2019 2nd International Conference on Electronics Technology

The Design and Implementation of Smart Agricultural Management Platform Based on UAV and Wireless Sensor Network

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Abstract—**Traditional agricultural monitoring systems generally use static sinks to collect data that are often accompanied with some problems such as high construction costs, low precision, poor maintainability and so on. In this paper, we design and implement a smart agricultural management platform that can be divided into three layers: perception layer, network layer and application layer. In perception layer, a large number of ZigBee sensor nodes (SNs) are deployed to build ZigBee networks. In network layer, a mobile sink (MS) that consists of a gateway carried by an unmanned aerial vehicle (UAV) is used to gather data from the perception layer and send it to application layer. Besides, we deploy a full-featured web application in application layer to provide various kinds of services for users. The advice module of the web application is designed to provide users with countermeasures that ensure humidity and temperature are within the ideal range for plant growth. The experimental results show that an MS can gather data from a large number of lands in a short time, with excellent scalability and stable operability. These advantages allow the platform to apply very well to certain areas of particular terrain and it also alleviate the "energy hole" problem in the wireless sensor networks that use static sinks.**

Keywords-intelligent monitoring; wireless sensor network; UAV; mobile sink

I. INTRODUCTION

Nowadays, many fields, from health to education, industry to home are embracing the Intelligent revolution [1], [2]. In traditional agricultural production mode, producers often carry out agricultural production according to their own experience. However, whether irrigation should be carried out at some moment and how to ensure that the humidity, temperature and illumination are suitable for plant growth? No scientific answers can be given in traditional agricultural production mode. Undoubtedly, the traditional agricultural production mode will not only cause problems such as low efficiency and waste of resources [3], but also bring about many disadvantages such as environmental pollution caused by excessive use of chemical fertilizers and pesticides, making it difficult to guarantee the quality and safety of agricultural products.

With the rapid development of wireless sensor networks (WSN), many countries have embarked on a wave of smart agricultural construction. Through the WSN technology, producers can understand and control the state of lands accurately [4], thereby making agricultural production according to concrete conditions, making the best use of materials and maximizing production value. Considering the particularity of the agricultural production environment and construction costs, it is difficult to construct WSN on a large scale. Besides, in the WSN that use static sink, the nodes closer to the static sink exhaust their energy faster than the other nodes and die early which causes network partition due to the use of multi-hop communications, which is named “energy hole” problem [5].

To this end, previous works such as [7] and [8] apply one or more mobile sink (MS) to gather sensing data from WSN. The MS move within the WSN to collect data from sensor nodes (SNs) and thereby save energy that otherwise would be consumed by muti-hop communications [9]. In this paper, to gather sensing data from a large number of lands in a short time and solve the “energy hole” problem efficiently, a smart agricultural management platform that use a MS which consists of an unmanned aerial vehicle (UAV) and a gateway, is designed and implemented. In this way, agricultural data collection has become quick and easy.

II. SYSTEM DESIGN

In the design procedure of the platform, the typical Internet of things (IoT) architecture is adopted. The platform can be divided into three layers functionally, including perception layer, network layer and application layer, which provides users with various kinds of functions [10].

The perception layer, consists of a large number of ZigBee SNs. ZigBee is a low-rate, low-power, low-cost wireless network technology for automation and wireless control [6], widely used in intelligent monitoring systems. Among these SNs, a portion are equipped with humidity sensors, whereas the remaining SNs are equipped with temperature sensors. The function of this layer is to provide all kinds of sensing data needed by the platform. Specifically, there are two types of sensing data including humidity of soil and temperature of atmospheric over the soil. With these data, users will have a better understanding of the state of their lands.

The network layer, it is the link between the perception layer and the application layer, implements the function that send the sensing data generated by the perception layer to the database server located in the cloud through the MS and LTE network. These data will be stored in database server later. In this platform, the MS consists of a gateway carried by an

UAV. In this way, the number of data forwarding hops can be reduced so that the "energy hole" problem can be effectively solved and energy consumption in the network becomes more uniform and prolongs network survival time greatly.

Lastly, the application layer, contains an application server, a database server and various kinds of clients. The application layer is the top layer of the platform, its core function is “processing”, processing the data stored in the database server located in the cloud, so as to realize remote monitoring. In addition, the platform will automatically determine the current state of lands and inform users the results in real time. Last but not least, it will provide users with scientific countermeasures to ensure that lands are in the state which is suitable for plant growth. The overall architecture of the platform is shown in Figure 1.

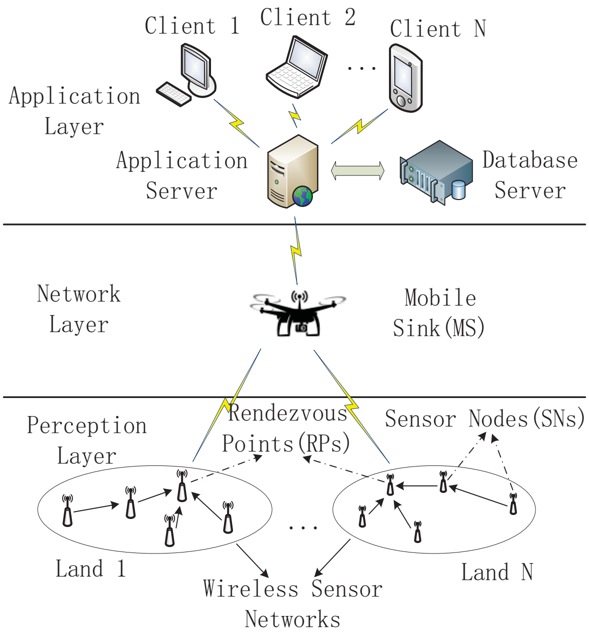

Figure 1. The overall structure of the platform.

III. System Implementation

A. *The Perception Layer*

Generally, lands are in a wide range, only one WSN network can not realize the data collection of all areas [11]. Therefore, multiple WSNs are deployed in many different lands. Every WSN contains dozens of ZigBee SNs, a portion are equipped with DHT11 humidity sensors and the remaining SNs are equipped with DS18B20 temperature sensors. Among these SNs, one of them will be selected as the rendezvous point (RP) in each land which is responsible for gathering sensing data from SNs and store it in cache until the MS accesses it. The others are non-RP nodes, they are responsible for collecting data including humidity of soil and temperature of atmospheric over the soil. These non-RP nodes will forward their sensing data to RPs through multi-hop communications. The structure of the perception layer is shown in Figure 2.

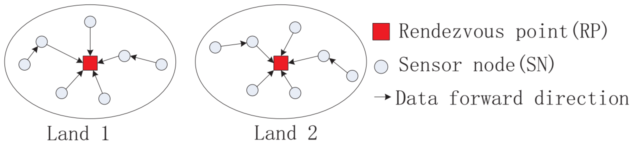

Figure 2. The structure of the perception layer.

Each land includes a RP and a series of SNs. Whether it is RP or SN, they make no difference in terms of hardware. These nodes adopt modular design, including sensing module, processing module, wireless transceiver module and power module. The sensing module is responsible for sensing and acquiring the detected data and converting it into a digital signal for processing. The processing module is responsible for storing and processing the data send by itself and other SNs. The wireless transceiver module is responsible for communicating with other SNs and the power module is responsible for supplying power to each of above units. The composition of SNs is shown in Figure 3.

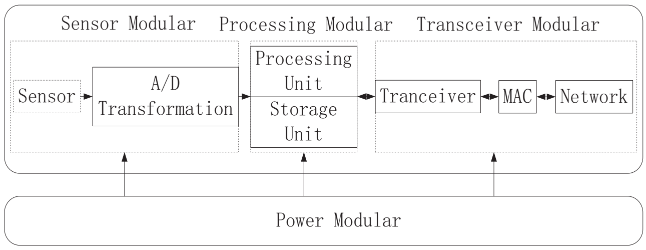

Figure 3. The composition of the SNs.

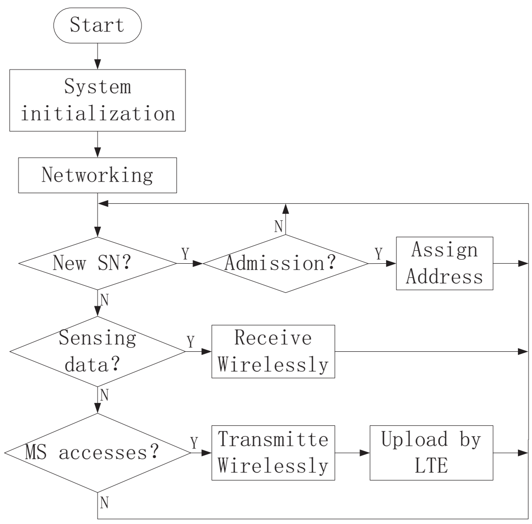

Figure 4. The software chart of the perception layer network.

CC2530F256 chip manufactured by TI company is adopted by the SNs as the core. It is a powerful system-on-chip (SoC) that is well compatible with IEEE 802.15.4 communication protocol [12]. This kind of SoC integrates an

RF unit and, essentially an enhanced 8051 controller. CC2530F256 has 256KB of flash memory and can support multiple operating modes, making it ideal for systems that require ultra-low power consumption [13]. On the other hand, it is convenient to set up its own wireless sensor network combined with Z-Stack protocol stack. The Z-Stack protocol stack is a concrete implementation of the ZigBee protocol, it is mainly used to implement communication between SNs and RPs. In this platform, SNs and RPs use different codes to implement their respective functions. RPs are responsible for establishing and maintaining the ZigBee network. After power up, the RPs initialize hardware and software firstly, and then establish a ZigBee network. After the ZigBee network is successfully established, SNs will join the established ZigBee network through RP. The software flow chart of ZigBee network is shown in Figure 4.

B. *The Network Layer*

The RPs in WSN do not access the public network, so the network layer act as a link between the perception layer and the application layer. Different from traditional monitoring systems, a MS is used to complete the transmission session in this platform. The MS is a gateway carried by an UAV, its motherboard is an ARM9 development board with i.MX287 multimedia application processor. The clock frequency is 454MHz, built-in 128MB DDR2 memory and 128MB NAND FLASH. It provides multiple functional interfaces, including: 1 TF card interface, 2 channel 10/100M Ethernet interfaces, 2 channels CAN bus interfaces, 6 channels UART serial ports, 1 channel USB host interface. Through the development board, data in ZigBee format can be parsed and converted to data in LTE format. After that, the sensing data from the perception layer will be sent to the database server located in the cloud through the on-board LTE communication module, thereby realizing data collection and storage.

After preliminary research, the PHANTOM 3 UAV System produced by DJI company is selected as the carrier of the gateway. This UAV system consists of an unmanned aircraft and a ground control station, be capable of hovering and cruising. Through the ground control station, it is easy to preset its route before the UAV takes off, ensuring it will fly over each piece of land during the flight. On the other hand, once the UAV is abnormal during the flight, users can send command to it via wireless control link. When the MS enters a RP's communication range, it will perform a hovering operation so that the MS can smoothly access the current wireless sensor network and receive the data sent from RP.

In order to achieve communication between the MS and the application server, we have to configure the IP address and port number of the application server on MS. The MS through HTTP communication protocol to implement link to the application server and through socket communication mode to transfer sensing data to the application server. Firstly, the application server reads data from the cache. Secondly, the application server will verify the data and parse it. After that, these data will be stored in the database server and feedback a state code to the MS that indicates whether the data is stored successfully.

C. *The Application Layer*

After implementing the collection and storage of the sensing data, various kinds of services can be developed. Specifically, a web application is developed in this paper. The development environment of the web application is MyEclipse 10+WebStorm 2018.2. In front-end development of the web application, HTML and CSS are used to design and beautify the pages. In addition, Java is selected to implement JDBC operation and MySQL database is used to store the sensing data from the perception layer. The web application apply B/S(Browser/Server) architecture that helps reduce pressure of clients [14]. The majority of the service logic is concentrated in the application server located in the cloud and users only need a web browser or a mobile phone. During the development of the web application, the popular framework Spring MVC+Spring+Hibernate is applied, with the gradle project construction tools, increase the development efficiency and improve the scalability and flexibility of the platform. The running environment of the web application is MySQL+JDK+Tomcat that deployed in the cloud.

In the platform, the whole web application includes eight modules, there are login module, registration module, information overview module, information details module, advice module, video module, data backup module, and technical support module. In these modules, information overview module, information details module, advice module and video module are main functional modules. In the development of the information overview module, Baidu map API is used to locate the lands that managed by users. In addition, in the information details module, we use AJAX technology to asynchronously read the data stored in the database server, with the use of ECharts to visualized it. Through the video module, users are able to obtain real-time images of lands. Furthermore, the advice module is able to evaluate the state of lands based on sensing data and provide scientific advice for users. The structure of the web application is shown in Figure 5.

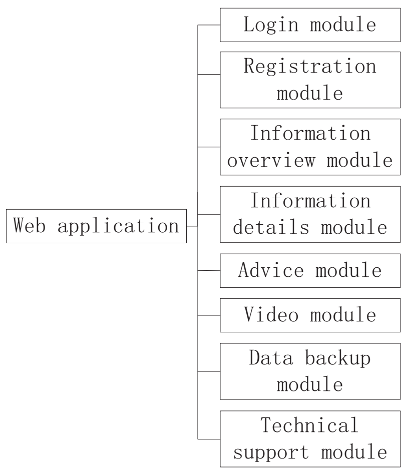

Figure 5. The structure of the web application.

IV. Advice Strategy

Different from the previous environmental monitoring system, the platform can evaluate and analyze the state of lands according to the soil moisture and atmospheric temperature over the soil collected by the perception layer. Furthermore, based on the results of the assessment, the corresponding scientific countermeasures will be sent to users.

Considering the great fluctuation of temperature over the soil because of the illumination, evaporation and other factors that result in use the temperature at a certain moment to evaluate is not accurate, so it is necessary to evaluate lands through average temperature over the most recent period. For example, a user plants corn in lands, after he chooses corn in the platform, the platform will read the ranges of humidity and temperature that best suited corn growth automatically. Then the platform calculates the average humidity and average temperature in the last three days. If there is a gap between average and ideal range, it will immediately notify the user. At the same time, it will provide the user with solutions to the gap according to specific situation of lands. We can clearly understand the logic of the advice module in Figure 6.

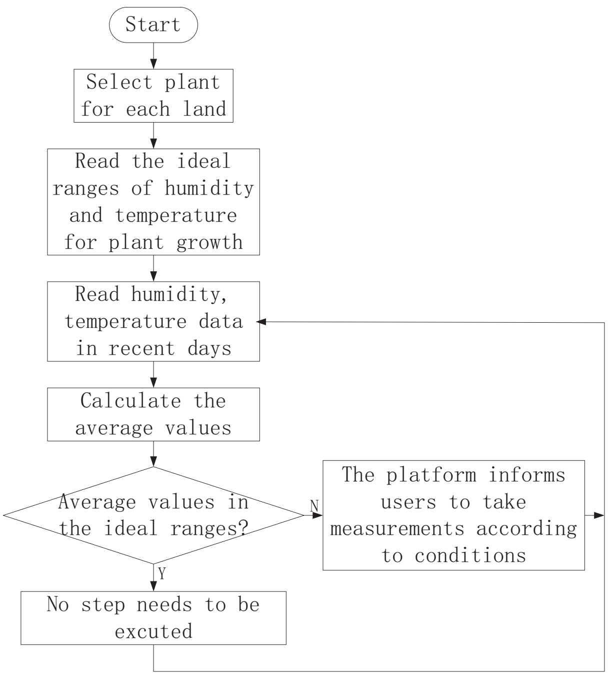

Figure 6. The logic of the advice module.

V. Pilot Experiments

The platform selects a lawn of the Nanjing University of Posts and Telecommunications to carry out actual pilot experiments. The shape of the lawn is a rectangular (100m*75m). During the experiments, the whole lawn is divided into two separate lands. We placed four SNs in each land, two SNs equip with humidity sensor and two SNs equip with temperature sensor. Before the UAV takes off, we preset the flight route of the UAV to ensure it will pass through two experimental lands. In addition, the UAV will hover for 20 seconds when it reaches each land to ensure that the MS successfully accesses the established ZigBee network and collects the data stored in RPs through wireless communication. The experiments last for 10 days, a total of ten pilot experiments are conducted. The application server is located in the cloud and server database is MySQL 5.7. The information overview module is shown in Figure 7, we can know about the approximate information of lands quickly, and part of the information details module is shown in Figure 8.

Figure 7. The information overview module.

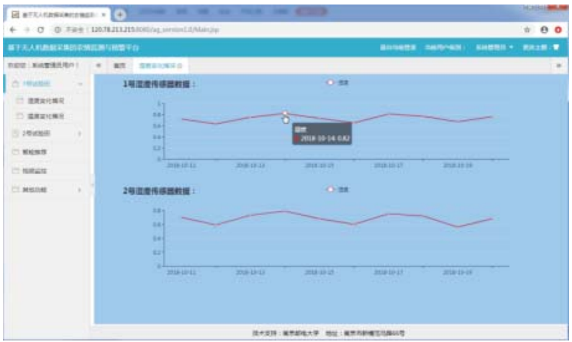

Figure 8. The information details module.

Next, we will perform functional testing on the advice module. In the aforementioned two lands, land1 plants orchids and land2 plants gardenia. First, we select the variety of plants in the platform, orchids and gardenia. Afterwards the advice module reads the ideal humidity range for orchid growth is from 60% to 70%, and the ideal temperature range is from 15℃ to 25℃. The ideal humidity range for gardenia growth is from 75% to 80%, and the ideal temperature range is from 16℃ ~ 18℃. After that, the advice module reads sensing data from database and calculates the average humidity and average temperature in the last three days. For orchids, the average humidity is 63% and the temperature is 12.3℃. And for gardenia, the average humidity is 59% and the average temperature is 12.3℃. At the same time, the platform immediately informs us that land1 needs to be illuminated, and land2 needs irrigation and illumination. The advice module interface is shown in Figure 9.

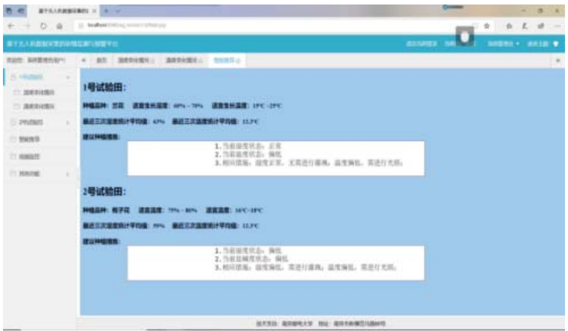

Figure 9. The advice module interface.

From the above results, it can be concluded that the platform works normally and in accordance with its designation. By using an MS, it is convenient to gather data in a short time and users will monitor the state of a large number lands by a browser that connected to the Internet. In addition, users will receive notification once humidity value or temperature value is not within the ideal range of the corn's growing, the only thing that users need to do is follow the platform's countermeasures. The platform enhances the intelligence of agricultural production greatly.

VI. CONCLUSION

In this paper, we design and implement a smart agricultural management platform based on UAV and wireless sensor network. During the development, the whole platform is divided into three layers including the perception layer, the network layer and the application layer. ZigBee network that consists of dozens of ZigBee devices is applied to gather data and send it to the MS which fly along a predetermined flight route. The MS accesses each ZigBee network during its flight so as to realize the data transmission from the perception layer to the application layer through LTE. A web application is deployed in the robust application server that located in the cloud to provide monitoring and management interface to users so as to achieve various kinds of functions of the platform. After experiments, the platform function is completely normal and operates stably. Further, the platform can be easily expanded by replacing modules due to its modular design. Using MS to realize data collection, not only can collect sensing data of a number of lands in a short time, but also greatly improved the intelligence of agricultural production, it is suitable to introduce this platform to smart agriculture construction. Since the data packets are collected by MS in each land, the number of transmission hops in WSN is greatly reduced, so the energy consumption of the network is effectively balanced. In this way, the total energy consumption of WSN is reduced and extend the time-to-live of WSN. This will effectively alleviate the "energy holes" problem in traditional WSNs that use static sinks. In future, we plan to introduce machine learning algorithms into the platform to predict the state of lands, thereby further enhancing the intelligence of the platform.

ACKNOWLEDGMENT

This work was supported by the Natural Science Foundation of Jiangsu Province (Grants No. BK20160900), and the NUPTSF (Grants No. NY215031, NY217032), and the Fundamental Research Funds for the Central Universities (NO. NJ20160027).

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