A New Agriculture Monitoring System Based on WSNs

Hui Chang[1], Nan Zhou[1], Xiaoguang Zhao[1], Qimin Cao[2], Min Tan[1],Yongbei Zhang[2]
1: The State Key Lab of Management and Control for Complex System
Institute of Automation, Chinese Academy of Sciences, Beijing, China
2:HaiNan State Farms Academy of Sciences, Haikou, China
Email:hui.chang@ia.ac.cn, cqm0217@sina.com, xiaoguang.zhao@ia.ac.cn, min.tan@ia.ac.cn

***Abstract*—Recent developments in information technologies provide facility agriculture monitoring system a new perspective of networking and automation. This paper presents a new agriculture monitoring system based on WSNs (Wireless sensor networks) with IP cameras, which can be controlled remotely to have close vision of plants. WSNs can deploy freely, collect sensor data periodically to the control center, process and store historical data, which could facilitate clients and experts in agriculture to monitor the conditions in a large field. Traditional WSNs monitoring system only focused on environmental parameters, such as temperature and humility. We integrate video information and environmental data. Also the sleeping methods based on small-scale time synchronization and alarming mechanism of our system achieve better communication and less power consumption. Through experiments we validated the system in a greenhouse and outdoors fields in Hainan successfully.**

***Index Terms*—WSNs; video; monitoring; agriculture; sleeping; alarming**

I. Introduction

Facility agriculture aims to provide high yield and good quality efficiently with less labor on limited lands. Taking advantages of modern engineering techniques and industrial production methods, facility agriculture makes a good use of the soil, climate and biological potential of fields to provide a controllable and suitable environment for plants so as to increase the productivity in specific regions [1]. Thus, the prerequisite step of facility agriculture is monitoring the farming environment effectively. An agricultural environment monitoring system includes data acquisition, transmission and management. Sensors technologies provide convince opportunities to data acquisition. Large amount of sensors can be deployed in the environment to collect environmental parameters and send them to the users through wireless data communication. However, a simple sensor cannot achieve the collection of various parameters of different crops on large farmlands. Remote sensors should be able to self-organized and to send data stably and periodically to the control center. Most existing monitoring systems are based on the serial bus via cables. But in the facility greenhouses with high temperature, moisture and soil PH, the life expectancy of these devices will be lowered and it will cause unnecessary costs to install and maintain the network with wiring problems. Therefore wireless communication technologies facilitate the innovations of agriculture. Rapid developments in advanced communication methods and intelligent control technologies provide us with a new perspective of automation and networking in facility agriculture. Wireless sensor networks (WSNs) are networks of small sensor nodes that can sense, process and transmit data to the user via radio communication [2].These sensors are small in size, low-cost, low-power, collaborative and allow random deployment, which ensure a large range of applications in environment monitoring systems. Furthermore, WSNs are applicable to facility agriculture for two key reasons. Firstly, MEMS(Micro-Electro-Mechanical Systems), LSI (Large Scale Integration) and embedded technologies are developed fast [3]. Secondly, WSNs are feasible, self-configured and easy to manage e.t, which solve the problem of networks and deployment through spatial spaces. In this paper, we propose a new agriculture monitoring system based on WSNs in Hainan province, China .The subtropical climate in Hainan with sufficient sunshine and water resources, but with limited satisfactory and controllable lands for some specific plants to grow. Therefore, they develop facility agriculture in order to grow off-season plants, which are low-size and sensitive to light, temperature and humility. Our lab cooperates with HaiNan State Farms Academy of Sciences to develop this monitoring system, which can collect real-time environmental parameters and video information effectively. The system also provides the software of human interface for users to monitor the deployment of sensor and camera network, to process historical data and to inquiry real-time and historical farming information. Furthermore, the system could cooperate with an expert system to schedule the facility system accordingly and create a suitable environment to improve the productivity and avoid resource waste. The subsequence of this paper is organized as follows. In section 2, some related works about agricultural environmental monitoring systems based on WSNs are shortly introduced. Section 3 describes the details and presents a comprehensive analysis of our new agriculture monitoring system based on WSNs in Hainan province. Then experiment results and data analysis are presented in Section 4 and Section 5 gives some conclusions we get and mentions the future work.

II. Related Work

Agricultural monitoring systems based on WSNs are driven by different applications and backgrounds. In 2002, the Intel

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Corporation firstly deployed approximately 18 motes based on Mica2 in a vineyard to monitor the temperature. Through the acquired parameters in several periods, they found that the quality of wine was closely related to the change of the climate in the vineyard [4]. The importance of their work was to bring the concept of WSNs on farmlands and boost wireless applications on agriculture. However, in paper [4], sensors were just deployed at limited spots. In order to characterize the accurate parameters across vineyard settings, Intel began another project which measured temperature with dense deployments of 65 sensors in dozens vineyards. [5] In different seasons, they found the correlation between the quality of wine and the temperature of the vineyards. Both of the works applied suggested and fixed routings to the network on specific lands. How to manage the routings is a big problem when there are large numbers of motes failed. To improve previous routing protocols, Baggio et al. presented the Lofar Agro project which is focused on monitoring micro-climates in a potato crop via MintRoute multi-hop routing protocol. Considering the radio waves are easily affected in different growth periods since the backgrounds are varied, we acted nodes as routers to ensure the network connectivity and improve efficiency of communication [6]. The MintRoute multi-hop routing protocol [7] kept routes estimates for each neighbor timely to maintain the links. However, it will consume much energy to maintain the network by retransmissions of radio packets. As various routing technologies have been developed, various wireless standards have been established. Among them, Bluetooth is one of the most robustness in short-range wireless communications. Kim et al. developed a Bluetooth RS-232 serial adaptor, which has a communication range of up to 1200m. Five in-field sensing station transmit the data to the base station from a distance of 700m via Bluetooth technologies. [8]Though they archived stable wireless signal connectivity, high power consumption and expensive equipment are required. Also, the Bluetooth networks are composed of piconets and scatternets, each of which connects one master node with up to 7 slave nodes. Thus, one base station only connected to 7 in-field sensing stations to monitor the environmental parameters without complex network maintenance algorithms. Among recent wireless standards, IEEE 802.15.4 [9] is suited to environmental monitoring and has many successful applications. Lpez et al. [10] deployed two sensor networks and one gateway mote in each network. The nodes in each of these sensor networks were interconnected via IEEE 802.15.4.The gateway motes were developed incorporating long-range modules since the central computer was 5.2 and 8.7 km away. But the long-range modules will consume more power and can only cover a limited space. It is necessary that the gateway mote can communicate with the Internet or mobile network and the remote centers can visit the gateway mote via protocols such asTCP/IP protocol. Previous studies presented inspire us to explore and improve agricultural monitoring systems based on WSNs. First, we mixed the fixed routing methods with the dynamic access. Fixed routing methods could assure the basic monitoring needs in the backbone structure consisted of fixed nodes and the dynamic access permit mobile nodes to connect to the network at any locations. Secondly, as it is not needed to organize a mesh network and repeat messages on farm, IEEE 802.15.4 is selected instead of Zigbee. Thirdly, gateway motes communicate with the control center or remote users via TCP/IP. The users and farmers can visit the monitoring system through the Internet for querying. Finally, we combine a vision camera network with the WSNs monitoring system to observe the growth of crop remotely through a human-interface system.

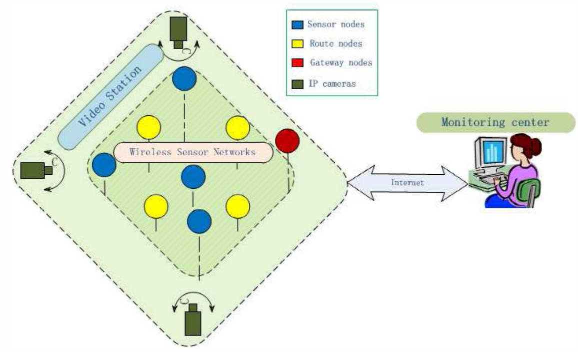


Fig. 1. The layout of the WSNs-environmental monitoring system.

III. MATERIALS AND METHODS

The new agriculture monitoring system based on WSNs we proposed is consisted of three layers. The layout of the monitoring system is illustrated in Fig.1. The top layer is the monitoring center. It stores all collected data and display the human-interface system on the screen. The middle layer is consisted of several spatial stations, which include IP cameras and gateway nodes. Equipment in this layer communicates with the top layer through TCP/IP. Finally, the lower layer is wireless sensor networks made of sensor nodes and routing nodes, which collect parameters of light intensity, air moisture, air temperature, soil moisture and soil temperature and send them to the gateway nodes through IEEE 802.15.4.

A. Wireless nodes

Wireless nodes are made of sensor nodes, route nodes and gateway nodes. The MicaZ mote nodes, is selected to be the based WSNs nodes. MicaZ is built by Atmega 128 microcontroller, which presents low-power consumption. And the CC2420 is used for transmit module, which is a single-chip 2.4 GHz IEEE 802.15.4 compliant RF transceiver designed for low power and low voltage wireless applications [11]. In addition, the software system in Atmega 128 is based on TinyOS [12]. In order to adapt long time moisture and high temperature environment in Hainan province, wireless sensors are covered by silicone and put into a waterproof box (Fig.2).

1) Sensor nodes: Sensor nodes are composed by wireless modules, data collection modules and sensor modules. Wireless nodes designed by our lab are used for wireless modules for communications. Figure 3 shows the hardware components of a sensor node. In order to make the system

Fig. 2. The module of wireless nodes.

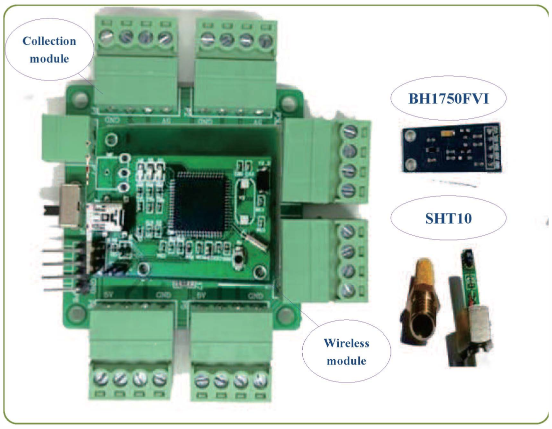


Fig. 3. Hardware of the sensor nodes.

scalable, we designed an information collection board based on STC12C5A60S2 for sensor data collections, which is connected with different sensors through serial ports. In this system, two kinds of sensors are used to detect the light intensity, air moisture, air temperature, soil moisture and soil temperature. Considering the subtropical climate in Hainan, sensors are selected accordingly. SHT10 is used for moisture/temperature sensor. It uses low power consumption of 80 W and has 2-wire digital output. The range of temperature measurement is from -40 to 123.8 with the tolerance error of 0.5 and the range of humility measurement is 0 100% RH with tolerance error of 4.5%RH. The light sensor, BH1750FVI, is with high resolution and the range is from 0 65535 lx. It also uses 2-wire serial digital ports, which is simple for measuring.

2) Gateway nodes: Fig.4 is the hardware of the gateway node. Gateway node is a bridge between the WSNs and the Internet. However, only using Atmaga 128 couldnt meet the processing needs. Thus, we chose the PC104 with the embedded operating system of Linux to be the processor. And the wireless node is responsible for receiving data from the WSNs and sending data to PC104. Then, the PC104 decompresses the data and recompresses data for TCP/IP protocols. Thus, remote centers can collect the data through the Internet at any time.

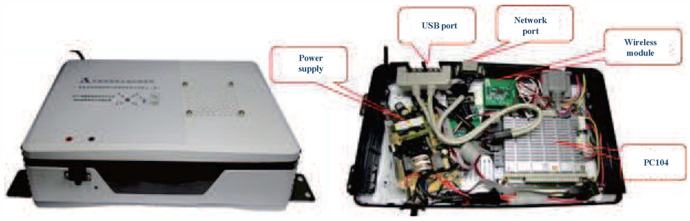


Fig. 4. The gateway node.

Fig. 5. IP camera.

3) Communications: In our system, IEEE 802.15.4 was chosen for communication between the sensor nodes and gateway nodes because it is simple to implement than other methods in small and spatial areas. Sensor nodes integrate all the sensed data and pack them with ID number, the sequence number and fixed data for the protocol ec.t. The packets are transmitted from the sensor nodes to the gateway nodes through some route nodes. The format of the packet among the WSNs is specified by Table I and Table II shows the effective data, which is called the payload.

B. Video monitoring

From the WSNs, we can collect the environmental parameters, which are important for clients to make smart decisions. However, nowadays more clients want to watch the growth conditions of the crop at any time remotely. Thus, a video monitoring network with several wireless cameras among crop fields are designed in our system. Farmers and scientists can view the videos or images through the Internet remotely. Whats more, they can schedule the cameras for rotation and focus through the monitoring software.

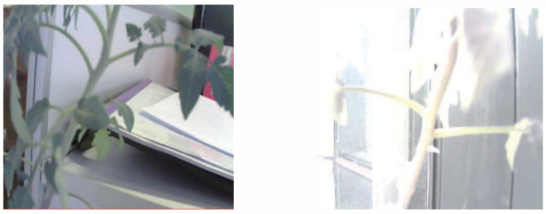
1) Wireless cameras: In the video monitoring network, IP cameras are used for wireless cameras, which can be deployed in the crops without any cables for networking or powering. IP camera (Fig.5) called the network camera can produce and transmit video streams via Wi-Fi. And the IP camera in this system has a PTZ, which can be controlled through the Internet. Then, remote clients only need the IP address of the camera and a password to get the right to control the cameras if IP cameras are connected to the Internet. Figure 6(a) is captured indoors and Figure 6(b), almost white, is captured outdoors by the same IP camera, we can see the IP camera is affected seriously outdoors. Thus, we used a cover and a filter.

TABLE I
THE FORMAT OF THE PACKET

Framer	Protocol	Space	Payload Length	Group ID	Handler ID	Payload	CRC	Framer

TABLE II
THE FORMAT OF THE PACKET

Framer	Protocol	Space	Payload Length	Group ID	Handler ID	Payload	CRC	Framer



(a) Indoors. (b) Outdoors.

Fig. 6. Captured pictures.

The picture then becomes almost the same as Figure 6(b), which could provide clear images and videos of the plants.

2) Networking method: Video streams are transmitted in TCP/IP protocols through the Internet. It seems that the video monitoring network and the WSNs are separated by different protocols. Thus, we configure the gateway node with a Wi-Fi transmitter .Video streams are also stored in the gateway node. Then the gateway nodes integrates the information from WSNs and the video network. Thus, clients can visit the gateway node for both environmental parameters and video streams.

C. Software

1) Human-interface system: Considering the function of the human-interface system based on MFC, it contains a displaying part and a command part. A map provides the deployment of the wireless nodes and the IP cameras. Real-time data, which is refreshed in certain period, is displayed separated by different nodes and environmental parameters. And all the data collected is stored in a database, which can be displayed if needed. Clients can send commands to the WSNs for waking up and sleeping any nodes at any time and also to video monitoring network for controlling the PTZ. In a word, human-interface system can provide remote clients with service such parameter monitoring and videotaping the crops with our new agriculture monitoring system based on WSNs.

2) Databases: Because the human-interface system is running in Windows, it is simple to use Access database. Useful information included in the payload is decoded and stored in corresponding sections. In order to inquiry historical data, time information is added to each received packet.

3) Network maintenance: It is vital to maintain the network outdoors because of limited power supply. Thus we designed a mechanism of power management including sleep, alarm and wake-up methods to extend the life range of network. Normally, the WSNs are in sleeping and low-power listening mode. It reports data every six hours to a remote center. If receiving monitoring commands, the WSNs will wake up enough time to transmit the real-time data. If unsupervised, when sensing dramatic parameters changes and dangerous situations, senor nodes will start the alarm mode to send emergency signals to all the clients.

4) Dormancy (Sleeping) mechanism based on small-scale time synchronization: The climate is not changeable in facility agriculture and clients dont need the data of every cycle. Since the environmental data changes not frequently in a limited period of time based on empirical data provided from Hainan Agricultural Reclamation Academy of Sciences, we designed sleeping mode based on small-scale time synchronization to extend the life cycle of the network. The TimerMilliC modules provided by TinyOS are used to set time because it can set more than1000 hours at most to meet a long time sleeping period. Though, the sensor nodes can be set in a low-power listening mode with duty cycle, large power is still consumed by sending and receiving data since the communication modules are open periodically. Sensor nodes in this system start sleeping mode without listening to the close antennas. Whereas sleep-mode mechanism requires time synchronization since the environmental parameters in different places at the same time are valuable to farmers. Traditional time synchronization is focused on the whole network highly synchronization to consume too much energy by sending time synchronization signals. We proposed small-scale time synchronization to ensure every base stations synchronization. In order to meet the farmers needs, we take two steps. First, sensor nodes send data not from the waking-up moment but from the average data in the sleeping time to supply relatively valuable data. Secondly, gateway node will send a sleeping command when it receives all sensor nodes in its range and all the sensor nodes will go to sleep accordingly at the same time to make up time shift.

5) Alarming mechanism: Alarming mechanism is designed special for the sleeping nodes to wake up in emergency. In order to monitor the environmental data in the sleeping period, sensor node are still collecting data from sensors because information collection modules consumed much less than the communication modules. If unsupervised, the agriculture monitoring system based on WSNs looks like a watchdog, which is sensitive to environment changes and ready to send warning signals. In other words, sensor nodes will send alarming signals to remote centers when the environmental data changes dramatically and farmers could detect and locate the emergency in control center easily.

Fig. 7. A greenhouse in Hainan.

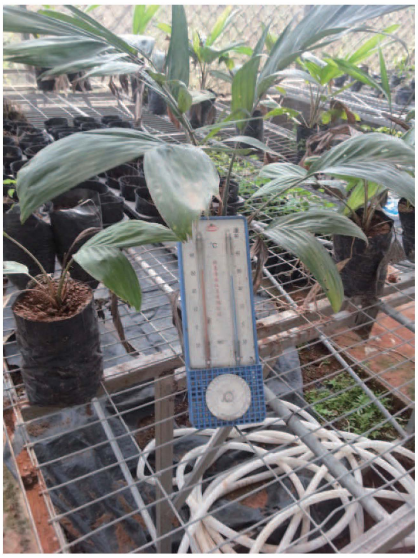


Fig. 8. Traditional measuring tools.

IV. SIMULATION & EXPERIMENT

A. Greenhouse experiment

The validation test was conducted in a facility greenhouse (Fig.7). In the house, traditionally workers used to measure the air temperature and air humility by analog tools (Fig.8]) and record the data manually every few hours. Traditional methods consumed too much human resources and may lead to unexpected errors if unsupervised. Based on our prototype, five sensor nodes with five IP cameras were deployed as the map designed. The results were showed in the human-interface software, which was showed by Figure 9 In order to test the accuracy of the data, we contrasted the actual data by the traditional way with the test data by our methods and concluded that the data was credible. We set the temperature range from 20-40 and humility range from 30 90 %RH based on the parameters from their historical database. If data overflow the safe ranges, the human-interface software will receive the alarm information. The report frequency was set by 5s in order to test communication quality. We found that some loss packets and error packets were existed. From about one hour test data, 2 4 packets per minute were error and 16 22 packets per minute were lost. We analyzed that the rate of loss packets was 0.26 0.36% and rate of bad packets was 0.05 0.09. Then we set the report frequency to be one hour, the rate of the bad packets was 0.02 0.06 and the rate of loss packets was 0.18 0.29%. So the sleeping mote can also improve the communication quality.

B. In-field experiment

Our system is also applied into outdoors, such as the in-field experiment (Fig.10) we did in a field of one acre growing with eggplants. The experimental data about the temperature or humility was similar to the greenhouse experiment. The great difference was that the light intensity was 65535 so that the light data displayed 0, which leaded to the images were almost white. Thus the light intensity impact greatly on images quality and some measures we have taken are listed in Part III. Through this experiment, we validated the effectiveness of our system in outdoor agriculture.

V. CONCLUSION

Contrary to conventional agriculture monitoring system which mainly depending on analog monitoring machines and deploying with large amount of cables, our proposed system is designed not only monitor the environmental conditions wirelessly, but to integrate video monitoring technologies to agriculture monitoring. Whats more, the agriculture monitoring system based on WSNs matches the sensed data in WSNs with images in video monitoring system because we deploy the IP cameras nearby known-position nodes. Farmers can quickly map the information from networks with location. Furthermore, clients may watch the spatial crops remotely by the designed human-interface system timely and query the historical database at any time. To validate our proposed system, we have deployed it in a greenhouse with testing plants and an outdoor field growing with eggplants. Both of the experiments received air temperature, air humility, soil temperature, soil humility and light intensity successfully. Also, the video streams were transmitted to the remote centers and workers can control the IP cameras remotely. However, the high light intensity made the images distorted greatly so that the images were almost white. After we implement the cover and filter, the images could provide useful information again. At last, we improve the communication quality by setting sleeping motes and the self-alarm modes. In the future work, the system will be deployed several separated areas of Hainan facility agriculture to test its robustness. Thus, we will concentrate on the problems, such as power supply, network maintenance and the further improvements of communication quality.

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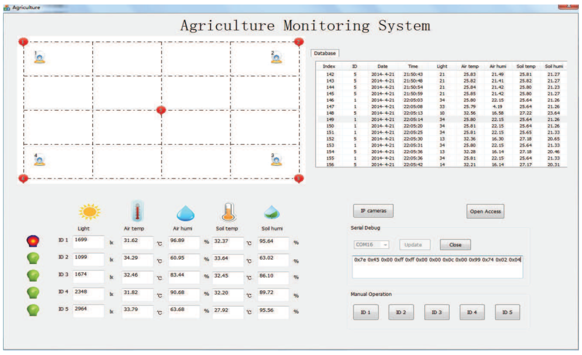

Fig. 9. The photo of human-interface system.

Fig. 10. The photo of human-interface system.

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