

Sustainable Agriculture through ICT innovation

An Agricultural-Cloud Based Greenhouse Monitoring System

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ABSTRACT

In recent years, precision agriculture (PA) has become an important issue in agriculture. Wireless sensor networks (WSNs) might be a great tool to monitor plant growth in greenhouses, because they can provide spatiotemporal sensing data converted from real world physical/analog signals with high-resolution. In Taiwan, there are many small contracting greenhouse producers who operate their businesses independently. Through the combination of WSNs and cloud computing, sensing data can be automatically recorded in an agricultural cloud. This new service aims to accumulate current and historical data to keep track of plant growth, helping farmers making more informed decisions. Farmers who use the service can benefit from detailed data on factors related to plant growth, such as soil moisture, leaf temperature, leaf width/length, temperature, and humidity. Cloud computing is an appropriate choice because it uses powerful computing servers and distributed resources shared by each measurement site to provide a smart service with useful information. Cloud computing applied to greenhouse monitoring will improve the efficiency of agricultural production and help conventional agriculture move toward PA. Researchers can also further analyze diverse data collected from different sites to provide important information/suggestions to farmers through such a cloud-based monitoring system. To promote the concept of PA, we propose a greenhouse monitoring system with an agriculture cloud. The proposed system collects environmental data from a greenhouse, and the data is stored in a database. A cloud computing service is provided to analyze the data. The proposed system is also able to send an alarm to users.

Keywords: wireless sensor networks; cloud computing; agricultural cloud

1. INTRODUCTION

In recent years, many studies have indicated the importance of precision agriculture (PA) because it pursues not only the improvement of agricultural production but also the reduction of environmental pollution. The agriculture industry in many countries has begun to promote the concept of PA.

In this study, we use the wireless sensor network (WSN) technology to build up a greenhouse monitoring system deployed in an orchid greenhouse in Chiayi, Taiwan. This system is composed of numerous sensor nodes and a gateway. The nodes can sense environmental parameters such as temperature, humidity and illumination, and the sensing data can be further analyzed. For greenhouse monitoring systems, using the WSN technology has many advantages, including small sizes, low power consumption, and ease of installation. With these advantages, WSNs are suitable for setting up in a

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greenhouse to monitor environmental parameters. In fact, some environmental parameters in a greenhouse, such as temperature and illumination, might not be uniform. This proposed system is able to offer the distributions of environmental parameters in the greenhouse to users, but such a service cannot be provided by traditional monitoring systems. This is thus an important reason why the WSN technology is used for greenhouse monitoring.

The monitoring data collected by the proposed greenhouse monitoring system will be sent to an agricultural cloud through an internet service. The agricultural cloud in this system provides services including alerting, data analysis, and data storage. The alerting service sends warning E-mails and text messages to users when some environment parameters show irregularities. For example, this service can inform users that their greenhouses have some problems that need to be checked as soon as possible. Furthermore, the agricultural cloud offers data storage and analysis services. The cloud also generates some charts and diagrams drawn from sensing data to show the changes in environmental and cultivation parameters. With such information, the changes in the environment can be detected. All data collected from greenhouses will be stored in a database so that researchers can analyze the data in detail. In addition, other agricultural cloud services may include work model construction and detection for quarantine species [1], but these services are beyond the scope of this paper.

The arrangement of this paper is depicted as follows. Section II discusses the related research that focuses on PA, greenhouse monitoring systems and agricultural cloud. Section III presents the concept of an agricultural-cloud based greenhouse monitoring system. The experimental results are shown and discussed in section IV. In Section V, we conclude this study and propose some possible research topics for future work.

2. RELATED WORK

PA is a new concept in agriculture. PA suggests that production environments should be monitored, and monitoring data can be used to achieve the most suitable decision on environmental management which employs control and adjustment solutions to obtain better product yields [2-3]. The goal of PA is to achieve instant surveillance as precisely and efficiently as possible [4]. WSNs seem to be a good choice for environmental monitoring and have been widely used to detect air pollution and fruit fly invasion [5-8]. WSNs generally consist of a large quantity of sensor nodes and exhibit the structure characteristics of self-organizing and multi-hop networking. The importance of WSNs arises in this context, due to their capabilities to automatize certain tasks in agriculture. With these features, WSNs are able to monitor targeted areas by measuring physical parameters such as temperature, humidity, illumination, soil humidity and the amount of pests.

The cloud computing technology has been introduced to various industries, including the agricultural industry, because of its powerful advantages and market potential. The hardware and software requirements of agricultural cloud are low, and the requirement for users to know computing and networking is also low. But users can enjoy a professional and more comprehensive computing service. However, the implementation of agricultural cloud still has a long way to go, as the infrastructure and

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information construction in agriculture are weak. Previous research [1,10,11] on agricultural cloud has mostly focused on the concept of the cloud computing in agricultural information management; agricultural cloud applications, however, are hard to find in the industry nowadays.

In this paper, an agricultural-cloud based greenhouse monitoring system is proposed and implemented. This system includes a wireless sensor network to collect meteorological data and an agricultural cloud to provide several services.

3. HARDWARE AND SYSTEM ARCHITECTURE

3.1 Wireless sensor nodes

In this study, the proposed system employed the Octopus II as the sensor node responsible for environmental sensing and data transmission. The MCU of the Octopus II was constructed by MSP430F1611. The Octopus II used a low power consumption CC2420 communication chip whose frequency was 2.4 GHz, and it adopted the IEEE 802.15.4 protocol and ZigBee specification. Besides, the Octopus II had fifty expanded pins for general purpose input/output, making the connection to other devices or sensors more conveniently [12].

3.2 Gateway

The M2M Smart Services Developer Kit was used in the gateway of the proposed system. The gateway had a number of IO interfaces, including universal serial bus (USB) ports and serial interfaces which could be used to activate some devices. With an advantage of low power consumption, the gateway was suitable for WSNs. The main function of the gateway was to control wireless sensor nodes in the whole network. The gateway asked sensor nodes to collect environmental data in a greenhouse. The sensing data collected by sensor nodes included the information of temperature, relative humidity, illumination, and these parameters might be the factors that affected the growth of crops.

3.3 Concept of Agricultural Cloud

Cloud application and services have advantages such as fast computing, low costs, and higher efficiency and service availability. By combining international cloud computing architecture with an internet service, a highly efficient information system can be built for users. With this technology, the pace of agriculture informatization can be accelerated. The establishment of an agricultural cloud service platform enables data sharing, remote data storage, interaction with farmers, consultations provided by agriculture experts and peasant household management [13].

In this paper, we proposed a greenhouse monitoring system with an agricultural cloud. The proposed system collected the environmental data from a greenhouse and analyzed the data through cloud computing. The agricultural cloud in this system provided several services including data storage and analysis, and sending alerting messages to users. The system architecture is shown in Fig. 1.

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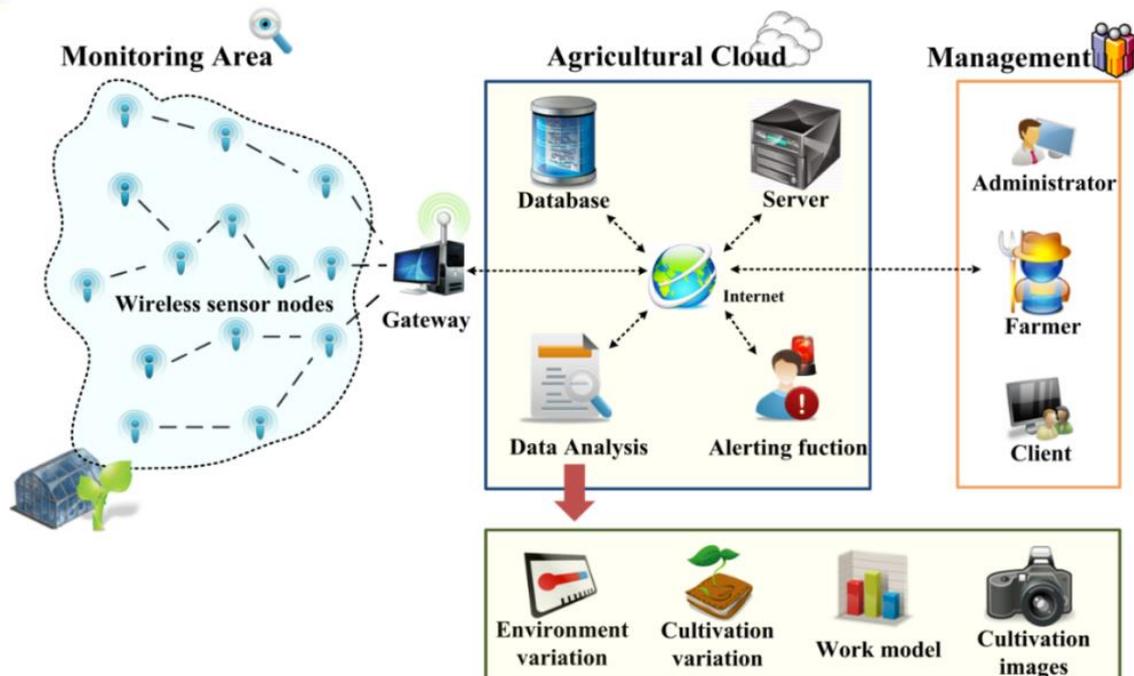


Figure 1. Architecture of the greenhouse monitoring System

- **Data Analysis:** The agricultural cloud offered different kinds of data analysis, such as showing environmental and cultivation variation and cultivation image processing. Environmental variation provided changes in environmental parameters, including temperature, humidity and illumination. Cultivation variation made a quality comparison between the targeted greenhouse cultivation and a cultivation model. Cultivation image processing used an image processing technology to evaluate the growth of crops. Traditionally, greenhouses were often monitored by only a few sensors that covered the whole greenhouse. The collected sensing data, thus, might not be able to truly represent the environmental parameters in those greenhouses. By contrast, the proposed monitoring system employed a large number of sensor nodes, so sensing data collected by the system could accurately reflect the variations in environmental parameters. In addition, the agricultural cloud was able to show temperature and humidity distributions in the greenhouse every 10 minutes, so users could obtain latest temperature and humidity information.
- **Alerting:** In greenhouses, temperature and humidity are generally controlled at a desired level, but the fluctuations in temperature and humidity may still occur, resulting in hindering the growth of plants. An alerting function was provided by the cloud to prevent such situations. In this system, thresholds for environmental parameters were set beforehand. The proposed system would send warning E-mails and text messages to users when some environmental parameters show irregularities. For example, *Phalaenopsis* is a crop with high economic value in

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Taiwan. The best growth environment for *Phalaenopsis* is that the temperature is set between 24 °C to 27 °C [14]. This monitoring system could set a threshold for each environmental parameter. It would automatically send a warning E-mail and message to users if some parameter readings exceeded their thresholds three consecutive times. Such a design was to prevent the misleading results caused by sensor errors.

- Data Storage: All data collected from greenhouses was stored in a database for further analysis.

4. EXPERIMENTAL RESULT

In this section, the effectiveness of the proposed monitoring system was examined by practically deploying a prototype system in an orchid greenhouse in Taiwan. The hardware layer of the prototype system was constructed on the Octopus II mote, and a 2.4-GHz 5-dBi omnidirectional antenna was installed onto each mote to get a better communication quality. Every node was attached to the poles in the greenhouse. During the experiment, each sensor node sensed environmental parameters in the monitoring area and sent the sensing data back to the gateway based on a fixed schedule.

The prototype system was deployed in a 36 m × 72 m × 10 m orchid greenhouse. The prototype system consisted of twelve wireless sensor nodes. The sensor nodes were placed following a checkerboard pattern of 12 m × 36 m. The practical experimental environment and layout are shown in Fig. 2 (a) and (b). The sensor nodes sensed data every 10 minutes.

When the agricultural cloud received sensing data, it provided several services after data computing. First of all, the cloud could show the information on temperature and humidity distributions in the greenhouse, as shown in Fig. 3. (a), (b) and (c). With this service, users could have a better understanding of the greenhouse environment. Taking the data shown in Table I, for example, a user may find that both temperature and humidity were higher in the middle area of the orchid greenhouse compared to other areas. With this information, the user might add some cooler devices in the middle area of the greenhouse to reduce the temperature. Second, the cloud could determine whether the environmental parameters were normal (or below their thresholds). If not, an alerting message would be sent out to the user, as shown in Fig. 4, so the user could take appropriate action in time.

The cloud also provided a database to store data collected from the greenhouse. Researchers could use the data to conduct further research to help improve greenhouse production or establish models of plant growth. The greenhouse might also benefit from these research results.

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Figure 2. Real world testing: (a) The practical experimental environment; (b) The layout of sensor nodes and a gateway

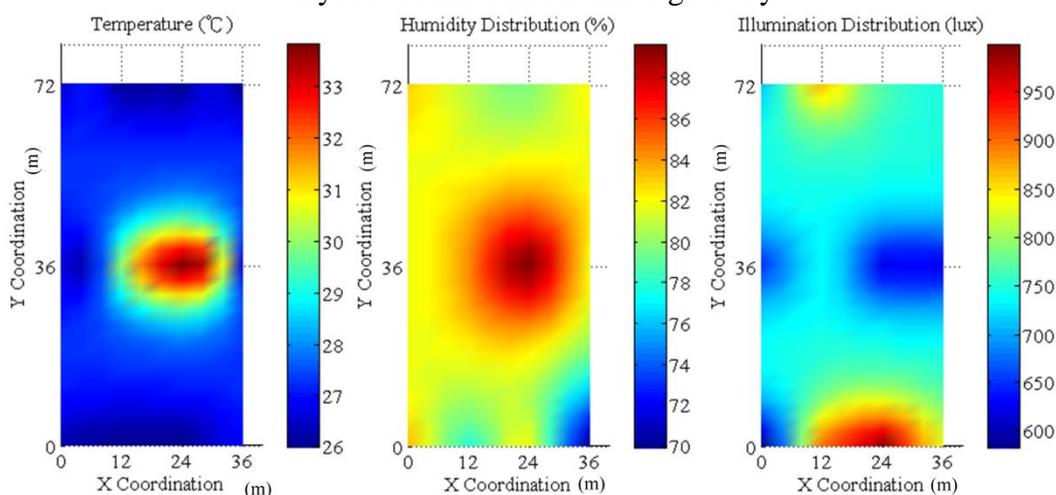


Figure 3. Environmental parameter distribution of a greenhouse:
(a) temperature; (b) humidity; (c) illumination



Figure 4. A warning message sent by the alerting function

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Table 1. Sensing data in the orchid greenhouse (May 2, 2013, 4:21 P.M.)

Node ID	Temperature (°C)	Humidity (%)	Illumination (lux)
1	26.3	83.3	583
2	26.0	77.9	900
3	26.1	81.9	998
4	26.0	69.9	834
5	33.6	81.8	648
6	26.5	84.2	734
7	26.4	89.6	623
8	26.4	81.9	625
9	26.4	83.0	709
10	26.1	80.7	867
11	26.5	79.6	768
12	26.0	82.2	748

5. CONCLUSION AND FUTURE WORK

PA is an important issue in agriculture world-wide. This study uses wireless network technologies to implement a fully automatic greenhouse monitoring system. This system not only has basic functions such as collecting environmental data but also provides a number of services by incorporating an agricultural cloud. The experimental results show that the agricultural cloud was able to provide several services, including data analysis, alerting and data storage. The analysis service allowed users to get information regarding environmental parameter distributions in a greenhouse. The users can take proper action based on the information, such as adding some devices like fans or spraying water to adjust the temperature and humidity conditions in the greenhouse. An alerting message was able to be sent out to users if any irregularities were found (i.e., some sensing readings exceeded their thresholds). The sensing data was able to be stored in a database for further analysis to help users find the best method to grow their crops.

The proposed system is expected to be applied to different agricultural areas. The agricultural cloud could also provide more services, such as on-line inquiry and instant feedback. Another mission of agricultural cloud is to automatically connect every device in a monitoring area through a feedback mechanism. We will put our effort on these developments in the future.

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