Smart water-saving irrigation system in precision agriculture based on wireless sensor network

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Abstract: Based on investigation and applications in precision agriculture, a self-designed moisture wireless sensor was presented in the paper, a wireless sensor network was established for monitoring moisture content and water height of field soil. The architecture of the wireless sensor network was constructed, and the smart irrigation control system was designed based on the network. The irrigation test was implemented by real-time moisture data and expert data. The system was proved to be applicable and feasible for applying in the rice growth process and to be a good exploration in the field of precision agriculture and sustainable water resources.

Key words: wireless sensor network, smart irrigation control system, precision agriculture, architecture
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0 Introduction

Wireless sensor network is used to sense and acquire various information from monitored objects by cooperation of different integrated miniature sensors. By means of embedded information process and random self-organization wireless network, the information is sent to user terminals to realize the philosophy of “Everywhere computing” [1]. Based on the features of automation, self-organization and data-centric, wireless sensor network can be applied to acquire data of field soil moisture, and then the data is fused and transmitted automatically to provide a high efficient acquisition platform of field moisture data so as to support smart water-saving irrigation.

Traditional field irrigation is usually manned and needs massive manpower and material resources, this led to deficiency of real-time and accuracy and went against the development trend of long-time agricultural production and sustainable utilization of water resources. Wireless sensor network is extensively used in precision agriculture and smart irrigation to overcome these problems[2-4].

G Vellidis and his colleagues[5] developed a prototype real-time, smart sensor array for measuring soil moisture and soil moisture that used off-the-shelf components. The array was consisted of a centrally located receiver connected to a laptop computer and multiple sensor nodes installed in the field. Integration of the sensors with precision irrigation technologies provided a closed loop irrigation system where inputs from the smart sensor array determined timing and amounts for real-time site-specific irrigation applications.

J Balendonck and his colleagues[6] developed a system named FLOW-AID which has the objective to develop and test an irrigation management system that can be used under deficit. The system focuses on development of low-power wireless sensor network for soil water monitoring. Six sensor nodes equipped with SM200 soil moisture probes and 3 repeaters were built and evaluated during 5 months under practical Mediterranean conditions for a container grown crop. John D Lea-Cox, et al[7] deployed two types of wireless sensor networks to provide real-time data for precision irrigation management by nursery and greenhouse growers. One of the networks was used to automatically monitor and control irrigation water applications.

Cui Jing, et al[8] developed a smart irrigation control and management system by GSM which includes real-time monitor module, decision support system and smart irrigation system. Gao Feng, et al[9] designed a wireless sensor node and a WSN-based crop precision irrigation system based on the stem diameter microvariation diagnosis method for water stress. Zeng Liancheng, et al [10], Wang Ji, et al[11], Kuang Qiuming, et al[12], Bing Zhigang, et al[13] proposed, designed and implemented a wireless sensor network with relevant hardware and software supports. They deployed the existing hardware such as SHT11 sensors,

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ZigBee wireless modules. The structure of wireless sensor network and smart irrigation control system are essentially identical.

Wireless sensor networks mentioned above are the foundation of smart irrigation control system; especially, all sensor nodes used to acquire the data from field by researchers and farmer are ready-made. Moreover, in order to implement the smart irrigation, the sensor nodes only acquire the soil moisture content, but not include water height. However, the water height is very important factor to the growth and development in South China. The smart irrigation control systems mentioned above usually use wire communication and centralized control pattern, the efficiency is low. In consideration of the cost, wireless sensor network can not apply to large-scale agriculture temporarily; therefore smart irrigation control system is developing slowly. So, the cost of wireless sensors, irrigation control devices and maintenance of hardware and software is urgent to be reduced.

The paper presents a self-designed wireless sensor for acquiring the moisture content and water height of field. We combine the moisture wireless sensor network based on the wireless sensors with smart irrigation control system to acquire real-time moisture data, analyze crops water requirement and implement smart irrigation decision. The system was utilized at Congyu vegetable field of Guangzhou as Fig.1. From the system, agriculture must be promoted to the direction of modernization and sustainable development.

Fig.1　Applications in Congyu Vegetable Field of Guangzhou

1　Architecture of wireless sensor network

The moisture wireless sensor network is consisted of wireless sensors, cluster heads, repeaters, base station, data center server and data backup server, its architecture is showed as Fig.2. The network is organized by chain structure; in practice, the structure is simple and efficient in large-scale moisture monitoring for field.

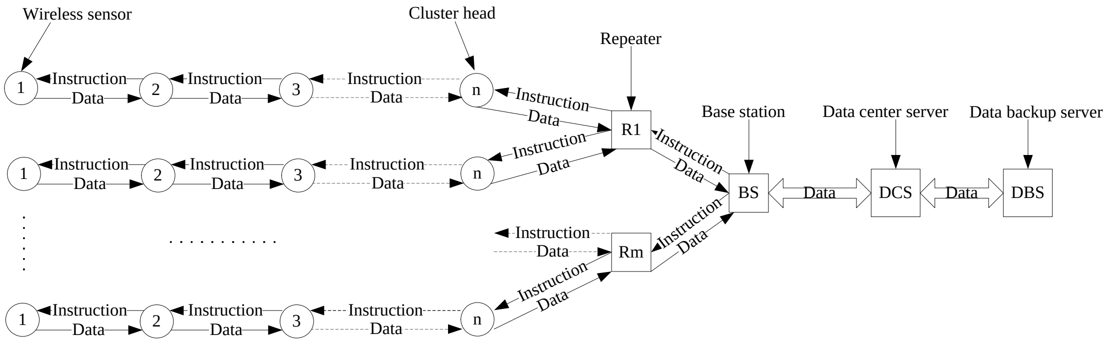

Fig.2　Architecture of wireless sensor network

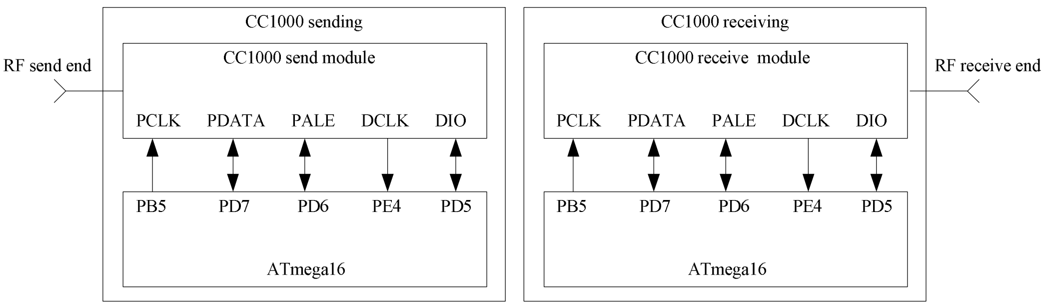

Fig.3　Connection between CC1000 and ATmega16

1.1　Sensor and cluster head

Sensor node is placed in field as Fig.1 to acquire the moisture content and water height, and then uploads the data periodically and stores the recent data locally. Sensor node receives the acquisition instruction from its parent node to implement the data acquisition and uploads the data to its parent node, and then switches to dormant state until wakened by internal crystal oscillator at the next acquisition period. The format of moisture data frame is not discussed here.

Sensor node is self-designed with ATmega16 micro processor as CPU, CC1000 as wireless radio module with frequency of ISM433MHz, and two stainless-steel needles inserted into soil as probe. To improve the transmission distance, sensor node is added a power amplifier circuit. CC1000 is connected with ATmega16 as Fig.3, and the connection needs corresponding program to simulate communication. The acquisition module uses E1648 frequency crystal oscillator supplied by 3.3–4.2 V direct-current source such as nickel-metal hydride battery and uses the approach of Frequency Domain Reflect (FDR)[14] to acquire the frequency, the frequency is converted to the moisture content and water height after calibration. In our application, the sensor nodes are powered by three 1.5 v dry batteries. By this energy supply, the sensor nodes can work periodically for a growth period of rice about 100 days.

Cluster head placed in field is the root node of chain wireless sensor network. Besides having function as sensor node, cluster head transmits acquisition instruction to child node and receives data uploaded from child node and sends the data to repeater.

Cluster head is identified with sensor node in hardware and equipped with 20 cm antenna, but costly, we will try to substitute rechargeable battery with solar panel for direct-current source. Cluster head is needed good mechanism of sleep and wake-up for its long-time work and massive transmission data.

1.2 Repeater

Repeater is set up as a transmitter of moisture data and instruction for improving transmission distance. Repeater is not responsible for acquiring the moisture content and water height and usually placed at a lofty place in field to get good communication.

Repeater is identified with sensor node in hardware and supplied by 12 V, 7Ah direct-current storage battery with 75 cm antenna. According to design scheme of wireless sensor network, repeater has the same mechanism of sleep and wake-up as other nodes. For the long-term work and environment protection, solar panel is a good alternative for direct-current source.

1.3 Base station

Base station is designed on S3C2440 ARM9 development board with Samsung S3C2440A as CPU, 64 M SDRAM as main memory, 64 M flash as external memory, and CC1000 as wireless radio module seen from Fig.4. Base station is usually placed in field management office.

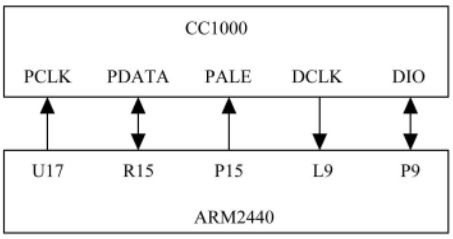

Fig.4 Connection between CC1000 and ARM 2440

Base station manages moisture data from sensor nodes and stores the data to SD card on the board, and then encapsulates the data according to the format of GSM (Global System for Mobile communications) and sends the GSM message to data center server. Instruction of data acquisition and clock synchronization are sent to repeater through base station, and further to every sensor node.

1.4 GSM gateway

The system has two GSM gateways, one connected with base station is base-station-end GSM gateway (BS-GSM), and another connected with data center server is data-center-server-end GSM gateway (DCS-GSM). The gateway connects with base station or computer by serial port.

Base station is connected with data center server by GSM gateway, so the distance between base station and data center server can be infinite. BS-GSM sends the data stored in base station to DCS-GSM periodically in GSM message format. DCS-GSM receives the messages from BS-GSM then transmits them to data center server.

1.5 Data center server and backup server

Data center server is the application core of moisture wireless sensor network and smart irrigation control system as Fig.5. Application program of moisture database system reads the GSM message real-time from DCS-GSM in RS232 serial port and decodes the message to get the data of moisture content and water height, and then writes the data into the database. Records in database include node identifier, acquisition frequency, acquisition time, etc. Moisture database application system provides time-moisture-content and growth-period-expert-data sequence chart to get visual changes of field soil moisture. According to curves in sequence chart, user can read the crops water requirement so as to get smart irrigation decision.

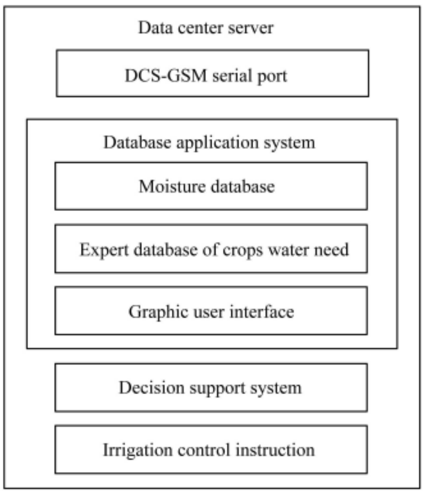

Fig.5 Structure of data center server

Expert database is used to store expert data of water requirement in growth period of crops. We build the water requirement model of crops according to type of soil, weather and water requirement at different time in growth period as the foundation of irrigation control system. Irrigation decision support system determines the time and water mount of irrigation by the difference between real-time moisture data and expert data, and then starts the smart irrigation control system to implement irrigation.

Data backup server connected with data center server is functioned as data backup and recovery server to improve integrity and security for moisture data. The server is a computer with good performance and mass memory and equipped with uninterrupted power supply.

2 Smart irrigation control system

Architecture of smart irrigation control system is figured as Fig.6. Moisture wireless sensor network is upper system that is responsible for moisture data acquisition and irrigation decision, smart irrigation control system is lower system responsible for irrigation implementation. Smart irrigation control system is worked following central control pattern and communicates with base station by CC1000 as Fig.7, and the connection between them needs corresponding program to simulate communication.

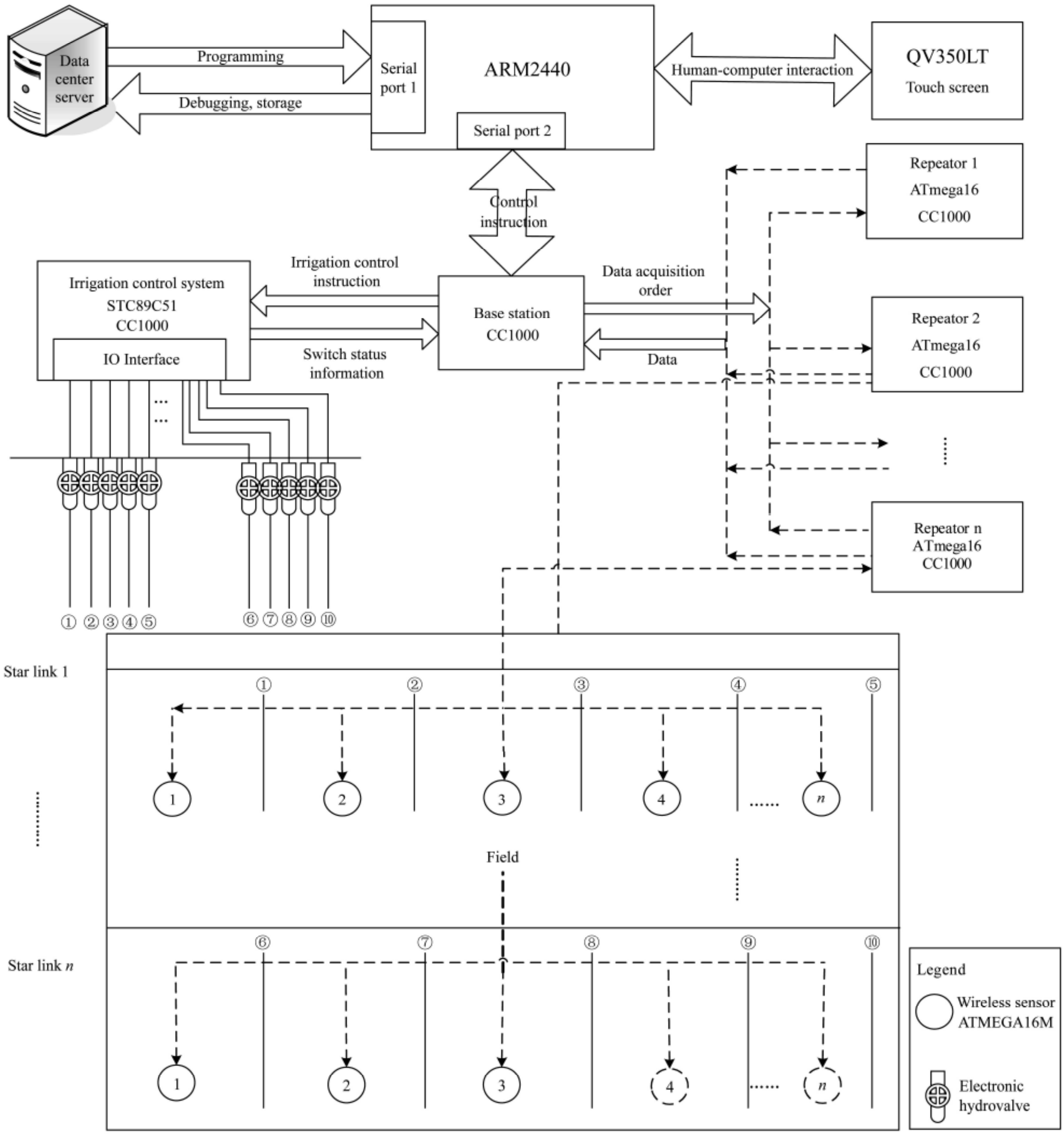

Fig.6 Architecture of smart irrigation control system

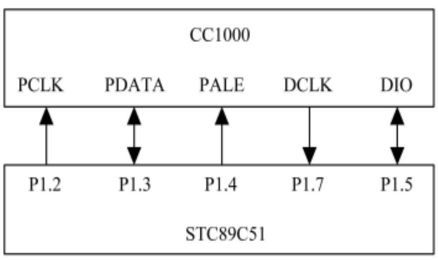

Fig.7 Connection between CC1000 and STC98C51

Smart irrigation control procedure is described as follows:

1) Data center server calibrates the moisture data from sensors respectively.

2) Database application system compares expert data with real-time moisture data to determine whether crops need to be irrigated and decides irrigation amount on unit area.

3) Decision support system sends irrigation instructions

to base station to designate irrigation position and total amount.

4) Base station sends irrigation instructions to irrigation control system.

5) Irrigation control system opens the electronic hydrovalve in given irrigation position, and then closes it after reach irrigation threshold.

6) Local irrigation ends, the process above moves in cycle.

3 Experiments and results

In the paper, we mainly describe calibration of sensors and the comparison between real-time moisture data and crops water requirement, namely irrigation decision.

3.1 Calibration for sensor

Soil moisture content and water height are important growth factors of rice, so the calibration of every sensor is essential. In our experiments, when soil mass moisture content is below 25%, the soil is thought to be dry; when soil mass moisture content is above 55%, the soil moisture is saturated. So we aim at 25%–55% for soil moisture content and above 55% for water height.

In calibration of soil moisture content, we use linear equation fitting as formula (1) and cubic curve fitting as formula (2), correlation coefficient is 0.8935 and 0.9901 respectively. Therefore, we consider cubic curve fitting is more accurate than linear equation fitting.

$$\omega=-66.4286f+611.2857 \quad (1)$$

$$\omega=-949.5f^3+1251.5f^2-582.5f+676.5 \quad (2)$$

In calibration of water height, we use cubic curve fitting as regression equation as formula (3) which correlation coefficient is 0.9942 as Fig.8. The unit of water height is centimeter (cm).

$$\omega=0.3204f^3-5.6286f^2+36.0584f+549.1415 \quad (3)$$

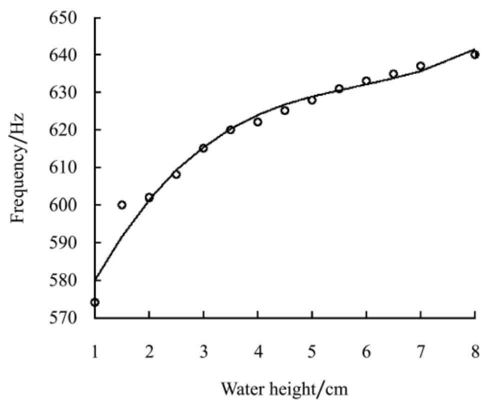

Fig.8 Frequency and water height curve

3.2 Irrigation decision

Irrigation object of the system is rice by precision hill-drop-drilling, so irrigation decision can be arranged by different stage of rice: tillering stage, young ear development stage, and mature stage[15]. Irrigation amount is measured by water volume per unit area (m^3/hm^2). According to water requirement of rice, we did two tests, one test is water-saving irrigation, and another is flood irrigation. In above three stages, irrigation amount is listed as Table 1.

Table 1 Irrigation amount in different stage by different way of irrigation

$m^3 \cdot hm^{-2}$

Way of irrigation vs. different stage	Tillering	Young ear development	Mature
Water-saving	685.5	898.35	512.85
Normal	1 069.2	1 382.25	763.05

From Table 1, water-saving irrigation is 65.22% of normal irrigation in total irrigation amount. The results show that the smart irrigation control system is practically water-saving and feasible for precision agriculture.

4 Conclusions

Based on the self-designed wireless sensor, we established the wireless sensor network to monitor moisture content and water height of field soil, presented the architecture of the wireless sensor network, and discussed the calibration of sensor and irrigation decision results for agricultural application. For the development of precision agriculture, we designed a smart irrigation control system based on wireless sensor networks and implement irrigation decision by real-time moisture data and expert data. The system was proved to be water-saving and feasible for precision agriculture.

Future work will deal with the stability of wireless sensor in communication by better software and hardware design. Especially, the rechargeable battery with polar panel will be equipped in sensor node and cluster head as energy supply to get longer working time. Moreover, design and implementation of software architecture for the smart irrigation control system need continuous improvement to meet various irrigation demands.

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基于无线传感器网络的精细农业智能节水灌溉系统

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摘　要：在精细农业相关应用和理论研究基础上，自行设计用于监测农田水分含量和水层高度的无线传感器，构建农田水分无线传感器网络体系结构，设计基于水分无线传感器网络的智能节水灌溉控制系统，通过实时农田水分数据和农作物水分需求专家数据形成灌溉决策，由灌溉控制系统实施定量灌溉。实际应用表明，该系统体现出可行性和高效性，有利于精细农业的发展和水资源的可持续利用。

关键词：无线传感器网络，智能灌溉控制系统，精细农业，构架