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Research on the Temperature & Humidity Monitoring System in the Key Areas of the Hospital Based on the Internet of Things

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Abstract

This paper designs an internet of things-based temperature & humidity monitoring system in the key areas of the hospital to address the problem that the temperature and humidity monitoring systems are independent from each other in the hospital. The establishment of a hospital-level temperature and humidity monitoring platform is able to realize the integrated monitoring and management on such areas as ICU, pharmacy and operation room etc, where both of the temperature and humidity must be monitored. In every temperature and humidity acquisition node, the collected environmental data about the indoor humidity and temperature will be sent over the 433M wireless sensor network to the internet of things (IoT) gateway, through which data will be uploaded via wifi or the wired access network within the hospital to the background server, where in addition to data collection and analysis, various reports will be generated and control commands will be transferred. Then all of the medical staffs can make a real-time inquiry and control on the environmental data by connecting their intelligent terminals (such as cell phone) to the server. Actually when the humidistat thermostat controller is designed according to the DDC principle and the integral-separation PID control algorithm, the control on the central air-conditioning units is able to realize the real-time control of constant temperature and humidity. Also a prototype system has been established to conduct the functional verification. The experiment shows that this system is able to run steadily with precise data collection and reliable control.

Keywords*: Internet of things, hospital, temperature and humidity monitoring, integral-separation PID*

1. Introduction

Although hospital is a place with dense population, numerous patients must take the treatment in a comfortable environment. In many cases, indoor temperature and humidity within the hospital has become an important factor to affect the patients during their treatment and rehabilitation, and even sometimes has been considered as a major therapeutic method. Researches reveal that the patients are more likely to get over in the environment with proper temperature and humility. Moreover, the key areas in hospital such as ICU, pharmacy and operation room etc have raised different requirements on indoor air temperature, humidity and cleanliness. In the " Technical Codes for the Construction of a Clean Operation Department in Hospitals", there are definite regulations about the following indexes such as temperature,relative humidity, pressure and air flow in a clean operation room.[1-2]What's more, the storage of hospital drugs also puts forward strict requirements on the ambient temperature and humidity[3].

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The internet of things technology is such a network technology that has been extended and expanded based on the internet technology for the purpose to achieve an internet of everything by extending or expanding the user end to any object or between any object. The internet of things technology can be defined as below: Connect any object to the internet for information exchange and communication according to the given protocol through the following information sensing devices such as RFID, infrared sensor, GPS and the laser scanner to realize intelligent recognition, positioning, tracking, monitoring and management. From the perspective of hierarchical dimensions, the internet of things in essence is a hierarchical network. Currently it's widely recognized that the internet of things architecture consists of the following three layers, including the perception layer, the network layer and the application layer. The perception layer has been established to identify objects and collect information through RFID, camera, sensor and GPS etc. The network layer has been constructed to process and transfer all of the information acquired in the perception layer through the mobile communication system or internet etc. The application layer is able to analyze and process all of the information acquired in the perception layer and the transmission network to make correct control and decision for the intelligent management, application and services[4].

Currently in a hospital, the management on the indoor temperature and humidity in the key areas such as the pharmacy and the operation room that are sensitive to the temperature and humidity requirements has been carried out mainly through the manual record. What's more, since all of the temperature and humidity control systems that are separated from each other are not systematized, it becomes very hard to make a comprehensive monitoring and management on the environment of the key areas at the hospital level. Nowadays the adoption of the PLC control cabinet to control the clean room air conditioning units has been an advanced method used in the humidity and temperature control system in the operation room, where generally online monitoring is not available. On account of this, it has become extremely necessary to adopt the internet of things technology to integrate the monitoring of the hospital temperature and humidity with the control on the clean room air conditioning units to realize the online and intelligent monitoring on the temperature and humidity environment in the key areas of the hospital.

2. Overall Architecture of the Temperature and Humidity System in the Key Areas of the Hospital

This chapter describes the integrated design of the temperature and humidity monitoring system in the key areas of the hospital based on the internet of things technology with the system architecture shown in Figure1 , where the monitoring system is designed to be a three-level hierarchy consists of the perception layer, the network layer and the application layer. The perception layer covers the temperature measurement terminal, the humidity measurement terminal and the integrated temperature and humidity measurement terminal, through which all of the user measuring data can be sent over the 433M wireless sensor network to the gateway of the internet of things, which will thus get access to the hospital intranet to upload the data to the background server after it's connected to the router via wifi. The background server mainly provides the following functions including the user authorization management, the management on the gateway and the devices in the perception layer, data storage and the generation of the analytical statements. Hence if the doctors or the administrative staffs are granted with the authority, they can utilize the terminal devices such as the smart phones to log onto the server to check the real-time information about the relevant regional temperature and humidity as well as the historical statistics. Or even they can design or make real-time control over the running of the air conditioning units in every region through their cell phones.

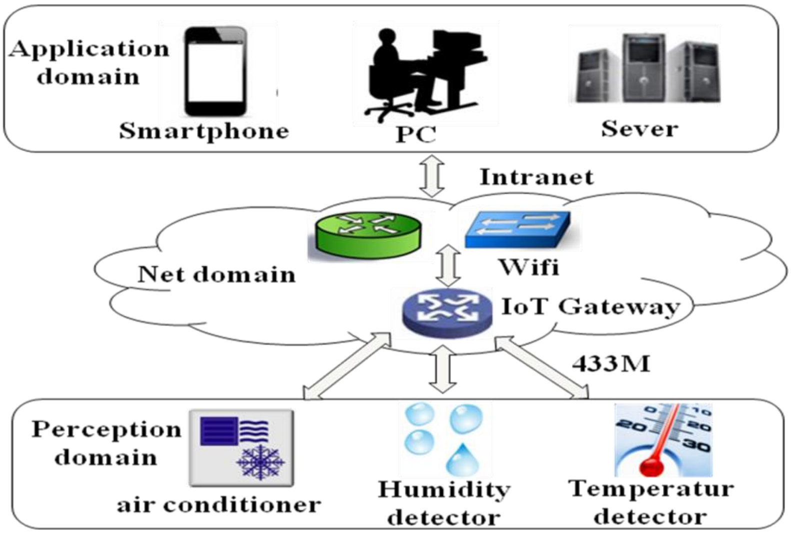

Figure 1. Architecture Diagram of the System

The following wireless communication modes are optional for the devices in the perception layer to get access to the internet of things: Zigbee, Bluetooth, wifi and the 433M wireless communication technology.

In the case that the Bluetooth communication protocol is adopted in the above technologies, it will lead to an unstable connection when simultaneous connection is established between multiple devices due to the limitation of the Bluetooth protocol that requires short distance and fewer devices to be connected [5] . However if node terminals are connected to the internet via wifi, it will also lead to an unstable network when too many online devices are connected to the router. Moreover due to high power consumption, wifi is not suitable to the temperature and humidity monitoring through the devices in the perception layer. As to the Zigbee technology, it has the following advantages such as large network capacity, low power consumption, long transmission distance, low cost, simple architecture and automatic networking etc [6][7]. However since it must be applied in the 2.4G band, the signal shows poor penetrability, which will lead to short transmission distance due to the serious signal attenuation when it’s used in such an indoor environment like hospital. Regarding the 433M wireless communication technology, it enables the devices in the perception layer to work in the 433M frequency band, where signal shows good penetrability and networking can be made flexibly. The comprehensive comparison of the advantages and disadvantages of the above wireless communication modes reveals that the wireless communication between the devices in the perception layer and the gateway can be made via the 433M wireless sensor network.

3. System Design and Implementation

This chapter mainly introduces the design and implementation of the various functional modules in the system including the design of the backstage management system in the application layer, the design of the internet of things gateway and the design of the temperature and humidity monitoring subsystem in the perception layer as well as the central air-conditioning fan coil control subsystem.

3.1 Design and Implementation of the Background Server

The backstage management system serves as a data processing and analysis center in the hospital temperature and humidity monitoring system with the functional system management unit mainly consisting of the user/device management module, the service response module, the data storage module and the data analysis & report generation module. The user management module has been developed for the authentication management on the users getting access to the system and the gateway that is connected to the system/ or the devices in the perception layer. The service response module serves for the real-time data query and the transfer of the control signals. As to the data storage module, it's used to store the monitoring data or the state information uploaded regularly from the devices in the perception layer. Regarding the data analysis and report generation module, it's used to generate the various environmental monitoring reports and the other statistical information as required by the users.

Since the management system can be implemented through the web server and the database server, then the users can communicate with the web server through their cell phones or the other intelligent terminals according to the http protocol, and the devices in the perception layer can communicate with the database server through the socket. As the web server is set up according to the Apache Tomcat server technology, then JSP technology can be adopted to feed back any web information in the server, where JavaBean and Servlet technologies can be applied to make a response to the user's request or handle the transaction. Also the web server is able to get access to the SQLSEVER database in the JDBC access mode.

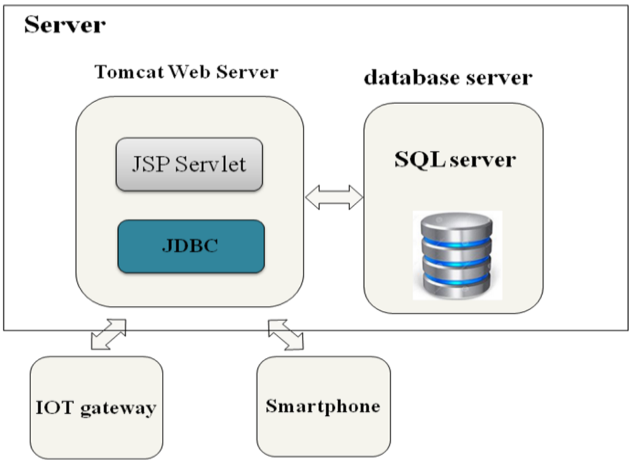

Figure 2. Block Diagram of the Server

3.2 Design and Implementation of the Internet of Things Gateway

The internet of things gateway has been an important device to constitute the network layer in the internet of things architecture, able to realize the transformation from wifi to the 433M wireless communication protocol during data communication in addition to the unpacking and repacking of the communication signals between the backstage management system and the devices in the perception layer with the structure diagram shown as figure3:

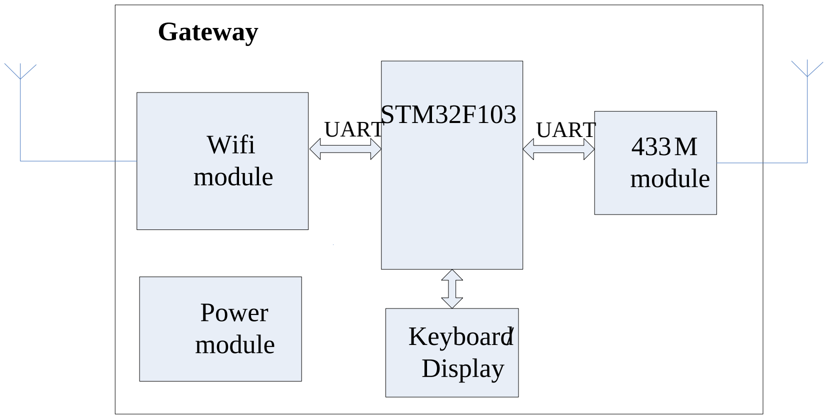

Figure 3. Block Diagram of the Gateway

Choose HLK-RM10 module as the wifi module, which is an embedded module compliant with the network standards based on the serial interface with a built-in TCP/IP protocol stack, capable to realize the conversion between the following three interfaces, including the serial port at the user end, the Ethernet and the wireless network (WIFI). Such a module can be configured flexibly since the embedded web server is able to make a parameter configuration on the module by getting access to the web page, or the parameter configuration can be made based on the relevant AT command sent via the UART, through which HLK-RM10 module is able to communicate with the control chip STM32.

Choose the HC-12 wireless serial port communication module as the 433M wireless communication module, which is a new generation of multi-channel embedded wireless data transmission module with the radio frequency in the range of 433.4—473.0MHz and able to be configured into multiple channels. The maximum transmitted power is 100mW (20dBm), while the receiving sensitivity is -116dBm when the over-the-air baud rate is 5000bps with the communication distance up to 1000m in an open area. Since this module contains an MCU, then the users won't have to work additionally on the module programming. Also with four communication modes, this module enables the users to make a choice through AT commands according to the operating requirements.

Choose the STM32F103 chip produced by ST company as the master controller, which adopts ARM Cortex-M3 as the CPU core. With 128KB of the flash program memory and up to 20KB of the SRAM, it shows a maximum operating frequency of 72MHz, capable to realize the single-cycle multiplication operation and hardware division operation.[8] Also with diversified peripheral devices, this chip has been provided with multiple serial communication interfaces, capable to cater for the simultaneous data communication with the wifi module and the 433M wireless module.

3.3 Design and Implementation of the Temperature and Humidity Collection Subsystem

The temperature and humidity collection subsystem that can be deployed according to the specific requirement mainly consists of the various devices in the perception layer including the wireless temperature collector, the wireless humidity collector and the integrated wireless temperature and humidity collector with the collected data sent to the gateway device via the 433M wireless communication. The figure4 as below shows the hardware block diagram of the integrated wireless temperature and humidity collector:

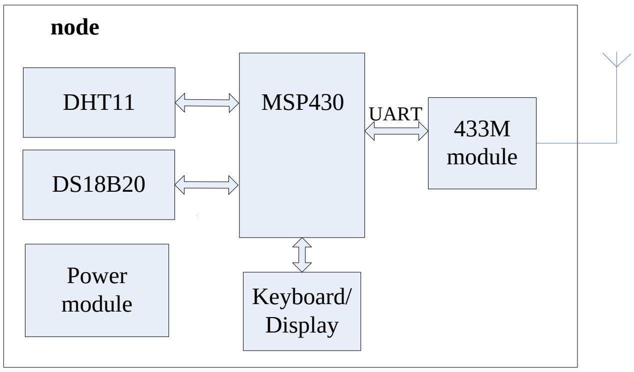

Figure 4. Hardware Block Diagram of the Temperature and Humidity Collector

Regarding the humidity sensor, adopt the DHT11 humidity sensor with calibrated digital signal output to provide a humidity measurement accuracy of +-5%RH in a measuring range of 20-90%RH. Every DHT11 sensor that has been calibrated in an extremely precise humidity calibration laboratory is designed with a single-wire serial interface to facilitate the connection with the micro-controller.

Regarding the temperature sensor, adopt the DS18B20 digital temperature sensor that is characterized by small size, low hardware cost, strong anti-interference capacity and high precision, able to provide a temperature measuring precision of +-0.5℃ in a measuring range from -55℃ to +125℃. With single bus digital output, such a temperature sensor can be connected conveniently.

As to the devices in the perception layer for temperature and humidity monitoring, they're featured with simple functions but sensitive to power consumption, which requires them to work for a long time when they're battery powered. Meanwhile choose the low power 16-bit MCU MSP430F149 produced by TI company as the micro-controller, which is characterized by low voltage and ultra-low power consumption. In the working voltage of 3.6V~1.8V, it's 280μA@1MHz in the normal operating mode, 1.6μA in the standby mode and 0.1μA in the power-down mode for the storage of RAM data. With this five-level power-saving mode, this micro-controller is able to satisfy the system requirements.

3.4 Design and Implementation of the Central Air-Conditioning Fan Coil Control Subsystem

When the central air-conditioning system in the hospital is integrated into the whole temperature and humidity monitoring system, the fan-coil control devices in every ICU or operation room will be taken as the devices in the perception layer to get access to the internet of things for temperature and humidity monitoring, where these devices will communicate with the gateway via the 433M wireless network to realize the background monitoring and the remote control & management.

1. Hardware implementation

Figure5 shows the block diagram of the fan-coil control devices, among which the control appliance is provided with a RS485 communication interface for the communication with the blower converter to control the motor speed and thus to control the air volume. Compared with the constant-frequency control, the frequency conversion control brings lower noise with obvious energy-saving effect. The controller is able to control the operation of the wet curtain or the electrical heating rod group in the coil through the relay. Regarding the working frequency of the curtain and the number of the electrical heating rod groups during the operation, both of them will be controlled according to the integral-separation PID algorithm. Meanwhile the coil differential pressure /temperature and humidity monitoring unit is able to feed back the wind pressure on the air ducts and the temperature & humidity of the outlet air to the controller on a real-time basis. In addition, the information about the running status of the fan will be sent to the gateway through the 433M wireless module, enabling the doctors, who are able to review on a real-time basis the running status of the air conditioner in every ward via their cell phones, to make a remote configuration on the temperature and humidity or send the on/off commands. Since all of the control devices are designed with local buttons and LCD, then it's optional for the doctors to perform local management on the devices as well.

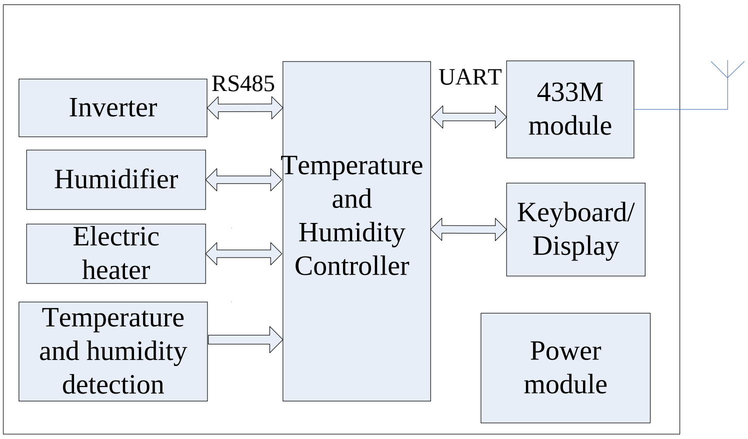

Figure 5. Block Diagram of the Fan-Coil Controller

2. The integral-separation PID control algorithm

In current market, most of the fan-coil control devices are not controlled via networking. Instead, they're controlled just through a simple relay switch, which might lead to a low control precision. The adoption of the PID algorithm to control the controlled quantities is able to improve significantly the response rate of the system and the control precision. Actually according to the difference between the temperature and humidity value preset by the user and the real-time value, it's possible to make a precise control on the fan delivery, the switching frequency of the curtain and the number of the heating rod groups that are in operation.

The purpose to introduce the integration element in the PID controller is to eliminate the static deviation and improve the precision. However it's inevitable that integral accumulation will occur in the PID calculation for a while when the system is started up/ powered off or when there's a significant increase or decrease in the preset value. All of these will bring about extremely huge controlled quantities after the calculation to cause high overshoot or even lead to system oscillation, which is absolutely not allowed in the control process. As a matter of fact, when the integral-separation PID control algorithm is adopted, it will contribute not only to the keeping of the integral action but also to the reduction in the overshoot to realize the significant improvement of the control performance [9].

This algorithm can be expressed by:

$$u(k) = K_P e(k) + aK_I \sum_{i=1} e(i) + K_D[e(k) - e(k-1)]$$

Where a , which is a logical coefficient for the integral term, can be indicated by:

$$\begin{cases} 1, e|(k)| \le \varepsilon \ PID\ control \\ 0, e|(k)| > \varepsilon \ PD\ control \end{cases}$$

Where ε is the preset threshold. Adopt the PD control algorithm when the deviation is greater than the threshold. But when it's lower than or equal to the threshold, adopt the PID algorithm.

4. Experimental Verification

4.1 Experiment on the System Functions

This experiment has been conducted mainly to verify if the devices in the perception layer are able to upload correctly the measured data to the background server, if the gateway and the devices in the node layer can be displayed correctly in the background software and if the measured data can be acquired correctly from the background server by the smart phone software to realize the remote control on the fan coil controller.

Figure 6 and Figure 7 show the pictures of the cellphone screen shot saved when the APP software runs on the smart phone. Figure6 shows the real-time temperature of an ICU ward and the historical temperature data displayed on the mobile APP, while Figure7 shows the real-time humidity and the historical humidity data.

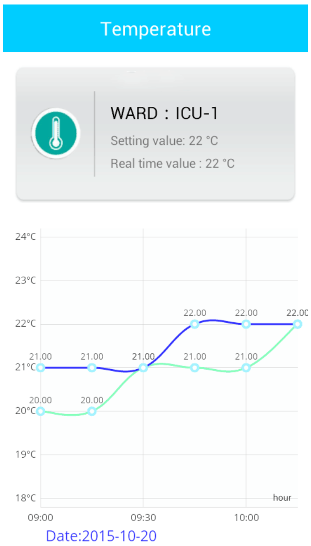

Figure 6 . Real-Time Temperature Display

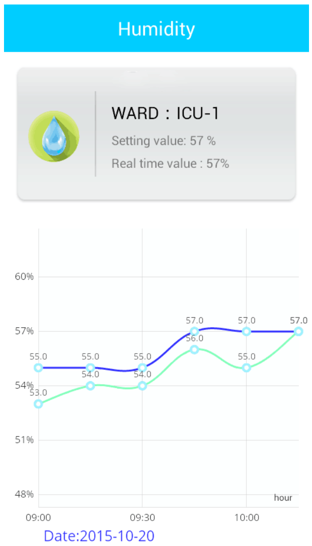

Figure 7. Real-Time Humidity Display

4.2 Experiment on the Temperature and Humidity Control Precision

In order to verify the precision in controlling the temperature and humidity, make a remote configuration on the temperature and humidity value for a certain ICU ward through the cell phone and then conduct the real-time monitoring on the temperature and humidity at equal time intervals (2 minutes) after the fan runs. Figure8 shows the tracking curve set for the target temperature and the real-time temperature, revealing that this system that is sensitive to response is able to provide high temperature control precision. Also Figure9 shows the tracking curve set for the target humidity and the real-time humidity, revealing that there's a certain error in controlling the humidity by the system. This is mainly because that the precision and the stability of the humidity measurement sensor is yet to be improved.

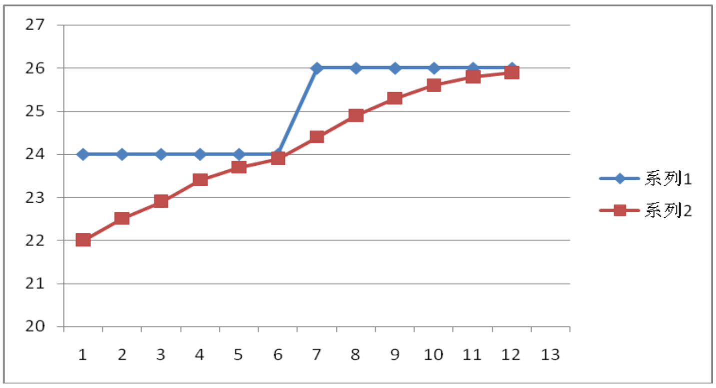

Figure 8. Tracking Curve for Temperature

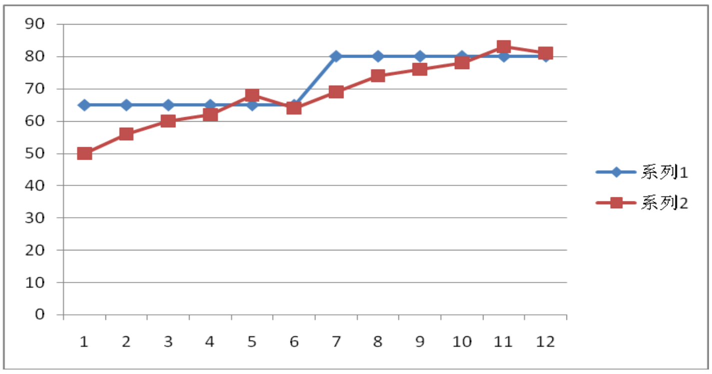

Figure 9. Tracking Curve for Humidity

5. Conclusions

This paper designs an internet of things-based temperature and humidity monitoring system in the key areas of the hospital to realize a precise closed-loop control on the temperature and humidity by controlling the air-conditioning fan sets according to the integral-separation PID algorithm. With the establishment of a background server, this paper also designs an internet of things gateway for wifi-433M wireless communication, a temperature and humidity monitoring subsystem and a fan coil control subsystem in the perception layer in addition to the programming of APP software for the smart phones. The experiment on the system functions verifies the feasibility and stability of the system. Meanwhile the experiment on the temperature and humidity control precision proves that temperature and humidity control is characterized by quick response speed. However the humidity control precision is yet to be improved. Therefore in the future, digital filtering algorithm will be applied to the humidity measurement to increase the stability of the measured data so as to improve accordingly the humidity measurement precision.

Acknowledgements

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