Power Station Flue Gas Desulfurization System Based on Automatic Online Monitoring Platform

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JDIM
Journal of Digital Information Management

ABSTRACT: *SO_2 and NOx are important components of atmospheric pollutants produced by coal combustion process and significant emissions of these gases keep deteriorating urban air quality and cause a great threat to soil, water and forest. The increasingly serious environmental pollution not only resulted in significant economic losses, but also had a great impact on human health. Application of automated on-line monitoring system is one of the effective ways to improve environmental monitoring technology. Therefore, according to actual needs, automated environmental monitoring technology is applied to build up an environmental monitoring system with intelligence, high precision and high reliability, which can be used in the specific environment of daily living and production. This study puts forward an automatic environmental monitoring technology. With comprehensive consideration of working environment particularity of the environmental parameter monitoring system as well as working characteristics of Single Chip Microcomputer (SCM) and front-end sensor, a design scheme for environmental parameter monitoring system with AT89C52 as the core is put forward. With a combination of data acquisition, analysis and processing, display and data communications, the scheme can ensure the efficient and stable realization of all design requirements by the system. According to the design requirements, signal acquisition and processing is realized, corresponding actuators are controlled and necessary assessment is provided. Meanwhile, all data are centralized displayed and uploaded to upper computer.*

Subject Categories and Descriptors
B.7 [Integrated Circuits]: Single chip microcomputer and sensor

J.6 [Computer-aided Engineering]: Environmental parameter monitoring

General Terms: Single chip microcomputer, software design

Keywords: Automation, Environmental Parameter Detection, sensor, Serial Port Communication, Single Chip Microcomputer

Received: 14 June 2015, Revised 19 July 2015, Accepted 25 July 2015

1. Introduction

China is a country with coal as its main energy source. For the past two years, coal consumption [1] has remained at around 30 billion tons. This energy structure determines that China's power industry is necessarily a coal units based one [2]. In China, more than 95% of the thermal power industry takes coal as raw material, so thermal power plant has become one of the major emission sources of air pollution. With the dramatic increase in coal demand in recent years, effect of flue gas on the surrounding environment has become increasingly serious. Therefore, monitoring on industrial pollution sources [3] and the atmosphere has become increasingly important.

The application of automatic monitoring system can realize the real-time and intelligent monitoring and control of each subsystem of coal production. Besides, prompt alarm is available when problem occurs, and monitoring personnel can also remotely activate or deactivate the device. In addition, query and statistics as well as generation and export of data report of production monitoring can be realized, which is beneficial for summary and analy

sis of the historical work. In a word, automatic monitoring system can greatly improve production efficiency and safety.

In recent years, many scholars in China and abroad have carried out researches on this aspect. For example, Jin Li, AN Hong guang, LI Jiu yi, et al. [4] studied on technological process of sintering machine ammonia desulphurization system, hardware configuration of DCS control system, main analog quantity control of SO_2 and pH, system sequential control and on-line flue gas monitoring system in 2011. Wang H, Song Q, Yang R M, et al. [5] found in 2010 that coal-fired boiler flue gas emissions of coal-fired power plants, metallurgical plants, chemical plants and cement plants caused serious harm to the atmosphere, and the real-time continuous monitoring of flue gas pollutants was an important prerequisite for effective governance of atmospheric polluting stationarysources. Ettouney R S, Fawzi N A, El-Rifai M A, et al. [6] put forward in 2012 a new method which could simultaneously measure two kinds of gas concentration based on absorption characteristics of SO_2 and NO in ultraviolet region, and accomplished concentration measurement of SO_2 independent existence and coexistence of SO_2 and NO_2. This study takes the power station flue gas desulfurization system based on automatic online monitoring platform as the research object and carries out the experimental study.

2. Scheme Design of Automatic Environmental Parameter Acquisition System

2.1 Overall Design of System Scheme

According to the basic step requirement, the overall design of automatic environmental parameter acquisition system includes: lower computer design of environmental parameter collector and transmission module constitution system; upper computer design made up of PC and corresponding transmission modules.

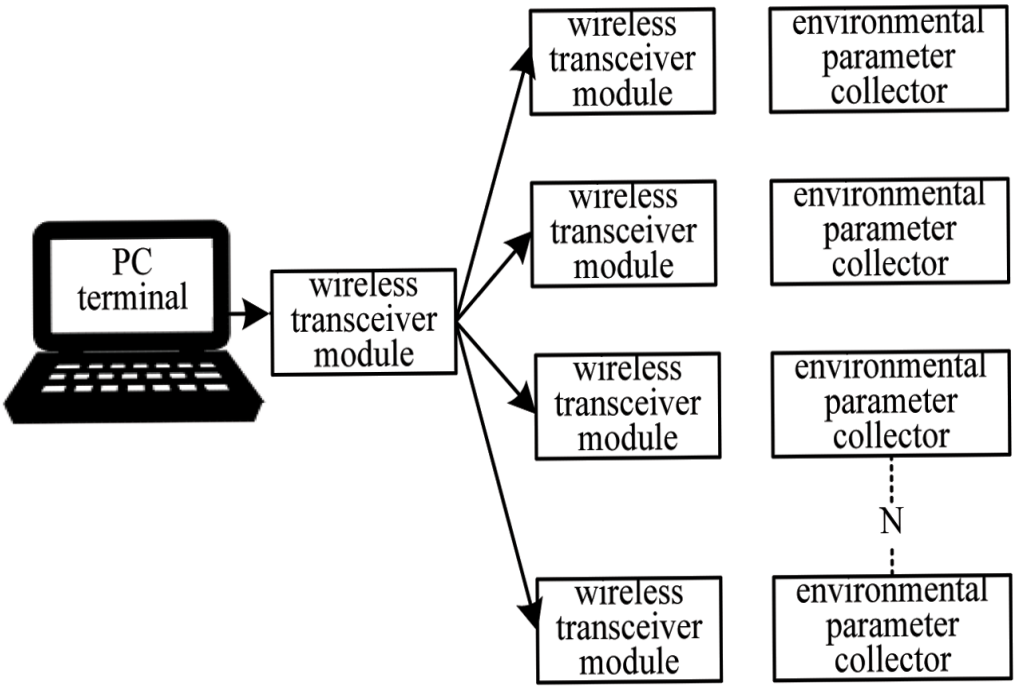

Figure 1. Design schematic diagram of environmental parameter monitoring system

2.2 Data Fusion Technology

2.2.1 Principle and Application of Two Level Information Fusion Technology

(1) Information Fusion Structure of Regional Environmental Monitoring

Data fusion structure adopted parallel connection before series connection and data fusion algorithm with small calculated amount and high accuracy was selected. That is to say, Bayes parallel fusion was carried out first on homogeneous data source and fusion analysis on grey relational degree was then carried on heterogeneous data source. After that, two level data fusion of partial parallel and overall serial was performed on regional environmental parameters [7], as shown in figure 2.

(2) Bayes One Level Fusion Data Preprocessing of Regional Environmental Parameters

Grubbs criterion can effectively sift out negligence and error in measured data with small sampling size, therefore is with high stability. Through repeated detection with equal precision on flue gas indicators (SO_2 and NO_2 concentration, particulate matter concentration) of flue gas desulfurization system, a set of column vectors was obtained: $X1, X2, X3, \ldots Xn$; then these vectors were arranged from low to high as follows: $Y1, Y2, Y3, \ldots Yn$ ($Y1 \leq Y2 \leq Y3 \leq \leq Yn$) and the measured value Yi ($i = 1, 2, \ldots, n$) obeyed normal distribution, then Grubbs criterion can effectively sift out negligence and error in measured data with small sampling size, therefore is with high stability. Through repeated detection with equal precision on flue gas indi

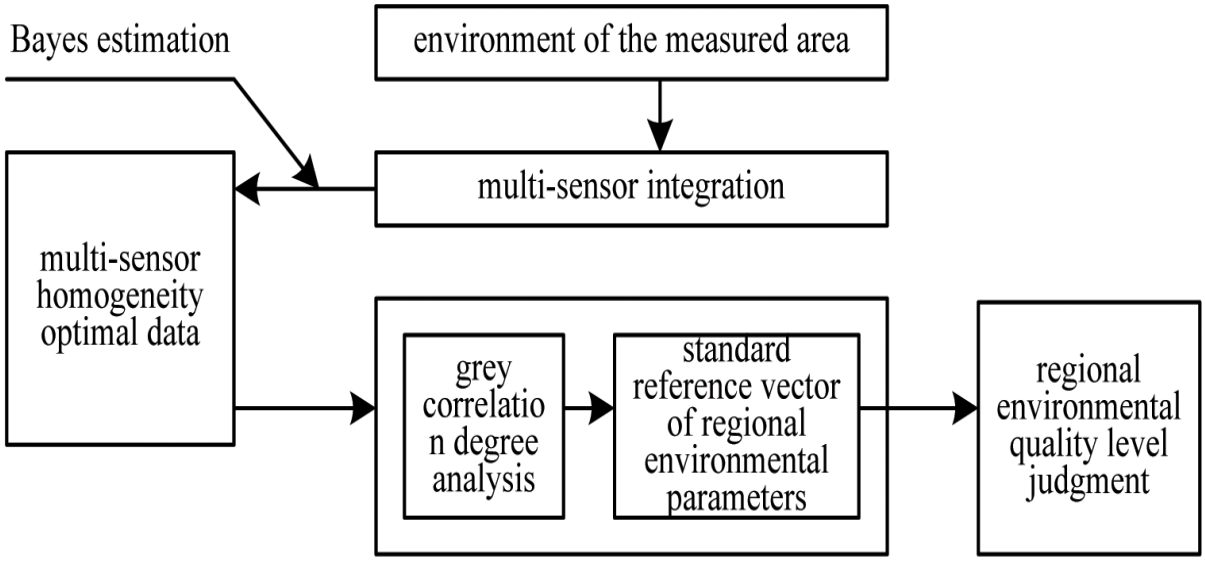

Figure 2. Information fusion process

cators (SO_2 and NO_2 concentration, particulate matter concentration) of flue gas desulfurization system, a set of column vectors was obtained: $X_1, X_2, X_3, \ldots X_n$; then these vectors were arranged from low to high as follows: $Y_1, Y_2, Y_3, \ldots Yn$ ($Y_1 \le Y_2 \le Y_3 \le,\ldots \le Y_n$) and the measured value Yi ($i = 1, 2, \ldots, n$) obeyed normal distribution, then

$$\overline{Y} = \frac{1}{n} \times \sum_{i=1}^{n} Y_i \quad (1)$$

$$V_i = Y_i - \overline{Y} \quad (2)$$

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} V_i} \quad (3)$$

According to order statistics principle [8], exact distribution of $g = \frac{Y_n - \overline{Y}}{\sigma}$ can be confirmed as standard normal distribution. Therefore, after given the significant level ±(generally 0.01 or 0.05), critical value of Grubbs statistics ga (n, σ) can be obtained through look-up table method, i.e., $P(g_i > g_a(n, \sigma)) = a$ is a small probability event, which should not appear when X_i observes normal distribution. Data fusion method based on Bayes estimation [9]. Definition 1 (Bayes estimation): suppose parameter θ in $F(x, \theta)$ as a random variable, for any decision function $d(\xi_1 \ldots \xi_n)$, if there is one decision function $d^*(\xi_1 \ldots \xi_n)$ which makes

$$\{B(d^*) = \min B(d)\} \quad (4)$$

Then d^* is called Bayes estimator of θ, of which, $B(d)$ is the Bayes risk of $d(\xi_1 \ldots \xi_n)$.Theorem 1: if quadric expression $L(\theta - d) = [\theta - d(\xi_1 \ldots \xi_n)]^2$ is selected as the loss function, then Bayes estimator of θ is

$$d(\xi_1 \ldots \xi_n) = E\left\langle \theta \middle| \xi_1 \ldots \xi_n \right\rangle = \int \theta P\left\langle \theta \middle| \xi_1 \ldots \xi_n \right\rangle d\theta.$$

Therefore, before seeking the Bayes estimated value, we only need to seek solution to $P(\theta|\xi_1 \cdots \xi_n)$ [10].

Suppose there are altogether m data samples after optimizing process of Grubbs criterion, R is the fusion set, then Bayes estimated value of R is:

$$R' = \frac{\sum_{i=1}^{m} \frac{R_i}{\sigma_1^2} + \frac{R_0}{\sigma_0^2}}{\sum_{i=1}^{m} \frac{1}{\sigma_1^2} + \frac{1}{\sigma_0^2}} \quad (5)$$

In equation (5), R_i represents the ith estimated value; σ_i represents standard deviation of the ith estimated value; R_0 represents the mean value of m estimated values; σ_0 represents standard deviation of m estimated values.

Combining Bayes estimation theory with Grubbs criterion, optimized data processing was carried out. Then, SO_2 values after processing can be used as optimal fusion data. Similarly, optimal fusion values of humidity, wind speed, noise and CO2 concentration can be obtained.

2.2.2 Two-level Fusion of Regional Environment Based on Grey Correlation Degree Analysis

Grey correlation degree analysis [11]: the correlation degree is judged by similarity degree on geometrical shape of sequence curves. The closer the connection is, the more similar the sequence curves will be on geometrical shape, the greater the correlation degree between the corresponding sequences. Through the analysis of system characteristic advantages based on grey correlation degree between feature vector and standard feature vector of environmental conditions, regional environmental conditions can be considered as a whole. Finally, according to the value of correlation degree r, judgment on regional environmental quality can be given by the monitoring system [12].

Suppose the feature vector $X=[x(1)x(2)x(3)]$ of the above flue gas indicators as the comparison sequence; $x(1)\sim x(3)$ represents SO_2 concentration, particulate matter concentration and NO_2 concentration respectively; Standard feature vector $Y=[Y1\ Y2\ Y3\ Y4\ Y5\ Y6]T$ is the feature sequence of the monitoring system, $Yi=[x(1)x(2)x(3)](i=1\sim 5)$. Then, grey correlation coefficient between X and Yi is as follows [13]:

$$r_i(k)=\frac{\left[\min_i\min_k|Y_i(k)-X(k)|\right]+\left[\rho\max_i\max_k|Y_i(k)-X(k)|\right]}{|Y_i(k)-X(k)|+\rho\max_i\max_k|Y_i(k)-X(k)|} \quad (6)$$

Of which, ρ is the resolution coefficient, ρ ∈ (0,1); the smaller the p value, the greater the resolving ability will be, generally ρ = 0.5 is taken. Grey correlation calculation formula is as follows:

$$r_i=\frac{1}{4}\sum_{k=1}^{4}r_1(k) \quad (7)$$

Finally, correlation r [14] between X and Yi can be obtained through calculation of feature vector X and standard feature vector Y of regional environment formed after Bayes approximation optimization according to equation (6) and (7). Then, environmental quality of the measured area can be obtained through grey correlation analysis.

3. System Hardware Design

3.1 Data Acquisition Principle of Automatic Environmental Parameters

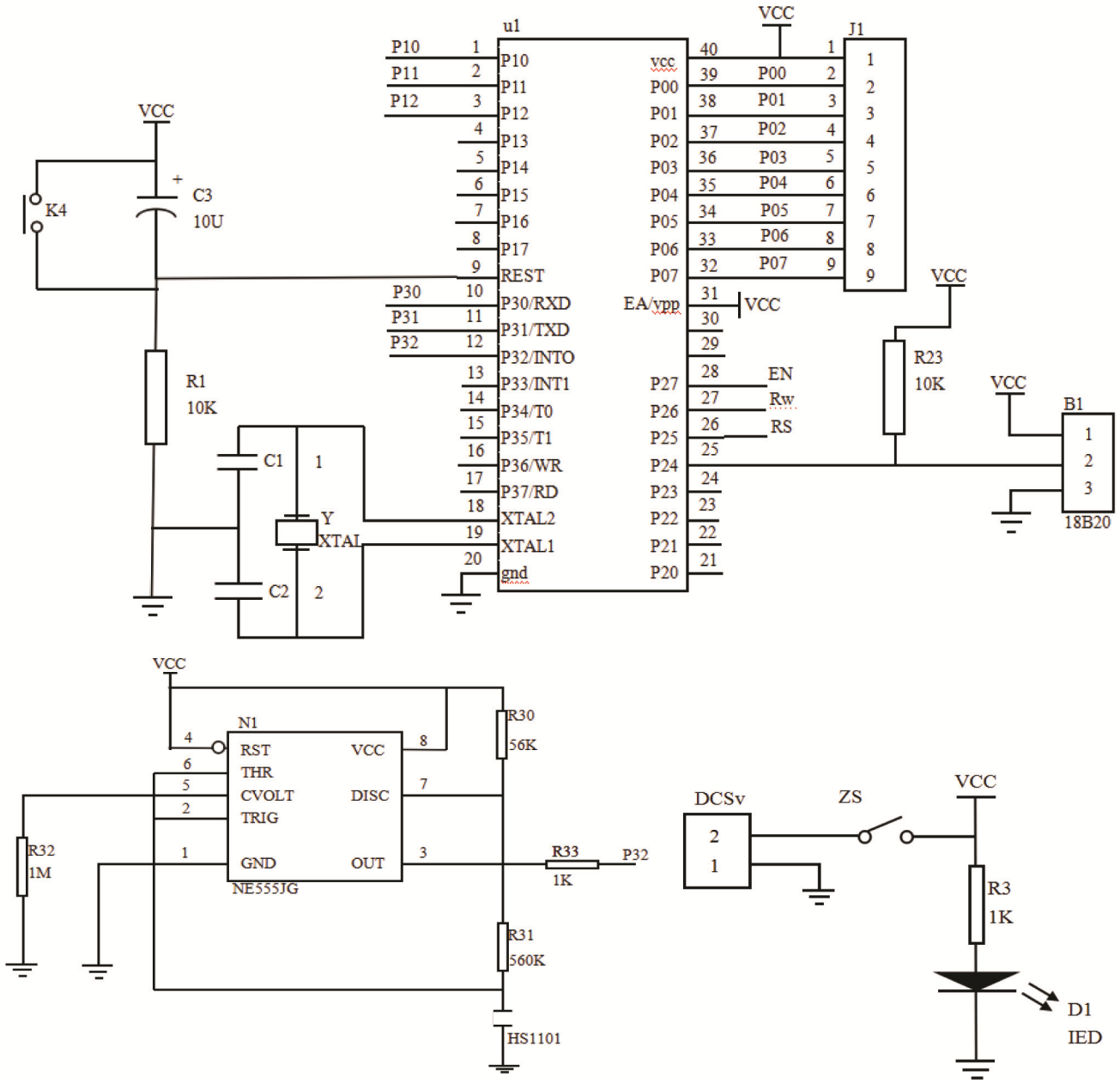

Figure 3. Schematic circuit diagram of the environmental parameter collector

Data acquisition connected computer to the external physical world, with the development of the environmental monitoring technology, it is becoming more and more important. The principle of data acquisition for environmental parameters is as follows: suppose to make a sampling on an analog signal $X(t)$ in Δt time period; of which, time interval Δt is the sampling interval period; $1/\Delta t$ is the sampling frequency; unit: number of samples/ second. The value of $X(t)$ is called sampling value. According to the sampling theorem, the lowest sampling frequency must be two times as large as the signal frequency; otherwise, if the sampling frequency is determined, the maximum frequency to display the signal correctly without producing distortion is called nyquist frequency, whose frequency value is generally a half of that of the sampling frequency.

3.2 Automatic Environmental Parameter Acquisition Based on Single Chip Microcomputer (SCM)

Environmental parameter collectors include: temperature sensor DS18B20, humidity sensor HS1101, SCM with main control chip AT89C52, SMC1602B liquid crystal display, power module, serial communication modular and peripheral circuits (schematic circuit diagram as shown in figure 3). Application of SCM AT89C52 can directly realize the on-site collection and display of parameters such as temperature, humidity, etc [15] by uploading data to PC in monitoring center for archiving and analysis through RS232 serial interface. The monitoring system makes continuous inspection on each subordinate node and temperature and humidity value intervals are stored in a specific time. For the abnormal temperature and humidity moments, the temperature and humidity values will be stored immediately for monitor terminal to check at any time.

3.3 Wireless Transmission Module Selection: Weikong Unvarnished Transmission Module

Weikong unvarnished transmission module has the characteristics of convenient use and high performance cost ratio and its main function is to realize unvarnished transmission within RS232 group and RS485 group. Flexible configuration of network and serial port parameters can be realized according to the actual need and configuration mode and working mode are mainly controlled by the dial switch (wireless transmission module system block diagram is shown in figure 4, connection terminal configuration is shown in table 1, serial port communication scheme adopted in this system is shown in figure 5).

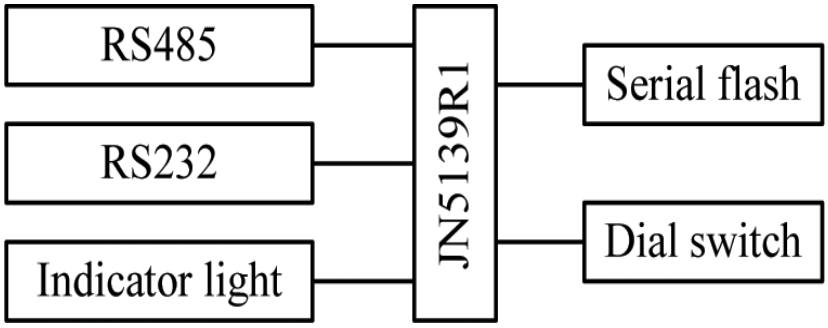

Figure 4. Block diagram of wireless transmission module system

Port description	Port number	Port name	Port description	Electrical characteristics
Input power	1	VI	power supply 9~36V DC positive	input
	2	GND	power supply point	ground
RS232serial port	3	TXD	serial port delivery	output
	4	RXD	serial port reception	input
	5	RPG	programming procedure pin	input
	6	GND	serial port	ground
RS485 serial port	7	D+	RS485 data line A	output
	8	D-	RS486 data line B	input

Table 1. Connection terminal configuration instruction

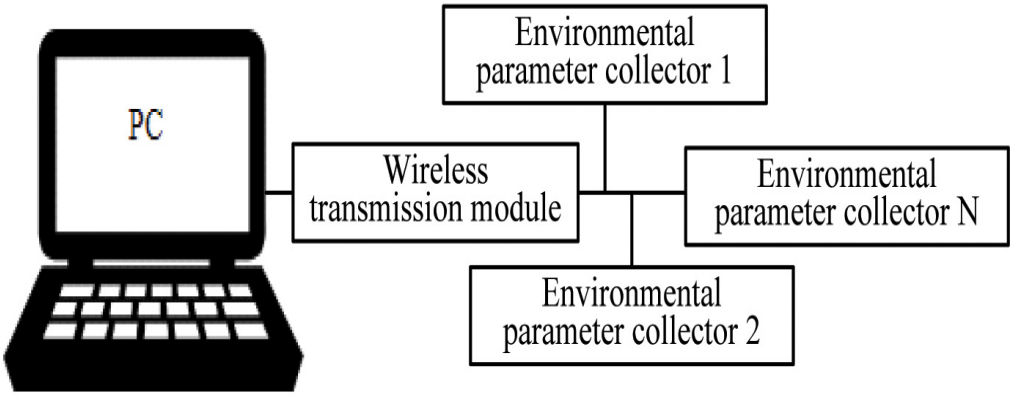

Figure 5. Serial port communication scheme

4. Design of System Software

4.1 Principle of Software Design

(1) Comprehensive consideration of software design and hardware circuit design is required. The design of computer control system includes both hardware and software. One of the key principles in writing control software is the correct matching of software and hardware so that they can play their own advantages to meet the needs of control system in different application fields.

(2) Function modularization of each part of the program design is required which is beneficial for debugging and modification of the system.

(3) Rational classification is required at the beginning of the design on program storage area, and data storage area and effective space should be reserved for function extension.

(4) Software design should give full play to the characteristics of high level language.

4.2 Software Overall Design

The main program flow chart of main control unit of environmental parameter collector in lower computer of the system is shown in figure 6.

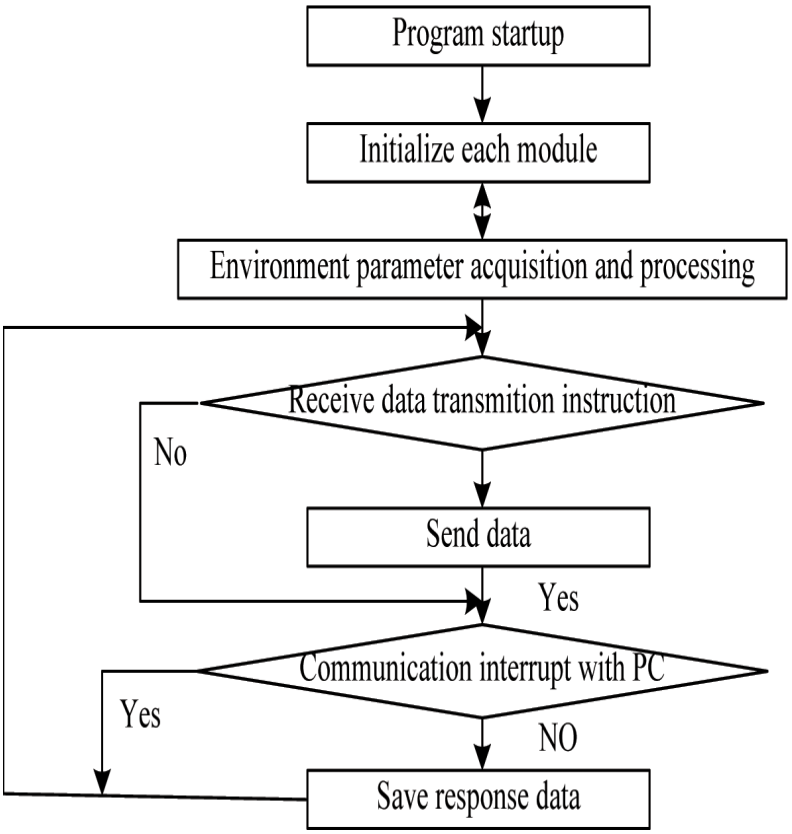

Figure 6. Main program flowchart

4.3 Communication Software Design of Upper Computer

The main communication function of upper computer is to call each lower computer and transfer control instruction [16].

The main flow chart of upper computer is as follows: the upper computer sends the data address of the lower computer which needs to be called and wait for the response of the lower computer. If the response is correct, control command can be sent. If not, the data address needs to be sent again. If several times of call has been performed on the same lower computer without receiving response signal within the required time or receiving wrong signal, then error is reported.

4.4 Communication Software Design of Lower Computer

The main communication function of lower computer is realized through series interruption and zone bit checking of sending and receiving state by SCM AT89C52. Serial interface mode selects asynchronous communication model [17] with eight data bits and two stop bits. Baud rate is set to be 9000, with global interrupt zone bit, so as to receive a serial port interrupt instruction (detailed program flow chart is shown in figure 7)

5. Test Results

The data obtained from environmental parameter acquisition system was processed with two level information fusion processing algorithm to get a relatively more accurate environmental quality assessment report of the measured area. Grubbs criterion was applied to process SO_2 content quality of PM2.5 particles in regional environment and the results is shown in table 2.

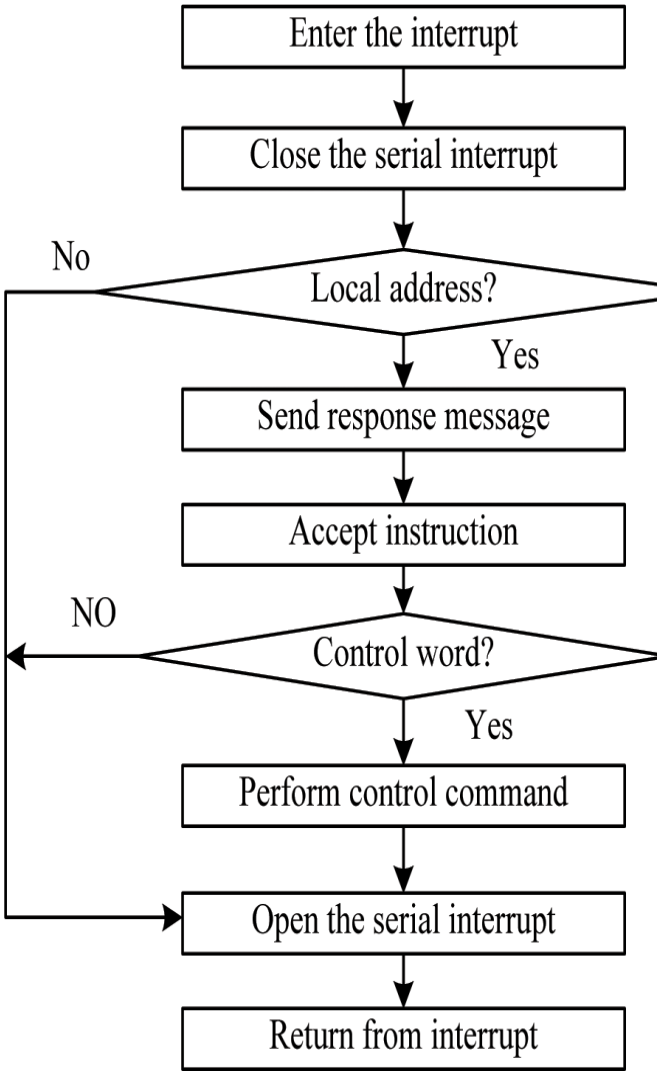

Figure 7. Processing flow chart of serial interrupt of lower computer

Vi	-7.76	-5.73	-4.72	-1.78	1.26	4.26	6.26	8.76
Yi	101	103	104	107	110	113	115	117

Table 2. SO_2 monitor data and residual error of β-ray particulate matter (/μ g.m-3)

By applying Grubbs criterion [18], $\alpha = 0.05$ was selected as significance level. Then, three negligent errors of 113, 115 and 117 were removed. Thus, consistent data of SO_2 quality per cubic meter of PM2.5 particles were obtained, as shown in table 3.

Similarly, real-time optimal fusion value of NO_2 and particle concentration can be obtained.

Vi	-7.76	-5.73	-4.72	-1.78	1.26
Yi	101	103	104	107	110

Table 3. consistent data of SO_2 quality per cubic meter of PM2.5 particles (μ g.m-3)

According to table 4, reference vector of air environmental quality was selected. $Y1 \sim Y6$ represented respectively air quality level of excellent, good, mild pollution, moderate pollution, heavy pollution and serious pollution. Correlation degree $r = [0.5571\ 0.5957\ 0.6445\ 0.7038\ 0.8170\ 1.0000]$ was obtained through calculation on regional environmental feature vector $X=[X_1, X_2, X_3]$ (X_1, X_2, X_3 are respectively measured value of SO_2, dust concentration and NO_2) and standard feature vector Y based on formula of grey correlation degree. From the perspective of correlation degree, they can be arranged from high to low as $r6 > r5 > r4 > r3 > r2 > r1$, suggesting that regional environmental feature vector X has the largest correlation with serious pollution. It means that the flue gas desulphurization

SO_2 / μ g.m-3	0-111	112-151	152-201	202-251	252-300	>300
PM2.5 particles/μ g.m-3	0-36	37-76	77-116	117-151	152-250	>250
NO_2/μ.m-3	0-61	62-81	82-101	102-121	122-140	>140
Air quality condition	excellent	good	mild pollution	moderate pollution	heavy pollution	serious pollution

Table 4. Air environmental quality condition

system of the power station mainly presents the environmental condition of serious pollution; moreover, correlation degree of serious pollution is much greater than that of heavy pollution. Therefore, quality level of dust particle concentration, SO_2 concentration and NO_2 concentration of the flue gas desulphurization system of the power station is evaluated as serious pollution. According to the environmental quality assessment form released by power plant inspection department, error is found small between flue gas indicators detected by the platform and actual situation, which shows that data processing method based on two level information fusion can accurately reflect the environmental quality condition of the measured area, suggesting further improvement of the desulfurization system at the same time.

6. Conclusion

Through overall operation of the system, desired results were achieved. Thus it can be seen that the design in this study has feasibility. This system is suitable for some small local area and the collector has the characteristics of simple structure, small size, high performance cost ratio, strong operability and good flexibility. Still, there are some details which need to be improved. For instance, serial communication part of the upper computer only realized data upload; visual basic human-computer interface design of upper computer failed to meet the control function and merely displayed data uploaded by lower computer; since the design is still in experiment stage, acquisition part of the lower computer can only test temperature and humidity parameters in actual hardware circuit design. For other parameters, for example, noise signal is connected with PC through using microphone as an acoustic sensor and acquisition processing is carried out based on Cool Editpro software. As a whole, this system designed a basic human-computer interaction interface which is convenient for operation, therefore has wide application prospect.

Acknowledgements

Project is supported by the Fundamental Research Funds for the Central University Special Fund Project (No. 11D11315), the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry (No.201109), the Master Dissertation Innovation Funded Projects (No. EG2013015), Program of Shanghai Subject Chief Scientists (14XD1424700)

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