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Data Acquisition Software for a Prototype of LET Spectrometer

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Silicon Micro-strip Detector (SMD) has been widely used in detecting charged particles. Using SMD as detector, and to measure the Linear Energy Transfer (LET) generated by the ionizing radiation in manned spacecraft, a prototype of LET spectrometer is designed. This paper presents the design of the data acquisition (DAQ) software for the LET spectrometer. To read out and preliminarily analyze the data, the DAQ software is consist of three modules, which are readout and control module, data real-time imaging module, and offline data analysis module. Multiple data tests are included in the DAQ software as a result of reliability requirement of the data. The DAQ software realizes the dual communication interface through the Ethernet interface of the back-end electronics, which are used to summarize the data generated from the three detectors of the prototype in the experiment, and the USB interface of the front-end electronics for debugging a single detector. Qt is used as the development tool for Windows platform, because of its excellent reliability and maintainability. Its cross-platform-ability is also important to operate in other platforms. Due to the small amount of data and high demand of efficiency, it is appropriate to choose C + + as the programming language. In the tests, the DAQ software shows good performance and fits the needs of application.

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1. Introduction

In manned space missions, ionizing radiation could be a big threat. The ionizing particle environment in space is the dominant source of ionizing radiation within space systems.[1] Solar energy particles (SEPs), galactic cosmic rays (GCRs) and trapped radiation are the main sources of space radiation. SEPs are consists of 92% protons, 6% helium ions and 2% HZE; GCRs are consists of 85-90% protons, 10-13% helium ions about 1% electrons and 1% HZE; trapped radiation mainly consists of protons and electrons.[2] In this case, measuring LET of charged particles is a method to evaluate the risk of ionizing radiation.

Aiming to measuring LET of charged particles and especially for ground tests, a prototype of LET spectrometer is designed. Figure 1 is the schematic diagram of the prototype. The prototype uses double-sided silicon strip detector (DSSD), which is a type of SMD and can obtain the incident position of particles from both of its sides (P-side and N-side), as detector. The DSSD used in the spectrometer has a total of 32 readout strips (16 strips for each side). The adapter provides two different gains, corresponding to two different range. As a result, 32 channels of signals from one detector are divided into 64 channels. The FEE is the front-end electronics of the prototype. It realizes the function of amplitude acquisition and analog-digital convention by ASIC. The data generated by three FEEs is collected by the data collection module (DCM) and is transferred to the upper computer. To read out and preliminary analyze the data, a DAQ software is designed and is proposed in this paper.

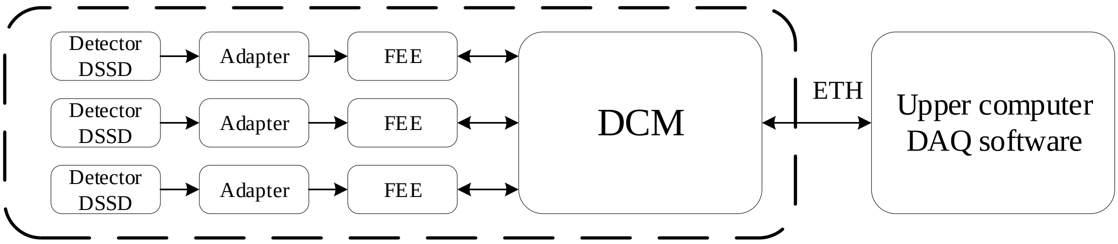


Figure 1: Schematic diagram of the prototype. In the dotted line are detectors and electronics. This part is composed of 3 detectors of the same specification, 3 corresponding FEEs and 1 DCM. DCM is connected with the upper computer through Ethernet.

The DAQ software can read out and save the data transferred either from a single FEE or DCM, in order to benefit debugging and operation. Data based energy spectrum and hit position map are shown on the software, which can be a tool for both prototype status check and data check. The algorithm that used to calculate LET of given kinds of particles is also realized in the software.

In this paper, the implementation of the DAQ software is introduced in section 2. And section 3 introduces the test results of the software

2. Software Implementation

2.1 Software Structure

The DAQ software is developed with Qt framework, and is designed to run on windows platform. To make software operation simple, a graphic user interface (GUI) is designed. As

Figure 2 shows, the software adopts a Model-View-Controller (MVC) structure. MVC is a design pattern used to decouple user-interface (view), data (model), and application logic (controller).[3]

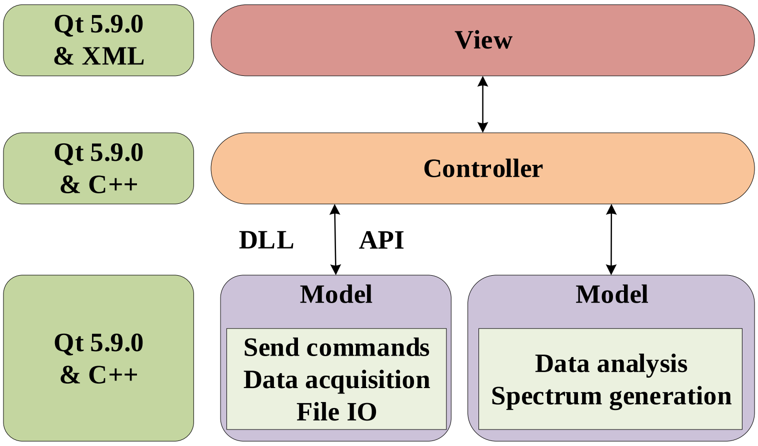


Figure 2: MVC structure of the software.

2.1.1 View

The view layer is designed with Qt 5.9.0. The design of UI interface is based on extensible markup language (XML). On this layer, users' operations are converted to messages, which are sent to the controller layer. The results of the program are also displayed on this layer.

2.1.2 Controller

The controller layer is designed with Qt 5.9.0 and C++. It receives messages from the view layer and emits signals to the model layer. The results are sent to the view layer through the controller layer. It controls the performance of another two layers.

2.1.3 Model

The model layer includes the concrete realization of the functions, and is written with Qt 5.9.0 and C++. The function modules are introduced as below.

2.2 Function modules

2.2.1 Readout and control module

Readout and control module receives the data and sends commands through Ethernet or USB 2.0. Figure 3 is the data format. In Figure 3, n is the number of data messages in one package, and it depends on the electronics.

Package head	Data	ID	Package tail
2 byte	[2 byte * 64 (channel, high gain) + 2 byte * 64 (channel, low gain)] * n	2 byte * n (bunch ID) + 2 byte (chip ID)	2 byte

Figure 3: Data format

After the hardware is connected, the software allows the users to make basic configuration. Connection status is shown on the software. To connect the upper computer with DCM through

Ethernet, the user needs to configure the IP address and port number. The USB way of connection is designed for debugging. The VID and PID of the FEE's USB interface are fixed, so that the users do not need extra configuration.

On the configuration page, a few commands that are necessary to configure the electronics' status are given. Besides sending these given commands, the users are able to send extra commands by typing in the dialog.

Raw data that received by the upper computer are firstly read into the random-access memory (RAM), and then stored in hard disk. The data is received asynchronously. Maximum rate of the data generated by the electronics is below 6 Mbit/s, and there are 3 layers of electronics. As a result, the data receiving rate of the upper computer will not exceed 18 Mbit/s. Low data rate makes it possible to process data in real-time.

2.2.2 Data real-time imaging module

Data real-time imaging module realizes online data analysis and real-time images rendering. Data receiving and processing are carried out simultaneously, which are executed in different computer process. Figure 4 is the flow chart of the process in this module.

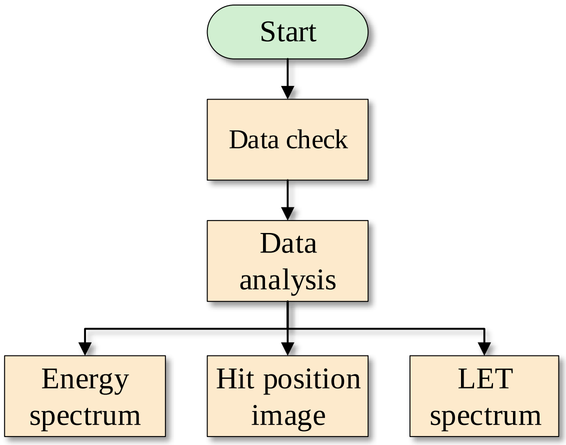


Figure 4: Procedure flow chart of data analysis.

After the data are received and stored in hard disk, the data in RAM will be offered to the part of data analysis. The first step is to check the integrity of the package of data. The packet that do not meet the format shown in Figure 3 will be discarded in the process. Then, data in the package will be recorded in the corresponding array according to the format. After this step, processed data that used in energy spectrums is passed to the drawing section, and the images are generated. To get hit position maps and LET spectrum, extra calculation is needed. Finally, the LET spectrum is generated. Methods for data analysis will be introduced in subsection 2.3.

2.2.3 Offline data analysis module

Offline data analysis module shares the imaging part and most of the analysis part with data real-time imaging module, but is more efficient for data analysis, and obviously uses different data interface. It builds the data index as the first step, and then analyzes the data.

2.3 Data analysis

2.3.1 Energy spectrum analysis

The values of data are the amplitudes of signals. As the result of calibration, the electronics' LSB corresponds to electrons of 0.4 fC (P-side) and 0.35 fC (N-side). The ADC values are used to indicate the energy. And the energy spectrum shows the distribution of energy in a specific channel under given gain.

2.3.2 Hit position calculation

The position of data in a package shows the channel it belongs to. There is a definite correspondence between channels and the strips of the detector. By counting the position of data, the hit positions of particles are recorded. Figure 5 is the schematic diagram of hit events occured on detectors. Table 1 shows the possible situations.

Table 1: Situations of hit positions

No.	Max hit num on a single layer	Triggered layers	Extra Info.	Validity
1	1	1	/	Invalid
2	1	2 or 3	/	Valid
3	2	1	/	Invalid
4	2	2 or 3	Adjacent	Valid
5	2	2 or 3	Nonadjacent	Invalid
6	>2	1~3	/	Invalid

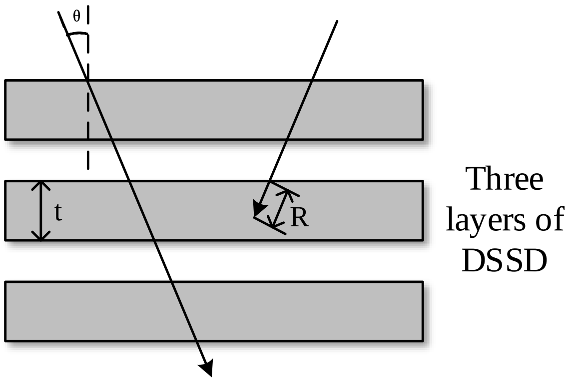


Figure 5: Schematic diagram of hit events occured on detectors.[4] θ is the incident angle of a particle. t is the thickness of one detector. R is the range of a stopping particle.

In situation 1 and 3, the triggers are considered as false triggers. Situation 5 and 6 are invalid, because the probability of multiple particles incident at the same time is very low and is unable to determine the angle of incidence. Situation 2 and 4 show single particle incident events, and the difference is that the number of triggered channels is different due to the incident angle. In situation 2, the hit position is defined as the center of the corresponding strip. In situation 4, the hit position is defined as the Center-of-Gravity (CoG)[5] of the strips.

2.3.3 LET calculation

To calculate LET, it needs to confirm the species of particles. To achieve it, ΔE-E method is used.[6]

Proton range in aluminum is as Equation 2 shows.

$$R_{Al}[\mu m] = \begin{cases} 14.21E_p^{1.5874}, 1MeV < E_p \le 2.7MeV \\ \dfrac{10.5E_p^2}{0.68 + 0.434\ln(E_p)}, 2.7MeV \le E_p \le 20MeV \end{cases} [7] \tag{2}$$

For heavy charge particles in different materials, the relation is as Equation 3 shows.

$$\frac{R_1}{R_2} = \frac{\rho_2}{\rho_1}\sqrt{\frac{M_1}{M_2}} [8] \tag{3}$$

Then R is determined.

Equation 4, 5 and 6 are used to calculate LET.[9]

$$LET_S = \frac{E_d \cos\theta}{t} \tag{4}$$

$$LET_S = \frac{E_d}{R} \tag{5}$$

$$L_\infty = 1.193 \times LET_S \tag{6}$$

Using energy and position messages analyzed from the data, LET is calculated with these equations. And then the LET spectrum is generated.

2.4 Protocol

2.4.1 Transmission control protocol (TCP)

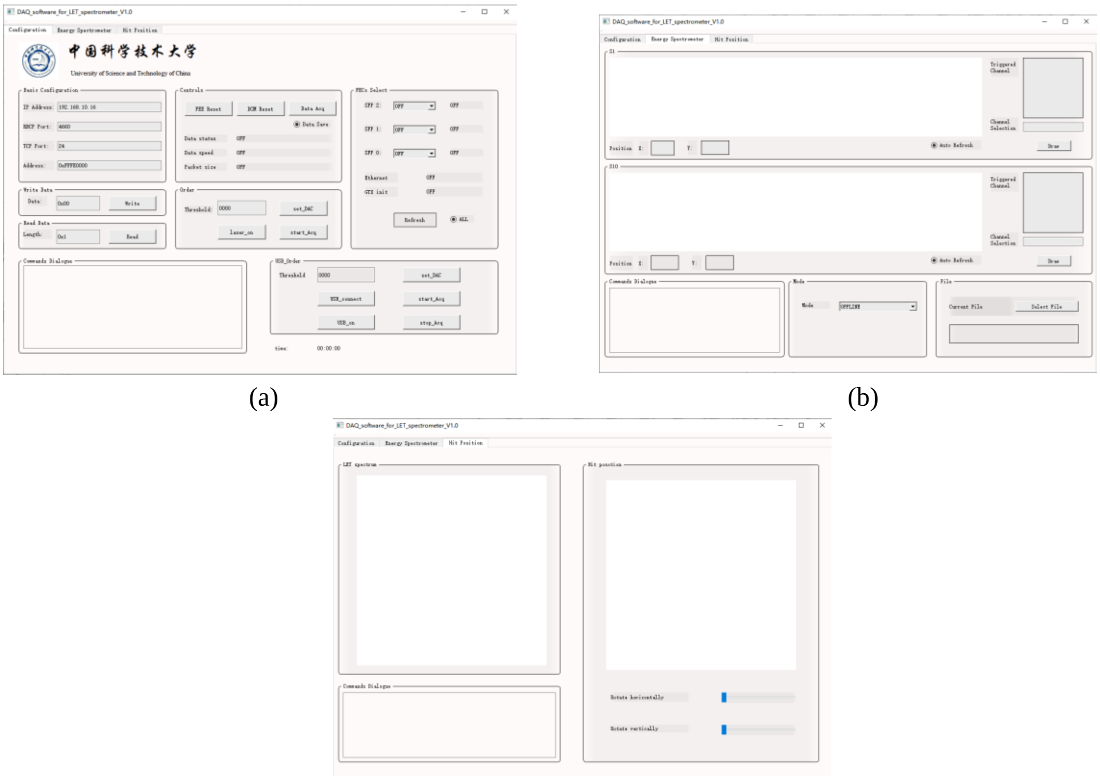
The Transmission Control Protocol (TCP) is intended for use as a highly reliable host-to-host protocol between hosts in packet-switched computer communication networks, and in interconnected systems of such networks.[10] The DAQ software uses TCP as the protocol of the Ethernet communication. The TCP communication class QtTcpSocket shows good performance and is widely used. So the software uses QtTcpSocket class to realize its function.

2.4.2 Universal serial bus (USB) 2.0

USB makes the connection of peripheral devices to the computer easier and more efficient and hence addresses simple I/O.[11] The microcontroller of USB that used on the FEE is CY7C68013A, which is a Cypress product. For good performance, CyUSB, which is a DLL provided by Cypress. is used to realize the function in the software.

2.5 GUI

GUI of the DAQ software is divided into 3 pages, according to the functions. The “Configuration” page includes basic configurations and commands, which are used for configuring the electronics and controlling data acquisition. The “Energy Spectrometer” page and “Hit Position” page are designed to show the corresponding images. Figure 6 shows the GUI of the software.



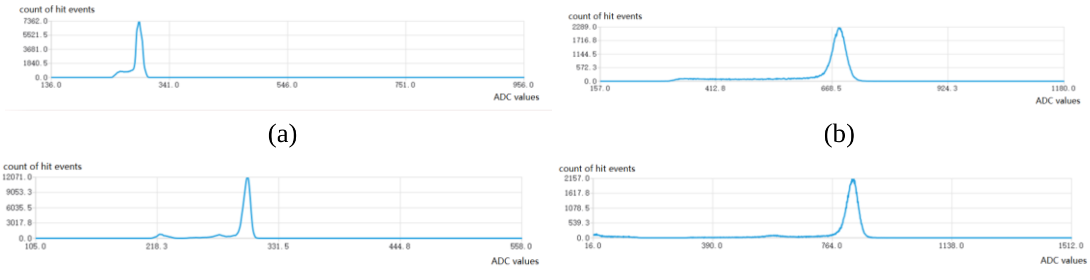
(a) (b)

(c)

Figure 6: GUI of the software. (a) is the page of "Configuration"; (b) is the page of "Energy Spectrometer"; (c) is the page of "Hit Position".

3. Laboratory Test

To evaluate the correctness of the DAQ software, an ^{241}Am radioactive sample and the prototype are used to test the software. The test result is as Figure 8 shows.



(a) (b)

(c) (d)

Figure 8: Test results of the software. The images are energy spectrums of an ^{241}Am radioactive sample. The data is from the channels with the highest counts. (a)(b) are from channel 54, (c)(d) are from channel 9. Gain of (a)(c) is the lower one, while (b)(d) have the higher gain.

There are 2 to 3 peaks in the spectrum. The one that has the highest count shows the energy spectrum of helium ions emitted by ^{241}Am (5.486 MeV). And the one close to it means that some of the particles hit the gap of two jacent strips. The results show that the DAQ software successfully reads out and analyzes the data from the prototype, and fits the needs of application.

4. Conclusions

A DAQ software for a prototype of LET spectrometer is proposed in this paper. The structure of the software is modularized. Real-time analysis and LET calculation are supported in the software. The software meets the needs of ground tests.

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