The development of the online detection network system of coal mine safety instrument and meter

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Abstract. As the main equipment that directly reflects the concentration of various flammable, explosive, toxic and harmful gases in the working environment of mines, the coal mine gas sensors are widely used in coal mine safety monitoring and supervision systems. However, these sensors cannot accurately display the concentration of the detected gas due to problems such as zero and span drift of the catalytic element. Therefore, regular testing is required according to coal mine safety regulations. In this paper, the network system of coal mine safety instrument testing center is designed, and a network on-line testing system of coal mine safety instrument's input, inspection, output, certification and finance is established, which integrates the network server, company LAN, upper computer automatic analysis, lower computer real-time processing and takes barcode as the identification. It realizes the network operation of sensor storage, waiting for inspection, verification, sending and achieves the goal of improving efficiency and reducing labor intensity.

1. Introduction

Nowadays, coal mine gas sensors are widely used in coal mine safety monitoring and supervision systems to ensure the safety of coal mine production. Almost all domestic methane sensors are made of carrier catalytic elements. However, due to zero point and range drift of its catalytic element, it will cause errors in the displayed concentration, which will seriously affect the safety of downhole production [1]. Therefore, the National Metrological Verification Regulations and Coal Mine Safety Regulations have strict regulations on the calibration of various gas sensors. They must be adjusted every 7-10 days in coal mines, and calibrated every 3-6 months [1]. The existing coal mines mostly use manual verification, although the detection process has been automated to a certain extent. The main calibrators used are CBZ-5 gas alarm sensor calibration station produced by Beijing Lingtian Century Automation Technology, KTQJ8-II gas alarm sensor calibration device of Qingdao Ruihai Safety Equipment Technology, and JZ-1 mine gas sensor verification device of China Coal Mining Company, and unmanned mine gas sensor intelligent online analysis equipment developed by our team. All these have played a huge role in promoting gas sensor detection to a new level.

The CBZ-5 gas sensor alarm calibration station can manually adjust 5 sensors at the same time and the adjustment data can be printed online; KTQJ8-II gas alarm sensor calibration device can manually adjust 8 sensors at the same time; developed by our team The intelligent online analysis equipment for
unattended mine gas sensors developed by our team proposes multiple online detection methods such as multi-concentration automatic, single-concentration automatic and individual selection intelligence, which realizes one-key simultaneous detection and online analysis of 64 gas sensors.

Although the above-mentioned research has realized the automation of the detection process in a certain sense, it has not yet established the network of sensor storage, waiting for inspection, verification and sending. Besides, the full monitoring of the detection process has not been realized, and the rate of missing detection is still very high.

Based on the above problems, a network on-line testing system of coal mine safety instrument's input, inspection, output, certification and finance is established, which integrates the network server, company LAN, upper computer automatic analysis, lower computer real-time processing and takes barcode as the identification. It realizes the network operation of sensor storage, waiting for inspection, verification, sending and achieves the goal of improving efficiency and reducing labor intensity.

2. System description
The networked online detection system designed in this paper mainly includes the following aspects: network server, company LAN, upper computer automatic analysis and lower computer real-time processing. The entire system includes system maintenance, initial login management, pending inspection management, verification module, certification module that integrates security instrument file management, verification automatic control, data communication record query and analysis. The information of each module forms a data link from the system maintenance. The data will be automatically transferred to the next module after the completion of the previous module. At the same time, the detection network system realizes the implementation of bar code management of coal mine

Figure 1. Plots of load and loading step of muddy siltstone under a single cutter.
safety instruments and meters, and the detection results can be transmitted to the network database and the website of the detection center in real time. All upper-level departments and users can query various verification services on the website of the testing center in real time, so that the testing process can be fully monitored. The upper-level departments at all levels prepare data browsing modules for real-time random browsing. The network structure of the detection system is shown in Figure 1.

The system maintenance enters basic information such as place names, models, and manufacturers to be used in the entire system for subsequent use.

2.1. Initial login management

The measuring and testing instruments must log in to enter the testing center for testing. The main function of login management is to receive equipment submitted for inspection by the coal mine.

First of all, enter the inspection unit, contact phone number, date of receipt, specific information volume, quantity, recipient and other information of the equipment to be inspected into the receipt form, use this as the receipt and dispatch voucher, and print the receipt and dispatch receipt, and the serial number of the receipt and dispatch order as the basis for inquiry.

Second, create a bar code for the equipment. The content of the bar code includes the inspection unit, sensor type, manufacturer, specification model and instrument number and the barcode is the unique identification of the device. The LAN storage table of the testing center adds a record and publishes the status of the device from the website.

2.2. Module to be inspected

After logging in for the first time, the front desk will send the equipment to different laboratories for testing. By scanning the barcode, the equipment information to be inspected is recorded in the data sheet for users to query the current status of the equipment in the testing center.

2.3. Verification module

The verification module is the core of the verification process, including the upper computer intelligent control and analysis part and the lower computer real-time control and processing part. The upper computer intelligent control and analysis part is designed based on PowerBuilder, and the lower computer real-time control and processing part is based on the 8051F020 and its peripheral interface circuit. The communication between the upper computer and the lower computer is MODBUS communication protocol.

This module can realize automatic detection of methane sensor, methane alarm, carbon monoxide sensor, carbon monoxide alarm, optical interference methane sensor, wind dust sensor, wind speed sensor.

2.3.1. Overall control of lower computer. Figure 2 is the block diagram of mine gas sensor detection based on 8051F020.

8051F020 single-chip microcomputer system can check 64 analog sensors at the same time, and receive commands from upper computer through serial port interruption. According to different detection function requirements of upper computer, it can realize automatic monitoring and manual detection of N analog sensors in different modes, and provide standard gas meeting the flow requirements [2]. In order to ensure that the reading of the sensor is effective, the sensor data must be read after each standard gas is injected for a certain period. At the same time, the read value is transmitted to the upper computer in real-time. According to the difference between the read data and the standard gas value, the upper computer automatically sends out the adjustment infrared signal, so that the analog sensor reading is consistent with the standard gas. The microcontroller automatically controls the solenoid valve to open the corresponding gas outlet according to the information of the sensor position, quantity and concentration contained in the command, and controls the electronic control valve to open the corresponding standard air inlet gas path, so that the controller can supply the flow of the standard gas corresponding to the sensor to be measured.
2.3.2. Multi-channel sensor information collection. For the analog sensor whose transmission output is a frequency value, the 8051F020 calculates its cycle by collecting the time between the two rising edges, and then uses the RS485 bus to transmit to the upper computer with the MODBUS protocol.

Due to the large number of I/O ports required to measure 64-channel sensor information and limited CPU resources, this design is realized by analog multiplexer HCC4067BF to simultaneously collect the transmission and output of 64 channel mine gas sensor. A piece of hcc4067bf can be connected with 16 channels of sensor output signals, which is controlled by 8421BCD code at a, B, C and D terminals, and different sensor signals are connected to the I/O port of the single chip microcomputer by time-sharing strobe. The 64-channel sensor output signals are collected to the P1 port of the single-chip microcomputer when they pass through the analog multiplexer component composed of four HCC4067BF. Four pieces of HCC4067BF have 4 signals to be collected each time, and the concentration values of 64 sensors are collected after 16 times of control.

2.3.3. Control of standard gas intake and sensor on-off gas. The detection of mine analog gas sensor mainly uses the standard gas with known concentration to detect the sensor. The main parameters of the analog sensor are zero-point and linearity. The zero-point detection is mainly adjusted by using air. The linearity detection is through several different concentrations of standard gas such as 0.5, 1.0, 1.5, 3.0 [3], and the gas path control block diagram is shown in Figure 3 [4-5]. In the detection process of mine analog gas sensor, the gas path part needs to control the switch between air and standard gas with different concentrations.
The whole control circuit is realized by 8 SN54ALS164J cascaded. Each chip has 8 outputs, which can control up to 64 sensors. The position information of the upper computer is output through the P0.4 of the 8051F020 single-chip microcomputer. Under the action of the clock signal, the information will appear on the parallel output port of the chip in sequence, and the switching state of the solenoid valve is controlled after being amplified.

2.3.4. Analysis of the upper computer.

(1) Interaction with lower computer

The development platform of the automatic detection system is PowerBuilder. In the main control interface, there are icons of air, standard gas concentration I, standard gas concentration II, standard gas concentration III and standard gas concentration IV, and the standard gas concentration grade is marked in its tag attribute. The control, standard gas concentration and the position and quantity of the detector to be verified are transmitted to C8051F020. According to the control command issued by the upper computer, C8051F020 controls the switching and conduction of the input gas path of the standard gas and the output gas path of the detector.

During the detection process, PowerBuilder starts to read data after the value of the gas sensor is stable, and compares the read data with the calibration gas value. When the difference exceeds the required value, it compares the read data and sends infrared control until the difference between the display value of the sensor and the calibration gas value meets the requirements of the detection regulations, and gives "pass" result [5]. If the sensor reading value cannot be adjusted to the required value after a given number of consecutive tests (such as 20 times), the test will be stopped and an "unqualified" result will be given. The result indicates that the sensor has been damaged and cannot be used, and the upper computer displays "the nth sensor is unqualified at the Nth concentration!".

After the detection, the data of qualified sensors should be integrated, and various reports conforming to the national testing regulations should be printed out. In the verification, 5 (or 6) times should be tested at certain concentrations to calculate the zero drift and range drift, and each concentration should be tested at least 3 times. Through effective database management, the sensor parameters will be collected and stored for users to query.

(2) Flow control

According to the regulations of metrological verification, the standard gas flow rate of each sensor should be controlled at a fixed value, otherwise, the measurement concentration will fluctuate and calibration errors will be caused. The constant flow control of standard gas is related to many factors such as fluid density, relative humidity, temperature, flow rate, standard gas pressure, number of detection sensors and standard gas concentration. At the same time, the relationship between the flow rate and these factors is complicated with hysteresis. Therefore, the system adopts radial basis neural network to control the flow rate. Figure 4 is the structure diagram of the radial basis function neural network. It has a hidden layer and the hidden unit is the basis function. In practice, the Gaussian function is selected:

![Figure 4. RBF neural network.](image-url)
\[ \Phi(x, x_i) = \exp\left(-\frac{1}{2\sigma^2_i} \|x - x_i\|^2\right) = \exp\left[-\frac{1}{2\sigma^2_i} \sum_{k=1}^{N} (x_k - x_{ik})^2\right] \]  (1)

Then \( f(x) \) can be obtained:

\[ f(x) = \sum_{i=1}^{N} \omega_i \exp\left(-\frac{1}{2\sigma^2_i} \|x - x_i\|^2\right) \]  (2)

The training of RBF neural network includes the training of output unit weight \( \omega_i \), hidden unit center \( x_i \) and function width \( \sigma \). \( \omega_i \) is directly calculated by the least square method, and the latter two parameters are selected by clustering methods such as K-means clustering. The center of sample clustering is taken as the center of RBF, and the difference between each quantity and center is taken as the function width [6-7].

In the gas sensor detection system, six signals including flow rate, standard gas pressure, number of detectors to be calibrated, standard gas concentration, relative humidity and temperature are selected as input \( x \), so the number of hidden layer units is also selected as 6. Through clustering, the standard reference value of the corresponding input sample is taken as the center \( x_i \) of the six corresponding hidden units, and the output \( f(x) \) is the predicted flow rate value. In this way, a radial basis function neural network with six inputs, one output, and six hidden units is obtained. Then, according to the value of \( f(x) \), the monitoring system sends D/A value to the MCU by the upper computer [7]. The specific training process will not be repeated due to space limitation.

(3) Data and image collection

Since the alarm has no transmission output, the operator can only input the readings into the computer one by one which makes the error rate high. Therefore, the system adds image processing methods to identify its readings.

When the gas concentration is unchanged, the photos collected by the calibration platform are read and saved. After preprocessing the collected images, the display value comparison model based on multiple features is established [8]. The reading values and position of alarms from different manufacturers are identified by artificial neural network, and the corresponding expert knowledge base is established [9-10].

2.4. Certificate module

Register the prepared certificate in the prepared certificate library. After the certificate registration and stamping are completed, it will be handed over to the business hall and the barcode of the certificate will be scanned. The software will extract the corresponding information from the archive library according to the barcode to provide query services for other users. Figure 5 is the login interface.

![Figure 5. Login interface.](image-url)
2.5. Sending module

Register the verified device and certificate to the issuing library, and the user can query the corresponding information from the issuing library by scanning the barcode on the device. Figure 6 is the query interface of the issuing library.

![Query Interface](image)

**Figure 6.** The query interface.

2.6. Statistics module

In addition to meeting the general query requirements, the compilation center should perform statistics on various equipment inspections based on the name of the inspection unit, manufacturer, receiving date, issuing date, and given time period. Quantity, analysis on-time completion rate, error rate, comparison with the previous period and other functions, and print out various reports. Figure 7 is the Equipment detection statistics interface, from which we can get the detection status of different detection units and different sensors at each period.

![Statistics Interface](image)

**Figure 7.** Equipment detection statistics interface.
3. Conclusions
The system implements bar code management in the whole process of measuring and testing instruments from entering the testing center to completing the verification until sending out. The file information resources of the testing instruments are shared, and the testing data can be automatically uploaded to the server and saved, so that the detection of safety instruments can be fully covered and the process can be fully monitored. At present, the system has been applied in Changzhi coal mine safety instrument detection center, including initial login, certificate issuing, equipment issuing, financial accounting, etc. Seven computers are used to complete the detection of methane sensor, methane alarm, carbon monoxide sensor, carbon monoxide alarm, optical interference methane sensor, wind dust sensor and wind speed sensor. The module data and test data form the information resources shared by network server and company LAN. Users can query the detection status of their own equipment on the website of the center, which greatly improves the automation level of verification.

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References
[1] Wang Congxiao 2008 Online checking and signing method of sensor in safety monitoring and control system of Coal Mine[J]. Industry and Mine Automation 8(4) 66-67
[2] Pan Zhuojin C8051F020/1/2/3 Mixed signal ISP flash microcontroller data book New China Dragon Electronic Co., Ltd. Rev 1.4 2005.2
[3] Shanxi kezhicheng Technology Co., Ltd. An intelligent calibrator for mine gas sensor based on DSP[P]. Chinese patents: CN101988912A 2011-03-23
[4] Tian Muqin, Liu Xiqing, Wang Xuesong, et al. 2011 Mine gas sensor unattended intelligent calibrator[P]. Chinese patents: ZL 201110274028.0 2011，10
[5] Guo Yan 2015 Mine gas sensor unattended calibration and exhaust treatment system[D]. Taiyuan University of Technology
[6] Zhao Yaoyuan, Tian Muqin and Zhang Yanpeng 2014 Research and development on intelligent calibration and verification instrument for 64 gas sensors[J]. Journal of China Coal Society 39(0z1) 267-272
[7] Song Bai and Liu Zhijun 2010 Development of Calibration Device of Mine-used Gas Sensor[J]. Industry and Mine Automation 3(03) 81-84
[8] Tian Muling and Yang Jieming 2016 Optimization of Structural Element in Froth Image Denoising of Coal Flotation[J]. International Journal of Pattern Recognition and Artificial Intelligence 30(4) 1654002-1--1654002-26
[9] Tian Muling, Tian Muqin and Yang Jieming 2018 Optimization of RBF neural network used in state recognition of coal flotation Journal of Intelligent & Fuzzy System 34(2) 1193-1204
[10] Feng Xinying, Ji Hua and Zhang Huaxiang 2012 Multi-label RBF neural networks learning algorithm based on clustering optimization[J]. Journal of Shandong University 47(5) 63-67