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The improvement of centralized intelligent control architecture and data collection algorithm

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Abstract

The commonly used structure of centralized temperature control systems is the bi-layer structure with upper computer directly controlling thermostats. But this kind of structure has obvious drawbacks, such as high cost, inability to scale up, low degree of intelligence, etc.. This paper presents a design scheme of an intelligent three-tier structure, namely thermostats, intelligent logging devices, and upper computer. The upper computer can read data directly from both thermostats and logging devices. This scheme can solve the problems in bi-layer structure well, and it is also suitable for other types of large-scale control system. However, there still exists data loss problem in this scheme when systems reach a great scale. A method of using historical data in the database and linear feature of temperature curves is also proposed in this paper to improve data collection algorithm, which preferably solve this data loss problem. Appropriate products have been developed based on the techniques of this scheme, and have been applied in practical industrial production and experimental teaching.

Keywords: Thermostat, Intelligent logging device, Upper computer, Data collection

1 Introduction

1.1 Problem proposition

Temperature control systems are widely used in chemical, food processing, motor painting [1] and tobacco processing industries, most of which adopt bi-layer control structure with intelligent and more complex thermostats at the bottom, as shown in Fig. 1.

From the perspective of practical application effects, there are several deficiencies [2] in this control structure: (1) thermostats are required to possess more powerful processing and storage capabilities; (2) upper computer uses sophisticated software and must always be with power on; (3) the number and location of temperature control points are limited; and (4) the price is high but the cost performance is relatively low.

2 Intelligent design scheme

To solve the above problems [3], the author proposes a control system with a three-layer structure, called intelligent centralized temperature control system. This system can solve the above four problems preferably, whose structure is shown in Fig. 2.

2.1 The system constituting

At the bottom are still the most common portable thermostats (also called basal meters), simple hardware components without CPU used as the control equipment of the proportional-integral-derivative (PID) controller. Intelligent centralized temperature control detectors (or intelligent logging devices for short) are located at the middle layer. Intelligent control system is consisted of MS51 series chips, possessing strong processing and storage capabilities. At the top layer [4] stands the upper-computer system.

2.2 System advantages

Thermostats [5] (basal meters) at the bottom can adopt the simplest design and are not required to have powerful

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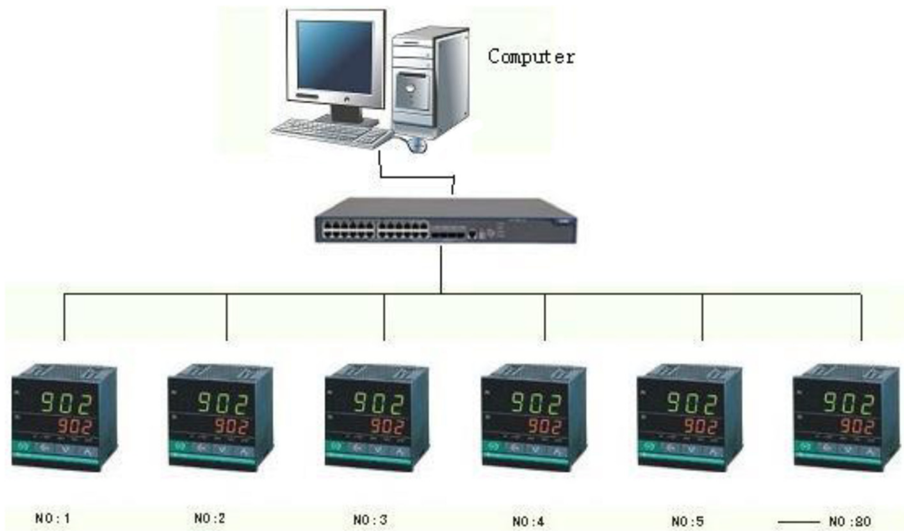

Fig. 1 Temperature control systems with bi-layer control structure

processing and storage capabilities, the cost is greatly reduced. At the same time, RS485 communication interface lines is used to improve the transmission distance, the number of temperature control points which can also be flexibly customizable, thus widening geographical scope. The functions such as collecting and storing data can be performed by intelligent centralized temperature control detector, which is a good solution to make up for the deficiency of the bi-layer control structure. The control management function between upper computer and thermostats is also performed by intelligent logging devices, thus more control functions are extended to services, such as providing queries for historical data, comparing historical data with the current data, statistically analyzing reports in many ways and many directions, monitoring the real-time state of thermostats, intelligently adjusting temperature curves, generating and drawing temperature curves, missing data complement tours [6], etc. Good solution to the bi-layer control structure in the second defect. Intelligent data logging devices using intelligent design will be focused on the next section.

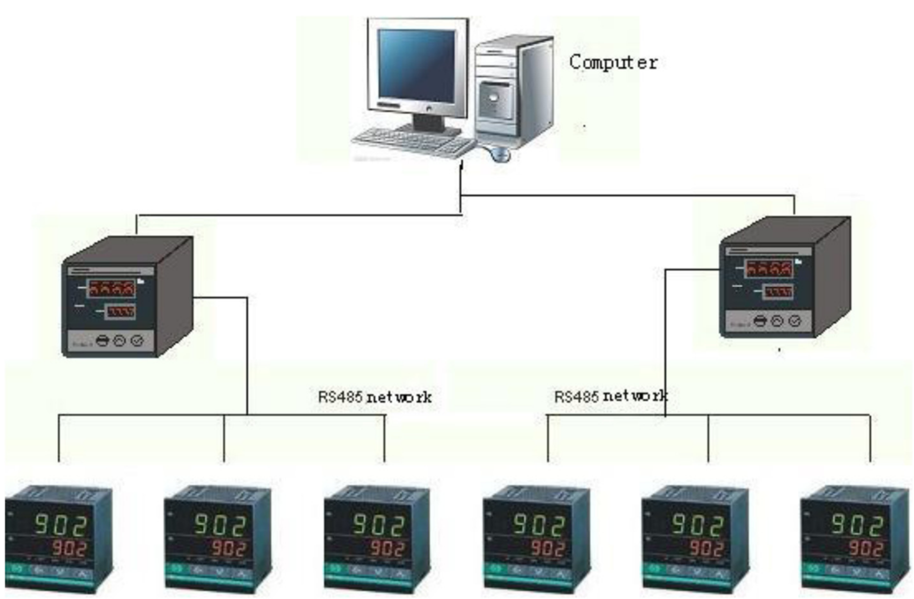

Fig. 2 Temperature control system with a three-layer structure

Table 1 Some protocols and commands

Offset	Content	Explanation
0	Sign	1 byte. 0 × 41
1	Basal meter address	1 byte. 1~80
2	Value of temperature	2 bytes. Lower byte is at the front and the unit is 0.1.
4	Year	1 byte. 0~99
5	Month	1 byte. 1~12
6	Date	1 byte. 1~31
7	Hour	1 byte. 0~23
8	Minute	1 byte. 0~59
9	Second	1 byte. 0~59
A	Retain	6 bytes

3 Intelligent logging devices

Intelligent logging devices [7] play a role in connecting link between the preceding and the following because the basal meters adopt the simplest design with PID controller and thermocouple as the core components, and it can concentrate the scattered thermostat together. This can well solve the problems of expanding control scale, reducing the cost [8], keeping upper computer in working state all the time, or allowing it to stay offline, etc.

3.1 Composition

Intelligent logging device is composed of MS51 series CPU chip, RS485 communication interface, 8 K and 32 K RAM. Each intelligent logging devices [9] can connect up to 80 thermostats, an acquisition cycle using RAM approximately 1.2 KB.

3.2 Function

The functions of the intelligent logging devices are to collect, to store and forward thermostat data, to control the action of thermostat, and to receive the order from upper computer [10] (Table 1).

Table 2 Test data

Thermostat Number	Upper computer data acquisition cycle	Acquisition data time intelligent logging devices	ROM usage	RAM usage	Data transfer time
16	3 s	200 ms	2 K	256 b	250 ms
24	3 s	130 ms	2 K	384 b	300 ms
48	3 s	70 ms	2.5 K	768 b	630 ms
64	3 s	50 ms	2.5 K	1024 b	860 ms
80	3 s	40 ms	2.5 K	1.2 K	1 s

Table 3 Test data

Logging devices number	Thermostat number connected logging devices	Upper computer data acquisition cycle	Acquisition data time intelligent logging devices	RAM usage	Data transfer time
80	80	120 s	15 ms	1.2 K	1 s
The time each intelligent logging devices occupy serial port		1.5 s	The time each intelligent logging devices for collecting 80 thermostats		500 ms

3.3 Intelligent logging devices tested

Test conditions were CPU MS51, RAM 8 M, communication port is with a bit rate of 9800 RS485, and simulation of the thermostat is 16 to 80.

Table 2 shows that the ROM data is essentially the same, the resources needed for the program, RAM use is up to 1.2 K in a collection cycle. Due to 32 KB of RAM, therefore the data can be stored in the case of 30 cycles upper computer offline. An upper computer data acquisition takes 4 s. Assuming moderate precise temperature control system, the acquisition cycle is 2 min, according to the design requirements of this article: to achieve 80 logging devices, each logging devices connected 80 thermostats. Have done a test shown in Table 3. Because the time to transmit a data to upper computer is with a fixed value of 1 s, 80 thermostats need 80 s to upload data logging devices; therefore, each logging devices can only capture 80 thermostats with a 0.5-s time data, that is, for each collecting data logging device, temperature data can only be used 6 ms, but the actual test time is 15 ms. The phenomenon of data loss occurs. In another paper of this issue, "intelligent control system based on centralized upper computer data acquisition algorithm" was discussed in detail. To this end, a third experiment was made to find an optimal system design size. Most of the final products are based on the data in Table 4.

Table 5 shows the test data comparison of the non-centralized structure of the system and centralized architecture system; at the same time, the data collection and the transmission of data points with the host computer,

Table 4 Test data

Logging devices number	Thermostat number connected logging devices	Upper computer data acquisition cycle	Acquisition data time intelligent logging devices	RAM usage	Data transfer time
4	80	120 s	15 ms	1.2 K	1 s
The time each intelligent logging devices occupy serial port		1.5 s	The time each intelligent logging devices for collecting 80 thermostats		500 ms

Table 5 Test data comparison

The decentralized system (80 thermostats)			The centralized system (80 thermostats, 4 logging devices)		
Start collecting and data storage	Data transferring time	Collecting cycle	Collecting time logging devices	Data transferring time	Collecting cycle
Negligible	1 s	80 s	15 ms	1 s	4 s

the data logging devices acquisition cycle is 300 ms, and the obviously centralized structure of the system acquisition cycle is short, easy for system expansion.

Decentralized architecture with a strong thermostat system control functions are programmable, and having a CPU processing power and storage capacity. Table 6 is the same size of the temperature control system in accordance with the moderately priced under market conditions, the price comparison of the two control schemes.

4 Upper computer software

The intelligent logging device is required to be connected to upper computer, and its parameters are set through the upper computer programs. The main content of upper computer programs includes the following:

1. System initialization
   To set the number of logging devices, the number of basal meters connected to each logging device, and the location of each meter.
2. Initialization of basal meter function
   Serial port setting, clock correction, determination of the number and address of basal meters, meter curve setting, intervals (or cycle) of meters collecting data, and intervals (or cycle) of upper computer collecting data from logging devices.
3. Inspection function
   To read out or repeatedly read out the current data from the specified basal meter; to clean up the data of logging devices; and to read out data from logging devices in real time.
4. Curve plotting
   To plot the current temperature inspection data curve graph of some specified meter or several meters.
5. Historical data inquiry and historical curve plotting
   To store the inspection data in database as historical data allowing managerial staff to inquire or draw curves according to requirements.
6. Warning function
7. Report printing
8. Real-time communication between logging device and basal meters (Fig. 3)
9. Shift of basal meters
   The shift of basal meters refers to the shift of meters from one logging device to another. Thus, system is required to perform shift operation, delete the basal meter information from the original logging device, and add the meter information to the new device.

5 Experiments

After completion of the study design of the entire system, two laboratories, Wuhan University of Textile Industry and Wuhan University of Light Industry, both use the system for more than 2 years. They believe that the basic design requirements met their needs. Figure 4 shows centralized three-tier structure of the temperature control system. Figure 5 shows interface screenshots of the major upper software during field trials.

6 Contrast

Using a centralized control system whose system performance, scalability, and cost price is significantly better than the non-centralized. The comparison between the specific descriptions is shown in Table 7.

7 Data collection algorithm improve

The intelligent centralized temperature control system hardware structure is shown in Fig. 2.

The topmost is called upper computer which is the heart of the system and where all the inputs and outputs are performed. At the middle layer are the logging

Table 6 Price comparison (US dollar)

The decentralized system						The centralized system					
80 thermostats		2 switches		1 upper computer		80 thermostats		4 logging devices		1 upper computer	
Price	Subtotal	Price	Subtotal	Price	Subtotal	Price	Subtotal	Price	Subtotal	Price	Subtotal
0.14	11.2	0.3	0.6	0.6	0.6	0.1	8	0.22	0.88	0.6	0.6
Total 12.4						Total 9.48					

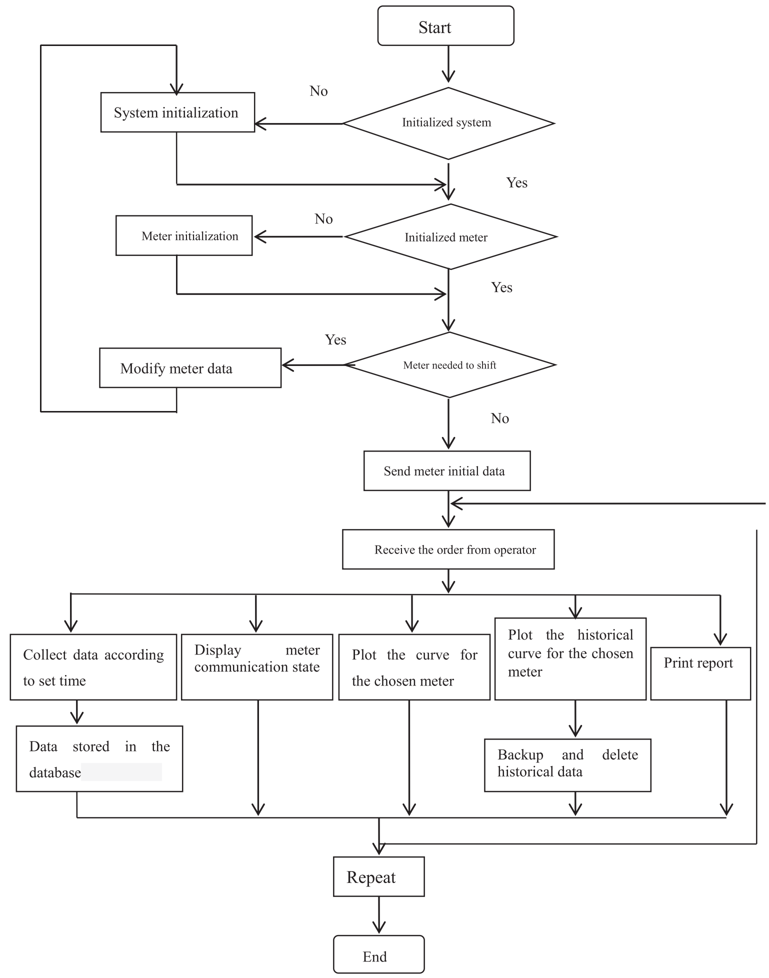

Fig. 3 Flowchart

devices which can distribute temperature curves, collect data from basal meters, and control meters. There can be at most 80 logging devices connected at this layer. At the bottom are the basal meters (or thermostat) which perform such functions as raising temperature, reducing temperature, keeping constant temperature, communicating with logging device and warning, etc. For each logging device, there can be at most 80 thermostats connected at this layer.

The merits of this structure are as follows:

(1) The scale of the system can be expanded flexibly
(2) Upper computer can be shut and then the real-time data of basal meters can be stored in the logging devices
(3) The design complexity of basal meters can be greatly simplified, reducing the system costs considerably

In theory, the value of temperature control points connected to intelligent centralized temperature control

Fig. 4 System consisting of three intelligent logging devices

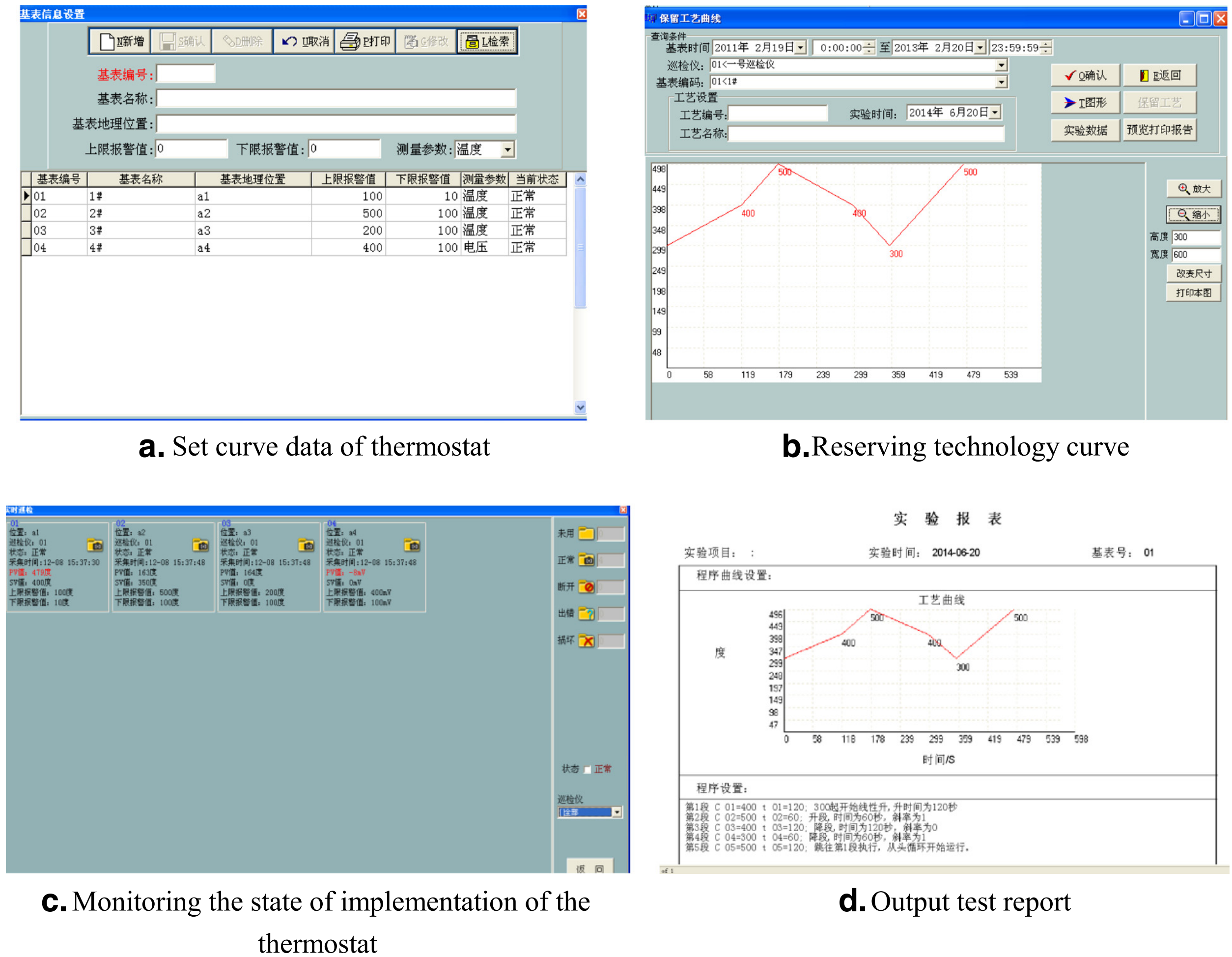

Fig. 5 Several major upper computer software interface screenshots of field experiments. **a** Set curve data of thermostat. **b** Reserving technology curve. **c** Monitoring the state of implementation of the thermostat. **d** Output test report

system is 80 × 80, which means the upper bound of logging devices in the system is 80 and that of thermostats is also 80; thus, the upper limit of the number of thermostats in the system is 6400. Logging devices collect data every 1 ms, 10 ms, 100 ms, and 1 s, and then, the upper limit values of collecting cycle are 6.4, 64, 640, and 6400 s, respectively (Table 8). In the case of temperature control accuracy is not very high, most devices collect data every 100 ms and 1 s; the upper limit value of collecting cycle being 11 and 110 min. In the actual industry, however, temperature during this period must have been changed; thus, the collected data will not be continuous, the plotted temperature curve will be on and off. This means that there are possibilities that data is lost when upper computer collects data according to the theoretical maximum of temperature control points:

1. The logging device sends wrong data due to environmental interferences and the upper computer loses this data
2. Because of too many temperature control points, the upper computer just misses them in acquisition cycles and data which logging devices have collected

Table 7 Performance, price, cost, and scalability

Centralized control system					Decentralized control systems				
Maximum data collection point	Operating Performance	Reliability	Comprehensive cost	Stability data collection	Maximum data collection point	Operating Performance	Reliability	Comprehensive cost	Stability Data collection
6400	Well be off line	High	40 % reduction	High	80	Not off line	Medium	High	Medium

Table 8 Data acquisition cycle (with the thermostat 6400)

Acquisition interval	1 ms	10 ms	100 ms	1000 ms
Logging device acquisition cycle	80 ms	800 ms	8000 ms	80000 ms
Upper computer acquisition cycle	6.4 s	64 s	640 s	6400 s
Result	Normal	Normal	Loss	Loss

on the period covered by the new data, the original data cannot be read and loss, severely creating a vicious circle. The upper computer does not read out data, resulting in data loss

The author proposes data sampling compensation algorithm in order to use computational methods to make up the lost data on acquisition points, keeping data integrity when system draws temperature curves in real time, and at the same time, adding this data into database to preserve the integrity of experiment data.

7.1 Design philosophy

If thermostats are to be read every 1 min, the upper limit value of acquisition is 11 min, which means every thermostat loses 10 data. We can acquire these 10 data by computation through the following formula. To simplify the computation, we fetch the upper or lower limit of the interval (60, 6400) as the number of thermostats described in the algorithm, i.e., 60 or 6400.

Linear equation method: let x be time and y be temperature value of thermostats, then the linear equation of any segment of temperature curve is:

$$Y = (y_2\text{-}y_1)/(x_2\text{-}x_1) * X + (y_1 * x_2\text{-}y_2 * x_1)/(x_2\text{-}x_1) \quad (1)$$

where x_1 and x_2 are the beginning and ending time of some section of the curve; y_1 and y_2 are the temperature value at the beginning and ending of the curve section.

Historical data reference: let U_{ji} be lost temperature value and V_{ji} be the temperature value of the same basal meter i and the same logging device j at the same moment during the same temperature control period of the same prescribed temperature curve in the database; $\sum V_{ji}(t = 1......n)$ is the sum of n historical data; Y_{ji} is the value of the same meter computed according to the prescribed temperature curve value, that is, formula (1), then U_{ji} is formula (2) or (3).

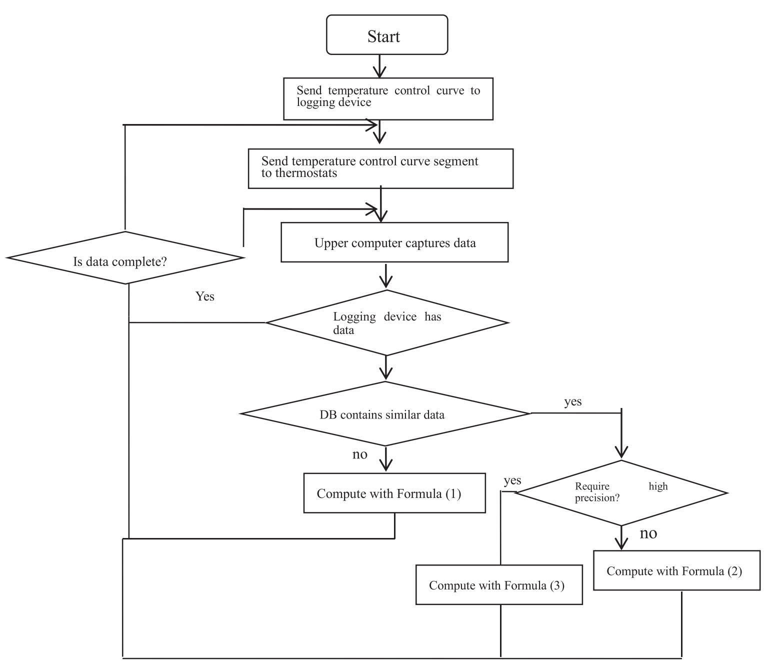

Fig. 6 The work flow

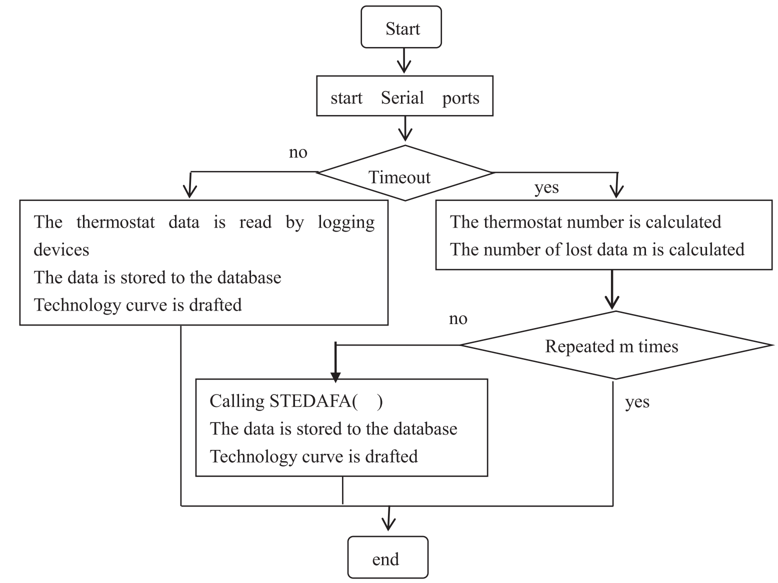

Fig. 7 Upper computer acquisition process

$$U_{ji} = \mathrm{Min}\{(Y_{ji}\text{-}V_{ji})_1{}^2,\ (Y_{ji}\text{-}V_{ji})_2{}^2,\ (Y_{ji}\text{-}V_{ji})_3{}^2 \ldots\ldots (Y_{ji}\text{-}V_{ji})_{n\text{-}1}{}^2,\ (Y_{ji}\text{-}V_{ji})_n{}^2\} \tag{2}$$

$$U_{ji} = \sum V_{ji}/n \tag{3}$$

Simplified system workflow Fig. 6.

7.2 Algorithm design

(1) Description of algorithm STEDAFA (Statistics Temperature Data Fitting Algorithm)

The data fitting algorithm for temperature control data acquisition is described with pseudo-C language as follows, where $60 \le \mathrm{ThermostatNum} \le 6400$ for the thermostat number, $1 \le j \le 80$ for the logging device number, $1 \le i \le 80$ for the number on the thermostat logging devices connected, U is calculated compensation value, vector V_{ji} $[n]$ for the same point, the same process temperature curve in, earlier time different values of n.

(2) Temperature data collecting algorithm

Within the prescribed sampling period, logging devices may without send data or send wrong data; temperature data collecting algorithm means that upper computer reads out the real-time temperature values may not right. In the paper, we proposed temperature data collecting algorithm. The algorithm can resolve the defect of missing data and wrong data. The algorithm is called TDCA(int j, int i). Its work flow can be seen in Fig. 7, and its pseudo-C language code is described as follow. The variables ThermostatNum, j, and i meaning the same with STEDAFA (ThermostatNum, j, i). U is the collected or calculated compensation value, m is the number of losing data and num is the loop control variable.

7.3 Contrast

(1) Performance contrasting

According to the proposed algorithm, the hardware and software designs are completed, and a centralized control system is realized. The system has been used by many university laboratories and a number of enterprises recently. The users who offered statistical results are reflected in Table 9.

(2) Curve contrasting

An experimental comparison of the technology curve is displayed in Fig. 4. The experimental conditions, which are a simulation environment, are shown in Table 10. Data can be collected by upper computer read from logging devices once per minute. There are 10 logging devices. Each logging devices connected to 80 thermostats.

Table 9 Performance contrasting

Without using data fitting algorithm				Using data fitting algorithm			
Accuracy	Scale	Reliability	Satisfaction	Accuracy	Scale	Reliability	Satisfaction
General	Poor	Good	60 %	wonderful	wonderful	Good	90 %

Table 10 The simulation environment

Devices/number Parameter	Upper computer	Logging device	Thermostat
	1	10	800
Sampling interval	1 s	100 ms	1 ms
Sampling period	6000 ms	8000 ms	80 ms
Upper computer using time	600,000 ms	(losing data)	

After several tests, the ideal technology curve, missing data technology curve, and after using the algorithm (shown in Fig. 4) technology curves are shown in Fig. 8. In this test, t0 to t8 are time 0 to 120 min. The temperatures are 20 to 60 °C. Obviously, after the adoption of this algorithm to compensate for the lost data, the curve seemed to be more complete in this process.

(3) Price contrasting

In order to correctly compare different scale systems, the sizes of the assumed temperature control system are 160, 640, 1280, and 2560 units; according to the market price of modest hardware equipment, the system using data fitting algorithm and system without using data fitting algorithm, these results are recorded in Table 11.

7.4 Software screenshot

The upper computer software has been completed, temperature control, for example, and is currently being controlled on-site corporate and university laboratories test run, looking forward to the follow-up gradually improved (Fig. 9).

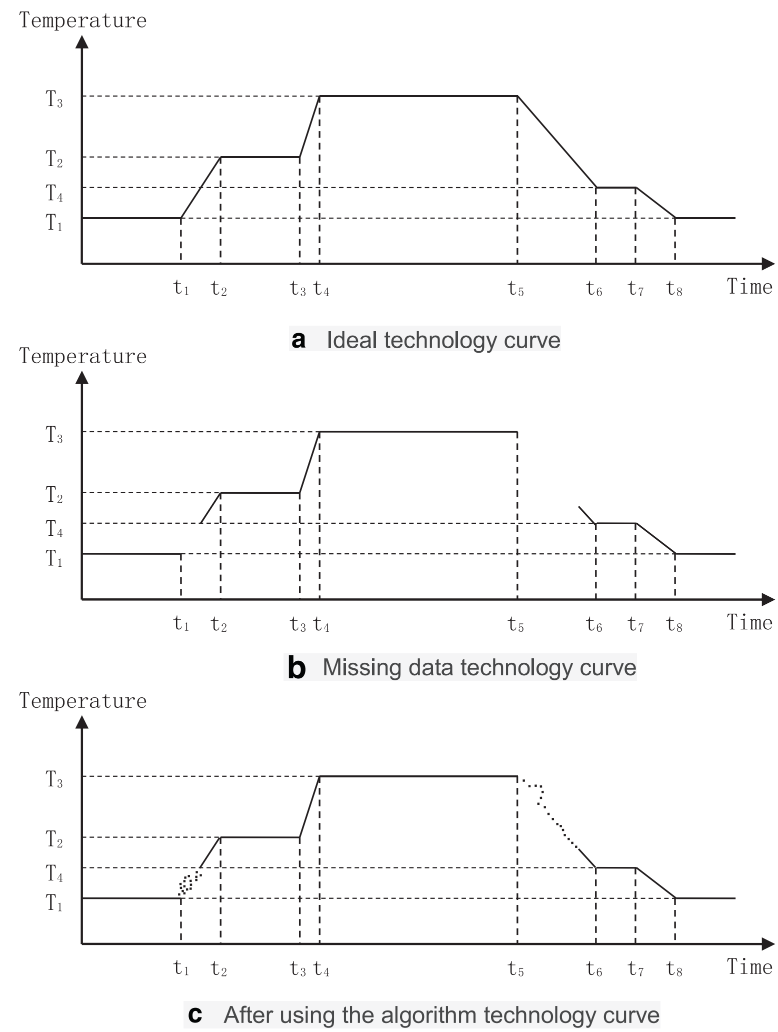

Fig. 8 Contrast of technology curve. **a** Ideal technology curve. **b** Missing data technology curve. **c** After using the algorithm technology curve

Table 11 Price contrasting (ten thousand US dollar)

Without using data fitting algorithm				Using data fitting algorithm			
160	640	1280	2560	160	640	1280	2560
2.3	11.2	21.4	45.8	Reduction 15 %	Reduction 23 %	Reduction 31.5 %	Reduction 38 %

8 Conclusions

Temperature control system structure used mostly for the upper computer is connected directly to the control thermostat decentralized bi-slayer structure, which has obvious flaws, such as high cost, not to scale and low intelligence. This article proposes a design scheme of intelligent three-layer structure including thermostats, intelligent logging devices, and upper computer; it can be called centralized control systems. Upper computer can read out data not only directly from thermostats, but also from intelligent logging devices. This scheme solves the problems in the application of bi-layer structure preferably, and it is also suitable for larger scale control systems of other kinds. Based on it, the corresponding products have been developed and applied in practical industrial manufacture and experiment teaching. There are still some imperfections in this scheme, for example, the logging intelligent devices may lose the collected data.

There also exists data loss during data gathering of upper computer in this scheme when systems reach a great scale. In this article, the author proposes an algorithm making use of the historical data in DB and the linear characteristics of temperature curves to improve data collection, preferably solving the problem of data loss. For this algorithm, we have applied for the country

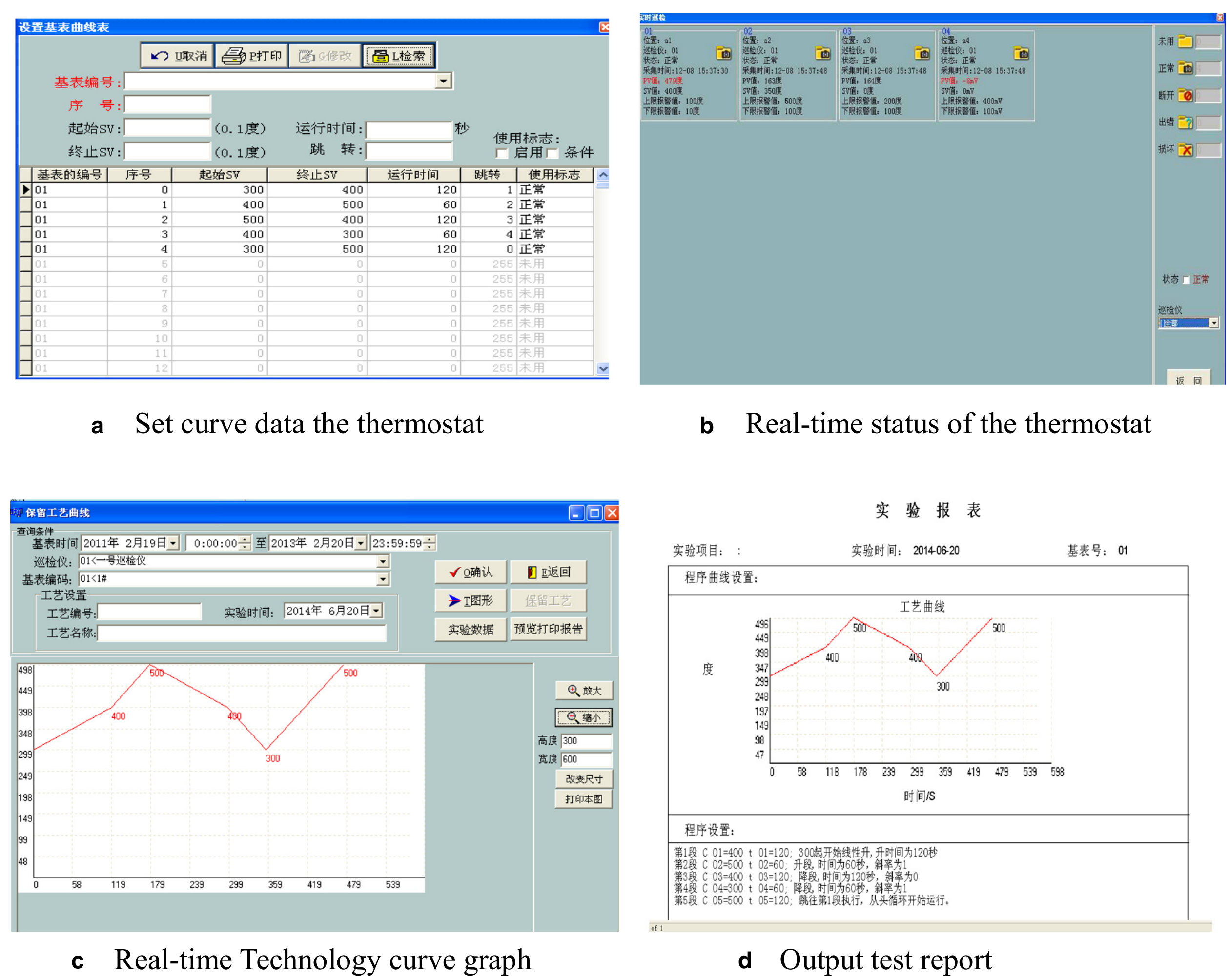

Fig. 9 Test shots. **a** Set curve data the thermostat. **b** Real-time status of the thermostat. **c** Real-time Technology curve graph. **d** Output test report

patent of invention and have already succeeded in applying it to the products of centralized temperature control system.

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