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An Improved Green Energy Granary Monitoring System Based on Wireless Sensor Network

[1] Bin Wang, [1] Jun Guo, [2] Dong Su

[1] College of Electronic Engineering, Chongqing University of Post and Telecommunications, Chongqing 400065, P. R. China

[2] 26th Institute of Electronics Technology Group Corporation, Chongqing 400065, P. R. China

[1] Tel.: +86-18602328202

E-mail: wangbin1@cqupt.edu.cn

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Abstract: In the study of granary monitoring, many research projects are involved in environmental monitoring in recent years. However, most existing studies are interested in the outdoor natural environment monitoring. Few of them focus on the indoor monitoring. This paper presents a system based on wireless sensor network (WSN) for granary monitoring including grain temperature and humidity. The whole system adopts sensors DS18B20 to measure the granary temperature, DHT11 to measure humidity, and the data is processed by transceiver CC2530, which is a true system-on-chip (SoC) solution for IEEE 802.15.4 applications. To deal with energy consumption problems effectively, the scheme of solar battery board is proposed in order to produce a kind of clean and renewable energy. In addition to showing the temperature and humidity monitoring and alarm mechanism, the system can set up or modify the working parameters through keywords at control terminals. The overall system architecture is described in detail. What is more, the network deployment and wireless communication protocol etc. are introduced. Experimental results in actual granary show that the proposed new system is convenient, efficient, and correct. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: WSN, DS18B20, DHT11, CC2530, IEEE 802.15.4, Solar battery board.

1. Introduction

With the rapid growth of population and improvement of person’s life quality in china, the grain storage plays an important role in current society, and its requirements are also gradually improving. The granary type of our country could be divided three types: The first one is the old granary which is simulated the Soviet Union-type structure position for the main body. Their storage capability is so large, more than billion kilograms. As they built for a long time, part of the environment of granaries is poor and lack of supporting of some mechanization facilities, at that time, they usually used artificial monitoring and natural ventilation.

Then the next category is built in the 80's and 90's. These storehouses are divided into the simple room type granary, the round brickwork granary, the underground storehouse and the mountain storage cavern primarily. As the underground storehouse and the mountain storage cavern are at low temperature the whole year, the food deterioration is slower and the keeping cost is lower.

Since then, the granaries’ structure have been changed, which the main type is warehouse, and the other categories are shallow silos and vertical silos. We have the abundant granary construction history more than 50 years, accumulate rich experience in the positions, and there are also many painful lessons. Granary construction should be fully guaranteed the grain storage safety in the first place.

However, in the process of the grain storage, the quality of grain is directly affected by the change of temperature and humidity in granary. Consequently, the veracity and reliability of the grain monitoring system is immediately concerned about the application of grain storage and the quality and safety of the grain.

In recent years, researchers have done a lot of efforts about the environment monitoring, from manpower to automation, from wire to wireless. The conventional way is outdated, for example, sampling data by artificial consumes a lot of labor force and low efficiency, poor accuracy. In addition, the complex wiring type has low anti-interference capacity and poor maintenance, which restrain its application and popularization. Comparing the traditional way, the Wireless Sensor Network (WSN) technology appeared on the scene, especially in the agriculture (such as the granary monitoring). Wireless Sensor Network is a specific network consisting of an increasing number of low-power sensor nodes with a self-organizing way which can gather environment information and transmit the data by wireless. [1]

In order to effectively monitor the granary environment and enhance the efficiency, a simple and intelligent granary measurement and control system based on ZigBee wireless sensor network is proposed in this paper, which the core is radio frequency chip CC2530 connecting with temperature sensors, humidity sensors and the executive devices, and the object of controlling and monitoring temperature and humidity is complemented, at the same time, the temperature and humidity parameters can be real-time displayed on the computer.

2. Base Theory

2.1. What is ZigBee

ZigBee is a standard that defines a set of communication protocols for low-data-rate short-range wireless network [2]. Short-range wireless networking methods are divided into two main categories: wireless local area networks (WLANs) and wireless personal area networks (WPANs). WLAN is a replacement or extension for wired local area networks (LANs) such as Ethernet (IEEE 802.3). A WLAN device can be integrated with a wired LAN network, and once the WLAN device becomes part of the network, the network treats the wireless device the same as any other wired device within the network [3]. The goal of a WLAN is to maximize the range and data rate. WPANs, in contrast, are not developed to replace any existing wired LANs. WPANs are created to provide the means for power-efficient wireless communication within the personal operating space (POS) without the need for any infrastructure. POS is the spherical region that surrounds a wireless device and has a radius of 10 meters (33 feet) [4]. WPANs are divided into three classes (see Fig. 1): high-rate (HR) WPANs, medium-rate (MR) WPANs, and low-rate (LR) WPANs [5]. An example of an HR-WPAN is IEEE 802.15.3 with a data rate of 11 to 55 Mbps [6]. This high data rate helps in applications such as real-time wireless video transmission from a camera to a nearby TV. Bluetooth, with a data rate of 1 to 3Mbps, is an example of an MR-WLAN and can be used in high quality voice transmission in wireless headsets. ZigBee, with a maximum data rate of 250 kbps, is classified as an LR-WPAN.

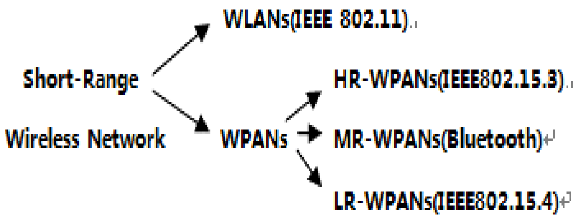


Fig. 1. Short-range wireless networking classes.

While most wireless standards are striving to go faster, ZigBee aims for low data rates. While other wireless protocols add more and more features, ZigBee aims for a tiny stack that fits on 8-bit microcontrollers. While other wireless technologies look to provide the last mile to the Internet or deliver streaming high-definition media, ZigBee looks to control a light or send temperature data to a thermostat. While other wireless technologies are designed to run for hours or perhaps days on batteries, ZigBee is designed to run for years. And while other wireless technologies provide 12 to 24 months of shelf life for a product, ZigBee products can typically provide decades or more of use. The market category ZigBee serves is called “wireless sensor networking and control” or simply, “wireless control”. In fact, the slogan for ZigBee is, “Wireless Control That Simply Works”.

2.2. Working Principle of ZigBee Technique

ZigBee is synonymous with IEEE 802.15.4 protocol. ZigBee-based wireless devices operate in 868 MHz, 915 MHz, and 2.4 GHz frequency bands. In the 2.4 GHz frequency band, it has 16 channels which are global standards, free of charge, non-application. ZigBee is targeted mainly for battery-powered applications where low data rate, low cost, and long battery life are main requirements. In many ZigBee applications, the total time wireless device is engaged in any type of activity is very limited; the device spends most of its time in a power-saving mode, also known as sleep mode. As a result, ZigBee enabled devices are capable of being operational for several years before their batteries need to be replaced.

Since the late 90 s, a lot of scientists in America, Europe and China have devoted themselves to the study of wireless measurement and control system, in which ZigBee technology with high reliability and lower consumption is applied, not the other short-range wireless networking methods, Bluetooth or IEEE 802.11b. As shown in Fig. 2 and Table 1, we compare the power consumption, complexity, cost and data rate. So, we can conclude ZigBee is a candidate for wireless communication technology of WSN.

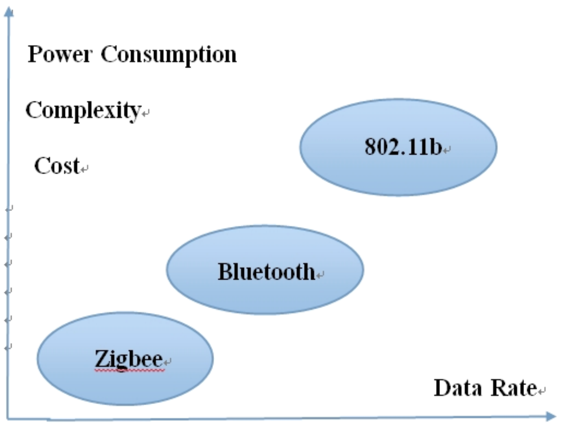


Fig. 2. Comparing the ZigBee standard with Bluetooth and IEEE 802.11b.

Table 1. Analysis the specific features of ZigBee, Bluetooth and IEEE 802.11b.

Target / Type	Data Rate	Typical Range	Application Examples
ZigBee	20 to 250 kbs	10-100 m	Wireless Sensor Networks
Bluetooth	1 to 3 Mbps	2-10 m	Wireless Headset Wireless Mouse
IEEE 802.11b	1 to 11 Mbps	30-100 m	Wireless Internet Connection

2.3. ZigBee Network Topology Structure

In order to enable suppliers to offer the lowest possible power equipment, IEEE (Institute of Electrical and Electronics Engineers) defines two different types of equipment: one is the full function device (FFD), the other is reduced function device (RFD). In Fig. 3, we can see that ZigBee networking can support three main wireless networks: star network, net network, and clusters network. FFD can support any kind of topological structures, which can be used as a network negotiator and the general coordinator, and it can communicate with any kinds of equipment. RFD only supports star structure, which can't to be any negotiator. But it can communicate with network negotiator, and the process is very simple.

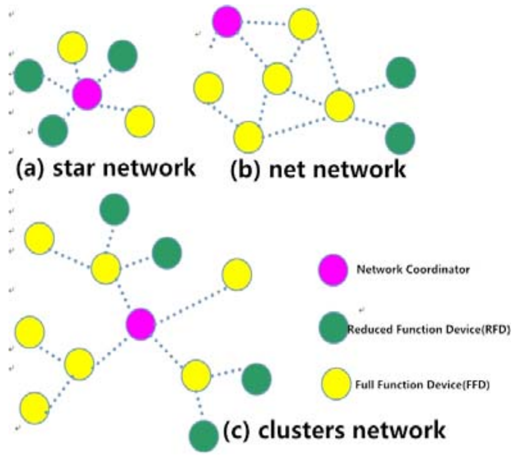


Fig. 3. Three main types of wireless network.

3. Design the Green Granary Monitoring System

3.1. Description of the Granary Location

The barn we have monitored is located in Chongqing, China. It is well known that Chongqing is a mountainous area with the subtropical inland climate. In summer, we can hardly breathe because the highest temperature can reach to 43.8 °C. However, autumn and winter are often accompanied by the rainy weather, and the lowest limit temperature can reach to minus 3.8 °C. Especially from July to August, the highest temperature is mostly between 27 °C and 38 °C. Therefore, the drop temperature is large, saving the grain is even more important.

3.2. Wireless Sensor Network Architecture

In this system we proposed here, the star network topologies (see in Fig. 4) are used by us to monitor and control the granary. The average size of a granary holding in the region is around 11232 m^3, which the length, width and height are 78 m, 24 m, 6 m. The distance from the granary to controlling core is about 100 m, and it means that the ZigBee network can transmit the data effectively. In the granary, we use the sensor node DS18B20 to monitor the temperature, the DHT11 to measure the temperature and humidity. Compared with the traditional sensor network of sensor pattern, we introduced a new sensor network of temperature measurement cables pattern. The new sensor network architecture is shown in Fig. 4, the granary monitoring network by a "sink node" and tens to hundreds of cables with temperature and humidity sensor nodes. "Sink nodes" can be placed anywhere in the barn, mainly responsible for receiving all the uploading data of sensor nodes. Sensor nodes with temperature measurement cables can be placed over the surface of grain, but the temperature cables should be buried in grain. Since the top of grain surface is a barrier-free space transmission and the transmission distance is large, sensor nodes collect data from temperature measurement cables by cycle or timing type, and report to "sink node" through the way of self-organizing network.

Combining with the wired monitoring structure analysis of medium-sized barn, it shows that more than 50 cables installed sensor nodes and a “sink node” can be composed of grain temperature and humidity measurement system. The advantages of this network are obvious, which temperature measurement cables installation and removal are more convenient than the current bus-type grain monitoring system. Due to the existence of wireless ad hoc network in granary, you can always maintain the failed nodes or cables without affecting the other nodes, but also saving maintenance costs. Thus we solve some problems fundamentally of electromagnetic interference, lightning stroke etc., causing the system to crash through the introduction of transmission bus. However, the disadvantage is that domestic specialists and abroad ones don not conduct a comprehensive study for this application mode, network topology and feasibility may need to assess in a long time.

As Fig. 4 shows, there will be two-way communication between the sensor nodes and the monitoring software at the base station (BS), by means of the corresponding gateway. With this implementation, large areas can be covered, even if scattered, avoiding the difficulty of developing and implementing mesh/cluster topologies (a smaller number of devices is required) and reducing the energy consumption of the devices that perform sensory functions (since they do not perform data routing functions).

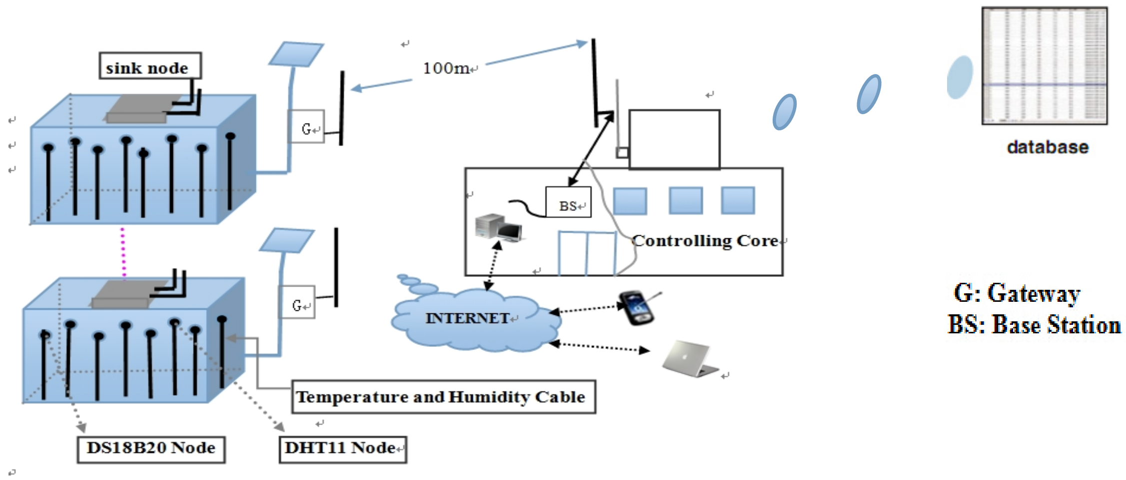


Fig. 4. Architecture proposed for the monitoring of granary.

4. Simulation for the WSN Design

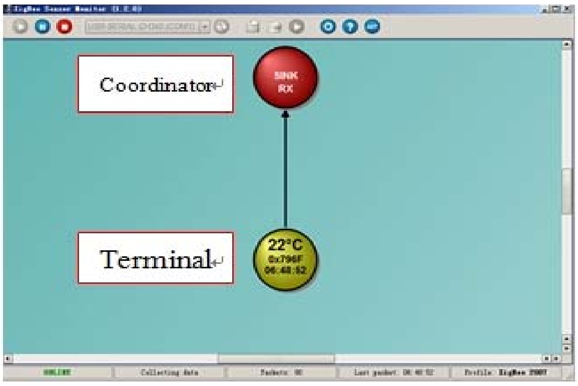
4.1. Selection of the Software, Hardware and Communication Protocol

In order to establish the basic components (temperature node, temperature and humidity node and gateway) of WSN architecture, a number of physical devices (radio module and sensor elements) were selected: CC2530 radio transceiver (Texas Instruments, USA), DS18B20 digital temperature sensor (DALLAS company, USA), DHT11 digital temperature and relative humidity sensor (domestic electron company, China), and temperature measurement cable or called hotspot detector.

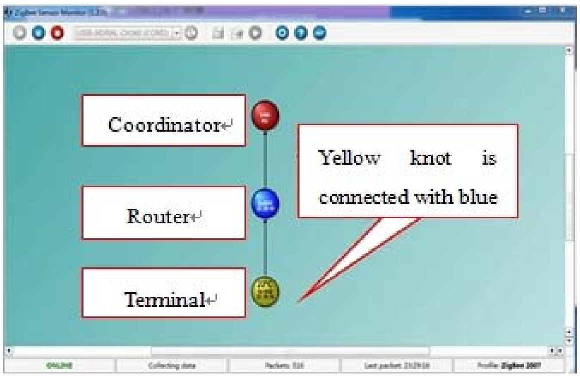
Another important component of the architecture is to select the communication protocol. The standard of the field of wireless sensor network is IEEE 802.15.4, which presented the greatest commercial development, and the ZigBee system is composed with these services [7]. It is a appreciate technology that implementing communications between wireless devices and the gateway due to the low cost and little energy consumption. In order to complete this standard, a whole mechanism has been listed to provide even the lower consumption. A B-MAC mechanism was selected as the medium access control protocol to arbitrate the communication of multiple sensors over the radio channel [8]. As we know, IEEE802.15.4 has its own medium access control protocol called slotted Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA), however, a specific system which features Low Power Listening (LPL) specifically designed for low power consumption. Therefore, the B-MAC mechanism exploits a scheduled scheme operation that nodes know the reasonable interval in which they must be awaken for receiving information. But the nodes are always awakened until they receive data in the active period of a slotted CSMA-CA protocol, so that it wasted more energy. The data frame formats of the standard IEEE 802.15.4 have been used, but B-MAC was used as the protocol for accessing to the radio channel.

4.2. Experiment Environments and Simulation Results

In order to test the performance of designed node, we built a simple temperature and humidity test environment based on two terminals, one router and one coordinator. After a period of debugging, the wireless communication of the system is realized. Fig. 5(a) and (b) show the topology structures of single hop and multi-hop between end device and coordinator, and the red, blue, yellow knots present coordinators, routers, terminals.



(a) Single hop



(b) Multi-hop

Fig. 5. Communication between terminal device and coordinator.

Simulation of the sensor network is a necessary first step prior to the actual implementation. It was carried out using the software of ZigBee Sensor Monitor, and we can see that blue knot has been started as a router. At the same time, it is obviously that the blue one has already connected to the red node, and starts to send data to the red node.

5. Design of the Hardware Node

The main elements of the hardware nodes (see Fig. 6(a) are sensors and the CC2530 transceiver. CC2530 is a true system-on-chip (SoC) solution for IEEE 802.15.4 applications. It combines the excellent performance of a leading RF transceiver with an industry standard enhanced 8051 CPU, the memory arbiter, the 8-KB SRAM, the IEEE 802.15.4-compliant radio transceiver, and some other powerful features. It also has in increasing number of operating modes, making it perfectly suited for systems where low power consumption is required.

The battery consisted of 5 V alkaline battery can supply energy for sensor node, or to deal with energy consumption problems effectively, the scheme of solar battery board is proposed in order to produce a kind of clean and renewable energy. A 3.3 V low-dropout DC/DC converter has been added to adjust the battery voltage (over 4 V when charged). The DS18b20 sensor node and DHT11 sensor node, which are connected to the I/O interface, are both fitted on the wall and in the grain by cable.

In addition to the CC2530 transceiver, the gateway includes a long-range radio module to provide two-way communication between the sink nodes and the farm offices. What is more, this device has no output interface for connecting sensors. The device is set on the 5 m high wall which is also fitted with a photovoltaic solar panel to supply power. At the same time, this solar panel charges a 12 V/6.5 Ah lead-acid battery. The device is further equipped with two antenna, one gain is 8dBi and the other one is 4 dBi.

As Fig. 6 (b) shows, the main peripheral circuits of central node are given.

The wireless sensor network nodes are composed of processor module, wireless communication module, power module and sensor module. As we know, the processor module and wireless communication module are integrated on CC2530 chip, which greatly simplify the RF circuit design. The temperature sensor DS18b20 and temperature humidity sensor DHT11 are used in the sensor module.

The single-wire digital temperature sensor DS18b20 is produced by American DALLAS semiconductor company, which is in 3-pined TO-92 small volume seal form. The temperature measurement range is from -55 to +125 °C, programmable for 9-12 bits conversion accuracy and temperature measurement resolution reaches 0.0625 °C. And the sign-extended 16 bits digital value serial output is used for the measured temperature. It requires only one report wire for DS18b20 CPU to communicate with numerous DS18b20, which occupies less microprocessor port so that it can save plenty of leads and logic circuits.

The DHT11 is a very widely used digital interface temperature and humidity sensors, which measure the humidity range of 20 % to 90 %, temperature measure range of 0~50 °C, measurement accuracy of 5 %, and it is consistent with the needs of the measuring system. DHT11 uses a single bus data transfer structure, which is easy to connect with a variety of MCU and the signal transmission distance up to 20 m or more, as well as ultra-low power consumption.

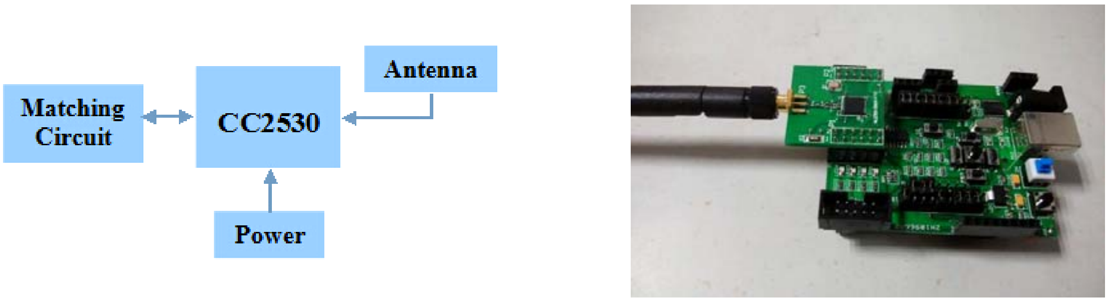


Fig. 6 (a). The manufactured sensor node picture.

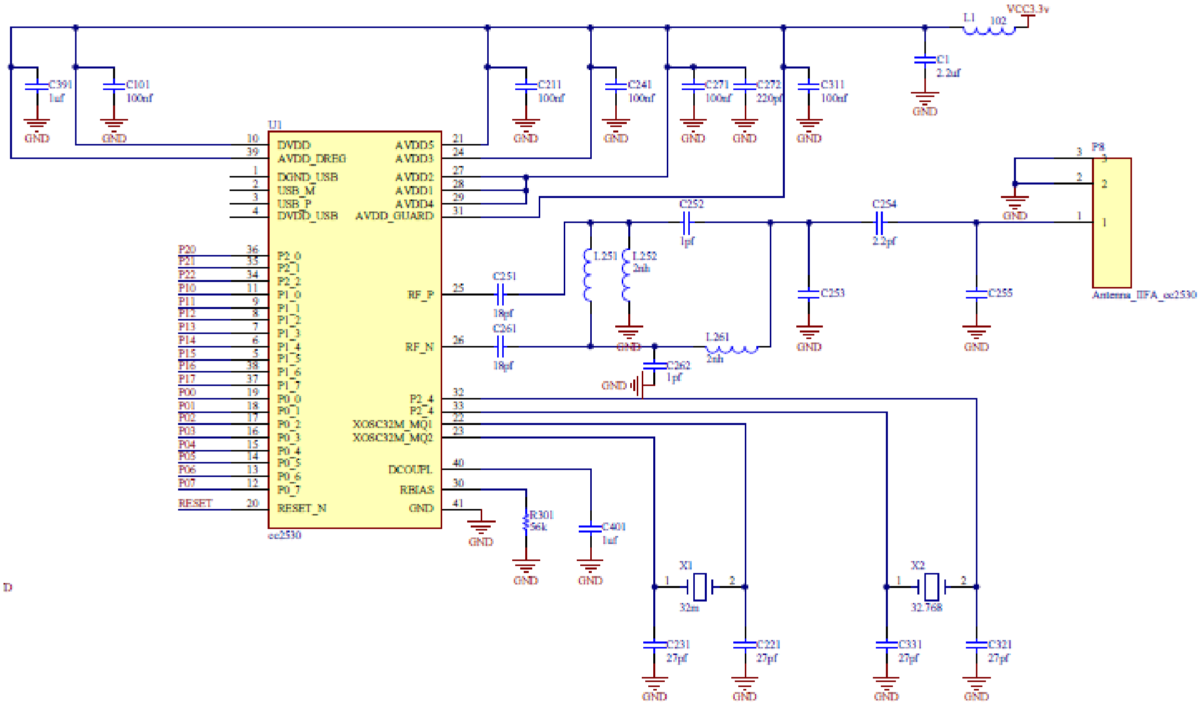


Fig. 6 (b). Main peripheral circuits of central node.

The commonly used antennas of wireless sensor network node include dipole antenna, PIFA antenna and integrated ceramic antenna. They have omnidirectional radiation pattern, simple structure, low production cost etc., and it is particularly suitable for use in the sensor nodes. After the analysis of the three types of antennas, based on cost and two important indicators of the signal attenuation, we conclude that a PIFA antenna may be the best choice, which the center frequency can reach 2.4 GHz.

6. Experimental Results in the Grain

To illustrate the advantage compared the traditional way, when the design of wireless granary monitoring system is completed, it is necessary to verify its performance in real granary. The overall layout of the testing granary is shown in Fig. 7.

The gateway (G) was connected with two antennas (one is 4.2 dBi monopole antenna and the other is 8 dBi omni-directional antenna), and the first one is placed on a wall 6 m high. As to guarantee line-of-sight between the gateway and the offices, the 8 dBi omni-directional antenna was placed on the office roof 9 m high. Wireless communication between the Base Station (BS) and the rooftop antenna was achieved by means of repeater.

These nodes were installed in the first week of December and we began to gather experimental data. During this time the cumulative rainfall was 40 mm, moderately strong winds of up to 60 km/h and low temperatures (4 °C in average).

As we know, before this technology was introduced, the workers monitored their grains in the traditional way, which wasted a lot of time and time. But now, with the technology that has been developed, grain variables can be ascertained in real time. Fig. 8 shows that this system could monitor the granary in real time that the optimum conditions for the grain storage were preserved (temperature between 10-28 °C, and relative humidity in the range 30 % - 80 %), and can use the stored information for future analysis and statistics purpose.

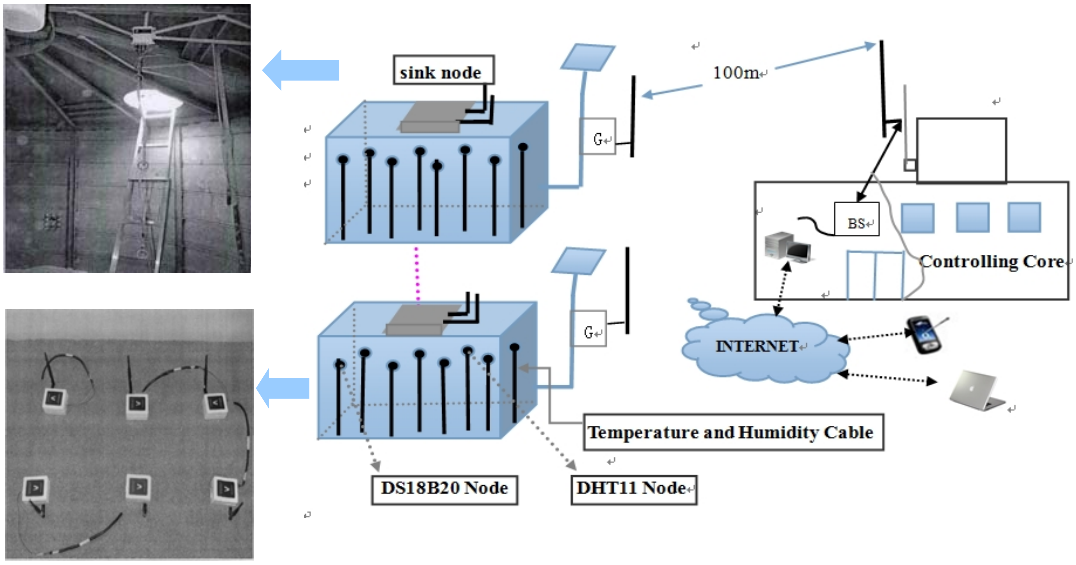


Fig. 7. The overall layout of actual testing granary.

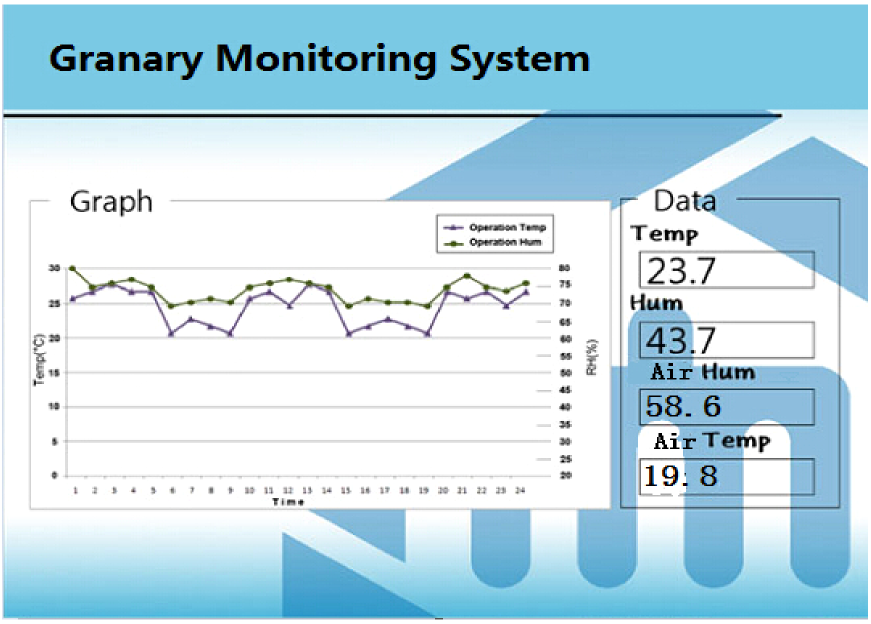


Fig. 8. The real-time monitoring system.

7. Conclusion

An innovative system which can achieve temperature and humidity monitoring and alarming is proposed. Meanwhile, we can deal with energy consumption problems effectively, and the scheme of solar battery board is proposed in order to produce a kind of clean and renewable energy. Then we introduce that gateway is one of the most important parts to connect wireless sensor network with internet. Experimental results of actual granary show that the proposed method not only overcome the lack of traditional wire network, but also can monitor the granary efficiently, conveniently and accurately. So we can believe that it is essential to research grain storage based on wireless sensor network.

Acknowledgements

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