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Design for Indoor Environment Monitoring System based on Embedded System and Multi-sensor Data Fusion Algorithm

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Abstract

This paper aims to construct an environmental monitoring system for newly decorated room. Digital temperature-humidity sensors, formaldehyde sensors, benzene sensors, ARM11 and Linux embedded system were selected. According to the application characteristics of the sensors, hardware device drivers were designed, generated kernel module files were loaded into the Linux kernel, and the user application programs operating the sensors' devices were written. To get accurate measurement and reliable evaluation for environmental condition, a two-level fusion algorithm was designed, which was composed of data-level fusion based on adaptive weighted fusion algorithm and decision-level fusion based on fuzzy set theory and judging principle of composite index. The system was capable of realizing the real-time acquisition and transmission for environmental data. Thus, the indoor environment quality could be accessed conveniently by users via PC terminal on the Internet.

Keywords: *ARM, indoor environment, monitoring, data acquisition, data fusion*

1. Introduction

Temperature, humidity and the concentration of harmful gases such as formaldehyde, benzene are indispensable parameters to demarcate environment conditions [1], especially for newly decorated rooms. So it is of great significance to measure them accurately. At present, remote monitoring and control for indoor environment by using the embedded technology combination of wireless sensor network to construct Internet of Things has become the development trend and research focus in the smart home [2-4]. To develop an indoor environmental quality monitoring and control system with high real-time performance, portability, reliability and accuracy, sensor array module constituted by the temperature and humidity sensor, sensors of gases such as formaldehyde, benzene were used to detect various factors of indoor environment quality. When the information was collected by the sensor module and processed with the multi-sensor data fusion algorithm in microprocessor, the indoor environment quality grade could be obtained. And then control strategy would be made by the system in accordance with the environment level to determine whether it carries out acousto-optic alarming or controlling action of air conditioner or fan to improve indoor environment quality.

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2. Design of Hardware and Software Architecture

The system was required real-time acquisition of indoor environmental data by sensors [5]. And the data was processed with high efficiency and transmitted to a remote PC by network interface for the user's monitoring. The overall structure of the system is shown in Figure 1. The indoor environmental monitoring system is composed of field monitoring system and remote monitoring center (PC). Field monitoring system includes the sensor data acquisition module and the main controller.

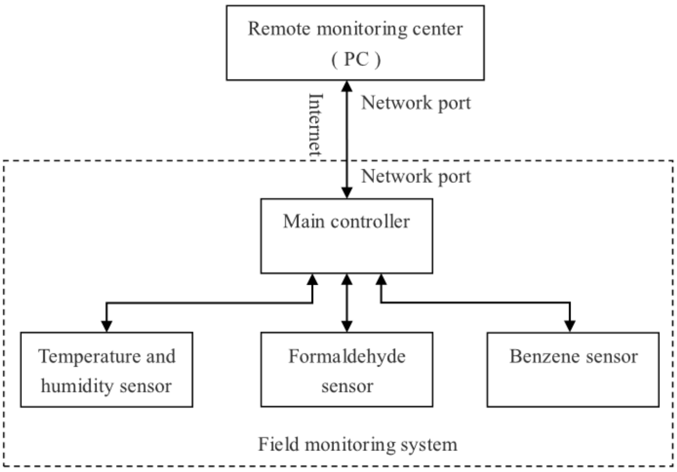

Figure 1. System Structure for Indoor Environment Monitoring

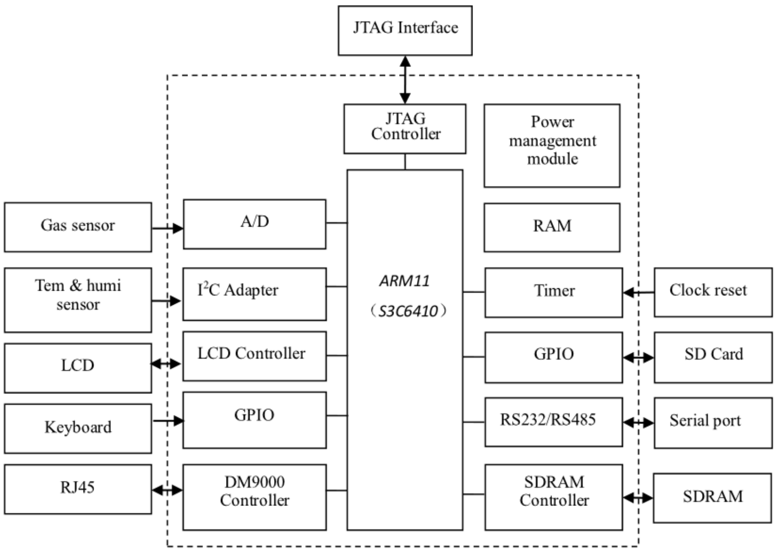

Figure 2. The Hardware Architecture of the Scene Monitoring System

The various sensors locate at the bottom of the monitoring system to detect the environmental factors and send the signal to the main controller after A/D conversion. Main controller receives data from the sensors, stores and displays it, and communicates with the remote monitoring center, equivalent to the gateway. The remote monitoring center is mainly for integrated processing of the collected data, finishing the fusion calculation, environmental analysis and evaluation, remote management, and for users to view.

The hardware architecture of the field monitoring system is shown in Figure 2. The system hardware is mainly composed of two parts: one is the circuit for gas sensor array, including the heating circuit for sensor, signal acquisition circuit and signal conditioning circuit. The other is the peripheral circuit of S3C6410, including FLASH and SDRAM memory circuit, LCD interface circuit, sound and light alarm circuit, keyboard circuit, JTAG interface circuit for program debugging, and the power supply circuit that converting voltage to system needed 5V, 3.3V, 2.5V. ARM11 processor S3C6410 is used as the main controller of the system [6]. DHT90 is digital temperature and humidity sensor which has good performance and high precision. Both formaldehyde sensor and benzene sensor selected are produced by the German Drger company. The extension interfaces of the system are abundant, and would provide data interface for other gas sensors such as carbon monoxide sensor, sulfur dioxide sensor, *etc*.

Linux operating system serves as the software platform, and the software part of environmental monitoring system in accordance with the function can be divided into three parts [7]. (1) The embedded Linux system, namely, the embedded Linux system is constructed according to the system demand. The boot loader, Linux kernel and file system in embedded Linux system are cut and customized in detail, the Network Interface driver is mainly increased, the I^2C bus interface configuration and its related function are added into the configuration, and the function such as kernel dynamic loading is added, in addition, the support for the NFS file system is opened. (2) Device drivers, sensor hardware device drivers are written, and are compiled into the kernel module file, and the kernel module is dynamically loaded into the Linux kernel according to the communication protocol of temperature and humidity sensors and technologies such as I^2C architecture in Linux system, timer interrupt, and so on. (3) User application program, the data are transmitted between host and client through the network. Based on the Linux system, the procedure is designed by combining the Socket network communication technology and sensor driver user interface functions to operate the sensor and measure and read the environment data so as to implement acquisition and transmission for environment data.

2.1. Master Controller S3C6410

The S3C6410 based on ARM11 framework is the core processor. It has 64/32 bit internal bus structure, 256 MB SDRAM memory, 1 G NAND FLASH memorizer. It internally installed a lot of hardware peripherals, including the commonly used I^2C bus interface, 4 channel UART, 24 bit LCD controller, system management controller (clock, *etc*.,), 4 channel timer, PWM interface, 32 channel DMA, general I/O port, USB main equipment, SD main equipment, high-speed multimedia card interface and the PLL used to generate clock. Resources of ARM11 series chips S3C6410 are rich, their interfaces are flexible, and can easily join up and remove the sensor and network communication interface. This provids a hardware solution with the low cost, low power consumption, and excellent performance for indoor environment monitoring system.

2.2. Temperature and Humidity Sensor DHT90

DHT90 is the digital temperature and humidity sensor based on SHT10 chip design. It is able to measure temperature, humidity and dew point at the same time, and can also directly output the digital signals by the calibration. Its inner integrated temperature sensitive element, humidity sensitive element and amplifier, A/D converter, calibration data memory, digital bus interface and voltage regulator circuit, support I^2C bus. Moreover, it has high measurement precision, stable performance, rapid response, and high price/performance ratio. The highest resolution of DHT90 temperature value is 14 bit, and measuring precision can be up to ±0.5 ℃. The maximum resolution of humidity value is 12 bit, and measuring precision can be up to ±4.5%.

DHT90 provides 4-needle single-row pin encapsulation. It uses SCK/DATA serial interface and automatic adjustment of voltage, and is easy to integrate and replace. Its peripheral circuit design is shown in Figure 2. S3C6410 controller connectes with DHT90, just by data line DATA and clock line SCK of DHT90, connectes with the I^2C bus data line SDA and I^2C bus clock line SCL, respectively. DHT90 pin function is as follows [8].

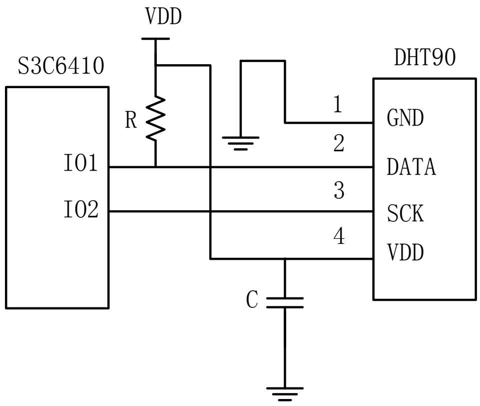

Figure 3. The S3C6410 and DHT90 Interface Circuit

(1) Power input, and the end (VDD and GND): electric voltage of DHT90 sensor power supply is in the range of 2.4 to 5.5 V, and the typical value is 3.3 V. For decoupling filtering of signal, it is needed to join up a 100 nF capacitance between the pins of VDD and GND.

(2) Serial clock input (SCK): it is used for the clock signal synchronization between the processors.

(3) Serial data (DATA): it is used for data communication between processors. DATA change state after the falling edge of SCK clock, and only effective on the rising edge of SCK clock. During the period of DATA transmission, the DATA must remain stable, when the SCK clock is high level. To avoid signal conflict, the microprocessor needs to put the DATA in low level. At this time, signals are lifted to high level by externally connecting a10 kΩ pull-up resistor.

DHT90 has a two-wire serial bus interface. The sensor conducts the data communication by simulating I^2C protocol of this interface. It cannot carry out communication in accordance with the standard of I^2C protocol. When I^2C bus does not connect other I^2C devices, DHT90 sensors can be connected to the I^2C bus, but the processor must operate sensor according to DHT90's own protocol. That is to say, the communication protocol of DHT90 sensor needs to be written, and is used for data communication with the processor. According to the communication protocol, the corresponding program of DHT90 temperature and humidity sensor can be designed.

2.3. The Circuit of Benzene Sensor

The MQ135 is selected as benzene sensor whose signal conditioning circuit is shown in fig. 4. The sensor is connected in series with Rs whose voltage drop is the sensor's output voltage. If benzene is detected, resistance of benzene sensor will be decrease. Meanwhile, the voltage of Rs will rise. Thereby, the circuit outputs a voltage corresponding to concentration of benzene. In consideration of the sensor resistance related to temperature and humidity, temperature-compensation circuit is designed and consists of U_1, R_1, R_2, R_3, R_4, Rt. The resistance Rt is a negative temperature coefficient thermistor which can sense the change in temperature.

2.4. The Circuit of Formaldehyde Sensor

The formaldehyde sensor is constant potential electrolysis type. It is a three electrode electrochemical sensor, the three electrodes referrs to the working electrode (W), reference electrode (R) and the counter electrode (C). Its typical interface is shown in Figure 5. The sensor works based on the principle of electrochemical reaction. A current will be output after an electrochemical reaction which is proportional to the concentration of measured formaldehyde. The formaldehyde concentration will be measured by measuring the current generated in a certain potential electrolytic.

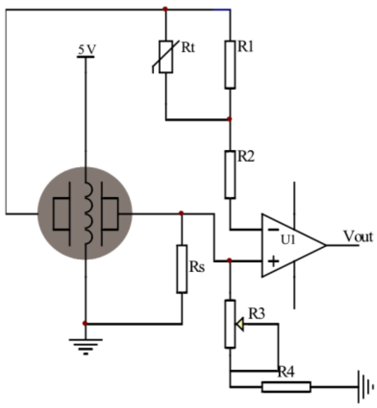

Figure 4. The Circuit of Benzene Sensor

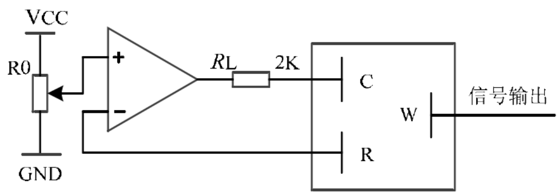

Figure 5. Typical Interface Circuit of Three Electrode Gas Sensor

3. Design of System Software

Red Hat Enterprise Linux 5 is used as a Linux host system. Arm-Linux-gcc-4.3.2.tgz and cross-4.2.2-eabi.tar.bz2 are cross compile tools which can realize the compilation of bootloader and the Linux kernel.

The host and the target are connected by the serial port line. It is displayed and operated in the host when burning bootloader file, Linux kernel file and system image onto the target board. The design of the Linux kernel module, device driver and application program are carried out in the host, and then the generated files and programs are delivered to the target board by the network cable. To facilitate the development of embedded system, NFS file system model is used in the target machine, which makes the module and program compiled in the host conveniently transported to the target machine.

According to the hardware circuit, the U-Boot image u-boot.bin, the Linux kernel file zImage and the file system image root.yaffs2 are produced. The host and development board are connected via a serial port, the development board is started, and hyperterminal of Windows operating system programmes the u-boot.bin, zImage and root.yaffs2 to flash. After completing the work, the development and transplantation of embedded Linux system for hardware device is completed [9].

3.1. Overall Structure of the System Program

The overall structure of the system program is shown in Figure 6. System program mainly includes client programs to run in the host and the hardware device drivers running in target machine and the server application programs. The workflow of the system program is shown in Figure 4. Target machine runs the server program, and the client's connection request is monitored by starting socket network. The socket network connection is established after receiving the client connection request information, and then hardware device driver is visited through a variety of file operations function (open, write, read, *etc.*,). The temperature, humidity, concentration of harmful gases in air and other environmental data are collected, and then transmitted to the host again through the socket communication.

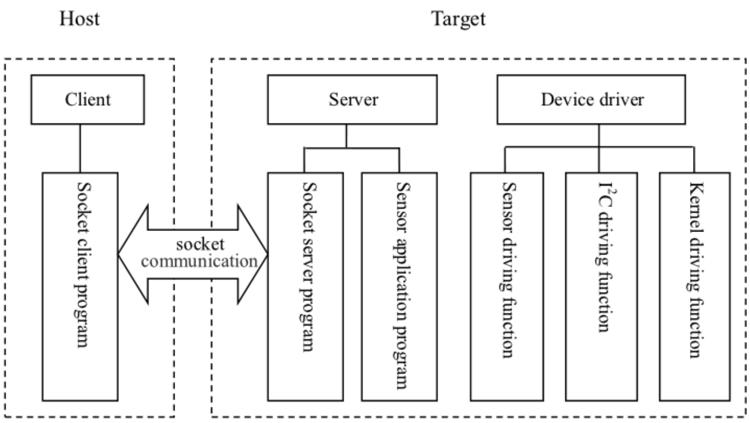

Figure 6. Overall Structure of System Program

3.2. The Design of Data Acquisition Program

The programs of environmental data acquisition include kernel driver and user application program, running in kernel space and user space respectively (shown in Figure 7). Linux system can realize sending and receiving data of the kernel space and user space at the bottom of the data by the copy_from_user and copy to user functions. The commands and data transmission between the two spaces can be implemented by the operation of function for files such as open, ioctl and read, etc. encapsulatd by virtual file system. Among them, hardware device drivers which run in the kernel space mainly include three parts program of the kernel module, sensor measurement and development board control. Users operate various functions to visit the device files by the application program files such as "open( )", "ioctl( )" and "read( )" in user space, and operate device driver in the kernel space.

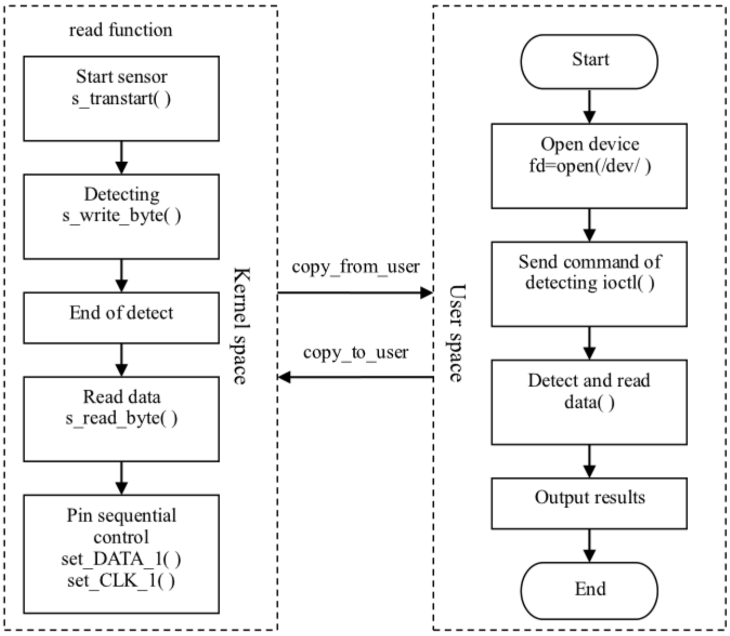

Figure 7. Program Designed for Environmental Data Acquisition

For example, temperature and humidity sensor uses the serial data to simulate the communication mode of I^2C bus. The communication protocol of temperature and humidity sensor and the related technology of embedded Linux are used to design DHT90 sensor program [10].

The application programs accesse to the device file /dev/DHT90 by the functions such as ioctl, open, read, write, *etc*. If the users want to operate DHT90 temperature and humidity sensor, firstly, call the corresponding files operation function in the kernel module program file operation (mainly dht90_ioctl and dht90_read function). Dht90_ioctl function accepts measurement instructions from the user, determines the user to measure the temperature or humidity, and then assigns the surveying marker bit. Dht90_read function is used to measure the temperature or humidity according to the surveying marker bit determined by dht90_ioctl function, and calls the corresponding sensor measurement program, then controls electrical level of hardware pin through the sensor measurement process. The communication timing of the sensor is finally designed and implemented.

4. Multi-sensor Data Fusion Algorithm

The structure of multi-sensor data fusion system is shown in Figure 8. It is a two-stage fusion system. The first level is data fusion with classical algorithm of adaptive weighted data integrating [11], which helps to overcome the uncertainty and limitations of individual sensor, obtain the consistent interpretation and description for the object to be measured. The secondary level is decision fusion based on fuzzy set theory.

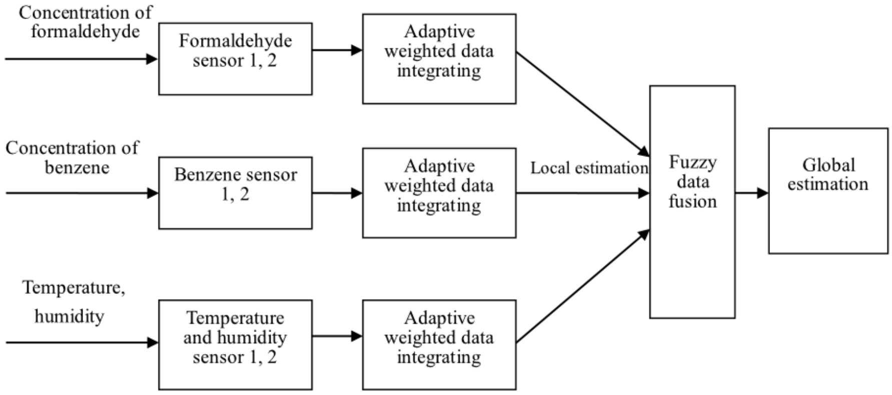

Figure 8. The Structure of Multi-sensor Data Fusion System

For each indoor environment parameters, there are two sensors to test at the same time. And the 4 collected values from each sensor are respectively used for adaptive weighted data integrating. And the single factor evaluation matrix is built with factor sets, evaluation sets. Moreover, the weight vector for each environmental factor sensor is established and the appropriate composition operator of fuzzy relations is selected. The indoor environmental quality comprehensive index is calculated by the formula 1 based on data fusion [12]. Compared with the indoor environmental quality grade and classification standard, the environment level is finally concluded.

$$I = \sqrt{\max\left(\frac{x_i}{x_{max}}\right)\sum_{i=1}^{4}\frac{1}{4}\frac{x_i}{x_{max}}} \tag{1}$$

Where I the indoor environmental quality is comprehensive index; x_i is the measured value of the environment quality factor i ; x_{max} is the maximum allowable value of the environmental quality factor i .

Table 1. Measurement and Processing Results in a Room

sensor	observed value				fused value	environmental quality level
formaldehyde sensor 1 (ppm)	0.321	0.356	0.344	0.334	0.345	rather poor
formaldehyde sensor 2 (ppm)	0.336	0.343	0.333	0.359		
benzene sensor 1 (ppm)	0.152	0.157	0.148	0.162	0.152	
benzene sensor 2 (ppm)	0.150	0.153	0.144	0.161		
Temperature sensor 1(℃)	26.5	26.8	26.9	26.6	26.3	
Temperature sensor 2 (℃)	26.1	26.2	26.4	26.2		
Humidity sensor 1(%RH)	60.2	60.5	60.3	60.1	60.2	
Humidity sensor 2(%RH)	60.3	60.4	60.3	60.2		

5. Results

The system is used for detecting a newly renovated room to which applied the two level fusion algorithm. The fusion result is shown in Table 1. It can be seen in the table that the output data from the same kind of two sensors is very consistent with each other. It indicates the system has small measurement error and instability. The result of the data fusion conforms to the actual situation of indoor environmental quality evaluation.

6. Summary

An indoor environment monitoring system is designed to detect temperature and humidity, concentration of formaldehyde and benzene, and to evaluate the quality of indoor environment by using the algorithm of multi-sensor data fusion. The system is built on the basis of ARM11 processor S3C6410 and embedded Linux operating system, with a two-level fusion algorithm which greatly improves the accuracy of measurement, and provides a reliable basis for the later evaluation and control of indoor environment. It has small volume, low power consumption and high reliability, can be used for long distance data communication, and is very suitable for the environment monitoring of newly decorated rooms.

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References

[1] C. Bur, M. Bastuck, D. Puglisi, A. Schütze, A. L. Spetz and M. Andersson, "Discrimination and quantification of volatile organic compounds in the ppb-range with gas sensitive SiC-FETs using multivariate statistics", Sensors & Actuators B: Chemical, vol. 214, **(2015)**, pp. 225-233.
[2] C. Kim and K. Kim, "Implementation of a cost-effective home lighting control system on embedded Linux with OpenWrt", Personal & Ubiquitous Computing, vol. 18, no. 3, **(2014)**, pp. 535-542.
[3] Z. Bolan, "ZigBee mesh connects Internet of Things", Canadian Electronics, vol. 30, no. 1, **(2015)**, pp. 12-13.
[4] M. N. Ismail, "Early Fire Detection: Development of Temperature Sensor Device in Smart Home Monitoring Systems Using Mobile Phone, International Journal of Academic Research, vol. 4, no. 5, **(2012)**, pp. 41-49.
[5] J. J. Patel, N. Reddy, P. Kumari, R. Rajpal, H. Pujara, R. Jha and P. Kalappurakkal, "Embedded Linux platform for data acquisition systems", Fusion Engineering & Design, vol. 89, no. 5, **(2014)**, pp. 684-688.
[6] "Use's Manual of S3C6410X RISC Microprocessor [EB/OL]", Samsung Electronics Co. Ltd., **(2008)**.
[7] C. H. Chou; T. H. Yang, S. C. Tsao and Y. D. Lin, "Standard Operating Procedures for Embedded Linux Systems", Linux Journal, no. 160, **(2007)**, pp. 88-92.
[8] J. Dong, H. Li, Y. Liu, Y. Guo and G. Tang, "Design of a Wireless Monitoring Network for Granary Temperature and Humidity Based on Zigbee", International Journal of u- and e-Service, Science and Technology, vol. 7, no. 2, **(2014)**.
[9] S. Hong, Y. Chen, Z. Na and J. K. Feng, "The Design of a Hospital Environment Data Acquition System Based on ARM11 and Embedded Linux", The International Conference on Computer Science and Electronics Engineering, **(2013)**; Hangzhou, China.
[10] J. Ramsey, "Controlling the Humidify with an Embedded Linux System", Linux Journal, no. 188, **(2009)**, pp. 54-61.
[11] X. Wang, H. Hu and A. Zhang, "Concentration measurement of three-phase flow based on multi-sensor data fusion using adaptive fuzzy inference system", Flow Measurement & Instrumentation, vol. 39, **(2014)**, pp. 1-8.
[12] X. Zhang and W. Luo, "Application of multisensor dato fusion technology in indoor environmental quality monitoring and control sysem", Instrument Technique and Sensor, vol. 2, **(2012)**, pp. 103-105.

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