Study on Remote Monitoring Method of Indoor Temperature and Humidity in Large Space Buildings

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Abstract: Aiming at the shortcomings of the traditional method for temperature and humidity monitoring, such as low accuracy and poor anti-interference, a method combining a stepwise regression model and artificial bee colony algorithm is proposed for monitoring indoor temperature and humidity in large space buildings remotely. The fast frontier transform is utilized for spectrum-estimating indoor temperature and humidity, and frequency domain characteristics of temperature and humidity signal spectrum estimation results are analyzed to establish the evaluation standard for frequency domain characteristics, and the standard is applied to the monitoring model to ensure the accuracy of the monitoring results. The experimental results show that the proposed method can monitor the indoor temperature and humidity in large space buildings accurately and remotely, and the monitoring results are better.

Keywords: Large Space Buildings; Indoor Temperature and Humidity; Remote Monitoring

1. Introduction

In large space buildings, the temperature and humidity affect people's comfort. Through the monitoring of temperature and humidity, changes of other indoor factors can be realized (Cui, Liu, Li, 2017; De et al., 2016). At present, in widely used system for monitoring indoor temperature and humidity in large pace buildings remotely(Fedoseeva, 2015; Jia et al., 2015; Lee et al., 2015), the hardware circuit of upper computer utilizes ultra-low power microcontroller MSP430 and high precision temperature and humidity sensor SHT10 as temperature and humidity detection component, and connected with wireless ZigBee transceiver; lower computer employs National Instruments LabVIEW software to achieve wireless transmission to the computer, and with an intuitive display and operation of visual interface and operation to achieve temperature and humidity on-line detection. This method is the main method to solve the problem because of its good anti-interference performance With the deepening of the research content, fruitful research results have been produced (Meikle, Holst, 2015; Ren et al., 2015; Shi, Zhang, 2015).

Shi et al. put forward the wireless detection method of temperature and humidity based on ZigBee and LabVIEW (Sang, Lee, Yi, 2015). However, this method has low monitoring accuracy due to poor anti-interference in signal monitoring. A design method of temperature and humidity monitoring system during storage and transportation based on cos II is proposed (Savoie et al., 2015). The low power strategy is adopted to reduce the minimum power consumption to below 200 μA by embedded design. The temperature and humidity data collected by this method is easy to be lost, thus affecting the accuracy of monitoring. Zhu et al. presented a design method of temperature and humidity monitoring system used in museums (Zhu, Qin, Wang, 2016). It takes SI4432 wireless transceiver and STM8L microprocessor as the core, and uses SHT15 to collect temperature and humidity information. However, the temperature and humidity monitoring system designed by this method affects the accuracy of monitoring because of the higher error rate and packet loss rate of the temperature and humidity data. Aiming at the above problems, a method for monitoring indoor temperature and humidity of large space buildings remotely is proposed based on the stepwise regression model and artificial bee colony algorithm. The experimental results show that the proposed method can timely and accurately monitor temperature and humidity of the large space buildings.

2. Remote Monitoring Methods of Indoor Temperature and Humidity in Large Space Buildings

2.1. Modeling of indoor temperature and humidity in large space buildings based on artificial bee colony algorithm and stepwise regression model

A temperature and humidity vector d in a large space building can be decomposed into a humidity component d_H, a temperature component d_T and time component d_q, of which the humidity component has linear relationship with heights H^1, H^2, H^3, H^4 of collection point, that is:

$$d_H = \sum_{i=1}^{n} a_i H^i \tag{1}$$

Wherein, $n \in (1,2,3,4)$, generally $n=3$ for the indoor of large space buildings.

For the problem of indoor temperature and humidity of large space buildings with n groups of observation data, the regression model can be expressed as:

$$\begin{cases} y_1 = a_0 + a_1 X_{11} + a_2 X_{12} + \cdots + a_p X_{1p} + e \\ y_2 = a_0 + a_1 X_{21} + a_2 X_{22} + \cdots + a_p X_{2p} + e \\ \vdots \\ y_n = a_0 + a_1 X_{n1} + a_2 X_{n2} + \cdots + a_p X_{np} + e \end{cases} \tag{2}$$

That is:

$$y = Xa + e \tag{3}$$

The estimation of parameters of regression model needs to meet the following assumptions:

1) there is a linear relationship between dependent variable y and independent variables $X_1, X_2, \cdots, X_p$;

2) the random error e has 0 mean and equal variance, and obeys the $N(0, s^2)$ distribution;

3) there is no strong correlation and multicollinearity among independent variables $X_1, X_2, \cdots, X_p$.

The mathematical model of stepwise regression is:

$$y = bX + e \tag{4}$$

Among them, y is the effect set, X is the influence set, and b is the coefficient of influence set, that is, the regression coefficient, and b is the random error. There are k independent variables $X_1, X_2, \cdots X_k$, and X_1 has n groups of observation data $(y_i, X_{i1}, X_{i2}, \cdots X_{ik}), i \in [1, n]$, there is:

$$X = \begin{Bmatrix} 1 & X_{11} & \cdots & X_{1k} \\ 1 & X_{21} & \cdots & X_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & X_{n1} & \cdots & X_{nk} \end{Bmatrix} \tag{5}$$

The artificial bee colony algorithm is a swarm intelligence optimization algorithm, which is based on the self-organizing simulation model of bee swarm intelligence. It is successfully applied to the problem of function numerical optimization. Position of each nectar source in the program algorithm (i.e. decision variable of the unknown function) represents a feasible solution of the optimization problem, the quality of nectar source is the quality of corresponding feasible solution.

In the remote monitoring of temperature and humidity, the nectar content of the food source corresponds to the fitness of temperature and humidity:

$$FIT_i = \begin{cases} \dfrac{1}{1 + fit_i} & fit \ge 0 \\ 1 + abs(fit_i) & fit < 0 \end{cases} \tag{6}$$

In the Equation, fit_i represents the quality of corresponding nectar, and higher nectar quality corresponds greater fitness. The possibility of bee to choose certain group of nectar source is:

$$X_{ij} = x_{ij} + f(x_{ij} - x_{kj}) \tag{7}$$

Where f is the random number of $(-1,1)$, $j \in (1,d)$, $k \in (1,n)$, here k is randomly selected, but $k \ne i$. The neighborhood range of original nectar source is controlled through this, and nectars can learn from each other and get closer with optimal solution. With the gradual approximation to the optimal solution, the neighborhood range is gradually reduced, and the step size can be adaptively reduced. If a nectar source has not been improved after limited numbers, the position is given up, and operation of scout bees are performed:

$$X_i^j = x_{\min}^j + rang(0,1)(x_{\max}^j - x_{\min}^j) \tag{8}$$

Here $x_{\max}^j$ and $x_{\min}^j$ are the upper and lower bound for $\in (1,2,\cdots,d)$ of j dimensions, the purpose is to reduce the blindness of the new random nectar source, and improve the anti-interference of monitoring. Through the above discussion, we can get the process of artificial bee colony algorithm as shown in Figure 1.

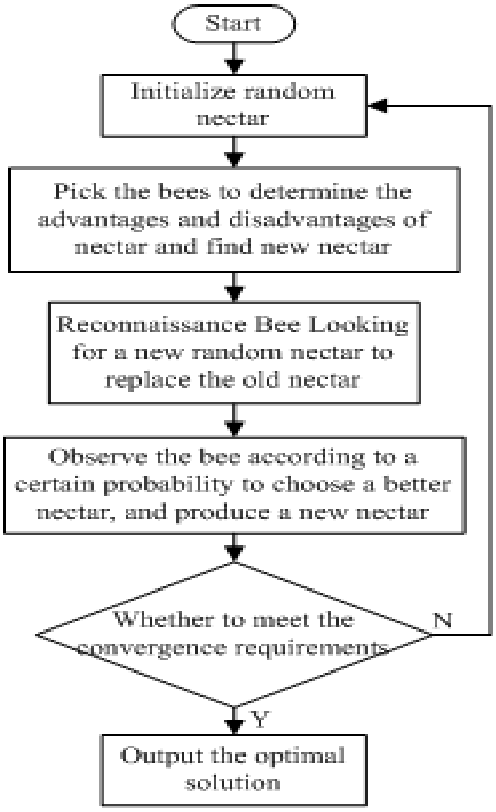

Figure 1. Flow of artificial bee colony algorithm

(1) based on the stepwise regression analysis model to the regression model is established;
(2) let load coefficients as decision variables of the objective function of artificial bee colony algorithm, to make full use of the stepwise regression analysis. The decision variable x_i is valued randomly in the domain of definition $(x_{\min}^j, x_{\max}^j)$, so as to improve the optimization speed and efficiency;
(3) the residual sum of square is regarded as the objective function to convert it into an optimization problem for the external function, if there are s groups of observation samples, the real temperature and humidity is y_i, and the prediction of artificial bee colony algorithm of stepwise regression model is $\hat{y}_i$, then the objective function is:

$$\min(g) = \sum_{i=1}^{s} (y_i - \hat{y}_i)^2 \quad (9)$$

(4) after the new solution is obtained, we calculate the statistical parameters of the model and compare it with the original model. This process is repeated until the decision variable reaches the satisfied precision. Through the above discussion, the indoor temperature model of large space buildings is established.

2.2. Frequency domain characteristic analysis of temperature and humidity monitoring

Fast Frontier transform is the fast algorithm of discrete Frontier transform, which is based on parity properties of the discrete Frontier transform. It greatly reduces the computation of discrete Frontier transform.
The N point discrete Frontier transform of the finite temperature and humidity sequence $X(n)$ is:

$$X(n) = \sum_{n=1}^{N-1} x(n) W_N^{kn} \quad k = 0, 1, \ldots, N-1 \quad (10)$$

In the above Equation, $x(n)$ represents the term in the temperature and humidity sequence, W_N^{kn} represents the weight of the Fourier transform of temperature and humidity, and the length of sequence $x(n)$ is N, and satisfies that $N = 4^M$, $N = 4^M$ are natural numbers, then the fast Fourier transform of $x(n)$ can be expressed as :

$$X(k) = \sum_{n=4r} x(n) W_N^{kn} + \sum_{n=4r+1} x(n) W_N^{kn} + \sum_{n=4r+2} x(n) W_N^{kn} + \sum_{n=4r+3} x(n) W_N^{kn} \quad (11)$$

The above process includes the addition of the data window and the lattice window, so that the obtained power spectrum is an approximation and $\hat{P}(k)$ is the estimation result of the classical spectral. To minimize the error between the estimated result and the actual result, we obtain finite sequence $x_N(n)$ of length N from the infinite length random sequence $x(n)$, and then divide the square of the modulo by N to obtain the spectrum estimation:

$$\hat{P}(e^{jw}) = \frac{1}{N} \left| X_N(e^{jw}) \right|^2 \quad (12)$$

If the sampling sequence is uniformly sampled, then $\hat{P}(e^{jw})$ can be rewritten as $\hat{P}(k)$, i.e.:

$$\hat{P}(k) = \frac{1}{N} \left| X_N(k) \right|^2 \quad (13)$$

The obtained set $(x_i, y_i)(i = 1, 2, \ldots, m)$ of temperature and humidity data aligned with Gaussian function distribution features can be described with the Gaussian function when curve fitting is performed.
The Gaussian distribution is also called the normal distribution, and its distribution function is:

$$y_i = y_{\max} \cdot \exp\left(-\frac{(x_i - x_{\max})^2}{S} \right) \quad (14)$$

In the above equation, $y_{\max}$ represents the peak of the Gaussian distribution function, $x_{\max}$ represents the peak position, and S represents the half width information.
Natural logarithm is taken for both sides at the same time, there is:

$$\ln y_i = \left(\ln y_{\max} - \frac{x_{\max}^2}{S} \right) + \frac{2x_{\max}}{S} x_i - \frac{1}{S} x_i^2 \quad (15)$$

Setting $\ln y_i = z_i$, $\ln y_{\max} - \frac{x_{\max}^2}{S} = b_0$, $\frac{2x_{\max}}{S} x_i = b_1$, $-\frac{1}{S} = b_2$, the quadratic polynomial is obtained:

$$z_i = b_0 + b_1 x_i + b_2 x_i^2 \tag{16}$$

All obtained data is expressed in matrix form as:

$$Z = X \cdot B \tag{17}$$

In the above Equation, $Z = \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_n \end{bmatrix}$, $X = \begin{bmatrix} 1 & x_1 & x_1^2 \\ 1 & x_2 & x_2^2 \\ \vdots & \vdots & \vdots \\ 1 & x_n & x_n^2 \end{bmatrix}$, $B = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix}$, according to the least squares principle, the generalized least squares solution of the matrix B is:

$$B = (X^T X)^{-1} X^T Z \tag{18}$$

From B, three coefficients $y_{\max}$, $x_{\max}$ and S to be determined can be calculated.

Through the above discussion, the frequency domain feature evaluation standard is established, and the standard is applied to the monitoring model to ensure the accuracy of the monitoring results and realize the remote monitoring of the indoor temperature and humidity.

3. Experimental Results and Analysis

Experimental equipment: a computer, 5 Zigbee acquisition/relay nodes, a coordinator. Figure 2 shows the experimental equipment.

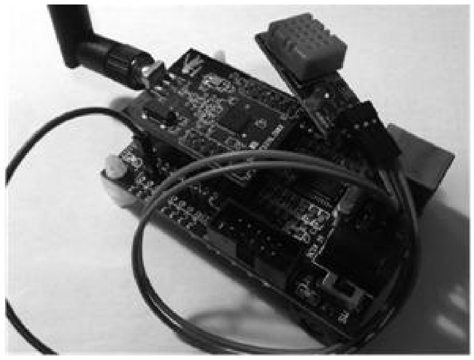

Figure 2. Experimental equipment

Experiment preparation:

(1) Configuration of nodes

After setting up the Z-stack protocol stack on the PC side, the IAR software is utilized to open the coordinator project file. Coordinator EB-Pro is selected under Workspace, and Project-> Rebuild All is chosen for compiling. The successful interface is shown in Figure 3. After compiling, the emulator is applied to connect the PC and the coordinator. Before downloading the program, the emulator reset button is pressed. After the emulator light is on, click Download and Debug button of the IAR software to download. When the download is complete, debug window appears at the upper left corner. When the reset button of the coordinator is pressed, then LED1, LED2 flashes, the burning of program in coordinator node is successful.

The IAR software is used to open the acquisition/relay node project file, and select End Device EB-Pro under Workspace, and then compile and download. Afterwards, the configuration of five acquisition/relay nodes are performed in the same form as that of the coordinator.

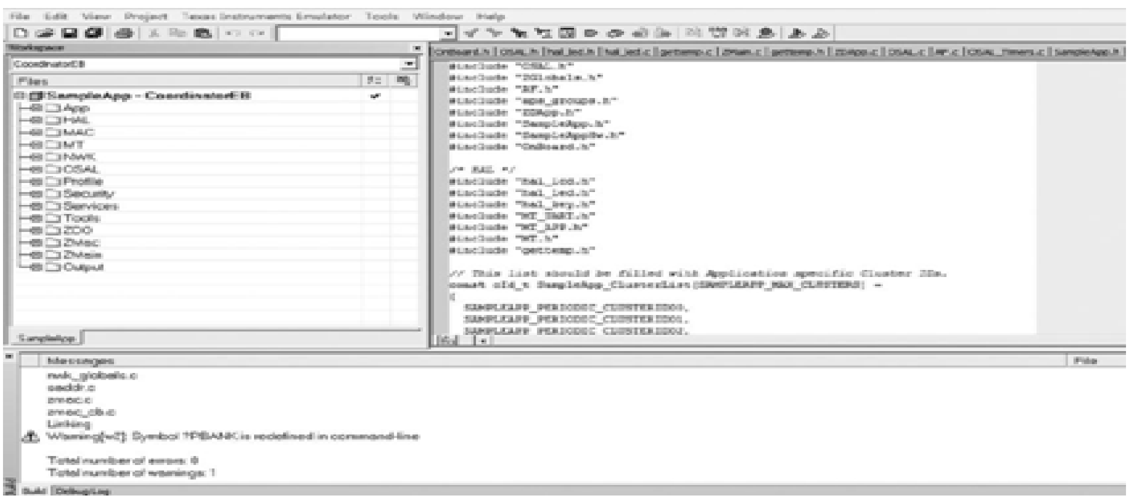

Figure 3. IAR compilation diagram

(2) Device initializations

After each node program is configured successfully, the coordinator is connected to the PC through the data cable.

When the green and red lights are on, it indicates that the connection is successful. Then, a Zigbee acquisition/relay node is opened. When the two yellow lights blink, the communication between the devices is successful. Afterwards, the other four acquisition/relay nodes are opened. After all the Zigbee nodes have joined the network, the test can be actually initialized.

(3) Turn on the host computer

The well-written Lab VIEW host computer program is open to enter the main interface, as shown in Figure 4. First, the "node selection" drop-down list is pressed to manually select the node to view. According to the actual situation, we can manually adjust the acquisition time. The upper and lower limits of the system temperature and humidity are set in advance. Once the temperature and humidity inside the building are beyond this range, the corresponding alarm lights will turn red to indicate the staff. The collected data is displayed in the temperature and humidity history data block so that you can view the temperature and humidity data in the lab in real time and store the data in a path of the computer.

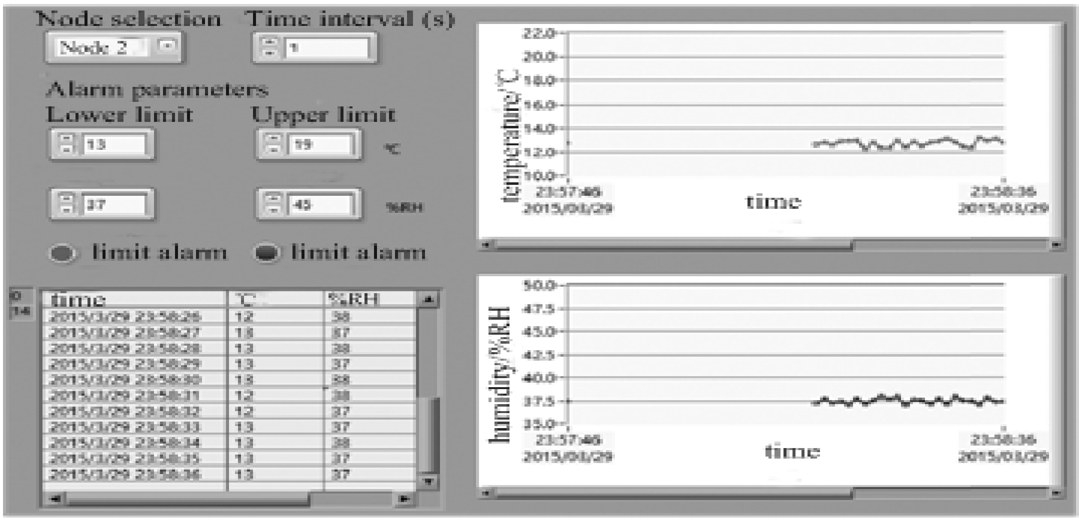

Figure 4. Main interface of remote monitoring

In order to verify the method described in this article can accurately monitor the temperature and humidity, and find and fix problems timely. The experimental environment has been adjusted to be close to the actual situation, each node is placed in a separate large space room, there are walls and other obstacles between rooms to block, and temperature and humidity values of each laboratory are not the same. Figure 5 shows the location of the node distribution map, where each box represents an isolated large space room. The coordinator and the host computer are placed in A, and five nodes are positioned in the B, C, G, I, J five large space rooms. As can be seen from the figure 5, there are wall barriers between the nodes, which directly lead to some nodes cannot be directly connected with the coordinator, that is, nodes in I and J rooms, so they need to be routed to communicate with the coordinator normally.

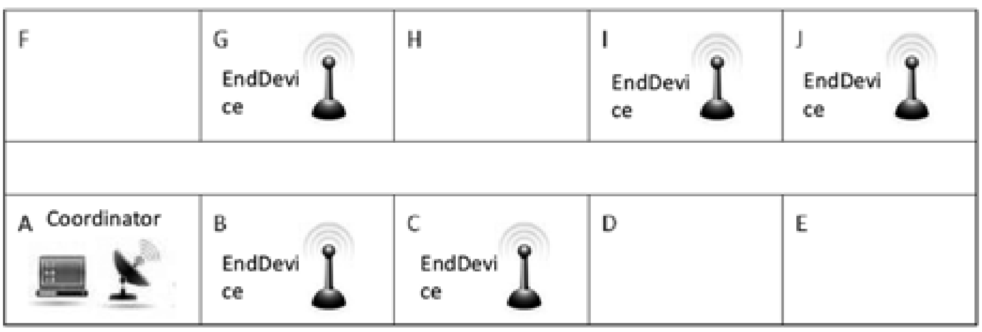

Figure 5. Distribution of nodes

The following is the actual test, Figure 6 is the test results of node C. The actual temperature inside the large space building room is 17.3°C, and the actual humidity is 43% RH. It can be seen from the figure 6 that, the system temperature and humidity test is quite accurate, the temperature and humidity curve doesn't appear significant fluctuations.

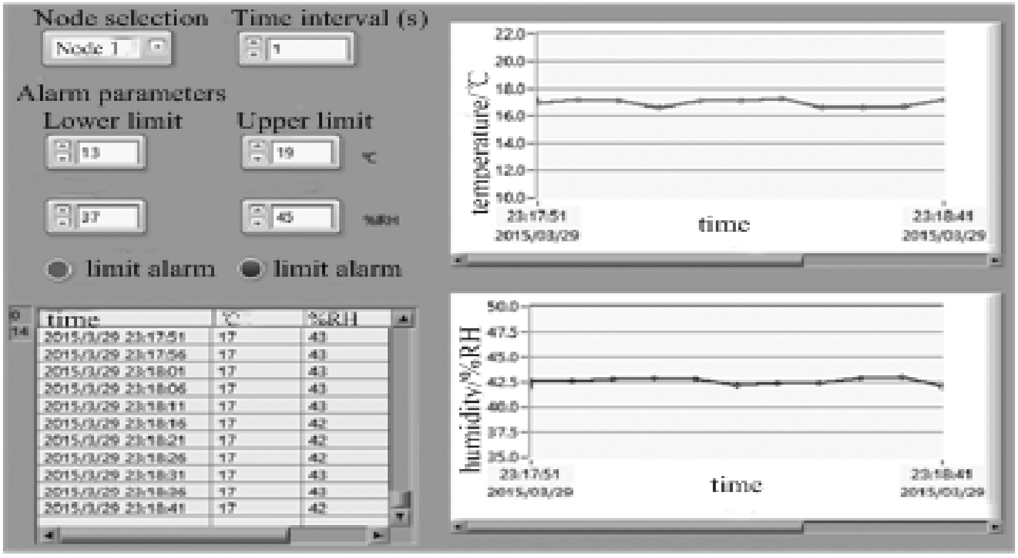

Figure 6. The results of node C

Figure 6 shows the results of node J. It can be seen from this figure 6 that although the distance of the node increases and there are many obstacles between the nodes, it will be routed through the routing node to the network and eventually send the data to the coordinator. In addition, for the same node, the measurement data are very stable, there is no significant fluctuations, indicating that the proposed method is very stable, and the test data is also very accurate.

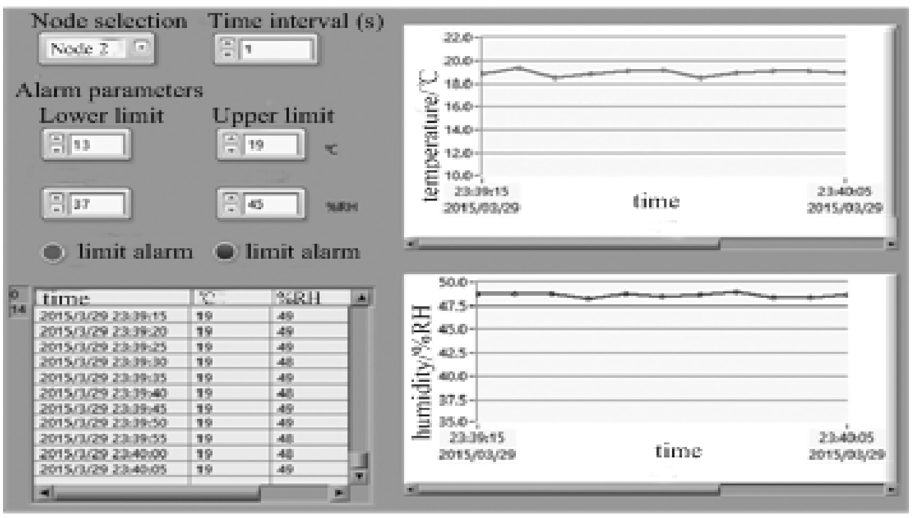

Figure 7. The results of node J

Because this method is used for environmental monitoring in large space buildings, the actual environment is complicated and changeable, so it is necessary to ensure that the method can be used normally in complex environment. In this test, several special environments are simulated, including high temperature test, low temperature test and room temperature test. We put a node into the high temperature box, set the temperature to 50°C, a node into the low temperature box, set the temperature to 5°C, and then a node is placed in the outdoor temperature, set the node to collect data every minute. After working for 24 hours or more, the working state of the system is observed. As shown in Figure 8, the operating status of the system can be observed in the LabView interface of the host computer, where the job log records all anomalies. As can be seen from the figure 8, two nodes have interrupted connection during the process of running, but re-connected in a few seconds to restore the normal work, which shows that the method has been initially equipped with self-repair capability.

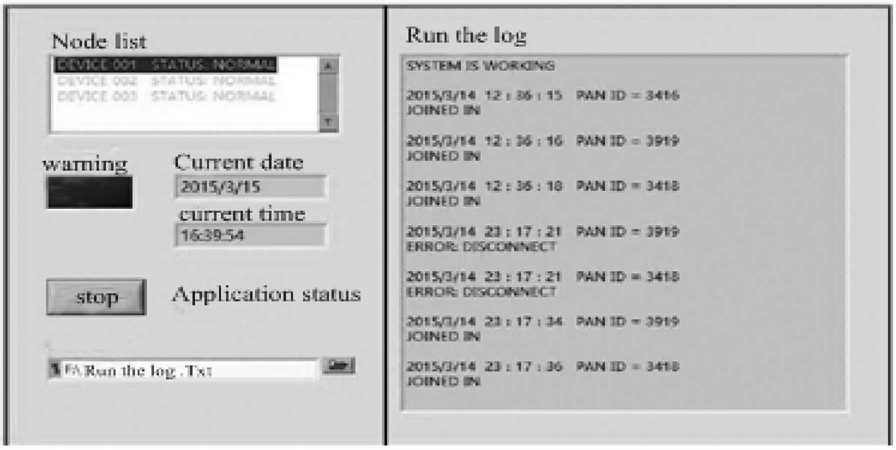

Figure 8. The operating status of the system

Through the above discussion, the hardware and software equipment needed for the construction of the experimental platform are introduced, which lays the foundation for the subsequent test work. Then, according to the performance index of the method, the experimental work is divided into three categories, namely: connection experiment, application experiment and reliability experiment. At this point, all experimental projects have ended, which fully meet the practical requirements of the application.

4. Conclusions

Indoor temperature and humidity monitoring in large space buildings can understand the indoor temperature and humidity conversion timely, and can grasp indoor air and other factors based on the change of temperature and humidity to ensure indoor safety. In order to ensure the accuracy of indoor temperature and humidity monitoring, this paper presents a method to realize the indoor temperature and humidity monitoring in large space buildings by using stepwise regression model and artificial bee colony algorithm. The main research contents are as follows.

(1) The process of stepwise regression model and artificial bee colony algorithm is discussed, and the artificial bee colony algorithm and stepwise regression model are combined to establish the indoor temperature and humidity monitoring model in large space buildings.

(2) Using the fast Fourier transform to calculate the temperature and humidity of the indoor, and the frequency domain characteristics of the temperature and humidity signal spectrum estimation results are analyzed, and the frequency domain characteristic evaluation standard of temperature and humidity signal is established. Then, the standard is applied to the monitoring model to ensure the monitoring accuracy, so as to achieve indoor temperature and humidity remote monitoring in large space buildings.

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