A Distributed Infrared Temperature Monitoring System Based on Embedded Technology and Visualization Technology

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Abstract

For the contradictory issues of the transmission rate and flexibility in the current temperature system, this paper puts forward a novel fast rate, high flexibility, and visualization monitor system, and presents its architecture principle design and software-hardware of the whole system. Controller area network (CAN) bus acting as multi-host and high-speed field bus is selected to design the distributed communication system, ZigBee technology based on CC2530 and embedded system centered with ARM Cortex-M3 microprocessor STM32F103VET6 are selected to design the flexible data acquisition network, and embedded Ethernet is select to design remote and distributed monitoring. Based on the distributed system, visual monitoring software is developed; it can achieve data display, data query, and real-time monitoring and give an early alarming of accidents caused by temperature. After a number of experiments show that the system is stable, temperature flexible, highly real-time, and the temperature measurement accuracy can be up to 99.37%.

Keywords: temperature monitoring system; distributed; visualization technology; controller area network (CAN); ZigBee; embedded Ethernet

1. Introduction

With the complex of factory electrical equipment, the operational efficiency of equipment will affect the entire workshop operations. When electrical equipment is in an abnormal state, the device will heat and damage or even cause a fire [1-3], so the temperature is an important parameter [4-5] of normal operation. So a large number of temperature measurement technology appear [5-6], which are divided into contact temperature [7] and non-contact temperature [6] according to temperature measurement methods. The contact temperature measurement obtain the device temperature by temperature sensor full accessing to the device, however, this temperature measurement methods may affect the normal operation of equipment, and the temperature is not flexible, dangerous. The non-contact temperature measurement uses principle of thermal radiation to obtain the device temperature without contact with the measured object, and does not interfere with the normal operation of device under testing, such as some of the infrared thermometer, radiation thermometer, but these methods need to patrol inspection personnel to operate the device to obtain the temperature, there are some limitations on flexibility. According to the communication, these technology are mainly divided into wireless and wired thermometer temperature measurement technology, wireless temperature measurement are primarily used in some sensor networks, installation flexibility, low power consumption, but the small amount of data transmission, the transmission distance is short, vulnerable areas restrictions [8]; wired temperature measurement system is the application some of the field bus, they have high transmission

rate, far transmission distance, high real-time, but poor installation flexibility, high power consumption, limited measurement range of nodes [9].

For the shortcomings of traditional measurement system, the paper design a distributed infrared temperature monitoring system based on embedded and visualization technologies, The system has the following characteristics: (1) using microprocessor equipped with non-contact infrared temperature sensors to get the device temperature, eliminate errors caused by personnel operation; (2) using ZigBee technology and controller area network (CAN) bus technology to achieve multi-zone temperature collection, distributed temperature measurement; (3) building Ethernet server in the data concentrator for distributed temperature monitoring and remote monitoring; (4) developing visualization software for system operation and real-time monitoring, to achieve "centralized monitoring, decentralized control". Finally the system is assessed and measured according to the national standard of alarm and control system for electric fire prevention (GB14287) series of country (China) issued [10], the test results show that the system is has a good advantage in the measurement accuracy and response speed.

The remainder of this paper is organized as follows. Section 2 shows the Structure and principle of the whole system. Section 3 and Section 4 present hardware design and software design of the distributed monitoring system. Finally a test is given to test the performance of the system in Section 5 and conclusions are present in Section 6.

2. Structure and Principle of the System

The system consists of monitoring hosts, CAN bus concentrator and many field data collection networks. Data collection networks consists of a CAN bus stations, a coordinator node and many router nodes. The system structure is shown in Figure 1.
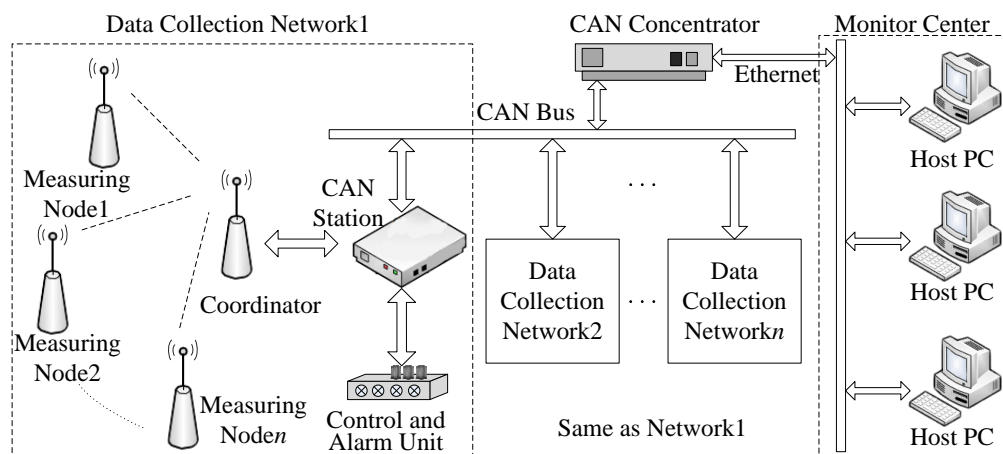

Figure 1. Structure of the System

ZigBee network is responsible for collecting temperature data and transmitting data to CAN station, and then the data is uploaded to the CAN concentrator through CAN bus, during which the CAN station can give an early alarming when needed. CAN concentrator is responsible for communication between CAN bus and monitoring center, it can upload the data to host PC when a connection is built between them through Ethernet, then visualization software running on host PC can monitor every data collection network, display its history curves and real-time control the equipment on the spot.

3. Hardware Design of the System

Hardware design is adopted modular structure, mainly includes filed data collection network design and CAN concentrator design.

3.1. CAN Communication and ZigBee Technology

CAN bus is a kind of serial communication network which effectively supporting the distributed real-time control, it has simple structure, high reliability and strong anti-jamming ability, the direct transmission rate is up to 10km/5kbps, and the number of devices can be connected reaches 110 [11]. As ST's high performance microcontroller, STM32F103VET6 has ARM Cortex-M3 kernel, its highest working frequency is 72MHz and also contains advanced communication interfaces [12]. Taking STMicroelectronics STM32F103VET6 as the centre microcontrollers CAN station and CAN concentrator are designed, which access CAN bus through CAN controller in STM32F103VET6 microcontrollers and SN65HVD230D as the transceiver.

In the aspect of wired data collection, wiring is difficulty and high cost as a result of the equipment and places, and the number of supporting nodes is small, it cannot meet the requirements of this system. So ZigBee wireless network is adopted in data collection. ZigBee is a new kind of wireless transmission network. It not only has the low cost, low power loss and low complexity [6], but also has high reliability, self-recovery, and flexibility in architecture etc.

3.2. Hardware Design of Filed Data Collection Network

Field data collection network consists of ZigBee network, CAN station and some control units. In the field data collection network CC2530 [13] is taken as ZigBee controller chip, the module of ZigBee network consists of a coordinator and some router nodes, every node is an independent processing center. The router nodes in the network are responsible for temperature measuring, and it consists of TN901 Infrared temperature sensor and CC2530 microcontroller chip. The coordinator node is responsible for collecting data coming from router nodes and communicating with CAN station through serial port, in which way data can be uploaded to CAN bus concentrator though CAN bus. CAN station consists of STM32 microcontroller, instruction module and SN65HVD230 CAN transceiver module. Control unit provides some interface for device if it is need to take some action on temperature. Hardware structure is shown in Figure 2.
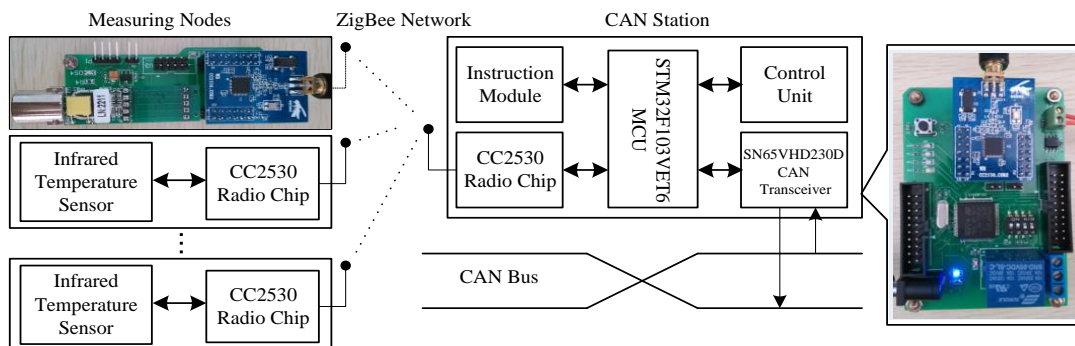

Figure 2. Hardware Structure of the Filed Data Collection Network

3.3. Embedded Ethernet Technology

Embedded Ethernet make it convenient to an embedded device for remote control and large amounts of data transmission. Microchip's ENC28J60 chip is a stand-alone Ethernet controller with an industry standard serial peripheral interface (SPI). It is designed to serve as an Ethernet network interface for any controller equipped with SPI. The

ENC28J60 meets all of the IEEE 802.3 specifications [14, 15]. It incorporates a number of packet filtering schemes to limit incoming packets. It also provides an internal DMA module for fast data throughput and hardware assisted checksum calculation, which is used in various network protocols. Communication with the host controller is implemented via an interrupt pin and the SPI, with clock rates up to 10MHz. Two dedicated pins are used for LED link and network activity indication. Any host PC in Ethernet network can connect with ENC28J60 and communicate with embedded device easily.

3.4. Hardware Design of CAN Concentrator

As the bridge between the monitoring network and CAN bus, the CAN concentrator has Ethernet interface and CAN bus interface at the same time. As mentioned above taking STM32F103VET6 as control centre, CAN concentrator access CAN bus through SN65HVD230D. STM32F103VET6 has high speed SPI and can access Ethernet through ENC28J60 [15, 16]. Hardware structure is shown in Figure 3 and the hardware layout is shown in Figure 4. Instruction module is used to indicate system state in which led blink is used, and SD Card module is used to save data collected from field distributed system, the interface is a high-speed and high-security secure digital input and output card (SDIO) interface.
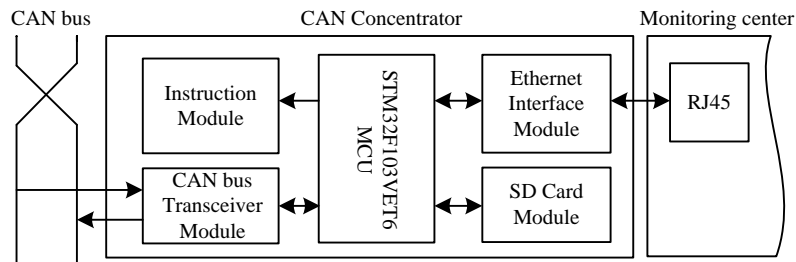

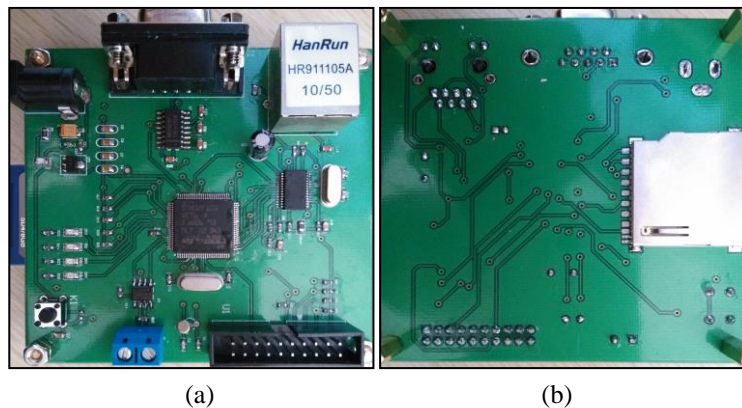**Figure 3. Hardware Structure of CAN Concentrator**

(a)   (b)

Figure 4. Hardware Layout of CAN Concentrator: (a) Front, (b) Back

4. Software Design of the System

The software system architecture comprises three parts: the ZigBee node software, STM32F103VET6 microcontroller software, and host PC monitoring software.

4.1. Software Design of the ZigBee Node

ZigBee software development is base on TI's ZigBee protocol stack (ZStack) [13, 16], and it consists of coordinator software and measuring nodes software. ZigBee coordinator is responsible to establish a network [17]. After coordinator node power-on; initializing of

ZigBee stack and hardware peripherals first; then PAN network creating [17]; after PANID setting, waiting for the adding up the router nodes; finally, receiving data from the router nodes. So ZigBee coordinator is in a sleep state until interrupted by coming data from measuring nodes and sends the data to CAN station through serial port. PANID is different from that in different data collection network. Software flow chart is shown in Figure 5.
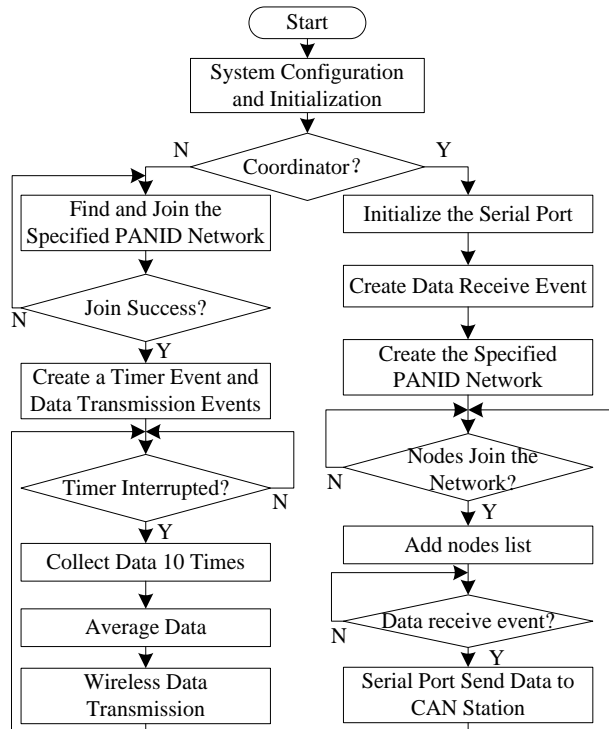

Figure 5. The Flow Chart of ZStack Software

The measuring nodes need power-on after PAN network is created, after which initializing of ZigBee stack and hardware peripherals; creating a timer event and a data transmission event; then finally this measuring nodes will automatically added to the specified PAN network. Same as coordinator node the measuring node is in sleeping state until interrupted by the timer, then it will drive infrared temperature sensor for temperature data collection 10 times, after which it calculating the average of these data after removing the maximum and minimum values and send data to coordinator node. Software flow chart is shown in Figure 5. Every measuring node has the only PanId and NodeId, which is manual definite in ZStack so that it can be located in the distributed system.

4.2. Software Design of STM32F103VET6 Microcontroller

STM32F103VET6 software design includes CAN station software design and CAN concentrator software design, and developed in Keil Integrated Development Environment for ARM (MDK-ARM) development environment, which can use the STM32F103VET6 C language firmware library. CAN station software is based on status programming and interrupt-driven approach, other time the system is in a low power state. The states are shown as Figure 6.
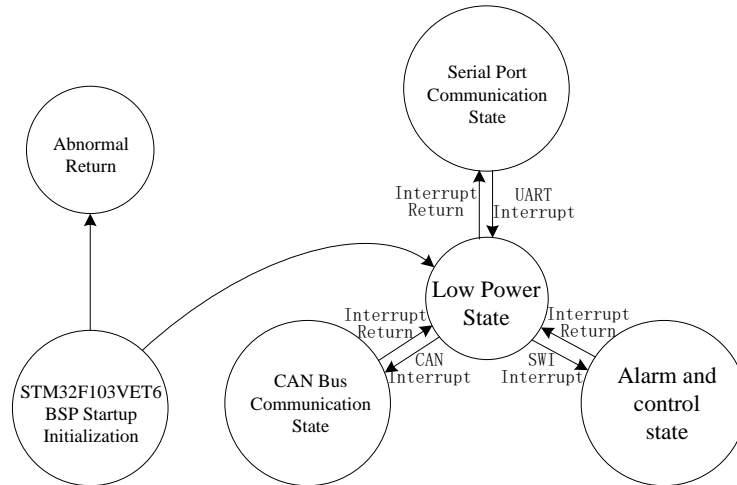
Figure 6. The Software States of CAN Station

The software system architecture of CAN concentrator is shown in Figure 7. It contains an embedded light weight IP (LwIP) [18] stack, an embedded file system, and some drivers such as those for Ethernet [18], CAN, led display and UART interface. A TCP server is established in concentrator system to ensure that monitor host PC can connect the sever and the serve can connect 10 PC at the same time, file system is used to store data from CAN stations, and communicate component uses LwIP stack's API communicate between the Ethernet and the CAN bus. The scheduling procedure is responsible for the management of the whole system.
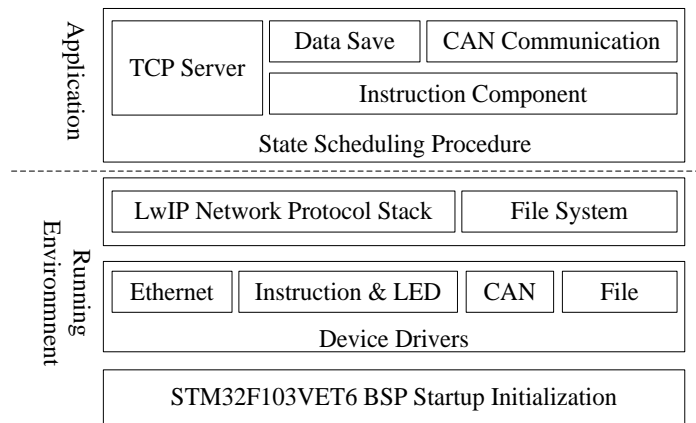

Figure 7. The Software Architecture of CAN Concentrator

4.3. Software Design of PC Monitoring Software

The design of this system interface uses PC installed Windows operation system as developing environment, and mainly use Qt Creator [19] as monitoring interface development tools. The monitor software is adopted modular structure and hierarchical programming, it has a friendly man-machine interface, mainly completes following functions: through long-distance transmission, sets the measuring cycle and cycling times of measuring node; communicates with the CAN concentrator through Ethernet; receives, saves and analyses all data; shows history curves of measuring nodes and device list; real-time monitoring on the specified measuring node; gives alarm when some nodes have unusual temperature change; print reports and curves in the form of files. The

experimental results shows that the monitoring software can play a great role on distributes system monitor. The architecture of monitoring software is shown in Figure 8.
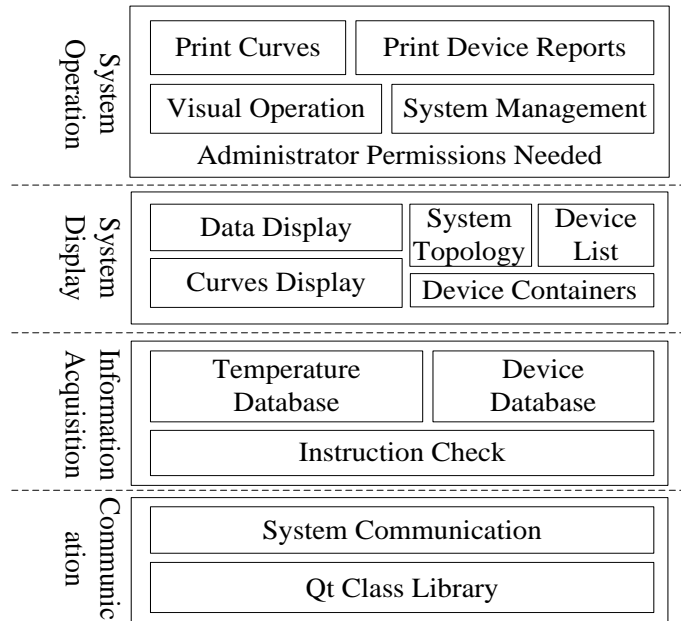

Figure 8. The Software Architecture of Monitoring Software

The application layer is the response and the feedback of the operation of the software, and it can input and output the information of the system, which is a human-computer interaction interface and need administrator permission. Display layer responsible for managing and displaying data. Acquisition layer is responsible for collecting and saving data from communication layer. The communication layer mainly translates the operation of the software into command and communicates which hardware device, and provides the interface for the operation of each layer above. Adopt to its software design the level of structure turn the construction is conducive to the upgrading of the software.

5. Test of System

According to GB14287.3 [10], the paper tests the distributed system designed, which includes accuracy, response speed, network communication and transmission distance. First, connect the hardware of system, including ZigBee, CAN bus, Ethernet; next turn on the power of the system and open the monitoring software; finally connect the PC and CAN concentrator through TCP and test.

(1) Place a measuring node into the temperature control equipment, and make the equipment temperature increase at less than 1 Celsius per minute rate until the monitoring software start alarming, and then record the value on the temperature control equipment. The operation is repeated 20 times and the result is shown as Figure 9 and Table 1. The table show that the accuracy of the infrared temperature system is up to 99.37%, and the error rate 0.63%.
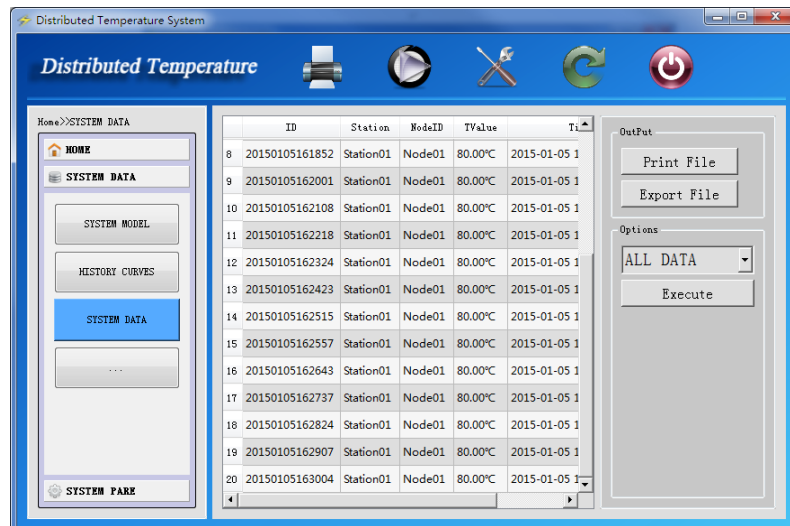
Figure 9. The Date Display of System Test

Table 1. The Data of Temperature Acquisition Accuracy

Times	1	2	3	4	5	6	7	8	9	10
The equipment value/°C	81.5	80.5	81	80	79.5	80	80.5	80.5	81	80.5
The monitor value/°C	80	80	80	80	80	80	80	80	80	80
Times	11	12	13	14	15	16	17	18	19	20
The equipment value/°C	81.5	80.5	80	81.5	80.5	80	81.5	80.5	79	80
The monitor value/°C	80	80	80	80	80	80	80	80	80	80

(2) Adjust the equipment temperature higher 20% than node alarm value, then place the node into the equipment and start timing. Record the time value when the monitoring software start alarming. The operation is repeated 20 times and the result is shown as Table 2. The result shows that the average response time of system is 13.3s.

Table 2. The Response Time of System

Times	1	2	3	4	5	6	7	8	9	10
The equipment value/°C	96.0	97.0	97.0	98.0	97.0	97.0	95.0	96.0	97.0	96.0
Response time/s	13	13	14	13	12	13	14	13	14	13
Times	11	12	13	14	15	16	17	18	19	20
The equipment value/°C	95.0	96.0	96.0	97.0	97.0	96.0	97.0	97.0	97.0	96.0
Response time/s	15	14	13	13	14	13	12	14	13	13

(3) Add 11 measuring nodes into network and adjust the temperature value lower than alarm value, the monitoring software is in monitor state. The running result of system is that there is no the phenomenon of false positives and false negatives. The stations can be display on the monitor software as shown in Figure 10.
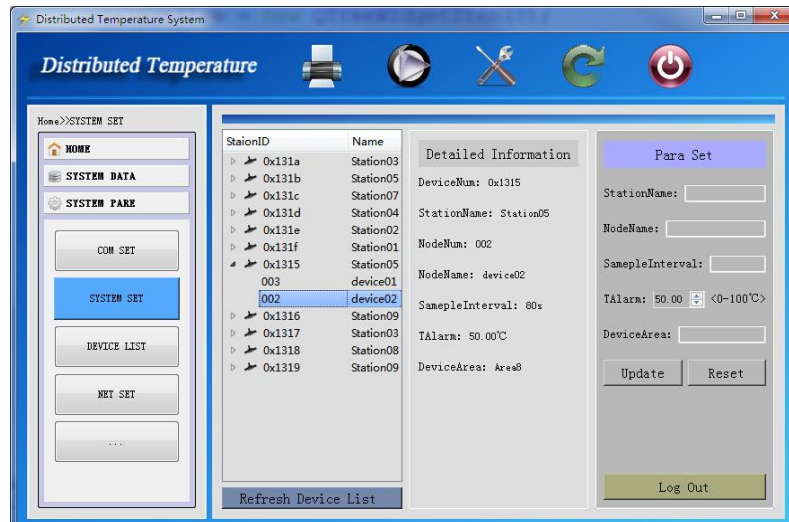
Figure 10. Device List of System Test

At last the paper proceeds performance test wireless network and CAN bus. In a laboratory environment, CAN bus distance is 300 m, and the system is stable running, and there is no package loss and leak during test. The system can correctly recognize a CAN station join the CAN bus or dropout, no unusual incidents.

6. Conclusion

In this paper, the use of embedded technology and visualization techniques for system design, improving temperature flexibility but also greatly improves the transmission rate of the system. Highly integrated system of hardware, simplifying system architecture, but also greatly avoid the interference of the outside of the system, to improve the stability of the system. In addition, in the realization of distributed temperature measurement system also can realize remote control and distributed control. Visualization software with powerful functions, achieves a variety of functions of temperature monitoring, and is easy to operate and manage. Following the above experiments shows that: the system's high accuracy, fast response, high stability of the system; applied to unmanned factories, the system can effectively avoid the occurrence of accident, and in the modern intelligent engineering it will play an active role.

Acknowledgements

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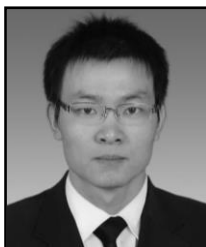
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