On the Design of High Precision Factory Temperature Control System Based on Wireless Sensor

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Abstract—Based on the investigation and analysis of the current status of pharmaceutical cold chain at home and abroad, this paper comes up with a solution for pharmaceutical cold chain temperature monitoring, develops an intelligent temperature recorder based on wireless sensor network technology, and makes a detailed introduction to the software and hardware implementation of the wireless sensor nodes of the recorder and the monitoring terminal. Besides, the author tests the performance of the recorder multiple times. The results show that the design basically fulfils the expected goals.

Keywords—wireless sensor, temperature detection, temperature control system, network node

1 Introduction

The ambient temperature of temperature-sensitive products has to meet certain requirements all the way from production to transportation. Otherwise, the quality of the products may be affected by the environment [1]. This gives rise to the “cold chain” a low-temperature system tool. The cold storage temperature varies from product to product [2]. For some rare pharmaceuticals, the temperature should be lower than -86°C, far below that for fresh agricultural products. In China, many high-grade biological agents are imported from foreign countries. If the cold chain does not support cold storage, the agents are very likely to degenerate, which causes great threats to the life safety of patients [3-4]. For example, in 2010, a vaccine “exposure accident” broke out in Shanxi Province. Caused by poorly controlled cold storage temperature, the accident killed or disabled several children. Therefore, it is very necessary to guarantee the quality of drugs by setting up a reliable pharmaceutical cold chain. This has become a research hotspot in recent years [5].

Precise monitoring and pre-warning of the cold chain involves complex factors and faces immense difficulties [6]. Thanks to the rapid development of microelectronics communication technology, the cold chain temperature monitoring can now be realized by wireless remote technology [7-8]. The new technology has contributed to the development of cold chain temperature monitoring. Relatively speaking, pharmaceutical cold chain is a newly emerging industry in China. The chain is often “broken” due to the lack of regulatory system, backward technical equipment and the low level of management [9]. Related statistical studies have also found that temperature monitoring equipment has not been applied to most of cold chain transports in China. Traditionally, the cold chain temperature is mainly monitored manually. The manual approach is low in efficiency and prone to human errors. With the rapid expansion of China's pharmaceutical consumer market, the pharmaceutical industry has an increasingly great demand of pharmaceutical cold chains. As a result, it is of great necessity to improve the existing monitoring system, and establish an automated cold chain temperature monitoring system [10].

In view of the above analysis, this paper explores the features and defects of the existing pharmaceutical cold chain monitoring systems, and develops a set of wireless intelligent temperature recorder in consideration of the temperature monitoring requirements [11]. The operation of the instrument depends on the wireless sensor network (WSN), which is extensively used in military, environmental monitoring, meteorology and warehousing. According to the actual use, the WSN can meet the temperature control requirements of pharmaceutical cold chain, and give full play to the function of the wireless intelligent temperature recorder. Designed for unmanned monitoring, the proposed temperature recorded is capable of effectively monitoring the operation of pharmaceutical cold chain equipment and the temperature within the cold chain [12-14]. Actual application indicates that the proposed temperature recorder plays a positive role in preventing cold chain equipment failures and operational errors, and ensuring the cold storage of vaccines. The specific design and production of the recorder are explained as follows.

2 The overall design plan for the temperature recorder

The structure of the temperature recorder is relatively simple. It mainly consists of several sensor nodes and an intelligent monitoring terminal. Figure 1 illustrates its specific structure. The figure also displays the use of wireless temperature collection nodes in the whole process of the production and transport of the refrigerated drugs. The temperature recorder gathers and processes the temperature signals of the refrigeration and mobile transport equipment, and sends the processed signals to the detection terminal. After processing the received data, the terminal issues a high/low temperature alarm message so that the supervisor can implement control measures based on the message he/she receives.

Often deployed in refrigeration houses and cars, wireless sensor nodes are mainly targeted at collecting and processing temperature signals, and sending the processed signals to the monitoring terminal. The data is sent through the radio frequency mode.

The temperature recorder supports real-time monitoring of the temperature of the cold chain equipment. The function significantly improves the monitoring efficiency, and the quality of the blood and vaccines in storage. It also reduces the operator's labor intensity and the occurrence of man-made operational errors. Therefore, it has a positive application value. Moreover, the recorder can also monitor and record the abnormal information of the cold chain in a highly efficient manner, and transmit the fault signals to the monitoring center, providing the basis for early warning.

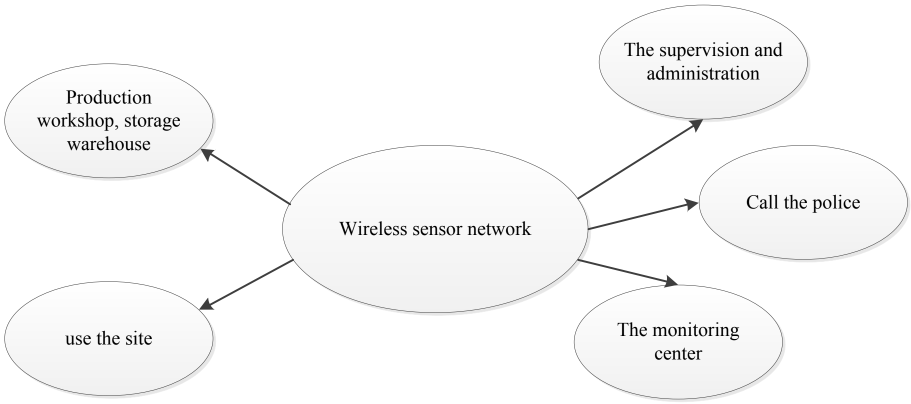

Fig. 1. The overall design of pharmaceutical cold-chain temperature recorder

3 The hardware design of the temperature recorder

3.1 The hardware design of the recorder

As mentioned previously, the structure of the temperature recorder is relatively simple. It mainly consists of several sensor nodes and an intelligent monitoring terminal. The temperature information collected by the sensor nodes are displayed on a LCD interface (Figure 2).

Each of the wireless temperature nodes is further divided into four parts: communication, power supply, sensor and control unit. The communication unit mainly sends the information gathered by the acquisition module to the monitoring unit, the sensor is used to collect the temperature signals in the monitoring area, while the control module controls and manages the workflow of the whole node. The power supply has two parallel alkaline batteries. With a very compact hardware composition, the recorder achieves the requirements of miniaturization, low power consumption, and high efficiency.

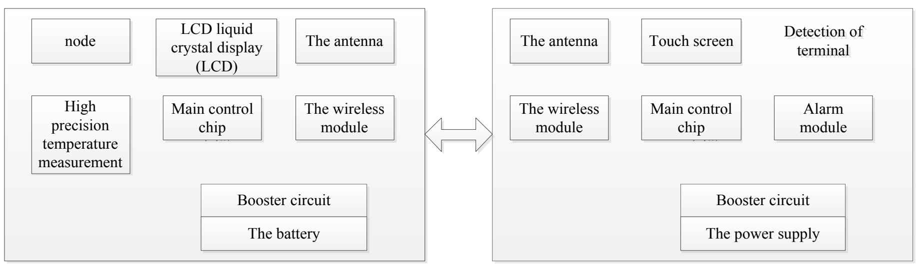

Fig. 2. The hardware design of the recorder

3.2 Device selection

Temperature sensor: There are many types of temperature sensors. The common ones are the diode type, thermocouple type, and resistance type. Platinum resistance temperature sensor boasts high temperature measurement accuracy, high stability, and wide measurement range. Currently, it is known as a typical high performance temperature sensor. However, it is applied to a very limited area, mainly precision-demanding temperature measurement, because of its high cost and low response. To meet the precision requirements for temperature measurement in this paper, the author selects the platinum resistance temperature sensor Pt100, which has high stability and measurement precision.

Communication module: The type of this module has a significant influence on the stability and reliability of the wireless network. This paper chooses to use the JTT-4432 wireless transceiver module, which is very small and easily embedded in the integrated circuit board. The module uses a standard 1.27DIP interface, which operates at the voltage of 1.8V- and consumes low power. There are many operating modes that can be selected as needed. In the standby mode, the operating current is 15mA, while in the transmission mode, the operating current is 30mA. With a sensitivity of -118dBm, it supports one-to-many communication, and realizes the programming function of all registers with "burst" data transmission. The communication module satisfies the working requirements of the temperature sensor as it employs high precision peripheral components, can work in a very complex environment, and features low power consumption.

3.3 Touch screen

In this paper, SK070AE is selected as the touch screen. Mainly used for human-computer interaction, the touch screen integrates a number of units, including the display unit, memory unit, input and output unit, control unit, etc. The performance of the touch screen is illustrated in Table 1.

Samkoon SK has a high compatibility with various communication interfaces. Besides, it is connectable to most of the current PLC communication equipment, and in support of the MODBUS protocol. Thus, it can easily exchange data with SCM. One can configure the drive settings and achieve some control requirements with the configuration software.

Table 1. Introduction to the performance of SK070AE touch screen

Touch screen type	**High precision resistance touch screen**
The resolution	800×480
color	262,144
Power supply	DC24V
User memory	12M
Communication interface	Two COM port(RS232/RS422/Rs485)
Configuration software	SKWorkshop4.0.0

3.4 Alarm unit

Embedded with a communication interface, the wireless communication GSM module TC35 can transmit data with personal computers and MCU. It is highly efficient in data transmission and voice communication. TC35 supports multi-band operation and consumes very small current and total power in the standby mode. The user can send data with the AT commands. According to the design plan, the alarm unit is mainly used to send alarm messages. The commands used to send alarm information are displayed in details in Table 2.

Table 2. AT commands

Function	Instruction
Online	AT enter
Set up a short message center	AT+CSCA="XXX"
Accept the short message	AT+CMGR=X enter
Delete the short message	AT+CMGD=X enter
Send a short message	AT+CMGS="XXX"

4 The software design of the temperature recorder

4.1 The software design of the nodes

The software composition of each node is rather complex. There are parts like the main program, display and temperature acquisition subprogram, radio frequency subprogram, etc. During the operation, the master node initializes JTT4432 and sets the signal acquisition frequency; then, it starts to collect temperature signals, preprocesses the data at the same time, and displays the results on the interface. The monitoring terminal sends the signals to the control terminal. Figure 3 depicts the workflow of the main program.

4.2 RF transceiver subprogram

The subprogram configures the JTT4432 module via the 4-wire SPI-compatible interface. In this case, the module is in a passive state. Before starting the RF transceiver subprogram, one has to initialize SPI, RF, etc. and sets the register. When the RF module starts sending data, it writes the data to the send buffer and then sends it automatically. After receiving data via RF, the subprogram generates an interruption signal to notify MCU or reads the received data.

In a single reception and transmission, the data frame is only 8 bytes. See Table 3 for the format of the data frame. Specifically, the first two bytes are respectively the data head and the command code, and the last byte is the end-of-string identifier 0xaa. As for the sent data frame, the meaning of the first two bytes remain the same, while the third byte is different from that of the received data frame.

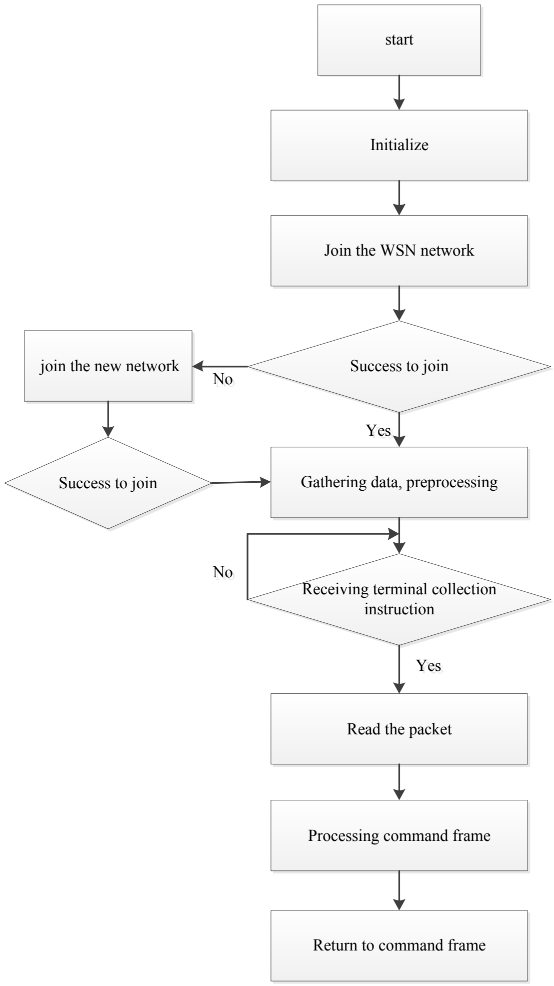

Fig. 3. The software flowchart of wireless sensor node

Table 3a. The format of the data format sent by RF

Data head	Command code	Node address	……	End-of-string identifier
0xaa	0xxx	addr	0000	0xbb

Table 3b. The format of the data format received by RF

Data head	Command code	Data	Node address
0xaa	0xxx	PlayloadData	addr

Each reading and writing via SPI contains 16 bits: 1 bit for the select bit, 7 bits for the address and 8 bits for the data. The R/W select bit is used to identify the reading and writing operations. 1 stands for reading, and 0 stands for writing.

4.3 The software design of the terminal

The terminal software mainly consists of the main program, the RF transceiver subprogram, the touch screen communication subprogram and others. Under terminal control, the master and slave control mode is selected and the data is transmitted via the MODBUS protocol. The touch screen triggers the SCM for a certain period of time, sends the acquisition command to the acquisition unit, and stores the received data in the set address for data processing. In the meantime, it analyzes the data returned from the nodes. In the case of failure, the touch screen serves as a protection and sends the alarm information to the monitoring center. See Figure 4 for the specific workflow of the terminal.

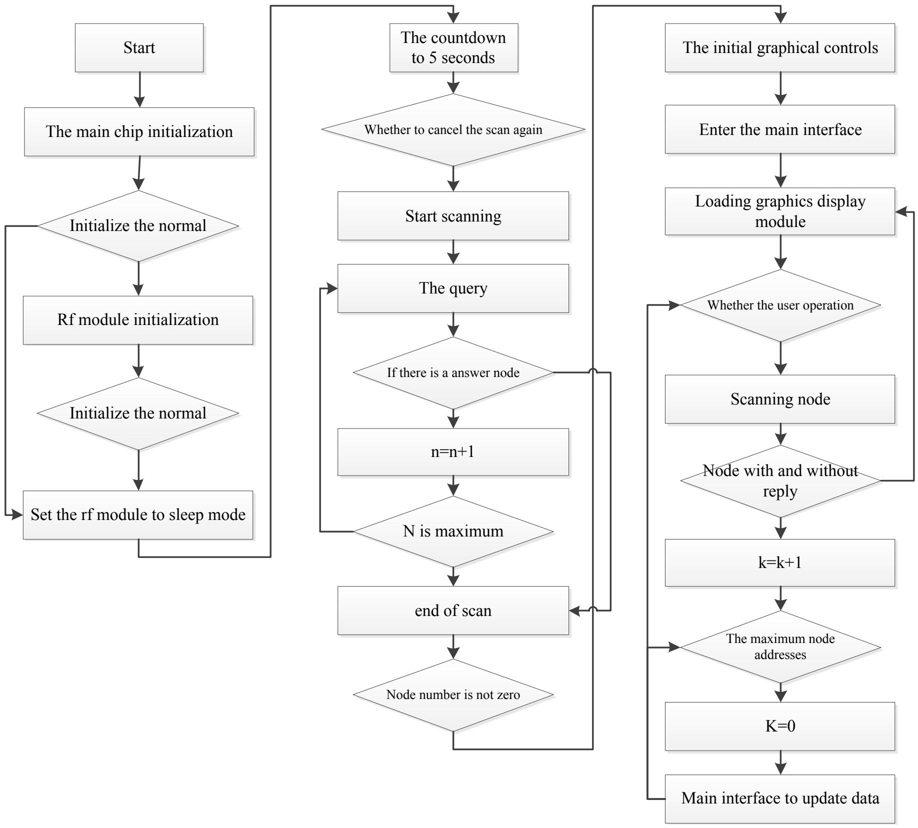

Fig. 4. The flowchart of the terminal program

4.4 SD card drive subprogram

The SD card is mainly used for data reading and writing. The operation is generally realized through the SPI mode, which is relatively easy to achieve. The reading and writing process of the SD card is explained as follows. After power on, initialize the

SD card, adjust the signal transmission frequency to a higher level, and send a certain number of clock signals, and write the command at the same time. In this way, the SD card is put into the SPI mode.

Then, read the information on the identification code of the SD card by the card reading sub-function. The card has a unique identification code.

To read and write on the SD card, it is also necessary to read and write the sectors. The sectors of the card contain 215 bytes. Each reading and writing handles 512 bytes simultaneously.

5 Complete debugging and performance analysis

5.1 Barrier-free communication test

Appropriate test environment should be chosen to ensure the accuracy of the results. Normally, the test is carried out in an open space outdoors. The tester should select a certain number of nodes, which have the same straight-line distance from the terminal, and carries out the test at the straight-line distance of 20m, 40m, 60m, 80m, 100m, 120m, 150m, and 200m. The nodes at each distance should be set into a group. Each group of nodes should be tested continuously for 3h and measured three times. The measured results should be averaged and the loss of data packets should be summed up. Table 4 displays the final results.

Table 4. The data loss rate of the barrier-free communication test

	Node	**Node**	**Node**	**Node**	**Node**	**Average**
20m	100%	100%	100%	100%	100%	100%
40 m	100%	100%	100%	100%	100%	100%
60 m	100%	100%	100%	100%	100%	100%
80 m	100%	100%	100%	100%	100%	100%
100 m	100%	100%	100%	100%	100%	100%
120 m	100%	98.3%	99.8%	99.7%	99.5%	99.7%
150 m	99.2%	98.4%	99.4%	98.7%	98.4%	98.5%
200 m	95.4%	96.8%	98.4%	98.6%	96.5%	96.6%

5.2 Barrier communication test

After that, the tester should conduct an indoor test. The conditions should remain the same except for a wall built in the middle. See Table 5 for the data loss rate.

It is manifested by the above test results that the proposed intelligent temperature recording device has achieved the requirements on automatic temperature recording, and is capable of meeting the requirements on stability, high precision, alarm, and query of monitoring history in the monitoring of pharmaceutical cold chain monitoring. The temperature recorder supports efficient temperature monitoring of cold chain equipment, which lays a solid foundation for the quality assurance of the refrigerated blood and vaccines. The recorder can also be used to verify the performance of cold chain storage and transportation. Besides, it is capable of improving the cold chain temperature monitoring efficiency, satisfying the requirements on temperature control accuracy, and reducing the labor intensity. According to the actual use, the recorder can positively prevent the errors in manual operation. Featuring all-weather monitoring and recording faults and abnormal information of the cold chain, the proposed temperature recorder has a great significance for the realization of the online monitoring function of the cold chain and the improvement of monitoring efficiency of pharmaceutical storage and transport. Coupled with high monitoring stability, the proposed recorder has very broad application prospects.

Table 5. The data loss rate of the barrier communication test

	Node	Node	Node	Node	Node	Average
20m	100%	100%	100%	100%	100%	100%
40 m	100%	100%	100%	100%	100%	100%
60 m	99.3%	99.6%	96.3%	99.5%	95.6%	99.6%
80 m	99.4%	95.8%	99.8%	99.6%	95.1%	95.4%
100 m	98.6%	99.1%	98.7%	95.4%	94.5%	98.2%
120 m	98.9%	99.6%	97.9%	94.6%	98.6%	95.6%
150 m	94.6%	99.4%	98.2%	96.8%	98.2%	98.2%
200 m	98.4%	99.8%	98.4%	98.8%	95.3%	99.7%

6 Conclusion

This paper studies and designs a set of intelligent temperature recorder. The author reviews the current status of pharmaceutical cold chains at home and aboard, offers a solution for temperature monitoring of pharmaceutical cold chains in reference to the relevant literature, and designs a temperature recorder applicable to cold chain transport. It consists of such two parts as wireless sensor nodes and the monitoring terminal. The author makes specific designs for the hardware and software of the two components, and tests the performance of the recorder in two test environments. The results show that the design basically realizes the expected goals. This paper mainly deals with the following:

1. Make a brief discussion on the current status of pharmaceutical cold chain temperature monitoring at home and aboard, and present a new design plan for pharmaceutical cold chain monitoring on the basis of relevant research results.
2. Give a detailed introduction to the wireless sensor network equipment, and select the appropriate network communication hardware.
3. According to the relevant performance requirements, select the circuit devices in the equipment, and design the main circuit, including the monitoring circuit, alarm circuit, RF circuit and control circuit. Finally, install the relevant electronic devices according to the circuit diagram.

4. Encapsulate the nodes and the terminal, make the specific design of the software flowchart, and prepare the programs so that each module can achieve its function.
5. Carry out the man-machine interface design, realize the data transmission between the touch screen and the SCM through programming, and display graphics via the man-machine interface.
6. Test the performance of the temperature recorder after completing the design. Verify the communication performance under different environmental conditions, analyze the test results, and draw the conclusions.

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