DESIGN AND IMPLEMENTATION OF DISTRIBUTED DATA ACQUISITION SYSTEM BASED ON FIELDBUS FOR LARGE SPACE FIRE TEST

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ABSTRACT

It is important to have reliable experimental data for studying compartment fire and developing fire models. A data acquisition system (DAS) based on "fieldbus" technology was developed to capture signals from full-scale burning experiments in the PolyU/USTC Atrium. Such system is demonstrated to have higher flexibility in its network architecture and provide more reliable signals than conventional techniques. In this paper, both the hardware of the instrument and the software for compiling the data will be discussed. This system is demonstrated to be a reliable tool for full-scale burning experiments.

1. INTRODUCTION

A full-scale burning facility, PolyU/USTC Atrium [1], of length 22 m, width 12 m and height 27 m was built in 1997, in celebration of reunification of Hong Kong with China. This is a long-term collaborative project between the University of Science and Technology of China (USTC) and The Hong Kong Polytechnic University (PolyU) on studying building fires. In addition to atrium smoke filling, atrium sprinkler design, smoke exhaust system (both natural and mechanical) and fire detection system, performance of special design, such as using the cabin concept in big terminal buildings and water gun, can be evaluated.

In carrying out full-scale burning tests, data acquisition system (DAS) [2-4] is a key element for handling numerous transient signals collected from sensors at various locations. Traditional central data acquisition systems using "4-20 mA" standards would have smaller capacity and lower expandability. The system is more difficult to maintain for handling large number of data buses. Also, there might be electromagnetic interference, generating noise while the signals travel long transmission distance.

Fieldbus technology [5] has been widely used in practical engineering applications such as large-scale distributed monitoring system. It can be applied to develop a high speed DAS with multi-functions, a large capacity, and good expandability for full-scale burning tests in big halls. Suitable intelligent processing unit and network communication ports can be used for transforming signals through the sub-station points. Data will be exchanged by computers for carrying out real-time acquisition. This will satisfy the requirements of high-speed, real-time, and accurate fire data measurement.

Development of a specially designed DAS for carrying out full-scale burning test is reported in this paper. The hardware including the sensors such as thermocouples and gas analysers for the DAS will be discussed. The software, developed from lower-level programming [6], for real-time data acquisition (DAQ) and signal transformation of more than 200 routes at 16 stations in 1 s will also be discussed. Dynamic display interface and data storage mechanism will be outlined.

2. EXPERIMENTAL SETUP

For the study, a small chamber of size 4 m by 3 m by 3 m was built inside the atrium as shown in Fig. 1. The chamber was located at the center of the atrium. The fire source was a fuel pan above an electronic balance at the centre of the chamber as shown in Fig. 2.

Three major physical quantities including the mass loss rate of the fuel, smoke layer temperature and smoke layer interface height within the atrium were measured in the burning tests. The mass loss rate of the fuel was measured by an electronic balance, signals from which were transmitted to the station. Since oxygen consumption of the fire cannot be measured using the current apparatus, only the mass loss rate and calorific value of the fuel were used to estimate the heat release rate. The smoke layer height and the smoke layer interface were determined by the measured temperature and temperature gradient.

To measure the smoke temperature, thermocouple trees were set up in both the big atrium hall and inside the small chamber. For the atrium setup, three thermocouple trees were placed at the south-east, north-east and north-west corner of the atrium as shown in Fig. 1. Each thermocouple tree consisted of 27 type K thermocouples without sheath at an interval of 1 m. The highest thermocouple was 27 m above ground. For the atrium alone, 81 (27 x 3) thermocouples were used to measure the temperature. The most remote thermocouple was 27 m away from the control panel. Self-welded thermocouples using wires of diameter 0.2 mm were used for better sensitivity. Cold junctions of all thermocouples were placed at the ground level for cold-end protection.

For the small chamber, shielded thermocouples (also type K) of diameter 1.5 mm were used. Two thermocouple trees with five thermocouples each at intervals of 0.05 m, 0.35 m, 0.35 m, 0.4 m, 0.4 m were hung vertically from the ceiling on one side of the chamber. Another tree of ten thermocouples was mounted into a "T" shape on the other side. The five thermocouples at the top were located horizontally at 0.4 m intervals at 0.05 m away from the ceiling. The middle five thermocouples were mounted at the same vertical height as the other two sets of thermocouples as shown in Fig. 2. There were altogether 20 thermocouples inside the small chamber. The thermocouples were shielded with porcelaneous pipe to prevent heat conduction to the wall through the thermocouple wire (The cold ends of the thermocouples were outside the chamber, so the signal cables in fact did not pass through the high temperature area).

The geometry and experimental setup of the PolyU/USTC Atrium and the small chamber are shown in Figs. 1 and 2.

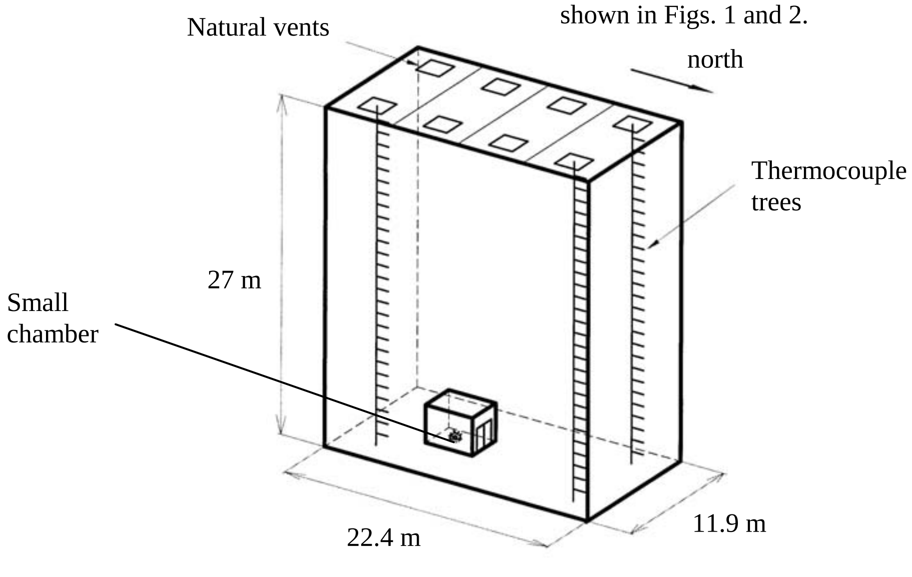


Fig. 1: Geometry of PolyU/USTC Atrium

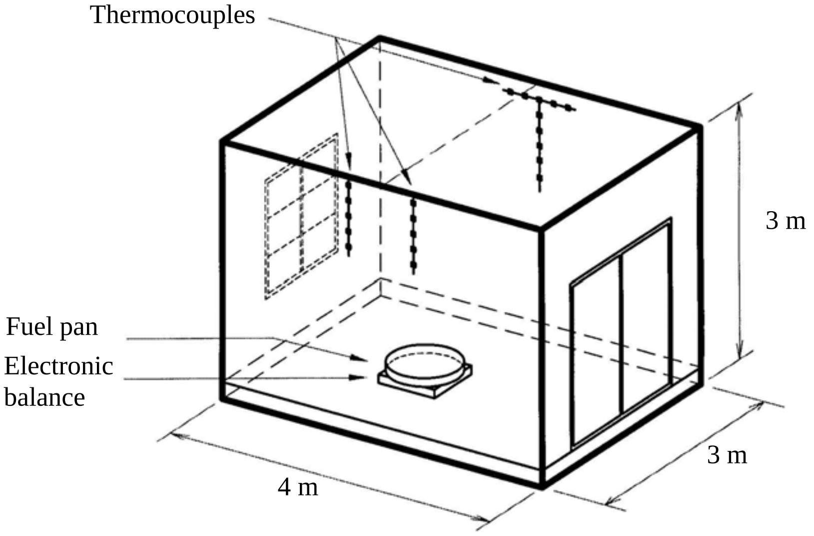


Fig. 2: Geometry of small chamber inside the Atrium

3. HARDWARE OF THE DAS

Due to the large area of space, signals from different sensors have to travel long distances before reaching the control panel. Electromagnetic interference from static, environmental electromagnetic coupling and radiation would cause signal distortion, especially those signals from thermocouples, and also the resistance of long signal cable would weaken the signals. Besides, traditional central DAS would require more data cables. The system is less expandable and flexible, and difficult to maintain. In order to cater for these problems, a distributed DAS based on fieldbus technology is developed. Fieldbuses are mainly applied as a special local area network for data acquisition and sensor control. Low-cost twisted pair cables are used for this network. The major difference between this network and traditional network is that it is optimized for the exchange of short point-to-point status and command messages [5]. It has the advantages of requiring fewer data buses, easier to adjust and more reliable. The concept of distributed acquisition is to process and transform the signals using intelligent module or single-chip computer. The signals will then be sent to the main control unit through communication network through signal controllers RS-485 [7,8]. In order to simplify the installation, the network structure based on EIA RS-485 [7,8] is used in this DAS.

The DAS should satisfy the following criteria:

- Simple, flexible and expandable

  To make the structure simple and easy to maintain, the DAS should have high flexibility and expandability for future development of a large number of experiments of various kinds.

- Rationality and economy of system

  This system should have a fast rate of DAQ to satisfy the experimental needs. The control part is not needed to reduce the cost.

- Modular design

  Signals are processed by the intelligent module unit including hardware filtering, signal transformation, calculation of physical quantities, and network communication. Standard installation is adopted for easy movement and maintenance.

The schematic diagram of the DAS is shown in Fig. 3. It is composed of acquisition stations, RS485 network, a communication transformation unit, and a main processing system.

Signals from sensors for field measurements are collected at each station. Only four stations were set up to accommodate the volume of data collected. However, the number of stations can be increased if needed. Stations 1, 2 and 3 are allocated to collect signals from the thermocouples in the large space atrium. Station 4 is for collecting thermocouple signals and mass loss rate of burning fuel of the chamber for evaluating the performance of cabin design. A total of 28 acquisition routes are allocated in each sub-station. Signals are transferred to the communication module through the 485 network for further computation.

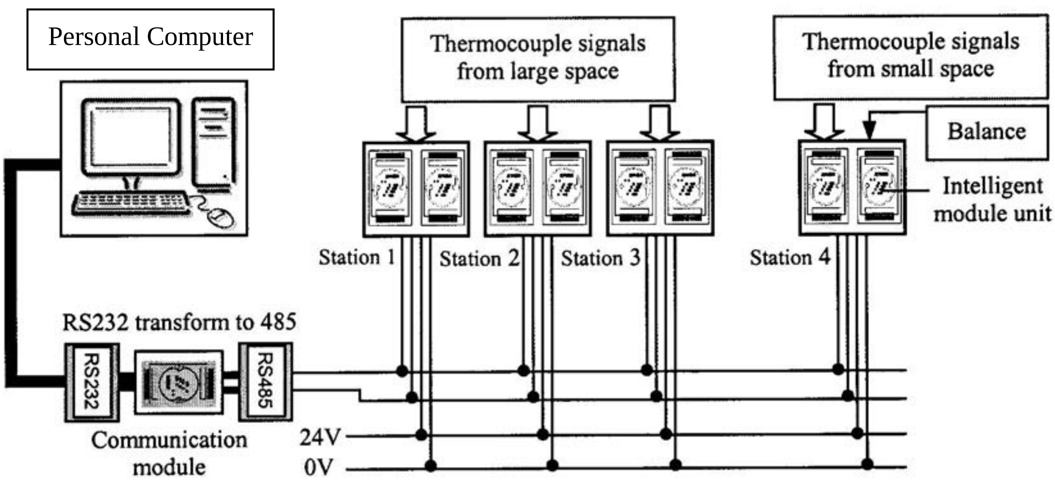


Fig. 3: Schematic diagram of the data acquisition system

There are two intelligent module units in each sub-station:

- Intelligent module [9] is used for collecting thermocouple signals. Its A/D transformation chip [10] is an 18-digit double integral model, which can process 0 ~ 512 mV signals directly, at a rate of 2 μV/bit. There are 14 acquisition routes with an acquisition frequency of 16 times per second. The modules have photo-electric separation with the communication port and cold-end compensation circuit.

- RM410 [9] module has a CPU (model AT89C51) [11], 2K ROM and 128 byte RAM with a schematic diagram shown in Fig. 4. Data compilation and analysis can be carried out rapidly. The main data processing and filtering procedure is encoded. Transformed voltage signals of temperature measured from the thermocouples and the signals from the electronic balance are updated and stored in the ROM of AT89C51 for further processing. MAX485CPA port chip is used in the RM410 module for each set of RS485 data communication system. This system can transmit signals through a distance of 1200 m at 250 Kb/s, and activate 32 station points. Address switch can be set in the module for easy identification of each channel.

RM450 [12] is selected as the communication module for port transformation from RS-232 to RS-485. A specially designed IC is fixed to control the flow direction of data automatically. RS232 control message is therefore not needed. This communication module supports RS-485 half-duplex communication speed and format. The maximum communication baud rate is 57.6 KBPS [12]. This system has made effective use of the rapid transmission of data through the network and its large data handling capability, and fully exhibits its ability to process distributed data. Real-time response and data processing ability are greatly enhanced. When the data from module address 01 is requested from the upstream computer, only 4 ASCII characters "@01R" are required, where "@" is the lead character, "01" is the address of front module RM410, and "R" is the read data.

RM410 [9] is based on 66 ASCII characters, which represent the data of 16 routes. Every 4 ASCII characters represent 1 route, giving 4 x 16 or 64 characters. The last two characters are for validation. The 4 ASCII characters for every route is a hexadecimal number. For example, "30 45 45 45" means "0FFF". The equivalent decimal number for 0FFFH is "4095". To simplify the calculation, when the input range is selected as "0 - 50 mV", the A/D potentiometer W is adjusted to full-scale for displaying the hexadecimal number C350H, i.e. 50000 in decimal system. In that case, 4095 means 4.095 mV is added to the route.

The network system simply has two data buses. Common electric wires are needed for connection between the stations. The construction cost is reduced and the system is easy to maintain. Transformed data of 66 bytes (including 2 bytes of validation codes) from 14 routes will be saved in the module's data register automatically every second. The maximum network communication time required to read 1 set of data is 60 ms. Data from at least 16 modules can be read within 1 s. The system can be expanded easily when more data are required for future experiments. Also, parallel acquisition between multi-serial port and multi-network can be realized through expanding the serial port PCI card. The capacity of this distributed system can be increased dramatically by using parallel calculation for terminal acquisition control in the main program.

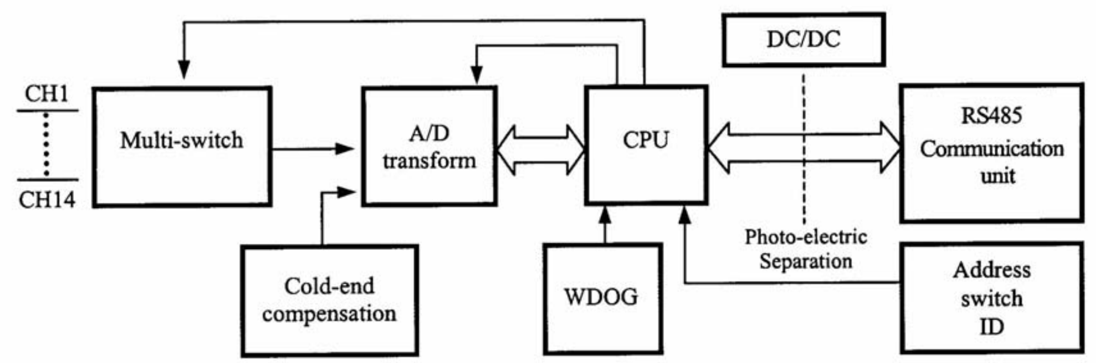


Fig. 4: Schematic diagram of the intelligent module RM410

Data transfer program is written and stored in the front ROM. Through processing by the front CPU, voltage signals are transformed into physical quantities such as temperature. This can reduce the workload of the computer. The control computers will be used for network communication and dynamic display. Therefore, the processing ability and network capacity are greatly enhanced. Filtering is important in system design. New transformed results from the front intelligent module would be saved every second. For medium filtering, acquisition delay is increased since multiple sets of sampling data are needed for averaging, so simple method is used in this system by logical judgement arithmetic. The signal measurement range can be determined from the signal behaviour of large space fire test. It is important to check the reliability of the measured signals by comparing the difference between the present signals with the preceding ones to confirm that the data is within the measurement range.

For example, the limit of temperature change in large space fire test was set as $20^{o}C/s$:

$$\left|T_n - T_{n-1}\right| > 20^{o}C \quad (1)$$

then

$$T_n = (1-\varphi)\, T_{n-1} + \varphi T_n \quad (2)$$

where φ is a predetermined power factor of positive value smaller than 1.

While $\left|T_n - T_{n-1}\right| < 20^{o}C$ (3)

$$T_n = T_n \quad (4)$$

In using this method, unreliable signals due to occasional strong disturbance of the intelligent module can be reduced. During network transmission, signal distortion can be eliminated by parity check in the main program to ensure accuracy of the data.

4. SOFTWARE REALIZATION

System acquisition procedure is developed using software [6] application platform with typical interface [13]. Multi-step menu as shown in Fig. 5 was developed. The menu will control event to stimulate operation. Quick tools column might be used as it is relatively simpler. Each procedure module can be accessed from the main interface through the menu or tool buttons. The main interface of the three-dimensional acquisition procedure is shown in Fig. 6. The main functions of the system software include substation inspection and acquistion parameters setting, signal acquisition and dynamic display, display parameter control, real-time and instantaneous data retrieval, image processing, and data storage.

- Substation inspection and acquisition parameters setting

  Network testing can be done in the parameters setting window by selecting the testing buttons to check the working status of the 485 network and serial port connection situation. This inspection function is useful for system maintenance and regular checking.

  Before carrying out the experiment, the following should be determined and set up in the window menu as in Fig. 7:

  - Workstation point: should be determined according to the actual acquisition situation.
  - Document file: for autosaving and storage of the experimental results. Data and image files are named automatically using the beginning time of acquisition with the station number. This function provides a systematic method for easy searching and checking.
  - Serial port of communication module connection.
  - Delay between modules: to ensure the work cycle is more than 1 s to enable update of results stored in the intelligent module unit.
  - Temperature of environment: for adjustment of cold-end compensation of thermocouples in the acquisition module.
  - Display interval and display module: for controlling the interval of document and images display during acquisition and the stations for dynamic display.

  All the parameters should be tested before proceeding to the next step.

Fig. 5: System menu

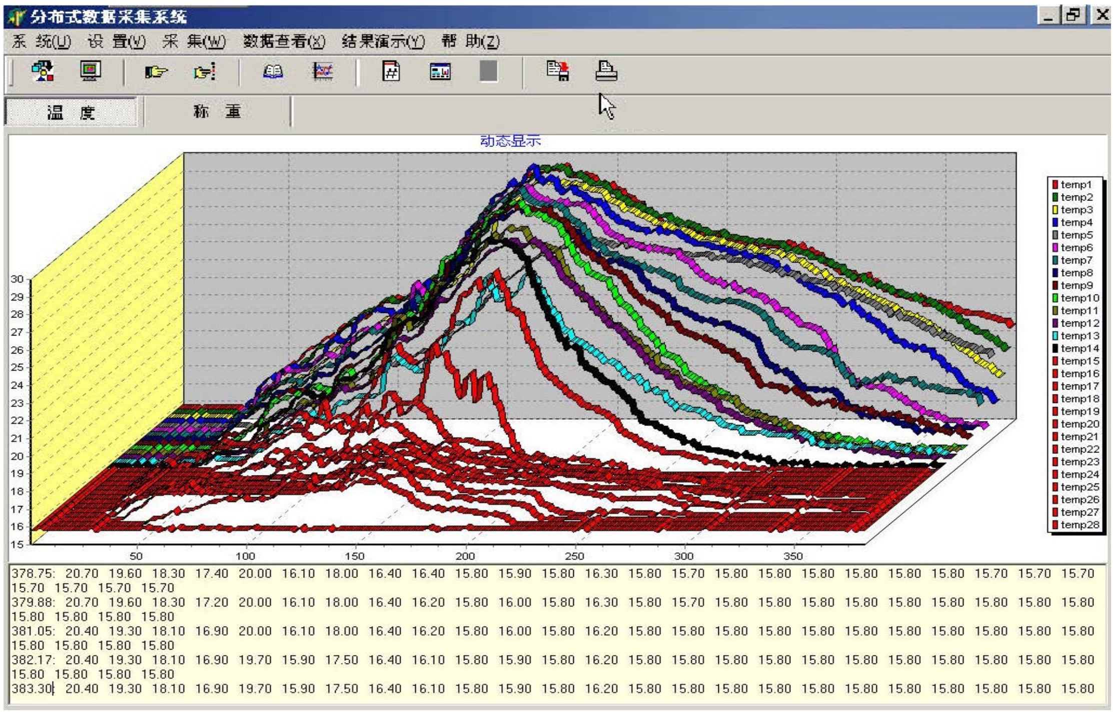


Fig. 6: Main interface of three-dimensional acquisition procedure

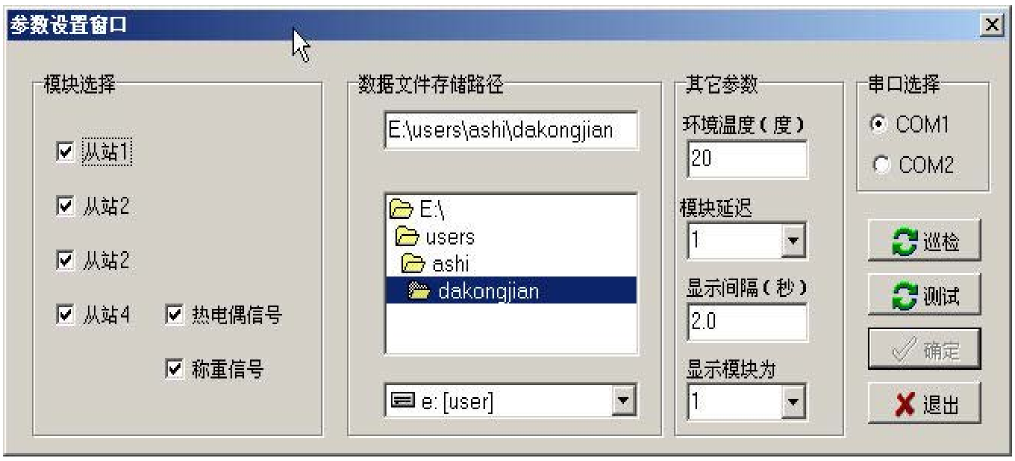


Fig. 7: Setup window

- Signal acquisition and dynamic display

Multi-linear work procedure is utilized in the central part of this acquisition system. Events and methods initiation , and all the windows are managed by the VCL main procedure. Acquisition linear procedure is responsible for network communication and reading acquisition results. Whether the data buffer is full will be tested at regular time intervals through the timer control. If the buffer is full, the data will be written into the document file for storage.

A display timer is set for dynamic display of the experimental results. TCHART and TMEMO components are used for displaying image and document respectively. Since TCHART display would consume lots of system resources, this system is responsible for displaying data of only one substation. Display station is selected at the setup window. Critical zone protection is used for shared resources between linear procedures. MSCOMM32.OCX [14] from Visual Basic is adopted as the communication control. MSComm ActiveX is used for serial port communication and the TEVENT event component is for simultaneous display.

Flowchart of central acquisition is shown in Fig. 8.

- Display parameter control

This provides end-users the port interface to display control as shown in Fig. 9. They can choose two-dimensional or three-dimensional image display mode and the 3D depth for three-dimensional mode. End-users can also choose the colour of the display interface. The vertical axis and time axis for dynamic display of image can be set as automatic compressed format or non-automatic compressed format, which the latter requires the input of range of axis. During the acquisition, selected image can be magnified for observation; and the route number for display can be chosen by pressing the right key.

Fig. 9: Control display

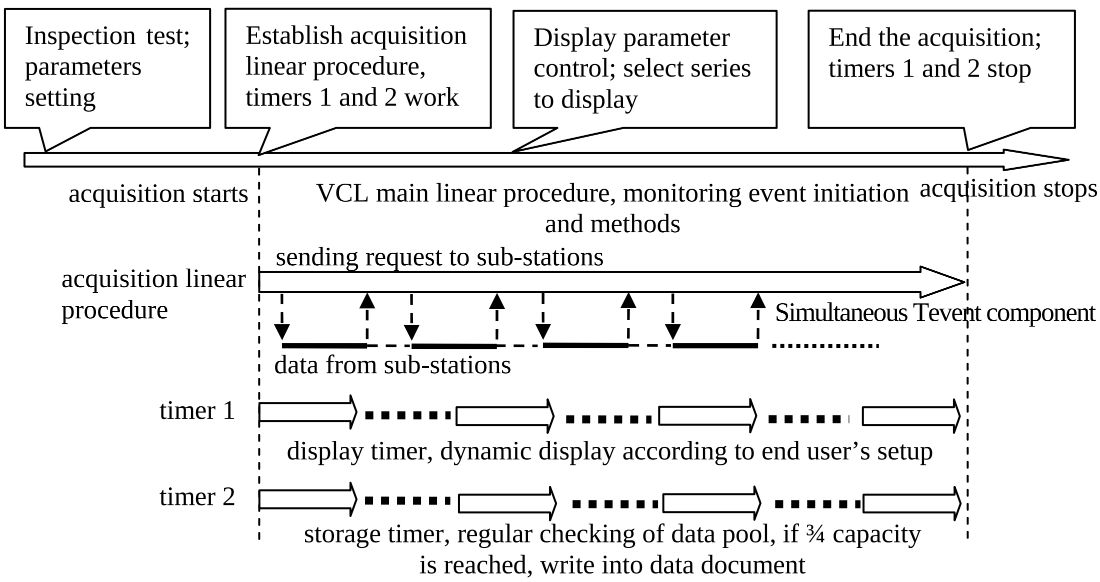


Fig. 8: Flowchart of central acquisition

- Real-time and instantaneous retrieval of experimental data

  There are two modes of display: instantaneous display and real-time display. Instantaneous mode can display the images instantly for convenient observation. For real-time display, time data is read from the data document, the display interval is controlled through the display timer. In order to simulate the real-time experimental process, the images obtained and the document data are displayed at regular intervals. End-users can choose the data document and the display mode for repeated display. They can retrieve the experimental results for many times conveniently and analyze the signal variation at any time frame. Two-dimensional dynamic display of a set of experimental results is shown in Fig. 10.

- Data and image processing

  This function allows the user to study and analyze the experimental data and dynamic images stored during the experiments. Content of a data file of typical experimental results is shown in Fig. 11.

- Storage and printing of experimental results

  This system procedure is simple, and the interface is user-friendly.

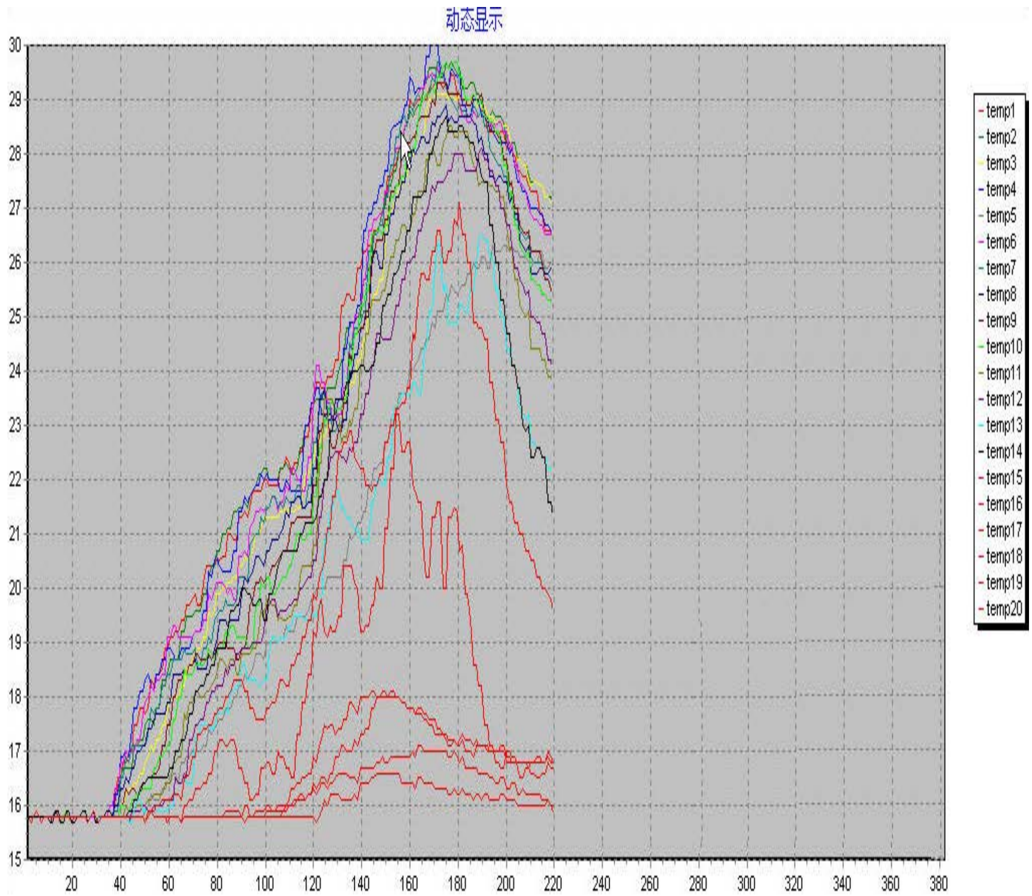
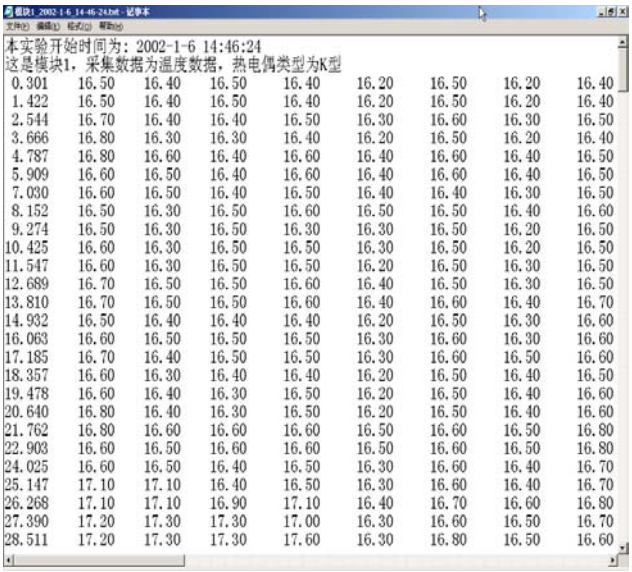


Fig. 10: Dynamic display of two-dimensional experimental results



本实验开始时间为: 2002-1-6 14:46:24
这是模块1，采集数据为温度数据，热电偶类型为K型

0.301	16.50	16.40	16.50	16.40	16.20	16.50	16.20	16.40
1.422	16.50	16.40	16.50	16.40	16.20	16.50	16.20	16.40
2.544	16.70	16.40	16.40	16.50	16.30	16.60	16.30	16.50
3.666	16.80	16.30	16.30	16.40	16.20	16.50	16.20	16.40
4.787	16.80	16.60	16.40	16.60	16.40	16.60	16.40	16.50
5.909	16.60	16.50	16.40	16.60	16.40	16.60	16.40	16.50
7.030	16.60	16.50	16.40	16.50	16.40	16.40	16.30	16.50
8.152	16.50	16.30	16.50	16.60	16.50	16.50	16.40	16.60
9.274	16.50	16.30	16.50	16.30	16.30	16.50	16.20	16.50
10.425	16.60	16.30	16.50	16.50	16.30	16.50	16.20	16.50
11.547	16.60	16.30	16.50	16.50	16.20	16.50	16.30	16.50
12.689	16.70	16.50	16.50	16.60	16.40	16.50	16.30	16.50
13.810	16.70	16.50	16.50	16.60	16.40	16.60	16.40	16.70
14.932	16.50	16.40	16.40	16.40	16.20	16.50	16.30	16.60
16.063	16.60	16.50	16.50	16.50	16.30	16.60	16.30	16.60
17.185	16.70	16.40	16.50	16.50	16.30	16.60	16.50	16.60
18.357	16.60	16.30	16.40	16.40	16.20	16.50	16.40	16.50
19.478	16.60	16.40	16.30	16.50	16.20	16.50	16.40	16.60
20.640	16.80	16.40	16.30	16.50	16.20	16.50	16.40	16.60
21.762	16.80	16.60	16.60	16.60	16.50	16.60	16.50	16.80
22.903	16.60	16.50	16.60	16.60	16.50	16.60	16.50	16.80
24.025	16.60	16.50	16.40	16.50	16.30	16.60	16.40	16.70
25.147	17.10	17.10	16.40	16.50	16.30	16.60	16.40	16.70
26.268	17.10	17.10	16.90	17.10	16.40	16.70	16.60	16.80
27.390	17.20	17.30	17.30	17.00	16.30	16.60	16.50	16.70
28.511	17.20	17.30	17.30	17.60	16.30	16.80	16.50	16.60

Fig. 11: Example of data file

5. CONCLUSION

Traditional acquisition system is not a suitable tool for data collection in the PolyU/USTC atrium due to the large space, huge amount of signals to be collected at numerous measuring points, and long transmission distance. This system suffers from the shortcomings of having an overwhelmingly large system, low reliability, lack of flexibility in expanding, signal depreciation and serious disturbance through long distance signal transmission. Also, higher investment cost is needed due to excessive transmission cables. Therefore, fieldbus technology [5] is introduced in the distributed DAS for achieving high speed, large capacity and good expandability. This system can collect data from more than 200 routes every second. The system network is simple, easy to maintain, flexible and expandable. User-friendly Windows interface is inherited in the system software. Since modular design is adopted, functions such as station inspection, real-time acquisition, dynamic display, autosave, and data retrieval can be performed easily. Multi-linear procedure is adopted for efficient processing. This distributed data acquisition system is demonstrated to be stable when carrying out fire experiments in the PolyU/USTC Atrium. Functions of acquiring signals of pressure, smoke density and radiation density can also be added into this system in future development.

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REFERENCES

1. R. Huo, W.C. Fan, L.M. Yuan, H. Dong, W.K. Chow, N.K. Fong and P.L. Ho, “Construction of a large space experimental burning hall and preliminary tests”, Fire Safety Science, Vol. 1, No. 7, pp. 8-13 (1998) – In Chinese.
2. M.J. Ma and C.C. Zhou, Data acquisition and processing technique, Xi’an Jiaotong University Publisher, September (1989).
3. R.G. Brown, Introduction to random signal analysis and Kalman filtering, Wiley, New York (1983).
4. M. Chidambaram, Computer control of processes, CRC Press, Boca Raton, Florida (2002).
5. W. Buchanan, Computer busses, CRC Press, Boca Raton, Florida (2000).
6. http://www.borland.com/
7. http://www.hw.cz/english/docs/rs485/rs485.html
8. H. Schumny, “Fieldbuses in measurement and control”, Computer Standards and Interfaces, Vol. 19, pp. 295-304 (1998).
9. http://www.ztic.com.cn/product/RM400/Readme/RM410.doc
10. http://www.maxim-ic.com.cn/Max038-157/Max132.pdf
11. http://www.atmel.com/atmel/doc0265.pdf
12. http://www.ztic.com.cn/product/RM400/Readme/RM450.doc
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14. Microsoft Knowledge Base Article – Q158008, http://www.support.microsoft.com/