Construction Site Environment Temperature Monitoring System Based on ZigBee and Virtual Instrument

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Abstract—Temperature is one of the important factors that ensure the quality and safety of construction. According to the characteristics of construction site environment, an automatic multi-channel real-time monitoring system of construction site environment temperature is developed based on virtual instrument technology. Combined with ZigBee wireless transmission technology, this system can realize remote real-time temperature monitoring for construction site. The system hardware consists of main controller, gateway, wireless sensor nodes and thermocouple temperature sensors. The temperature information is collected by thermocouples. Through wireless sensor network nodes, the data is sent to main controller terminal via gateway. LabVIEW graphical programming language is used for program design. The function of real-time remote temperature information data display, data analysis, limiting value alarm, trend monitoring and data storage for multiple objects simultaneously is realized in this system. And the developed automatic temperature monitoring system can provide support for the temperature-related management of construction site.

Index Terms—construction management; automatic real-time monitoring; ZigBee; virtual instrument; temperature sensor

I. INTRODUCTION

With the gradual expansion of the construction scale of China, a large number of resources are invested into construction process, such as labor, materials, equipments, tools, etc. Construction process has become increasingly complex and dynamic. Efficient resource management of construction site plays an important role in successful project management. Real-time monitoring of critical construction resources can make the project management benefit from the whole construction process. Temperature, humidity, light and other indicators of job site are important factors to guarantee the construction quality and safety, and effective monitoring of these factors is essential to construction management. In the process of construction management, a lot of works are influenced by construction site environment temperature seriously, such as mass concrete construction, winter construction, safety management of the dangerous materials on construction site, etc. Thus, timely acquiring the construction site environment temperature information is very important to construction quality and safety by means of taking effective temperature control measures. The traditional monitoring methods are based on manual data measurement, reporting, analysis and archiving. Previous observations on construction sites indicate that, on average, 30–50% of work time of field manager is spent on site data recording and analyzing [1]. And 2% of construction work is categorized as manual tracking and controlling [2]. This monitoring method leads to high staff work strength, low efficiency, high resources consuming, high cost and low measurement accuracy, which does not substantially play a role in real-time transmission of data and feedback control and cannot satisfy the requirement of modern construction management.

The real-time information acquisition of construction site is the basic premise of dynamic construction management. The lack of on-site real-time information can directly reduce the manager’s ability to find or deal with the variability and uncertainty of construction project [3]. During the construction process, the average duration of the activity is calculated in days, but the periodic reports that allow the project manager to know the detailed information of project progress are usually reported weekly or even monthly. This is not conducive to the project manager to make effective decisions for construction management in real time.

The realization of construction automation needs the support of advanced science and technology. In recent years, the emergence of advanced computer and network technology provides potential for automated monitoring on construction site. Currently, some automatic monitoring technologies have been studied extensively. The unique potentials of these technologies also provide large development space for the automatic monitoring on construction site. Barcode technology [4] can be used for asset management based on label reading recognition;
RFID technology, based on electronic signal detection, can make up the contact limitation of barcode technology and can be used for personnel identification, authorized access and resources tracking for its small size and non-contact recognition [5-7]; GPS technology can be used for positioning of outdoor resources on construction site; Ultrasonic and infrared technologies can be used for indoor positioning and monitoring that GPS does not achieve, but they are also affected by line of sight limitation; Bluetooth [8], Wi-Fi [9], Ultra-Wideband [10, 11] and ZigBee wireless network technologies [12-14] can be used for wireless transmission of information on construction site; video camera [15], laser scanning [16] and other monitoring technologies also can be used for automatic monitoring on construction site with their own characteristics.

The above studies mainly emphasize on construction resources tracking management, but the construction site involves in various resources, versatile environment conditions and a large number of uncertainty factors. At present, few researches about real-time monitoring of temperature, humidity, light, harmful gases and other important environmental factors of construction site have been published. However, these environmental factors play an important role and they need to be monitored timely to facilitate construction management.

For automatic real-time monitoring of environmental factors of construction site, the Zigbee and virtual instrument technologies provide great potential. ZigBee is an emerging global standard of wireless network technology deriving from improvement and expansion of the standard IEEE802.15.4 wireless personal area network [17]. With the characteristic of short-range, low-power, low data rate and high reliability, it is mainly suitable for automatic control and remote monitoring, and it can be embedded into a variety of hardware devices [18, 19]. Based on multi-hop network, ZigBee technology provides devices to communicate with each other in network through routing forwarding function. Also, ZigBee network has large network capacity for it can be extended by means of adding nodes. As the low data rate of ZigBee, the nodes in the network can enter sleep state of low power consumption when they don’t need to communicate with other nodes. Thus, adopting ZigBee technology for construction site environment monitoring not only can meet the requirement of data transmission, but also can achieve good energy saving effect.

Virtual instrument is a modern instrument based on the technology of computer hardware and software [20]. It is generally composed of measurement and control hardware, computer and application software [21]. The function of virtual instrument can be customized according to user’s actual demands and realized through powerful computer software and data processing capabilities. With the basic idea of “software is the instrument”, virtual instrument is flexible and open to be connected to the network and hardware equipment, so it has a broader development space than traditional instruments.

In this research, combining the automatic monitoring technology with construction management together, an automatic multi-channel real-time monitoring system of construction site environment temperature is developed. ZigBee wireless sensor network architecture is adopted and thermocouple is selected as the temperature sensor. Based on virtual instrument technology, LabVIEW graphical programming language is used for program function design. The function of real-time long-distance temperature information display, data analysis, limiting value alarm, trend monitoring and data storage is realized in this system.

II. SYSTEM STRUCTURE AND PRINCIPLE

A. System Architecture Design

It is not easy to implement a wide range of real-time monitoring on construction site using cable transmission as the construction site environmental condition is complicated and distribution span of the monitoring points is large. In light of this, ZigBee-based distributed network architecture is used for construction site environment temperature automatic real-time monitoring system. The system’s architecture is shown in Fig. 1. The system’s architecture is comprised of three layers, i.e., perception layer, network layer and application layer. The perception layer mainly includes a number of temperature sensors and is used for real-time information collection of construction site environment temperature; the network layer consists of wireless sensor nodes and gateway, it is responsible for system network configuration and data transmission; the application layer includes main controller and human-computer interaction program based on virtual instrument, it is used to provide users with operation interface for management and control about temperature-related information of construction site.

The ZigBee-based star type network topology is used for the system. The temperature sensor is connected with the wireless sensor node to measure temperature information in real time. The temperature data is collected by temperature sensor and sent to wireless sensor node. The ZigBee network has distributed processing function and each single wireless sensor node can connect multiple temperature sensors to realize multi-channel data acquisition. Based on ZigBee protocol, the gateway communicates with each wireless sensor node with international standard frequency of 2.4GHz. Through routing function, the wireless sensor network of the system can change the number of sensors conveniently, extend transmission distance and network node capacity and increase the transmission reliability as well. The users apply LabVIEW graphical programming language on the main controller, and realize data acquisition, processing, analysis and other specific functions via program running, can really achieve the purpose of automatic remote monitoring.
B. System Composition

Thermocouple and thermal resistance are two types of temperature sensors most commonly used in industry and lab. The thermocouple has characteristics of simple structure, low cost and easy use. In addition, in view of the complicated environmental characteristics of construction site, compared with the thermal resistance, it’s appropriate to adopt thermocouple because it doesn’t require a peripheral power. Thus, the thermocouples are used as temperature sensors of the system. Thermocouple is a temperature measurer composed of two different conductor materials and can directly contact with the object to measure temperature. The basic principle of measuring temperature using thermocouple bases on thermoelectric effect, that is, when there is a temperature difference between both ends of the metal conductors that form the closed loop, the loop generates electromotive force [22]. Then the thermoelectric potential signal can be converted to the temperature signal, and then the temperature of object can be measured. According to the different metal conductor materials that compose the thermocouple, thermocouples can be divided into several standard types, i.e., S, R, B, J, K, T, N and E. Considering the temperature measurement requirements of construction site and thermocouple’s own characteristics, the thermocouple of type K composed of nickel-chromium and nickel-silicon materials is selected as the system’s temperature sensor for temperature measurement for construction site. The components of thermocouple, gateway and wireless sensor node for the system are shown in Fig. 2.

The NI-WSN platform of National Instruments Company is used for wireless sensor network platform of the system. Two NI-WSN-3212 thermocouple measurement nodes are adopted as system’s wireless sensor nodes, and each sensor node can simultaneously connect with 4 thermocouples. Via connecting the thermocouple’s positive terminal to the TC+ interface of the node and connecting the thermocouple’s negative terminal to the TC- interface of the node, multi-channel data acquisition of eight thermocouples can be realized. In addition, the NI-WSN-3212 thermocouple measurement node has four AA batteries installed internally to provide power supply, so it can be flexibly arranged on construction site. Furthermore, NI-WSN-9791 Ethernet gateway is applied for network configuration and management. The gateway communicates with the NI-WSN-3212 thermocouple measurement nodes with IEEE802.15.4 standard, receives the temperature data measured by thermocouples from the nodes and then sends the data to the main controller. The Windows-based PC is adopted as the main controller and the LabVIEW-based software is installed on the main controller to realize the system functions.
III. REALIZATION OF SYSTEM’S HUMAN-COMPUTER INTERACTION PLATFORM

A. Design of Software Function Module

The LabVIEW graphical programming language developed by National Instruments Company is adopted for software design of human-computer interaction platform of automatic construction site environment temperature monitoring system. The LabVIEW language is a kind of graphical and modular programming language. Different from the programming way of previous text-based programming language which executes programs according to statement sequencing, LabVIEW language regards the data flow programming as the basic idea, adopts the icons similar to the traditional instruments to simulate the traditional instruments for program design [23].

Considering the characteristics of temperature measurement of construction site environment, the system software function module design is put forward. As shown in Fig. 3, the system software function modules mainly include five modules, i.e., data display, real-time monitoring, data analysis, limiting value alarm and data storage.

![Diagram of Software Function Modules](image)

When the main program starts running, the system parameters for temperature measurement can be set firstly, and then the temperature data can be collected. The data display module shows the current values of eight-channel temperature information measured by eight thermocouples, so the user can simultaneously monitor the real-time temperature values of the eight measuring points. The real-time monitoring module provides the real-time temperature graph of the respective measuring points, thus, the user can obtain the history of each measuring point’s temperature data and monitor the temperature change tendency of the respective measuring points. Through the data analysis module, the user can acquire the maximum, minimum and average temperature value of each measuring point in real time for temperature analysis. Via the limiting value alarm module, the upper limit and lower limit of each measuring point can be set up respectively. The system can alert automatically when the real-time temperature exceeding the predefined limit. By the data storage module, the real-time temperature information and analysis data of each measuring point can be stored in the computer, which is convenient for user to query and analyze the temperature data.

B. System Block Diagram Design

Software design by means of LabVIEW graphical programming language includes two parts, i.e., front panel design and block diagram design. The front panel design is to design the human-computer interaction interface for the user’s specific functional requirements.

The block diagram design is to design the corresponding daemon for the function modules. When the user operates the function controls on the front panel, the daemon runs accordingly. The block diagram of automatic monitoring system of construction site environment temperature is shown in Fig. 4. After the configuration of system hardware is finished, the corresponding I/O variables of each monitoring point are set up in the block diagram, and then the real-time temperature data measured by each thermocouple can be collected. The while loop structure is used as the main structure of the program, then the time wait function is set up and the input control for it is set to ensure the user can set the sampling time interval for temperature measurement according to actual requirements and the real-time temperature data can be collected continuously.

Display controls for the eight I/O variables output of the wireless sensor nodes are established respectively in order to show the current temperature value measured by each thermocouple directly. At the same time, the chart display control for each output of temperature data is set to graphically display the real-time temperature data of each monitoring point and provide the temperature change trend of each monitoring point as well.

For the limiting value alarm module, the input controls for the upper limit and lower limit of each monitoring point are set up. Different upper limit and lower limit can be set up according to the actual demand of different monitoring point respectively. Through the relational operator, the system can judge whether the real-time temperature value exceeds the limit or not. Moreover, the display controls of Boolean type for the judgment result of each monitoring point are established. So the system can determine whether to issue the upper limit or lower limit alarm according to the above judgment result. Meanwhile, through adopting the logical operator and shift register, when the real-time temperature value of each monitoring point exceeds its upper limit or lower limit, the system can record the alarm number for each monitoring point and realize the self-plus function of alarm number automatically. In addition, the outputs of upper limit, lower limit and the current temperature value are integrated together via the cluster function, and then the output of cluster function is connected to each chart display control of each monitoring point to ensure each temperature chart can display the real-time temperature curve as well as the upper limit curve and lower limit curve, and the system can dynamically monitor the temperature value whether exceeding the limit or not graphically.
Figure 4. The block diagram of system

For the data analysis module, the temperature data output of each measuring point is connected to mean function and extremal function respectively, and then the display controls for data output of mean function and extremal function are set up. Thence, the maximum, minimum and average temperature value of each measuring point can be displayed in real time.

For the data storage module, the Write to Measurement File VI of Express control in LabVIEW language is used to write the real-time temperature data measured by each thermocouple to LabVIEW data file. The temperature data can be stored in TDMS high-speed data stream file format and the saved file can be numbered automatically according to the system operation order. Meanwhile, the building path function is used to set the path of saved data file the same as the current program file path. Moreover, the TDMS high-speed data stream file format is compatible with the Microsoft Office Excel format. Thus, the saved TDMS file can be imported to Excel file and the real-time temperature data can be queried, analyzed and processed by user conveniently.

C. Realization of System Interface

The task of system interface design is to design the front panel using LabVIEW language. The system interface contains the input controls of the initial parameters and the display controls of the result data output. Due to the need of display and analysis for real-time temperature data measured by eight-channel thermocouples, the interface of automated temperature monitoring system of construction site consists of two parts, i.e., temperature display interface and temperature trend interface.

The temperature display interface is shown in Fig. 5. The interface provides the main parameters needed to be set initially for system running, including the input controls of the sampling time interval, the upper and lower temperature limits of each monitoring point. The interface also provides the acquisition controls, i.e., the acquisition starting, the acquisition suspending and the acquisition exiting.

Moreover, the interface provides the output controls of system time, data file storage path, each monitoring point’s real-time temperature value, the alarm notification and the alarm number. In addition, the thermometer icons are used to display the real-time temperature value of each monitoring point both graphically and digitally. And the warning lights of Boolean type are adopted for alarm notification. The warning light is green when the temperature value is within the normal range. Conversely, when the temperature value exceeds the limit, the warning light turns red and the alarm number accumulates automatically. Furthermore, all the temperature data measured by each thermocouple and temperature data analysis results can be stored in the LabVIEW data file automatically.
simulated obvious temperature variation was adopted in lieu of practical slight temperature difference of present construction site. The 20 time samples were adopted for the experiment to monitor the real-time temperature data of eight monitoring points with the sampling time interval of 10 seconds. The real-time temperature data of eight points monitored by the system is shown in Table I. The experimental results show that the experimental data in Table I is consistent with the real-time temperature data of each monitoring point displayed in the above temperature trend interface of Fig. 6.

In addition, the analysis results of real-time temperature data for eight monitoring point also can be acquired. The maximum value of temperature (°C) of each monitoring point is 36.83, 38.51, 39.59, 39.95, 38.64, 35.19, 39.80 and 39.36 respectively. And the minimum value of temperature (°C) of each monitoring point is 10.02, 10.93, 10.35, 15.09, 10.01, 14.60, 10.91 and 13.05 respectively.

The mean value of temperature (°C) of each monitoring point can be calculated by the system as 24.88, 23.58, 21.60, 27.77, 24.50, 25.55 and 26.93 respectively. During the experiment, the upper limit value (°C) set for each monitoring point is 38, 37, 39, 36, 37, 39 and 36 respectively. In the same way, the lower limit value (°C) set for each monitoring point is 13, 12, 14, 13, 13, 13, 15 and 12 respectively. The alarm counter of each monitoring point calculated by the system is 2, 4, 5, 5, 4, 0, 4 and 3 respectively as shown in Table II. Meanwhile, the time of maximum and minimum temperature value of each monitoring point can be also identified by the system. The maximum value, minimum value, mean value, time of maximum temperature value, time of minimum temperature value and alarm counter data of each monitoring point analyzed by the system in the experiment are shown in Table II.

V. CONCLUSION

Based on the requirement of construction site environment monitoring, this paper puts forward a ZigBee-based wireless sensor network architecture to develop an automatic multi-channel real-time monitoring system of construction site environment temperature based on virtual instrument. The system structure includes three levels, i.e., temperature sensors to sensor nodes, sensor nodes to gateway, gateway to main controller. Eight thermocouples connected with two wireless sensor nodes are selected as the temperature sensors for the system. The LabVIEW graphical programming language is used for block diagram design and human-computer interaction interface design. The function of real-time temperature information data display, data analysis, limiting value alarm, trend monitoring and data storage is realized in this system. And the developed automatic temperature monitoring system can provide support for the temperature-related management of construction site.
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