Sensors & Transducers, Vol. 174, Issue 7, July 2014, pp. 88-94

Sensors & Transducers

http://www.sensorsportal.com

Design an Indoor Air Quality Controller Based on LPC2478

Shi Shuheng, Shen Jie

Machinery institute, North China University of Water Resources and Electric Power,
Zhengzhou, Henna, 450011, China
Tel.: 15038006585

Received: 20 May 2014 /Accepted: 30 June 2014 /Published: 31 July 2014

Abstract: Indoor air quality is very important to our lives, because we spend most of our time indoor. In order to improve the air quality of indoor, this paper designs an indoor environment quality monitoring and controlling system based on ARM microcontroller LPC2478. It will do a real-time monitoring work for detecting the indoor environmental factors and comprehensively evaluate its air quality level. While the indoor air quality status is "poor", this intelligent system will automatically start the heat exchange ventilator for indoor environmental quality improvement. The results compared to traditional natural ventilation method show the better performance of proposed system. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Indoor air quality; PLC2478; Heat exchange ventilator; evaluation criterion.

1. Introduction

According to statistics, people spent about 80% ~ 90% in a day's time indoor, which is evidently more than the outside. Due to the lots use of air conditioning in the modern building, cause that the indoor air pollutant concentration is much higher than outdoor. If we stay too long time under this environment, people will cause itching, headache, cough, respiratory impairment and allergies [1], which we called Sick Building Syndrome, SBS [2]. The reason of this symptom is caused by indoor air pollutant concentration is too high and air exchange rate is too low to cause. Now the research on indoor air quality (IAQ) has become the hot topic [3-8].

The inferior indoor air quality is mainly caused by poor ventilation, indoor and outdoor pollutants, and many other factors. Among them, chemical pollution occupies a lot, such as TVOC volatile organic compounds, CO_2, NO_2 or HCHO gases etc. TVOC and HCHO are two main factors of affection indoor air quality [9, 10]. Take into account the above factors, indoor air pollution monitoring and controlling has become an important method to improve quality of the air. So design an indoor environmental quality monitoring and control system is particularly important.

In this paper, the research contents: data collection module of the system is mainly composed of temperature, CO_2, NO_2, formaldehyde and TVOC sensors, aims at real-time acquisition of indoor environment influence factors; Micro controller, LCD display and voice alarm circuit of the system control module, sensor data will be detected by the microprocessor USES genetic neural network algorithm processing, indoor air quality, according to the air quality is good or bad to decide whether to report to the police; Full heat exchange ventilator constitutes the executable module in improve the indoor air quality, to reduce the harmful gases harmful to human body, improve the quality of people's lives

This paper design an indoor air quality monitoring and controlling system based on microcontroller LPC2478, which could collector gas concentration of CO_2, NO_2, HCHO and TVOC. We design the hardware and software of detection circuit, if the monitored indoor air quality is poor, it will automatically start heat exchange fan to adjust the air quality. This system can effectively adjust the indoor air quality, to reduce the harmful gases and improve the quality of people's lives.

The rest of this paper is organized as follows. In Section 2, air quality rating standard and system design is given, includes sensor detection circuit, power circuit and software design. Section 3 presents the detail results and discussion about comparison between traditional natural ventilation and proposed smart method to adjust the indoor air quality. Finally, Section 4 concludes the paper.

2. Methodology

2.1 Air quality Rating Standard

In this paper, the influence degree of various pollutants of indoor air level, are shown as in table 1.

(1) First level, the indoor environment is very good and is suitable for people activity;
(2) Secondary level, can guarantee the public health;
(3) Level 3, indoor environment can live or in the office, could protect people health.

Table 1. Evaluation standard for indoor harmful gases.

Pollution gas	Level I	Level II	Level III
CO_2 (ppm)	600	1000	1500
NO_2 (mg/m^3)	0.04	0.08	0.12
HCHO (mg/m^3)	0.1	0.1	0.15
TVOC ($mg/m^{3)}$	0.2	0.3	0.6

In order to evaluate the indoor air quality according to the four factors shown as in table 1, namely CO_2, NO_2, HCHO, TVOC, a three layers BP neural network model is established [11], which are input layer, hidden layer and output layer. The input nodes of input layer is 4, the number of hidden layer nodes scope is commonly from 3 to13, but in order to get better training result, we expanded the scope to 6~16 [12], the model structure is as shown in Fig.1.

2.2 Overall Design

This system adopts the gas sensor array and temperature sensor for monitoring the real-time indoor harmful gas and temperature factors. The sensor signals are passed to the respective modulation circuit, amplification circuit, filtering circuit and A/D conversion, finally, sent into the ARM microprocessor, where all of these gases information are displayed on LCD. The system hardware scheme is as shown in Fig.2.

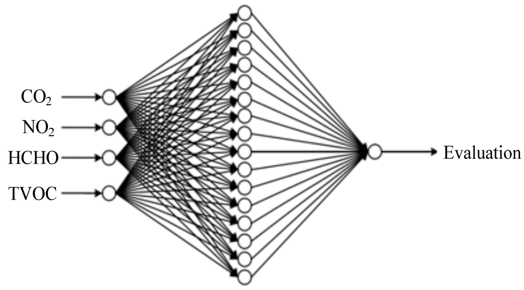

Fig. 1. Flowchart of DoL-RBFNN.

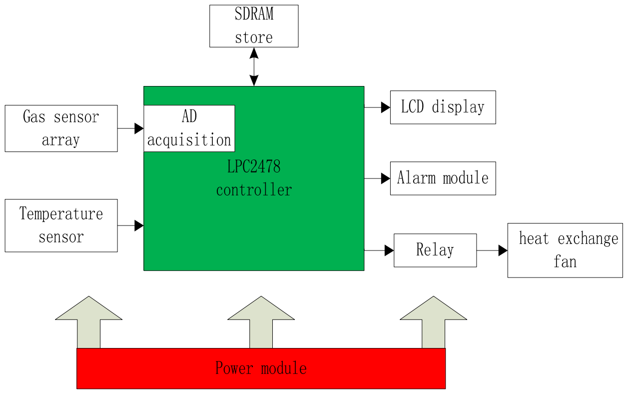

Fig. 2. System design.

The system hardware mainly consists of three parts:

(1) Signal collection and processing module, including multiple gas sensors, temperature sensors and A/D conversion circuit;
(2) Microcontroller processing module, including crystal oscillation circuit, memory circuit, LCD interface circuit, alarm circuit and JTAG interface circuit used for debugging;
(3) Control module, namely the heat exchangers of intake and exhaust fan circuit. Besides that, power module is a requirement to implement the system.

2.3 Sensor Detection Circuits

2.3.1 Temperature Sensor

We selected DS18B20 as temperature sensor, which is made by DALLAS semiconductor companies in the United States. It is a new type of single line digital temperature sensor, which uses one wire to communicate with microcontroller. Besides that the circuit of DS18B20 is very simple, as shown in Fig.3, a pull-up resistor with 4.7 kΩ is the only one needed device. The accuracy of DS18B20 could be selected, 0.5 ℃, 0.25℃, 0.125 ℃, 0.0625 ℃, according to the 9~12bits resolution [13].

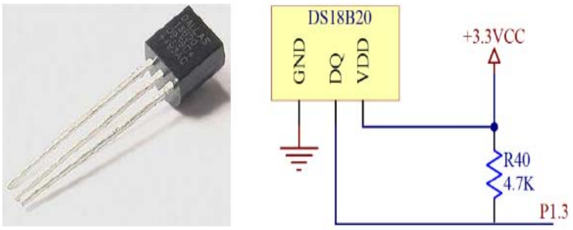

Fig. 3.DS18B20 temperature module.

2.3.2 CO_2 Sensor

This paper adopts the infrared absorption CO_2 sensor, which has many advantages compared to solid electrolyte or barium titanate composite type, such as wide measuring range, good sensitivity, fast response time, strong anti-jamming System design

The system hardware mainly consists of three parts:

(1) Signal collection and processing module, including multiple gas sensors, temperature sensors and A/D conversion circuit;
(2) Microcontroller processing module, including crystal oscillation circuit, memory circuit, LCD interface circuit, alarm circuit and JTAG interface circuit used for debugging;
(3) Control module, namely the heat exchangers of intake and exhaust fan circuit. Besides that, power module is a requirement to implement the system.

According to Lambert-Beer theory, the relationship among emergent ray, I, incident ray, I_0 and gas concentration C is as shown in equation (1).

$$I = I_0 e^{(-KLC)} \tag{1}$$

where K is the absorption coefficient, C is the gas concentration, L is the length of effect between light and gas. Transform formula (1), it is can be obtained the following equation:

$$C = \frac{1}{KL}\ln\frac{I_0}{I} \tag{2}$$

From formula (2), the gas concentration C could be measured by related parameters. The type of CO_2 sensor is JQAW-4, with output voltage is 0~5V, output current is 4~20 mA, and measurement range is 0~2000 ppm, the accuracy is suitable for indoor environment measurement.

2.3.3 NO_2 and HCHO Sensor

The gas sensor for NO_2 and HCHO are S100 and S-10 resistive sensors, respectively, which both the sensors have good sensitivity and stability. The indicators of NO_2 and HCHO sensors are shown as in Table 2, and the measurement circuit is shown as in Fig. 4. The circuit consists of two parts, one is the heating circuit, and the other is the test circuit.

Table 2. Performance of NO_2 and HCHO sensor.

Indicator	**NO_2**	**HCHO**
Range	0~10 ppm	0~20 ppm
Max load	50 ppm	20 ppm
Output signal	1200±300 nA/ppm	-600±150 nA/ppm
Resolution	0.05 ppm	0.1 ppm
Temperature range	-20~45□	-20~50□
Humidity range	15 %~90 %	15 %~90 %
Response time	<50 s	<25 s

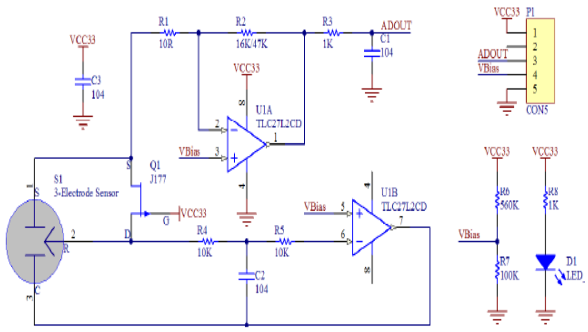

Fig. 4. Measurement circuit of NO_2 and HCHO.

2.3.5. TVOC Sensor

The sensor for TVOC is AJ82 resistive sensor, with measurement range is 5~1000 ppm, working voltage is 5~24 V. The measurement process consists two parts, namely high voltage mode and low voltage mode. The main function in high voltage mode is to remove the impurities produced during measurement process on the surface of sensor, which will take 60 seconds. On the other hand, measurement is happened in low voltage mode, which will take 90 seconds, so the whole working period of TVOC sensor is 150 seconds.

2.4. Power Circuit

Power module offers energy for all of sensors, LCD, microcontroller, which is the basic of system. Fig. 5 shows the schematic diagram of power circuit, input voltage is 9 V, the ouput volage changes 5 V after LM2576 converter, and then changes into 3.V after AMS1117-3.3 V voltage regulator chip. The function of diode D1 is avoiding input voltage reverse, for a protective effect of system.

The output voltage of LM2576 is expressed as:

$$V_{out} = 1.25V\left(1+\frac{R_{38}}{R_{39}}\right)+I_A R_{38} \tag{3}$$

where R_{38} is 3 kΩ and R_{39} is 1 kΩ, and both of them are precision resistors, furthermore, the value of IA is less than 100 uA, so the effection of $I_A R_{38}$ is very small to the output voltage, and can be ignored. Finally the output voltage is equal $1.25\ V \times 4 = 5\ V$.

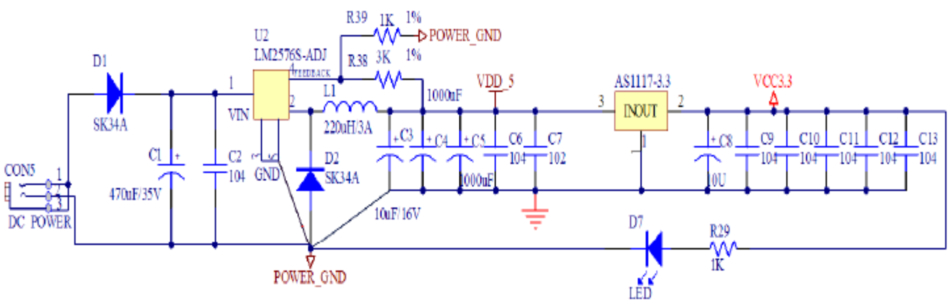

Fig. 5. Schematic diagram of power circuit.

2.5 Software Design

Detector is one of the important parts of in the indoor air monitoring system, which is related to the reliability and practicability of the whole system. Software design of the main principle is that as far as possible to reduce the rate of false positives and non-response rates. Fig.6 shows the flowchart of system, there are three main module of software design.

2.5.1 Update Data

This function was done through LPC2478 internal A/D module, with the measurement range is 0~3.3V. Before starting collecting data from sensor array, it needs to wait about 30 seconds, because these gas sensors need a response time. It will generate an interrupt signal to microcontroller when all the data have been acquired, to notify CPU reads the corresponding data.

2.5.2 Data Process

Data processing module is actually to evaluate the collected values of different gases according to the principle of genetic neural network algorithm. The algorithm can be divided into four parts, namely the BP neural network initialization, fitness calculation, selection of genetic algorithm to produce a new generation and the optimization of the weights of BP network.

2.5.3 Fan Control

It will cause great harm to human body, when the poor quality of indoor air quality to a certain extent. So we design a control module to change indoor air with outside, when this situation happens, a corresponding system will automatically start voice alarm system and start the fan until the indoor air quality changes good.

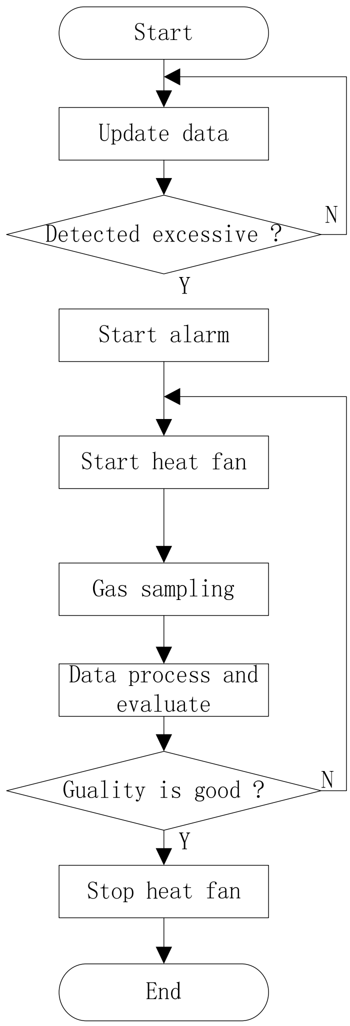

Fig. 6. Flowchart of system working.

3. Results and Discussion

Before the design of the intelligent indoor monitoring and controlling system put into use, we must do a test to verify the performance of this system. We will do an experiment to adjust the poor indoor quality under natural ventilation and proposed system, respectively, in the same environment.

The equipment needed:

(1) Gas generator: CO_2 generator, burning honeycomb briquet, paint;

(2) Sensors, CO_2 sensor, NO_2 gas sensor, HCHO sensor, and TVOC sensor;

(3) Ventilation way: intelligent heat fan vs. natural ventilation.

We need to do the experiment twice, first generates an air environment by gas generator, and then process it through natural ventilation method and intelligent indoor monitoring and controlling system. The experiment environment should be exactly the same in order to accuracy of results. The gas concentration is collected every 5 minutes, and the whole period of experiment is 60 minutes, so we could get 12 sampling points. The corresponding measurement results are shown as in Table 3 and Table 4, respectively.

Table 3. Gas concentration detection under natural ventilation condition.

Time (min)	CO_2 (ppm)	NO_2 (mg/m^3)	TVOC (mg/m^3)	HCHO (mg/m^3)
0	580	0.052	0.022	0.13
5	900	0.185	0.064	0.975
10	1189	0.25	0.11	1.25
15	1015	0.213	0.108	1.254
20	981	0.202	0.125	1.245
25	940	0.212	0.108	1.232
30	895	0.188	0.105	1.208
35	855	0.175	0.092	1.182
40	812	0.154	0.085	1.162
45	772	0.143	0.075	1.141
50	748	0.135	0.053	1.212
55	721	0.128	0.042	1.088
60	685	0.122	0.034	0.952

Fig.7~Fig.10 show the change curves of the four gas concentration under natural ventilation condition and proposed intelligent system. It is can be seen clearly that the indoor pollutant air concentration reaches maximum in about 10 minutes. If we use natural ventilation method, the pollutant gas concentration decrease slowly, especially for HCHO gas, the concentration changes from 1.25 mg/m^3 to 0.952 mg/m^3, with decline percentage is 23.84 %. On the other hand, if we use the proposed intelligent method, the HCHO concentration changes from 1.25 mg/m^3 to 0.06 mg/m^3, with decline percentage is 95.2 %, furthermore, at the 40 minutes, the decline percentage is 91 %. Besides that, the change trend of other three gases all show that proposed method better than traditional natural ventilation method.

Table 4. Gas concentration detection under proposed control method condition.

Time (min)	CO_2 (ppm)	NO_2 (mg/m^3)	TVOC (mg/m^3)	HCHO (mg/m^3)
0	580	0.052	0.022	0.13
5	900	0.172	0.065	0.975
10	1190	0.231	0.106	1.252
15	900	0.195	0.102	1.193
20	850	0.133	0.065	1.075
25	795	0.102	0.025	0.812
30	700	0.063	0.018	0.405
35	650	0.033	0.013	0.202
40	600	0.012	0.008	0.112
45	550	0.007	0.006	0.08
50	500	0.005	0.006	0.06
55	450	0.005	0.007	0.07
60	430	0.005	0.006	0.06

If we used the evaluation criteria to assess the performance of the two methods, we could get the same conclusion. The final output of natural ventilation data is (685, 0.122, 0.034, 0.952), the evaluation results of this set data is "poor". While the finally data set of proposed method is (430, 0.005, 0.006, 0.06), the output of this data is "best", furthermore, the evaluation of eighth data set (600, 0.012, 0.008, 0.112) is already reached "best" level.

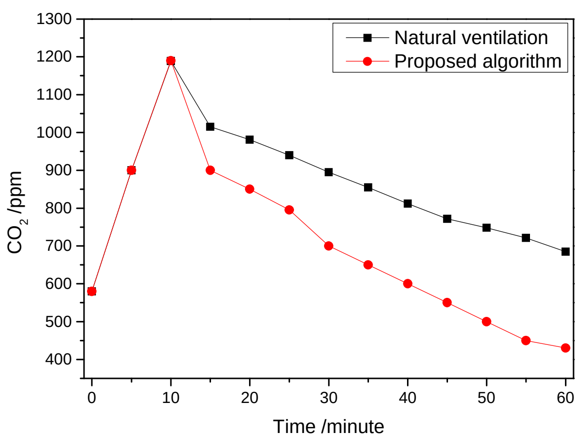

Fig. 7. CO_2 monitoring results.

4. Conclusion

The system proposed in this paper could not only monitor the indoor air quality, but also auto-control if the quality is poor, which is a high performance indoor environment control system. First we presented the evaluation indicator of four different kind pollutants, namely CO_2, NO_2, HCHO and TVOC, and then established a gas grade evaluation method based on genetic neural network model. This module could be used to evaluate or sort indoor air quality in different rooms. We designed the hardware and software of this systems based on LPC2478 microcontroller, which could measure temperature and other four pollutant gases. The results show that the system could adjust indoor air very quickly.

In the next phase work, we will add other kinds of sensors to extend the detection range, besides that, we should also consider the interference generated by other gases, and the Improve the air quality evaluation algorithm.

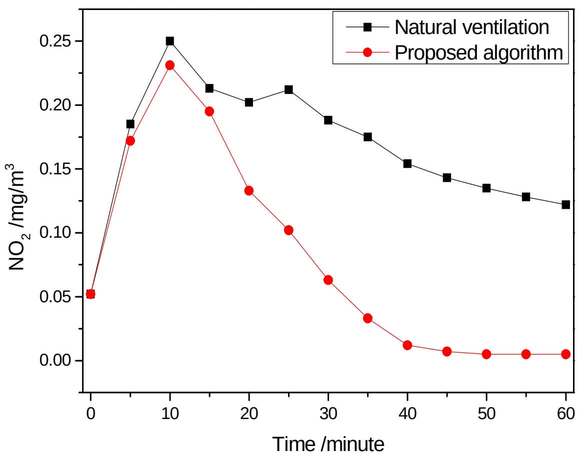

Fig. 8. NO_2 monitoring results.

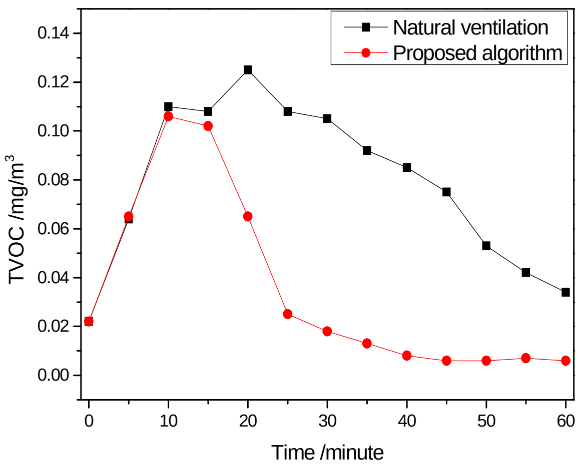

Fig. 9. TVOC monitoring results.

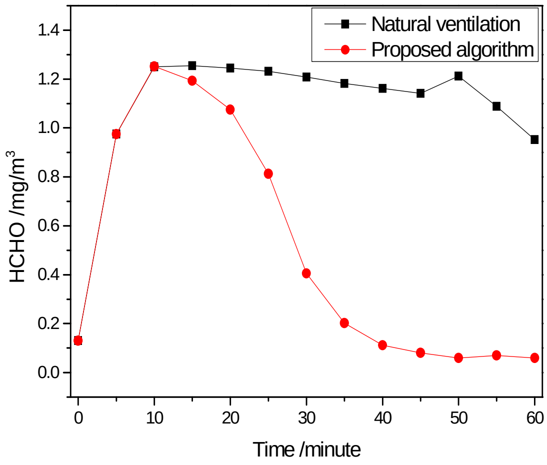

Fig. 10. HCHO monitoring results.

References

[1] World Health Organization, Indoor air pollutants:exposure and health effectt, *EURO Reports and Studies 78[R],Geneva:WHO*, 1983.

[2] L Molhave, The sick buildings and other buildings with indoor climate problems, *Environ Int* , Vol . 15. 1989, pp. 65-74.

[3] Al-Nimir, M.-Abu Nabah, B.-Naji, M., A Novel Summer Air Conditioning System, *Journal of Energy Conversion and Management,* Vol. 43, Issue 14, 2002, pp.1911-1921.

[4] Preethichandra D. M. G., Design of a smart indoor air quality monitoring wireless sensor network for assisted living, *Minneapolis, MN, United States: Institute of Electrical and Electronics Engineers Inc.*, 2013.

[5] Gi H. C., Gi S. C., Joo H. J., A framework for wireless sensor network in Web-based monitoring and control of indoor air quality (IAQ) in subway stations, *Piscataway, NJ, USA: IEEE*, 2009.

[6] Orosa J. A., Oliveira A. C., Hourly indoor thermal comfort and air quality acceptance with passive climate control methods, *Renewable Energy*, Vol. 34, Issue 12, 2009, pp.2735-2742.

[7] Del Mar Castilla M., Alvarez J. D., Normey-Rico J. E., et al., A multivariable nonlinear MPC control strategy for thermal comfort and indoor-air quality, *Vienna, Austria: IEEE Computer Society*, 2013.

[8] Fong A. C. M., Fong B., Indoor air quality control for asthma patients using smart home technology, *Singapore, Singapore: Institute of Electrical and Electronics Engineers Inc*., 2011.

[9] Saha C. K., Zhang G., Kai P., et al.Effects of a partial pit ventilation system on indoor air quality and ammonia emission from a fattening pig room, *Biosystems Engineering*, Vol. 105, Issue 3, 2010, pp. 279-287.

[10] Wei X., Li N., Zhou H, et al. Investigation and analysis summer on indoor air quality of one urban large commercial office building in Changsha City, *China, Nanjing, China*, 2009.

[11] Xiongyi LI, Weihua XU, Research on Applications of BP Neural Network in Forecasting Enterprise's Network Marketing Sales, International Conference on Management Science and Engineering, 2007, pp. 1018-1023.

[12] Wenjian Wang,Zongben Zu,Jane Weizhen Lu.Three improved neural network models for air quality forecasting, *Engineering Computations*. Vol. 20, 2003, pp. 192-211.

[13] Ping L I, Yucai Z, Xiangjun Z, et al.A Design of the Temperature Test System based on Grouping DS18B20, *2nd IEEE Conference on Industrial Electronics and Applications*, 2007, pp. 188-191.
