

# Development of an online gamma radiation measurement system

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**Abstract.** Raw coal is often interspersed with rocks as well as soil fragments, so natural  $\gamma$ -radiation measurement is used for online detection of coal quality in the coal mining and processing production process. To solve the problems of system development, data acquisition and transmission and online calibration in online  $\gamma$  radiation measurement, an online  $\gamma$  radiation measurement system was developed based on ATMEGA8L microcontroller. The upper computer software developed with Qt realizes the functions of RS485 serial communication between the upper computer and the lower computer, online configuration of the instrument working mode, real-time display and recording of the measurement results, and recording and query of the working log. After testing, the software of the upper computer is easy to operate, friendly human-computer interaction, and can realize the required functions to meet the current requirements for the intelligence of production instruments, and the RSD of the measurement results of the system is 1.1% for long time operation, with good stability.

**Keywords:** Online  $\gamma$ -radiation measurement; coal quality online detection upper computer; Qt

## 1. Introduction

Gamma radiation measurement instrument is a kind of measuring instrument which is specially used to measure the rate of gamma ray absorption in a certain energy range by using the combination of nuclear radiation detector and modern electronic measurement technology, it is the measurement of the total amount of gamma radiation, because it has the characteristics of simple and reliable, high flexibility, it has been widely used in the fields of geological exploration, radiation environment monitoring, industrial testing and so on. In coal mine production, because the raw coal contains traces of natural radionuclides such as U, Th and K due to the inclusions of stones, soil, etc., the ash content in coal can be determined by measuring the natural gamma radiation in coal[2][3].

The common  $\gamma$  radiation meter mostly adopts the integrated structure, integrating the detector, processing unit and display unit into a complete independent system, such design has its advantages, but in the gradual pursuit of instrument intelligence and simple operation today, the shortcomings of this design scheme are also exposed, such as the parameter setting operation is more cumbersome, the recording and query of measurement results are not convenient enough, and the measurement process cannot be visualized in real time, etc. In the process of online measurement, these problems may cause the decline of economic efficiency, so it is important to design a  $\gamma$  radiation measurement system more suitable for online measurement needs and application prospects.

## 2. Working Principle

$\gamma$  radiation meter generally uses scintillation detector, scintillation detector by the scintillator, photomultiplier tube (PMT) and the corresponding pre-processing circuit composition. After the rays enter the scintillator and interact with it to produce secondary charged particles, the scintillator absorbs the energy of the secondary charged particles and causes the internal atoms and molecules to ionize and excite, these excited atoms and molecules emit fluorescent photons when they are de-excited, the cathode of the PMT captures these fluorescent photons to produce photoelectrons,

the photoelectrons are multiplied on the pole, the anode of the PMT collects these electrons and The PMT anode collects these electrons and generates a current signal, which is sent to the processing unit (MCU) for processing after the pre-processing circuit, and then the MCU displays and stores the processed data according to the experimental or production requirements.

In order to make the measured data can characterize the  $\gamma$  radiation intensity of the measured sample, calibration should be carried out first, because there are often multiple coal seams in the same mine area, and the thickness of the ore material on the belt scale is variable, so the calibration should be carried out several times for different coal seams and different thicknesses, and the calibration coefficients will be saved as the measurement mode in the system database, and the corresponding measurement mode can be selected according to the coal seams and the thickness of the ore material during actual measurement[1][9].

### 3. Shielding Device

In the process of measurement, in addition to the  $\gamma$  radiation generated by the mineral to be measured itself, the natural  $\gamma$  radiation in the surrounding environment is also recorded due to the injection into the instrument, producing a measurement background, which in turn affects the measurement results. Since the natural  $\gamma$  radiation background of the mining environment itself is much higher than that in the ordinary environment, this effect is also more significant, and in order to improve the measurement accuracy, the whole detection system needs to be shielded.

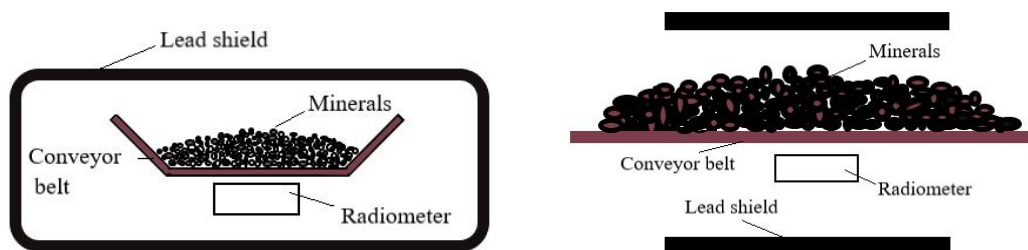


Figure 1. Schematic diagram of shielding device, vertical view (left), section view (right).

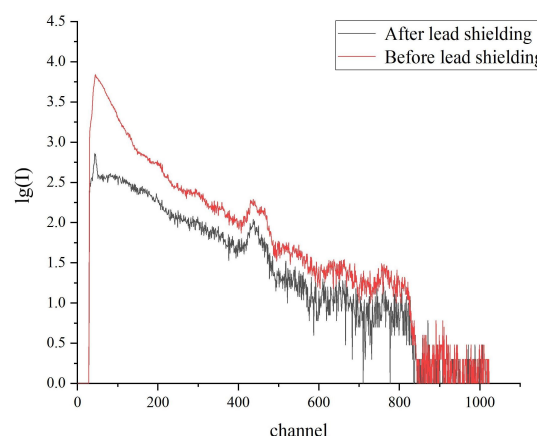


Figure 2. Logarithmic spectra before and after natural gamma radiation shielding.

Lead has a high absorption coefficient for  $\gamma$  radiation and is relatively inexpensive, and is often used as a shielding material for  $\gamma$  radiation, so lead is used as the shielding material for the system [6][7]. Natural  $\gamma$  radiation is dominated by natural uranium, thorium, potassium emitted by the medium-energy  $\gamma$  rays below 3 MeV, of which the majority are below 300 keV. Considering that the shielding layer should not be too thick for industrial applications, a shielding layer thickness of 3 cm is used, processed as a box structure with openings at both ends, and the schematic diagram of the shielding device is shown in Fig.1.

In order to verify the shielding effect of the shielding device on the low-energy end of the  $\gamma$ -ray, the experimental platform was built to measure the environmental natural gamma background, and the shielding effect before and after the 3cm lead shielding was measured respectively, as shown in Fig.2. As can be seen from the figure, after shielding, the total counts were reduced by 81.28%, the total counts in the spectral band below 300 keV were reduced by 81.38%, and the characteristic peak areas of nuclides such as uranium, thorium and potassium were significantly reduced, and the shielding effect was good.

The  $\gamma$  radiation instrument was placed in the lead shield, so that the scintillator was perpendicular to the measurement plane, and the direct measurement of the ore on the belt scale was performed by controlling the instrument through the PC after starting the instrument.

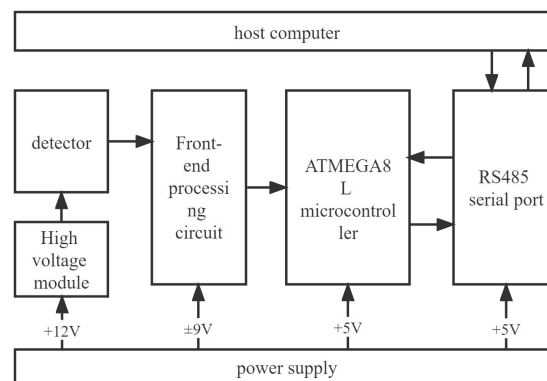


Figure 3. On-line gamma measurement system hardware structure sketch.

## 4. System Architecture

The system adopts a separate design for the upper computer and the lower computer, which communicate with each other via RS485 serial port. The upper computer is developed in C++ programming language based on the Qt framework on the computer side, using QCustomPlot control for real-time data display, and embedding SQLite lightweight database for recording and querying relevant configuration information [4].

The lower computer uses an ATMEGA8L microcontroller-based gamma radiation meter, which uses a 100\*100\*400(mm) NaI(Tl) crystal as a scintillator with high efficiency for  $\gamma$ -ray detection and large luminous efficiency, and its emission spectrum has the strongest wavelength of about 415 nm, which can match well with the spectral response of the photomultiplier tube. The system uses a rechargeable lithium battery pack to provide 8.4 V drive voltage and 700 mA drive current to support the system work, which is output to each part of the system for power supply after boost conversion.

## 5. Upper Computer Software Design

### 5.1 Software Architecture

The software part should meet the basic functions of receiving data storage, real-time data display, instrument parameter configuration and display, etc. In order to meet the industrial demand, it also adds the instrument parameter mode configuration function, work log automatic saving and convenient query function, operator information management and system login function to achieve a more intelligent interactive experience.

### 5.2 Serial communication module

RS485 is a two-wire communication interface, with good resistance to noise interference, long transmission distance and multi-station capability, and is more commonly used in industry [5][8].

Qt comes with QSerialPort class to access the serial port, add QT+=serialport statement in the pro (top-level project file) to create QSerialPort class object to achieve serial port parameters configuration and operation and other related functions. Qt's signal slot mechanism is very flexible, and the exchange of information between the instantiated objects of each class is completed through this mechanism. To facilitate the operation, the instantiation of the serial port class and the query and selection of the communication port are placed in the window class object corresponding to the parameter configuration serial port. When the CurrentIndexChanged signal of the port selection drop-down list is triggered, a query signal is sent by the window class, and the slot function is declared in the serial port class to process it.

### 5.3 Lower computer parameter configuration module

The type of  $\gamma$  radiation detector can be configured with 4 parameters, which are single measurement time, alarm threshold, calibration coefficient a and calibration coefficient b. The calibration equation is a linear equation, as shown in (1).

$$Y = a * x + b \quad (1)$$

Where x is the total single count of the actual measurement.

Table 1. Serial communication protocol for lower computer

Instruction/Data	Command function	Instruction/Data	Command function
cancel\$	Cancel/Start measurement	SAlrms\$	Alarm threshold setting
choose\$	Confirm	N=****\$	Alarm threshold data
jumpes\$	Stop measurement	SConfe\$	Calibration parameter settings
Stimes\$	Measurement time setting	a=****\$	Calibration factor a
T=***s\$	Measurement time data	b+****\$or b-****\$	Calibration factor b

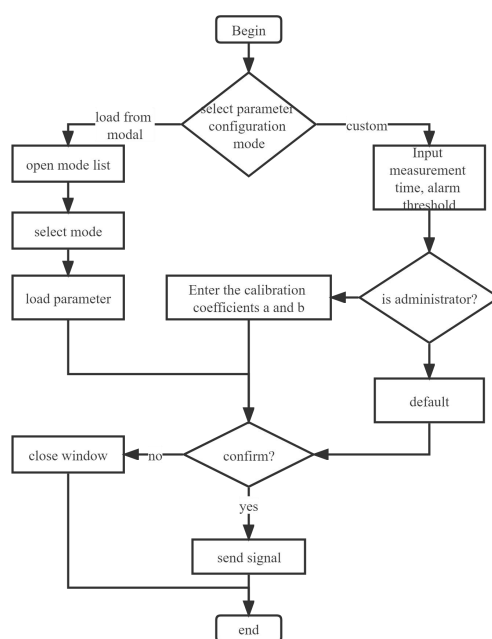


Figure 4. Parameter configuration flow chart of online  $\gamma$  measurement system.

According to the actual production practice requirements, two parameter configuration modes are set in the parameter configuration class, one is the user-defined parameter configuration mode, i.e., the single measurement time and alarm threshold can be configured arbitrarily, and the two coefficients of the calibration equation can be configured under the administrator authority; the other is the parameter configuration mode loaded from the mode, i.e., a series of parameters that have been set from the mode table in the database are selected and directly after confirming the parameters, the configuration command is sent to the lower

computer to start the measurement. The online gamma measurement system parameters configuration process is shown in Fig.4.

Table 2. Serial communication protocol for lower computer

Instruction/Data	Command function	Instruction/Data	Command function
cancel\$	Cancel/Start measurement	SAlrms\$	Alarm threshold setting
choose\$	Confirm	N=****\$	Alarm threshold data
jumpes\$	Stop measurement	SConfe\$	Calibration parameter settings
Stimes\$	Measurement time setting	a=****\$	Calibration factor a
T=***s\$	Measurement time data	b+****\$or b-****\$	Calibration factor b

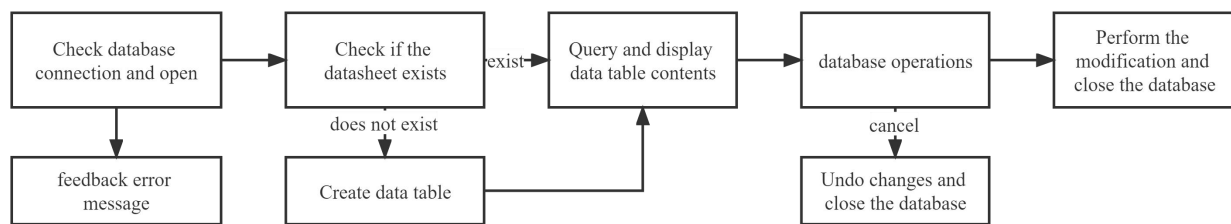


Figure 5.Database Operation Flow.

Table I shows the serial communication protocol of the lower computer. The instructions are divided into two categories, one executing function selection and the other executing parameter configuration, represented in the form of strings, and the procedures for receiving and processing these instructions are implemented in the microcontroller using the C programming language. It is worth noting that because the program in the microcontroller is executed sequentially, the instructions need to be sent in a certain logical order, and the cluster packet strategy is used in the development of the upper computer software to solve this problem.

## 5.4 Data manipulation module

The lower computer returns data every second, and the returned data frames follow a certain format and are sent to the PC via RS485 serial port for frame parsing, real-time display and storage according to the communication protocol.

### 5.4.1 Data acquisition and storage

Since the data returned by the lower unit is continuous per second in the continuous measurement mode, the received data is accumulated and grouped in packets using the Append() method of QByteArray, and is intercepted in the slot function of the timer timing overflow signal using the mid() method of QByteArray according to the format of the returned data frame to extract the remaining time and other information to realize The data is received.

CSV file (Comma-Separated Values) is a form of text storage of the table file The CSV file (Comma-Separated Values) is a form file stored in text form and supports opening in tabular form, which is used to store the received data because of its easy-to-use characteristics.

The format of the data returned by the lower computer is shown in Table II.

### 5.4.2 Real time display of data

Since the received data is just a series of values, it is not easy to observe the floating radioactivity level of the measured environment in real time, so it is very important to visualize the received data in real time, and Qt's graphics class QCustomPlot is used for dynamic scrolling display of the real time data.

The same signal in Qt can have more than one processing slot function, which is executed in the same thread in the order of connection, and another slot function is defined in the main interface class to process the signals sent by the serial port object with parameters.

## 5.5 Log file generation module

In practice, a day's measurement is often divided into several periods, and the data files generated by each measurement are independent, which brings inconvenience to view the working conditions of a day, so the log file function is added to automatically integrate the measured data in a day, and the generated data contains all the data of all the measurements of the day.

The log file is generated with a configurable path and non-configurable file name strategy. The first measurement of each day creates a .dat file named after the date of the day, and subsequent measurements detect the existence of the file and open it directly. Considering the large amount of data, the log files are saved in binary format, and QFile is used to generate file objects and QDataStream to generate data stream objects for reading and writing data. The binary file needs to

be read in the format deposited, and to avoid generating extra work, a query function for the log file is implemented in the host software to display the contents of the log file for the selected date simultaneously in the form of a table and a curve.

## 5.6 Database operation module

SQLite is a lightweight database following ACID, Qt has very good support for it, including complete driver code, providing QSqlQuery, QSqlQueryModel, QSqlTableModel three kinds of libraries for accessing the database, by adding QT+=sql statement in the pro file to achieve support for the database. very convenient.

The schema information of the measurement model and the login information of the login system need to be stored in the database. To facilitate management, QSqlTableModel is used to visualize the contents of the database and implement the interface functions for adding, deleting and changing.

## 6. Results

### 6.1 Control interface display

Figure 6 shows the main interface of the upper computer when the system is running. The corresponding menu item in the upper menu bar can configure the output file storage address and file name, instrument parameters, database and

other information, while the left graph dynamically displays the real-time data of single count, total count per second and y value respectively.

### 6.2 Stability check

The system was used in a laboratory environment for 8 hours of continuous static measurements of the environmental background, and the data obtained were statistically analyzed, and the results are shown in Fig.7.

In the figure, the mean value (NAVR) of the total counts of a single measurement is 546, the standard deviation ( $\delta$ ) is 6.03, the RSD is 1.1%, and its doubled standard deviation interval ( $NAVR \pm \delta$ ) is represented by the dotted line, which shows the good stability of the system [10].

## 7. Conclusion

The system realizes RS485 communication between the PC upper computer and  $\gamma$  radiation meter, and can make complete records and real-time display of the data measured by the radiation meter, the patterned parameter setting simplifies the control process, the staff login system and work log recording and query functions meet the needs of industrial production, except for setting parameters manually, all other operations can be done automatically by the system, meeting the design requirements of intelligent instruments. The experimental test results show that the stability of the instrument is good, the upper computer can accurately set the instrument parameters and record the test results completely, and the use of the system for  $\gamma$  radiation measurement work can simplify the operation process and improve the efficiency, which has practical application value. The system has achieved good results in the application of coal mine production in a place in Shandong.

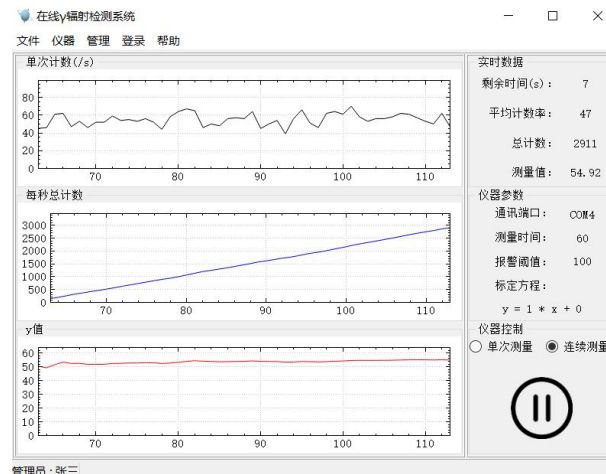


Figure 6. Online gamma radiation measurement system operation and control main interface

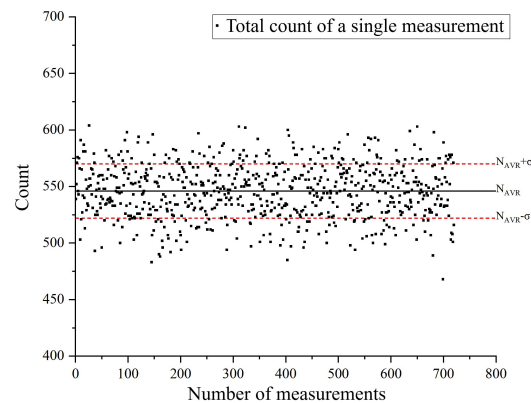


Figure 7. System stability for 8 hours of continuous operation

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