advanced techniques are under experiment to further enhance the crop capabilities by controlling their limitations with the help of advanced sensing and communication technologies. Among these methods, the more prominent is phenotyping, which is based on emerging crop engineering, which links plant genomics with its ecophysiology and agronomy, as shows in Figure 6. The progress in molecular and genetic tools for various crop breeding was significant in the last decade. However, a quantitative analysis of the crop behavior, e.g. grain weight, pathogen resistance, etc., was limited due to the lack of efficient techniques and technologies that we can now enjoy.

An IoT-based phenotyping platform, CropQuant, is designed to monitor the crop and relevant trait measurements that can provide facility for crop breeding and digital agriculture. Here, an automatic in-field control system was developed to process the data generated by platform. The provided trait analyses algorithms and machine learning modeling help to explore the relation among the genotypes, phenotypes, and environment where it grows.

IV. CONCLUSION

The focus on smarter, better, and more efficient crop growing methodologies is required in order to meet the growing food demand of the increasing world population in the face of the ever-shrinking arable land. The development of new methods of improving crop yield and handling, one can readily see currently: technology-weaned, innovative younger people adopting farming as a profession, agriculture as a means for independence from fossil fuels, tracking the crop growth, safety and nutrition labeling, partnerships between growers, suppliers, and retailers and buyers. This paper considered all these aspects and highlighted the role of various technologies, especially IoT, in order to make the agriculture smarter and more efficient to meet future expectations. For this purpose, wireless sensors, UAVs, Cloud-computing, communication technologies are discussed thoroughly. Furthermore, a deeper insight on recent research efforts is provided. In addition, various IoT-based architectures and platforms are provided with respect to agriculture applications. A summary of current challenges facing the industry and future expectations are listed to provide guidance to researchers and engineers. Based on all this, it can be concluded that every inch of farmland is vital to maximize crop production. However, to deal with every inch accordingly, the use of sustainable IoT-based sensors and communication technologies is not optional—it is necessary.

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