Application of Environmental Sensor Networks in Smart Agriculture

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Abstract. Applications of Internet of Things are regarded as one of the most advanced and proposed solutions to resolve hunger issues around the world and achieve SDG targets, as its aims of promoting a scheme called smart agriculture and increasing efficiency and accuracy. However, there are several challenges remaining in the field of IOT deployment and application, which impede the popularization of IOT technologies in agricultural sectors. This paper focuses on the specific challenges in the field including energy supply and consumption, network connectivity in rural areas, reliability and scalability and high cost. After reviewing papers on this topic, proposed solutions to these challenges and a description of current IOT applications in agriculture are provided in this paper. This paper may guide farm holders to optimize their schemes by optimizing techniques, improving allocation of resources, and considering comprehensive plans. Therefore, this paper aims to achieve a better optimized scheme of IOT in agricultural sectors, and then promote the popularization of IOT application in this field in the future.

Keywords: IOT, Smart agriculture, energy efficient, low cost.

1 Introduction

Nowadays, Internet of Things (IoT) has been an increasingly popular strategy to solve various sorts of issues around the world. The definition of IoT is a system of interconnected computing devices, digital and mechanical machinery, items, animals or people that are supplied with unique identifiers and the capacity to transmit data through a network without requirements for human intervention [1].

Agriculture is a scenario where IoT shows its effect. The production of crops should be promoted to feed people as the expanding population is predicted to reach 9.7 billion by 2050. On the other hand, the agricultural output is under the negative impact of diverse reasons including farmland decreasing, shortage of manpower, lack of resources, appropriate government policies and climate change. To meet the demand of feeding billions of people and cope with these negative conditions, we can implement IoT to agriculture.

Agricultural schemes adopted IoT applications are called smart agriculture as it can make decisions automatically and wisely. Interconnected physical devices communicate with each other through networks and information is sent to and

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collected in the cloud. This enables farmers to manage their farms through apps in mobile phones remotely and saves manpower. Additionally, environmental sensors sensing environmental parameters perform more accurately than people observation. Therefore, the smart agriculture schemes can increase agricultural productivity as well as reduce waste of resources. Sensors in smart agricultural are categorized into two main types with its functions. One is sensors detecting environmental conditions, the other is sensors monitoring plants and animals. Environmental sensor networks play an important part in IoT systems as they help to provide suitable surroundings for crops. This paper will focus on the current situation and problems faced by environmental sensor networks in smart agriculture and suggest some solutions.

2 Application

IoT applications utilized in smart agriculture are summarized into eight categories (see Fig. 1): UAV farming, monitoring farm, precision farming, tracking & tracing, supply chains management, monitoring forestry, aquaponics farms and analytic data & prediction [2]. This section will discuss these applications and their relations with environmental sensor networks.

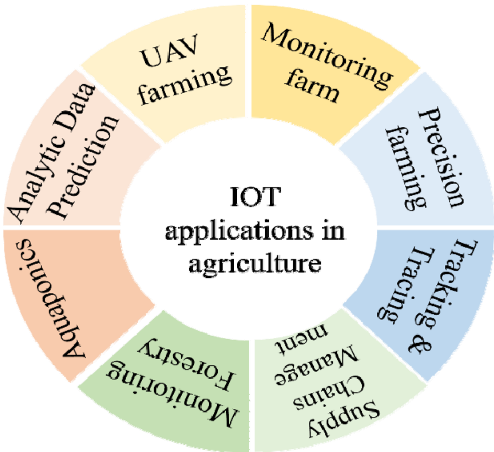

Fig. 1. Categories of IOT applications in agriculture

2.1 UAV Farming

Unmanned Aerial Vehicles (UAVs) was firstly introduced to smart farming for remote monitoring and observation. Now UAVs have been expanded into decision-making and diverse agricultural techniques such as weed control, herbicides, fertilizer, and irrigation [3]. In addition, combinations of UAS technology with advanced 3D reconstruction modeling methods and IoT technologies have been a prospect area. UAV technologies are recognized and a replacement of environmental sensors with its capacity of capturing images.

2.2 Monitoring Farm

Environmental sensors are involved in monitoring farm to provide farmers with convenience through distant access and control of farm environment. The sensor network is responsible for data acquisition from farmland. In this process, traditional sensors and actuators are utilized to execute tasks for ambient intelligence systems by constantly monitoring environmental parameters and optimizing the predefined parameters [4]. Various sensors detecting different parameters are applied: moisture and temperature sensors, light sensors detecting inhabitant intensity, pressure sensors detecting location of devices and power sensors for identification of the current state of the devices.

2.3 Precision Farming

By utilizing high temporal and geographical variability in environmental and agricultural characteristics of crops and environmental traits, Precision Farming is aimed at management with coherence and holistic approaches. Abiotic (like weather) and biotic (like pest and weed infestation) stressors, geography, soil properties, nutrient requirements, and yield potential variations are all covered [5]. Parameters including soil quality, weather conditions and moisture level are measured and ultimately optimized to increase the yield [6]. Weather parameters including temperature, humidity, wind, and air pressure are collected and transferred to clouds for analytic tools to generate future actions. Soil patterns include information about soil humidity, pH, moisture, and temperature are essential for agriculture activities.

2.4 Tracking & Tracing

Techniques such as RFID and GPS based on clouds can be utilized to track information like location and asset identification. Factors such as growing conditions, production circumstances, pest issues, management factors, storage conditions, transportation, and time to market may be tracked.

2.5 Supply Chains Management

IoT monitors the overall process of supply chain from the initial stage where manufactures purchase raw materials from the suppliers to stages such as production, distribution, storage, product sales and after-sale services. This will contribute to maintain the inventory required for ongoing sale and then result in customer satisfaction and improved revenue. This can also help us with diagnosis of repair and maintenance of machines [7].

2.6 Monitoring Forestry

Supporting above two-thirds of identified species worldwide, forestry plays a critical part in the carbon cycle. The parameters including temperatures and humidity of soil and air and different levels of gases can be monitored in a forest. These parameters offer preliminary warning and alert systems against forest fire and aid in disease monitoring.

2.7 Aquaponics

Aquaponics is the mixture of aquaculture and hydroponics, where necessary nutrients required by plants are provided by fish wastes. This system can efficiently and fully utilize resources and reduce waste. In such a farm, it is critical to continuously monitor parameters including quality and level of water, temperature levels, health of the fishes, salinity, pH level, humidity, and sunlight. In such a farm allowing transfer of nutrients between plants and fish, the precise data detected by sensors can increase the yield of fish and plants. The data can also be utilized for self and automatic management and adjustment of the farm in order to lessen human intervention.

2.8 Analytic Data Prediction

IoT provides big data over time for study and analysis to make estimations for the present environment. DA may be utilized to study the data perceived by different types of network sensors. Intelligent algorithm may be developed to forecast the changes of environment and generate data-driven terms of settlement. The data may also be utilized to forecast and alert farm holders with disease, emergencies or disasters in addition to helping farmers manage the farm.

3 Current Situation and Problems Faced by Environmental Sensor Networks Applied in Smart Agriculture

IoT technology is prospect and has been adopted in diverse agricultural practices to resolve problems such as resources shortage, lack of manpower, extreme and changing climate conditions, low agricultural output, and unexpected loss of harvest. However, there are remaining some problems related with IoT deployment and applications. To deploy environmental sensor networks in farms, requirements such as energy supply and consumption, network connectivity in rural areas, reliability and scalability of the network and reasonable cost need to be satisfied. Furthermore, these problems are often inter-knitted. Moreover, potential issues after implementing IoT systems are also critical. This paper will discuss the problems blocking regions and countries to adopt and promote environmental sensor networks in agriculture.

3.1 Energy Supply and Consumption

Energy challenges about sensor network deployments have remained for a long time. How to ensure sustainable energy supply and reduce power consumption for environmental sensor networks in agriculture is identified as one of the most crucial problems, especially for those located in a large area without wire layout.

Consisting of a significant number of interconnected devices, IoT networks require a high level of energy to maintain active. Energy is considerably consumed in these following sections: data transmission and communication, data processing and storage, sensors and actuators, network infrastructure and end devices. A significant amount of energy is required for continuous data transmission to clouds and other devices for data processing and storage. In the section of processing and saving data, a large volume of energy is required, especially for real-time data analysis and processing. Sensors and actuators executing long-time monitoring and controlling tasks require continuous energy supply for operation. Network infrastructure such as routers and relays require a significant quantity of power to maintain operation and network connection. Large-scale deployments of end devices will also consume relatively substantial energy. The energy also affects network performance. For instance, the energy state of a node indicates its stored battery energy, current and anticipated harvested energy and its energy load. Insufficient energy supply will also result in delay in data transmission, increase in respond time, instability of network connectivity and cloud servers and data loss.

The nodes possess alternate energy sources such as solar power in many smart agricultural scenarios. However, there are several issues existing such solutions for application of solar power in IOT systems or environmental sensor networks. Solar energy source is only available in daytime and easily affected by weather conditions. At other times, alternative energy sources or stored energy will supply the nodes with power. Batteries can store exceeded power generated previously and supply electricity. However, frequent battery changes raise maintenance costs. Therefore, energy efficient algorithms are required to minimize energy consumption of sensor nodes.

Furthermore, even if a solution is technically sound and practical from a design standpoint, it must withstand several operational and environmental issues when implemented in rural regions in order to function correctly and sustainably [8].

3.2 Network Connectivity in Rural Areas

As farms are often in rural areas, the infrastructure there is inadequate, especially in developing countries. First, some regions are inaccessible to Internet. Second, network connectivity is not robust enough against weather conditions and communication signals are not equipped with anti-interference against dense obstacles. For instance, tall and thick trees obstruct the reception of communication signals in the field. Third, bandwidth in rural areas is often under the level to satisfy the requirement of data transmission and real-time monitoring, which hinder the IOT applications. Fourth, network service providers tend to invest insufficiently in rural areas considering high construction and maintenance cost.

There are both advantages and disadvantages with different communication technologies currently applied in smart farms. Wi-Fi and Bluetooth have opposite performance on communication range and power consumption. While Wi-Fi has a long range with high power consumption, Bluetooth shows low consumption with a shorter range. Sensors occupy relatively low data bandwidth for communication.

3.3 Reliability and Scalability

IoT devices are used in open air with strict environmental requirements in smart agriculture. Hence, failures and delays of communication and data transmission to the cloud may be caused by external interference. This will lessen the reliability of the IoT ecosystem. Moreover, it is not recommended to use IoT devices with unlicensed spectrum interference proof, as it may increase the devices costs. Considering the growing number of IoT devices, significant number of gateways are required. In addition, in order to accommodate sophisticated applications, IoT agricultural databases and networks are also required to be dependable and scalable. Besides, insufficient energy supply and security issues are also factors.

For the scalability, issues concerned with device management, data processing, network load, security and energy consumption should be taken into consideration. For device management, a significant quantity of IoT devices is supposed to be involved in smart farms. Currently deployed gateways and protocols will be required to serve a significant amount of IoT devices or nodes. Therefore, there is a need for intelligent IoT management system for every node and identifiers.

For network load, as more and more devices being connected into the IOT system, we should consider potential network congestion and bandwidth bottlenecks.

3.4 High Cost

Cost issues around IOT deployment and application involve these following components: cost of infrastructure, cost of device, cost of data processing and storage, cost of maintenance and cost of energy supply.

The cost of infrastructure is extremely high and unreasonable. The network infrastructure which ensures network connectivity and signal coverage includes physical devices such as antenna and cables. The large-scale deployment of IOT raises a higher demand of network reliability, increases the number of connected infrastructure devices, so that increases cost.

The high cost of the sensors, actuators and related systems is a significant obstacle. The total hardware cost is one of the determining factors for sensor nodes selection. Sensors and actuators with high accuracy and quality usually have a higher price, especially customized devices for specific sectors or application scenarios. The cost also be affected by the types, functions, precision and performance of sensors and actuators. Deploying and installing sensors and actuators into real environments may add cost such as cost of labor, wiring, debugging and so on. Moreover, such activities may implement under the guidance of specialists, which adds cost as well. In addition, the external energy supply for sensors and actuators through means like batteries and cables may also add cost by battery replacement and arrangement and maintenance of power lines.

4 Suggestions

Having reviewed papers specialized in this area and evaluated possible solutions, this section will provide some practical ways to solve the problems above.

4.1 Energy

In general, the common solutions to increase energy efficiency can be sorted into two ways: energy harvesting and adopting methods to reduce power consumption. On one hand, for energy harvesting of alternative energy source, a number of researches developed solar cells to provide renewable energy for the whole system. On the other hand, to lessen energy consumption, measures including low-power communication technologies, optimized data processing algorithms and energy-efficient devices can be implemented.

Ambient, mechanical, human, organic and hybrid are the five most significant sources of harvested energy. The ambient energy sources are easily accessible without any cost as you can utilize them wherever there is sunshine, wind, stream flow and so on. However, the cost of the infrastructure for harvesting ambient energy can be high and the devices need periodic maintenance. Furthermore, ambient sources can be divided into the following categories: solar, Radio Frequency (RF), thermal, wind, and hydro based energy sources. Two mechanical energy sources, vibrations and pressure, are used specifically in environment for energy harvesting. Other scavenging energy sources include plants, animals, and humans through their physiology and movement. Different types of energy sources are often combined for generating sufficient electricity in case that utilizing only one source cannot meet the demand [9].

The amount of harvested solar energy heavily relies on geographic location, season, and deployment conditions. For example, solar energy sources are supposed to be appropriate to be deployed in lakes rather than rainforest. This is because the canopy cover in rainforest considerably blocks the sunlight. Therefore, solar prediction models that take these variations into consideration should be utilized to forecast the energy state [10].

Haseeb proposed a solution by developing an energy-efficient and secure IoT-based WSN infrastructure, which aims at monitoring the land and increasing agricultural production. In this framework, optimal decision function is utilized to select appropriate clusters heads. Moreover, the proposed framework also performs better for farmland of large size and the secure data transfer and accumulation from cluster heads to BS and from agricultural sensors to cluster heads are realize by means of secret keys and linear congruential generator requiring minimum processing and memory time. Consequently, this proposed architecture can perform well in minimizing energy consumption while ensuring reliable and secure routing for agriculture [11].

4.2 Network Connectivity in Rural Areas

To solve problems about network connectivity in rural areas, these following four suggestions are proposed.

First, extend network coverage. Stations and gateways, which are able to transmit data in distant, should be applied to extend network coverage. Schemes should be adjusted to local terrains and environmental conditions.

Second, appropriate communication technologies should be selected. LPWAN technology with low power consumption, long communication ranges and good penetration capabilities is suitable to be deployed in rural areas.

Third, reliable energy supply is also critical.

Fourth, local data storage and edge computing should be implemented. These technologies can reduce dependence on clouds, so that decrease respond time and promote reliability.

4.3 Reliability and Scalability

Solutions enhancing reliability and scalability of IoT ecosystems focus on areas of devices, infrastructure, data, clouds, architectures and accidental losses.

First, improve quality and reliability of devices. These devices should have been rigorously quality controlled and tested before deployment and maintained and updated regularly after application.

Second, the network infrastructure should also be reliable with Internet connectivity, robust network devices and reliable communication protocols. Redundant network paths and backup system can maintain operation of systems even if network failures and interruptions.

Third, data should be back up regularly in case of data loss caused by interruptions. Wireless sensor network (WSN) is regarded as the most prospective technology to realize data acquisition and processing systems.

Fourth, combined with clouds and edge computing, tasks should be allocated between local and cloud according to the requirements. This can reduce latency in data transmission and increase speed of system responds. Edge devices should be deployed with lightweight applications and algorithms to reduce reliance on cloud resources and promote scalability.

Fifth, micro-services architectures should be adopted to divide the whole system into small and independent services, which responsible for different functions.

Sixth, plans in case of disasters and emergencies should be developed. Back-up devices and databases should be deployed in different regions to maintain operation during disasters.

4.4 High Cost

Considering the factors mentioned in the previous section, the solution should follow these following criteria.

First, it is recommended to select off-the-shelf sensors and actuators rather than customized ones. Requirements should be fully assessed and understood before selecting hardware.

Second, choose appropriate communication technologies and network frameworks, so that satisfy the need of data transmission and controlling while reducing the cost. IoT specific networks and private networks could be applied to reduce cost and latency.

Third, optimize the process of deployment and installation. Simplified processes, reasonable wiring arrangement and easily installed and deployed devices should be taken into account to reduce practices involving manpower and long time.

Fourth, energy management technologies, such as dynamic power adjustment and sleep modes can adjust power consumption according to the demand, so that minimize energy consumption cost and extend battery life.

With advance of technologies, the whole systems and processes should be optimized continuously to increase cost efficiency.

5 Conclusion

Applications of environment sensor networks and IOT technologies bring numerous opportunities and challenges. Issues about energy supply and consumption, network connectivity in rural areas, reliability and scalability and high costs have been focuses in this field. We can resolve these issues in terms of techniques. However, collaboration among stakeholders should also be taken into account. The local government, communities and industries should have a joint effort to develop infrastructure, bridge digital gap and build a sustainable and resilient IOT system.

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