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Development of a Platform to Monitor User's Comfort Degree for Intelligent Environments

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Abstract: With the development of intelligent environments, people have increasing demands for comfortable living environments. The three major factors affecting users' comfort are thermal comfort, visual comfort and air quality. This paper presents a monitoring platform of comfort degree for intelligent environments based on ZigBee wireless sensor network that measures living environment's parameters and actively controls corresponding equipments according to the information collected and users' preferences. Wireless sensor network system is divided into three layers, the main node layer, function nodes layer and leaf nodes layer, respectively. The approach to routing is through a tree topology method. A Mini2440 development board is selected as the host computer, which communicates with the main node via serial interface. The monitoring platform presented in this paper is flexible, powerful, and scalable, which can be applied to the other monitoring fields with minor modifications. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor network, Monitoring platform, Intelligent environments, Comfort degree, Mini2440.

1. Introduction

People have increasing demands for comfortable living environments with the development of intelligent environments. ASHRAE indicated that the comfort degree is determined by three basic factors: thermal comfort (TC), visual Comfort (VC), and indoor air quality (IAQ) [1]. The TC is specified by PMV (Predictive Mean Vote) [2] index that mainly associates with temperature, humidity and air velocity, etc. The VC is specified by the level of indoor illumination. The IAQ is mainly affected by CO_2 concentration in the building [3]. Therefore it has important significance to build a monitoring platform of comfort degree for providing comfortable and healthy living environments according to users' preferences. The wireless sensor network synthesizes the technologies of micro-electronics, wireless communication, sensor and embedded information management that monitors the information of environments and devices by self-organization network and multi-jump modes. ZigBee [4] is a standard wireless network protocol for low rate control network possessing the advantages of low complex, low cost, low consumption and high safety. At present, The ZigBee wireless sensor networks have been widely applied in the fields of industrial control, automotive, consumer electronics and smart home, etc. The wireless sensor networks are so flexible that the household devices can be moved conveniently and can eliminate the trouble of arrangement line. In this paper, a monitoring platform of comfort degree for intelligent environments is developed based on ZigBee wireless sensor networks that measures the environment's parameters (temperature, humidity, wind speed, illumination and air quality, etc), and actively controls the corresponding equipments according to the information collected and users' preferences.

2. Hardware Design of Comfort Degree Monitoring Platform

2.1. Architecture of Monitoring Platform

ZigBee is a standard wireless sensor network protocol that defines three devices namely Coordinator, Router and End-device. Every wireless sensor network must have one Coordinator, which is responsible for assigning parameters and initializing the network that includes selecting a radio frequency channel, a unique network ID and the other operation parameters. The routers of ZigBee act as the repeater of remote devices to extend the network. The End-devices of ZigBee connected with sensors and effectors deal with data acquisition and control. Fig. 1 is the architecture of monitoring platform for intelligent environments. The wireless sensors network acting as the lower computer consists of three layers namely host node layer, sub-host node layer and leaf node layer with tree route. The Coordinator, Router and End device are host node, sub-host node and leaf node of the wireless sensors network, respectively. The sub-host nodes (also known as function nodes) include thermal comfort Agent, visual comfort Agent and air quality Agent that deal with collecting the information of field sensors and controlling the corresponding equipments, while they send the information collected to the host node and receive the commands from the host node. The leaf nodes include sensor Agents and device Agents. The ARM9 [5] embedded computer acts as the host computer that is the center of the whole system, and it is called management Agent [6].

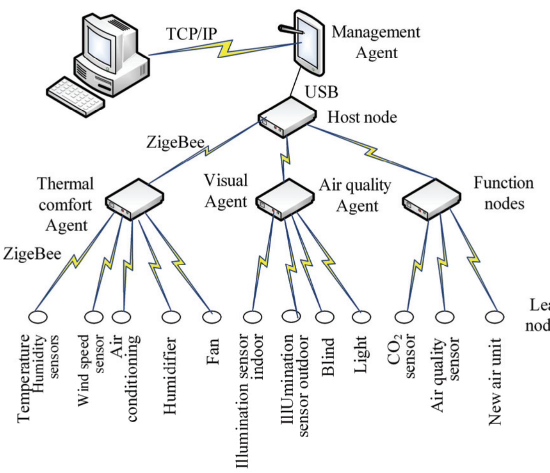

Fig. 1. Architecture of monitoring platform.

2.2. Design of Wireless Sensor Network Nodes

All the nodes in wireless sensor network adopt modular design. One wireless sensor network node can be divided into two parts of base module and expansion module. The base module consists of a microprocessor module, a wireless RF (Radio Frequency) module and a power module, and its type and quantity of composition are fixed. The expansion module includes a sensor module, an actuator module and a gateway module that can be configured arbitrary according to the needs of network nodes. The nodes structure of wireless sensor network is shown in Fig. 2.

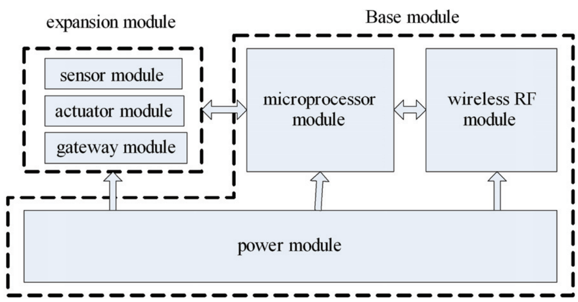

Fig. 2. Nodes structure of wireless sensor network.

2.2.1. Base Module

The MCU ATMEGA1281 of ATMEL AVR Series is chosen as the microprocessor module that is a core part of the wireless sensor node, which has the characteristics of advanced RISC architecture, rich chip resources, rich peripherals and rich serial interfaces (SPI, I2C, UART, etc). It has low-power design of sleeping and deep sleeping with µA level, so that it can save the power consumption of the sensor nodes significantly and decrease the collision probability of information reported. After finishing data acquisition or control task, the nodes send the relevant data to the host node. The AT86RF230 RF chip is chosen as the wireless RF module that is designed for the low cost ZigBee/IEEE802.15.4 application. All the critical RF components are integrated on the chip except for antenna, crystal and decoupling capacitors.

2.2.2. Sensor Module

Sensor modules include temperature-humidity module, wind speed module, illumination module, CO_2 module and air quality module according to the needs of the field leaf nodes. A SHT15 digital temperature-humidity sensor, which can quickly and accurately measure the temperature and relative humidity of the environment, is selected as the temperature-humidity module that connects with the microprocessor via a two-wire serial interface. The HD103T.0 air velocity sensor of Delta OHM is selected as the wind speed module that is a universal hot-wire anemometer with 4~20 mA (or 0~20 mA and 0~10 Vdc) output signal. The CdSe photoresistor is selected as the illumination module. Its sensitivity is the highest in the visible band, and its typical dark resistance and typical bright resistance are 520 kOhm and 2 kOhm respectively. It connects with the microprocessor via A/D channels. The QPA2002 [7] air quality sensor of SIEMENS is selected as the air quality module for measuring the indoor CO_2 concentration and VOC (Volatile Organic Compounds) with 0~10 Vdc output signal.

2.2.3. Actuator Module

The actuator modules are used to control the air conditioners, humidifiers, fans, lamps, blinds, new air handling units and other equipments that include relays, digital potentiometers and RS485 serial communication chips. The control of lamps includes "weak", "medium" and "strong" three illumination levels and "on-off" switch. The control of new air handling units includes "weak" and "strong" two levels. The control of blinds includes "on", "off" and "blade angle" three steps. The fans take stepless control for adjusting the wind speed and the humidifiers take "On-Off"control. Among them, the PS7112L-1A NEC's solid state relays are selected that are MOS FET Relays with the characteristics of low operating current and small size. The X913 digital potentiometers are used to steplessly adjust the speed of fans. The adjusting principle is that, the work voltage is regulated by changing the resistance of the digital potentiometer that controls the charging time of capacitor, and thereby controls the thyristor conduction angle. A RF75WDT air conditioning is chosen with a RS485 communication interface, as shown in Fig. 3. The sensor node communicates with the RF75WDT air conditioning via a RS485 converting circuit to achieve the network control. The converting circuit is shown in Fig. 4.

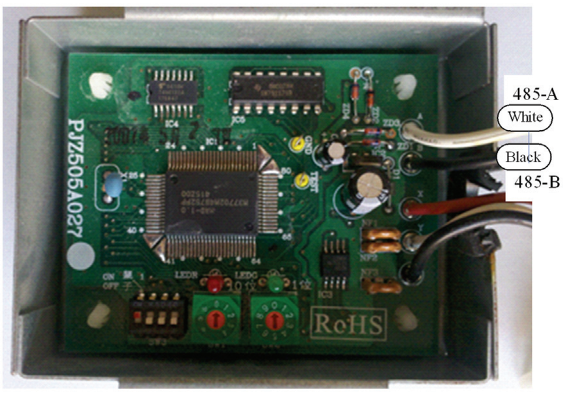

Fig. 3. RS485 interface of air conditioning.

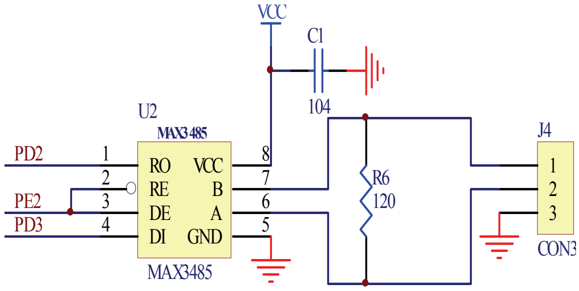

Fig. 4. Converting circuit of RS485.

2.2.4. Gateway Module

The MIB520 USB interface board is chosen as the gateway module that communicates with the host computer by USB interface. The USB interface can be seen as a virtual COM interface by the FT2232 chip of FTDI. The two virtual serial numbers: COM <n> and COM <n+1> are displayed when the host computer connects with the MIB520. The COM <n> deals with node programming and the COM <n+1> deals with COM communication.

2.3. Host Computer

The Mini2440 [8] development board of Friendly ARM is chosen as the hardware platform of host computer. The Mini2440 adopts S3C2440 ARM9 microprocessor of Samsung with the specification of primary frequency 400 MHz, the maximum frequency 533 MHz, 64 M SDRAM memory, RJ-45, USB, RS-232 and other interfaces, 3.5" LCD with touch screen, etc. The Mini2440 host computer supports Linux 2.6.32.2 + Qtopia-2.2.0 + QtE-4.6.1, which communicates with the gateway module in master node by USB interface in this paper.

3. Design of Software

3.1. Design of Software for Wireless Sensor Nodes

The software programming of wireless sensor network node adopts TinyOS [9] operating system that is an open source embedded operating system for wireless sensor networks developed by the University of California, Berkeley. It can quickly compile the application-specific software by linking the different components together. The component design method makes the core of the operating system small enough to effectively reduce the codes length, thereby to break through the restrictions of few hardware storage resources. The TinyOS operating system and its applications are basically programmed by nesC language. One complete application is programmed by many independent and interrelated components and interfaces. The user application components call the lower components through interfaces, to achieve all kinds of application functionality, such as data acquisition, data processing, wireless communication, host computer communication, etc. The programming of the sensor nodes proposed in this paper can be divided into three categories according to the node function and hardware configuration:

1) Using digital sensor module in nodes, such as temperature-humidity sensors, these nodes send or read data of sensors through the digital signal lines connected with microprocessor.

2) Using analog sensor module in nodes, such as air velocity sensor, illumination sensor, air quality sensor, etc, the programming of such nodes needs to add an A/D converter component.

3) Using serial communication module in nodes, such as RS485 serial communication module for the control of the air conditioning, the programming of such nodes needs to add a serial communication driver component.

In addition, the relays, potentiometers and other devices are primarily driven by the circuit designed of I/O pins, without adding extra components.

The following example is the software programming of temperature-humidity sensor nodes. The program components includes a system component "Main", an application component "SensorM", an Ad hoc router protocol component "MultiHopRouter", a general communication component "GenericCommPromiscuous", a data sample Component "SamplerC", a clock component "TimerC" and a LED component "LEDC". The programming chart of components is shown in Fig. 5.

In Fig. 5, the "SensorM" component connects with the "SamplerC" component via a Sample interface that configures the sample channels by calling the command "getSample" and starts sampling by calling the command "sampleNow". At last the sample data are sent to the "SensorM" component by the event data Ready. The main codes are as follows:

```
// Configure the sample parameters
   record[14]=call
Sample.getSample(0,TEMPERATURE,MISC_SAMPLIN
G_TIME,SAMPLER_DEFAULT);
   record[15]=call
Sample.getSample(0,HUMIDITY,MISC_SAMPLING_TI
ME,SAMPLER_DEFAULT);
……
call Sample.sampleNow();
   ……
event result_t Sample.dataReady(uint8_t channel, uint8_t
channelType,uint16_t data)
  {
     switch (channelType) {
          ……
    case HUMIDITY:
      atomic { tmppack=(DataMsg *)packet.data;
            tmppack->Data.datap6.humid =data ;
                        msg_status|=0x80;}
             break;
    case TEMPERATURE:
      atomic {tmppack=(DataMsg *)packet.data;
              tmppack->Data.datap6.humtemp =data;
                       msg_status|=0x100;}
                    break;
               ……
        default:
                    break;}
          }
```

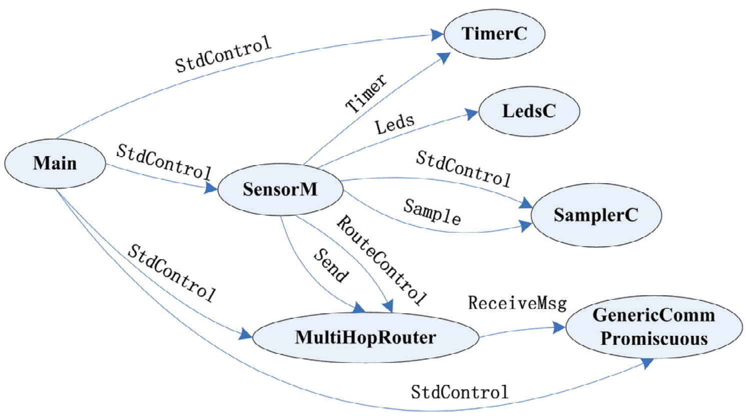

Fig. 5. Components connecting of temperature-humidity sensor nodes.

3.3. Software Design of Host Computer

The software design of host computer mainly includes those functions, such as serial communication, database migration, user interface design and control algorithm, etc. The Version of database is SQLite [10] 3.5.6, and the version of development environment is fedora 9.0 in the host computer. The arm-linux-gcc-4.4.3 cross compiler is used to migrate the SQLite database.

The Qtopia Designer is developed for application environment based on Qt/Embedded, therefore, the Qtopia is used for designing the user interface of the host computer. The two Qtopia development environments are used for programming, which are X86 x86-qtopia based on PC and Arm-qtopia based on ARM platform. The former qtopia is used to simulate the program compilation on PC, the latter qtopia provides the compiler to run the program on ARM platform.

The signals/slots are the core of Qt and replace the traditional callback function. It is extensively used for communication of objects in the Qt programming. When the signals of the object are changed, the signals will be emit. The slots as an ordinary object member function perform the corresponding application programming after receiving the signals. The connect( ) function of QObject is provided to connect the signals and slots, the codes format is denoted as:

connect("sender", SIGNAL("signal"), "receiver", SLOT("slot")),

where the "sender" is the sender of signal, the "signal" is the signal content, the "receiver" is the receiver of signal and the "slot" is slot function.

The simulation execution files under X86 are generated via "make" command. The project file folder is moved to Qtopia application environment based on ARM platforms after debugging success. Regenerating the "pro" file and "Makefile" files and running the "make" command by linux-arm-g + +Run compiler tools, the executable program is acquired after a successful compilation on the ARM platform.

The monitoring interfaces of the system mainly include mode selection interface (MODE), operation status monitoring interface (MONITOR), data query interface (QUERY), device control interface (CTRL) and chart Interface (CHART), which can be switched through the menu.

The MODE interface is selected as an example, shown in Fig. 6, which is used to choose the season and the running mode for thermal comfort system.

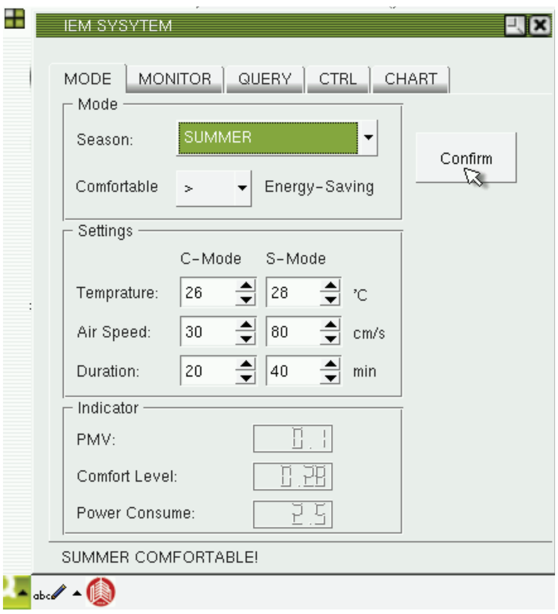

Fig. 6. Mode selection interface.

The seasons are divided into "SUMMER" and "WINTER" two types. The running modes include "Comfortable > Energy-saving", "Comfortable = Energy-saving" and "Comfortable < Energy-saving" [11]. The user can choose any of the three modes according to their thermal sensory preferences. After choosing the appropriate mode, then pressing the "Confirm" button, the system starts running. It runs alternately between the comfort mode and energy-saving mode to simulate the natural environment, thereby to realize the dynamic comfort control. The settings of temperature, wind speed and time duration as well as the PMV values measured from the thermal environment are displayed on the "MODE" interface. In accordance with the settings of the above parameters, the energy consumption of the system is the minimum under the same comfort.

4. Conclusion

ZigBee is a standard wireless network protocol for low rate control network possessing the advantages of low complex, low cost, low consumption and high safety. It will be the direction of the intelligent environments with the development of the wireless network technology. The paper presents a comfort degree monitoring platform for intelligent environments based on ZigBee wireless sensor networks that samples the environment's parameters and actively controls the corresponding equipments according to the data sampled and users' preference. The wireless sensors networks acts as the lower computer that consists of three layers namely host node layer, sub-host node layer and leaf node layer with tree route. The software programming of wireless sensor network node adopts TinyOS operating system. It can quickly compile the application-specific software that, the different components are linked together by interfaces. The Mini2440 development board of Friendly ARM is chosen as the hardware platform of host computer that communicates with the gateway module in master node by USB. The software design of host computer adopts SQLite database and Qtopia for user interfaces. The monitoring platform presented in this paper is flexible, powerful, and scalable, which can be applied to the other monitoring fields with minor modifications.

Acknowledgements

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