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Convenient design and implementation of ground calibration experiments of the Omnidirectional Ion Analyzer based on LabVIEW

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Abstract：The Omnidirectional Ion Analyzer is mounted on a Chinese navigation satellite to detect low-energy (5eV～25 keV) ions in the space near geosynchronous orbit. Before the detector in-flight, the ground calibration experiment is the key step to understand the ion detection results in space. According to the calibration experiment requirements of the Omnidirectional Ion Analyzer, a specific calibration experiment process is designed to manipulate the automation of complex experiments, so as to avoid the error caused by manually operating experiment and improve experimental efficiency. Aiming at the calibration experiment of the Omnidirectional Ion Analyzer, the method and program template of using LabVIEW to quickly design the calibration software system were presented, which provides a reference for the complex experimental design similar to the calibration of an ion analyzer and increases program reusability. The experiment results show that the test software runs stably and reliably, reduces the software development cycle, improves test efficiency, and can accurately control the multi-axis turntable and carry out real-time and accurate information processing.

Keywords：Omnidirectional Ion Analyzer; calibration system; LabVIEW; automatic control

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1 Introduction

In-situ measurement of space ions, electrons and neutral atoms by spacecraft directly provides the space particle distribution function of space plasma[1]. Particle analyzer instruments have been widely used in scientific exploration missions[2-4]. The Omnidirectional Ion Analyzer carried by the China Navigation Satellite[5] has a similar structure to those on instruments applied in many space plasma exploration tasks, such as FAST[6], Cluster[7], Wind[8], etc. The Omnidirectional Ion Analyzer detected the ion distribution function within the half space (360°×90°) and the energy range from 5 eV to 25 keV per charge in the Earth's synchronous geostationary orbit.

In order to correctly deduce the reality ions distribution functions from the observation by the ion analyzer in space flight, the analyzer must be calibrated on the ground while the responses of the analyzer to ion beams in different charge quantities, energy range and incident directions are demonstrated before the flight. The response of the ion analyzer to the incident ion beams is mainly related to the geometry factor[9] and detection efficiency[10] of the analyzer. The accuracy of geometric factor and detection efficiency directly depend on the precision of the calibration experiment system[11]. In the calibration experiment, it is necessary to use the ion beams of certain known energy and flux intensity to enter the ion analyzer from all directions and measure the response of the instrument. Fig. 1 shows that the Omnidirectional Ion Analyzer has a horn-shaped entrance system[12], a cylindrically symmetrical top-hat and a spherical electrostatic analyzer (ESA) structure[13]. On the horn-shaped entrance and the ESA, specific voltages were applied to generate electric fields to allow selected ion beams, whose direction and energy matched, to enter and be detected. Through sweeping all step voltages, the analyzer can complete the measurement of those incident ion beams in the predetermined directions and energy range. The value of the geometric factor is directly related to the field of view of the analyzer[8] at different energy ranges.

The field of view of the Omnidirectional Ion Analyzer was calibrated in specific azimuthal (α) and

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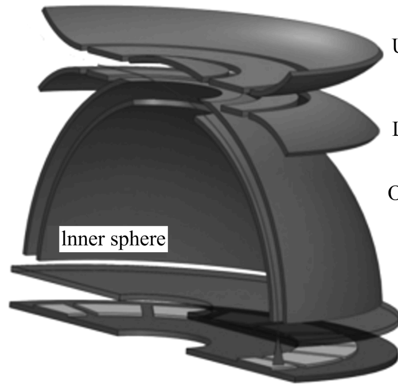

Fig. 1 The structure of the top-hat,entrance system and ESA.

pitch angle (β) separately. The azimuthal field of view is divided into 16 identical parts and each part has one detector to collect counts of those incident ion beams in an azimuthal direction[14]. The pitch angle of those ion beams entering the analyzer is determined by the step voltages, in 15 steps, on the deflector plate of the horn-shaped entrance. In this manner, the half-space field of view of the analyzer consists of 16 × 15 specific directions. The angular resolution of the Omnidirectional Ion Analyzer is 22.5°×11.25°. Since the positions of 16 detectors were fixed in the analyzer, the azimuthal angle of the incident ion beams was determined after the manufacture. However, the pitch angle of the incident ion beams was calculated indirectly by using the deflection step voltages at the entrance of analyzer. Establishing the relations between the deflection step voltage and the pitch angle acceptance of incident ion beams is a major goal of calibration experiments.

Performing precise control and handling efficient data acquisition in massive calibration experi-ments required a new automation design other than the manual experimental system. In this calibration experiment, we built an automated system, including the stepper motor controller, the encoder, and data acquisition.

In developing the automated calibration experi-mental system, another challenge comes from versatility. The space ions analyzer of every space mission may have a different method of detecting ion beams and field of view, but those calibration experiments are often handled in the same system, so that developing a more flexible automated experimental system is required. The graphical language, LabVIEW, is ideally used as a key pole in developing many templates in data acquisition and control[15]. For experimental physicists, using LabVIEW[16-19] can improve the efficiency of software development. In the following sections, we will provide a software control system template for the Omnidirectional Ion Analyzer based on LabVIEW.

2 Introduction to calibration experiment

The scheme of calibration system for the Omnidirectional Ion Analyzer is shown in Fig. 2. It has an ion source subsystem, a vacuum subsystem, a Faraday cup sensor, a high-precision multi-axis turntable, and a computer control system. The ion source subsystem is the Omicron ISE 5 GUN CONTROL, whose energy ranged from 0. 5 keV to 5 keV per charge, which provides a stable Ar^+ beams.

The high-precision multi-axis turntable is directly controlled by the stepper motor with controller SC-410. LabVIEW program on the computer sent commands to the SC-410 and collected the feedback from the encoder. The turntable can vary in the pitch angle from －45° to ＋45° and the azimuthal angle from 0° to 360° in 0.1° resolution. The analyzer was placed on the turntable and rotated to any specific direction as requested by the calibration experiments.

In the LabVIEW’s control program template design, the producer/consumer model was used to simulate the first-in-first-out (FIFO) structure, which was composed of nested queue operations, event structures, conditional structures and flat sequential structures in a while loop, as shown in Fig. 3.

The calibration system has multiple devices with different serial communication electrical interfaces. Multi-serial port drivers often conflict with each other due to the control timing and cause a communication handshake failure. Therefore, the LabVIEW program set up multiple VISA serial ports to match the communication ports and communication protocol of the devices and drive each serial port in order. When the device and the computer successfully established a stable communi-cation link, the device can work correctly.

3 Case analysis

The Omnidirectional Ion Analyzer calibration system is analyzed as an example to present the procedure for the quick establishment of such software systems.

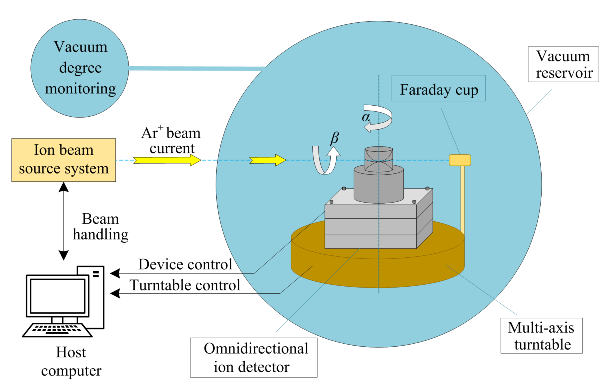

Fig. 2 Calibration system of the Omnidirectional Ion Analyzer.

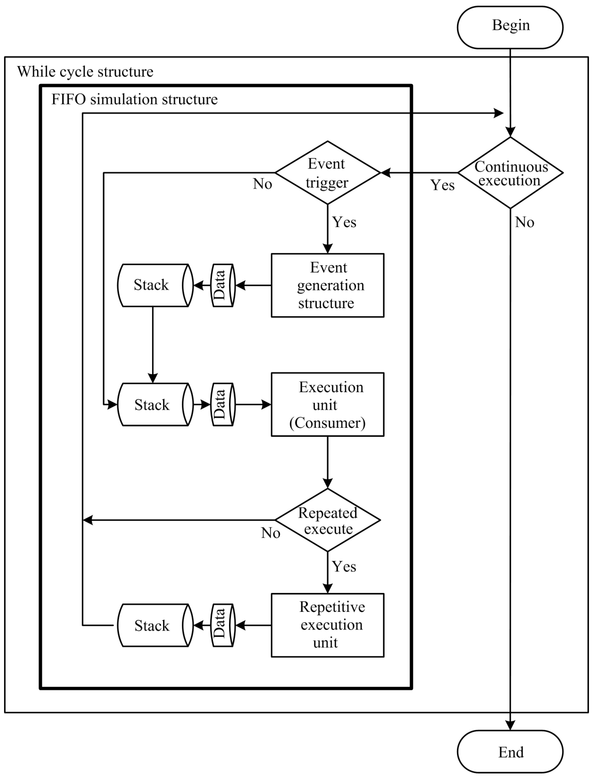

Fig. 3 Producer/consumer structure based on LabVIEW design.

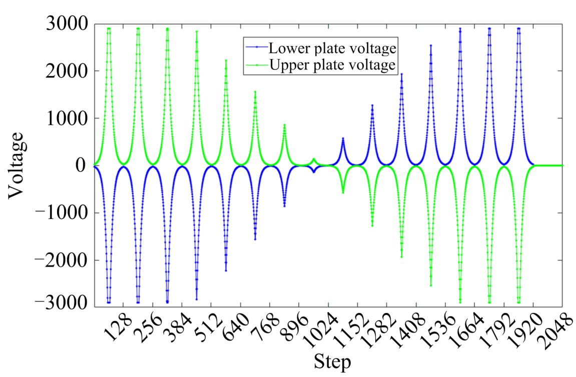

Fig. 4 Scanning high pressure of inlet system.

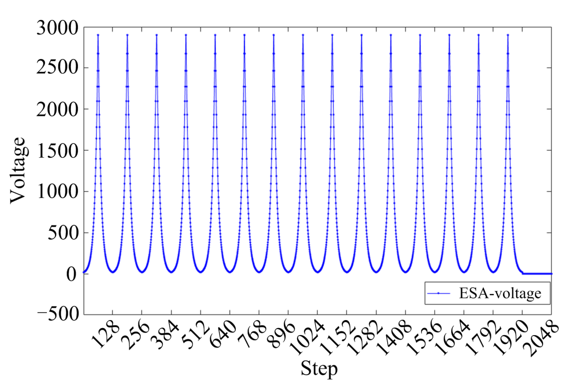

Fig. 5 ESA scan voltage.

3.1 Introduction to the working mode of the Omnidirectional Ion Analyzer

As shown in Fig. 4, first of all, the deflection voltage chose ion beams with a certain pitch angle and with a coarse energy range to reach the top hat, which is the entrance of the ESA. Then, the deflection voltage of the ESA (as shown in Fig. 5) selected ion beams with a specific energy to record. In Fig. 4, for example, the first increasing or decreasing sweep step voltage curves, voltages of the upper and lower plates of the entrance system, consist of 64 steps from 0 to ± 2800 V. At the same time, In Fig. 5, the increasing sweep voltage curve of the ESA also consists of 64 steps, corresponding to 64 energy levels, from 0 to $+2900$ V. These two types of sweep voltage were applied synchronously and selected ion beams in the full energy range and with pitch angle $\beta = -32°$. The next symmetric sweep voltage curves did the identical ion beams selection. Those 128 voltage steps (called a group) measured ion beams in the full energy range and in one specific pitch angle direction.

For the next group of 128 sweep voltage steps, as shown in Fig. 4, the sweep voltages of the entrance were different, but the ESA sweep voltages remained exactly same. The second group sweep voltages of entrance allowed ion beams with $\beta = -27°$ to be measured. In total, 15 sweep voltage groups corresponded to 15 different pitch angles from $-45°$ to $+45°$.

Because the azimuthal field of view of the analyzer is divided into 16 parts, the pitch angle field of view of each certain azimuthal angle need to be calibrated. The complete sweep procedure has 1920 steps of each azimuthal part to cover the half-space field of view.

3.2 Requirements of the software design

An ion analyzer needs to be calibrated with ion deflection constant, electrostatic analyzer constant, energy resolution, field of view, angular resolution, ion beam flux response factor and geometric factor. Most of those calibration experiments were related to ion beam directions and energy levels. Ion beam direction was fixed in the experiments. The relatively different ion incident directions were generated by rotating the ion analyzer. The turntable control was the kernel in the calibrations.

The software design must include the control of the stepper motor controller, the feedback encoder reading and the status judgement of the Omnidirectional Ion Analyzer, as shown in Fig. 6.

The computer transmitted commands, received encoder feedback data through two RS232 electrical interfaces and obtained measurement data through one RS422 electrical interface, which are marked as Interface 1, Interface 2, and Interface 3, respectively.

3.3 Calibration procedure design

In the calibration experiments, the energy levels of the ion beams are 1.8, 2.4, 3.0, 4.2, and 5 keV per charge. Half-space field of view in 16×15 specific directions required at least 1200 calibration experiments at

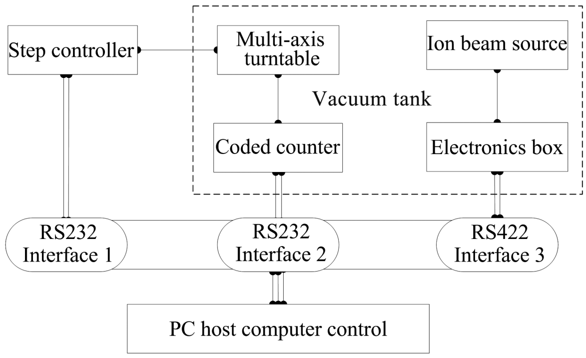

Fig. 6　Overall framework of software control.

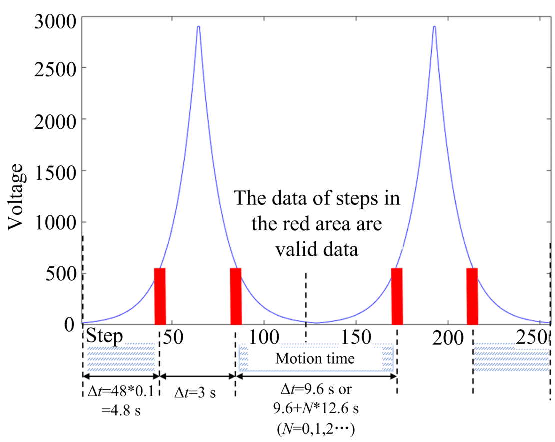

Fig. 7　Angle control scheme set by the calibration system.

different settings, so that an automated experimental system was designed.

In the calibration experiment, the ion analyzer continuously and independently performed voltage sweeps with a time interval of 0.1 between adjacent voltage steps. The rate of turntable angle adjustment is 1 degree per second. Further, the azimuthal and pitch angles need to be adjusted separately, thus direction change of the turntable is much slower than the analyzer's voltage sweep rate. Because the incident ion beams are fixed at a certain energy level, only one voltage step of ESA can be matched to allow ion beams to be detected. The duration of this one voltage step must be shorter than the stay of the turntable at the specified pitch angle position. After the detection, the automated program checked the current sweep voltage step and rotated the turntable to the next desired pitch angle before the next certain voltage step arrived. As shown in Fig. 7, the voltage step in the red area showed the time slot for the ion beams with desired pitch angle and energy level. The turntable should keep stationery at that red time slot.

3.4　Calibration software design

3.4.1　System design

During the software system design, functional template modules were selected according to the requirements. Those functional modules are shown in Tab.1.

These selected modules can be added in the execution unit, shown in Fig. 3, to design the program flexibly. The detailed modules involved in the figure are described later in this section.

3.4.2　Configure serial VISA resource

In the software design, LabVIEW's VISA serial port was used to match the serial port communication of many different devices. Fig. 8 shows the template module for the serial port settings of the two devices, and this LabVIEW template was defined as A1.

Tab. 1　Comparison table of functional applications.

Demand function	Module design
ESA scan voltage display	A1,A6
Inlet system scanning voltage display	A1,A7
Each channel ion meter numerical display	A1,A8
Scientific data storage	A1,A9
Control of multi-axis turntable	A2,A4
Offline data playback display	A6,A7,A8
The detector and multi-axis turntable linkage control	A1,A2,A3,A4,A5
Ion analyzer instruction sending	A1,A3

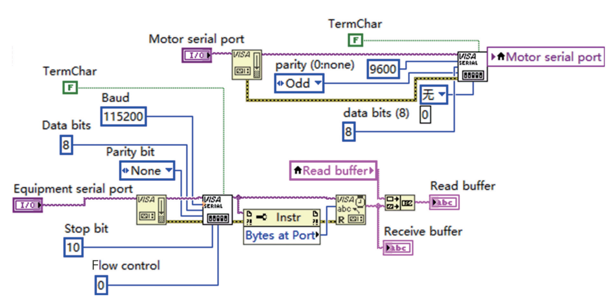

Fig. 8　VISA serial port resource configuration based on LabVIEW (A1).

Tab. 2　Comparison table of stepper motor speed control.

No.	Initial speed (Unit: Pulse)	Top speed (Unit: Pulse)	Accel time (Unit:ms)	Decel time (Unit:ms)
1	500	5000	24	30
2	500	2000	20	26
3	500	3000	24	30
4	500	4000	28	34
5	500	5000	32	38
6	500	6000	36	42
7	500	7000	40	46
8	500	8000	44	52

3.4.3 Automated control program design of the multi-axis turntable

The automated control program of the multi-axis turntable includes sending commands to the stepper motor controller and reading feedback from the encoder.

The parameters for the stepper motor controller were initial speed, maximum speed, acceleration time, and deceleration time, as shown in Tab.2. The module for the stepper motor controller was defined as A2, which is shown in Fig. 9. For any other payloads with different weights, the stepper motor may be set suitable parameters to keep a fast and stable rotation.

The command generated by module A2 was sent through the communication module A3, shown in Fig. 10, to the turntable. The turntable control also has the start/stop module as shown in Fig. 11 defined as A4. The automated control system was built through the combination of these modules.

3.4.4 Certain analyzer information reading module design

The rotation controls of the turntable of many other analyzer calibration experiments are very similar. However, those analyzers may have different working procedures and data structures. Such a specific procedure needs to be assembled in a new module for every new analyzer's calibration experiments. For the

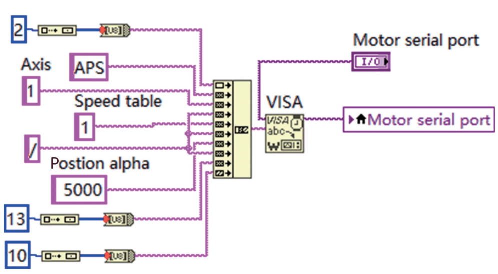

Fig. 9 The initialization of the stepper motor controller based on LabVIEW (A2).

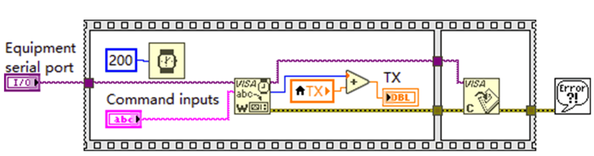

Fig. 10 Program design for command sending(A3).

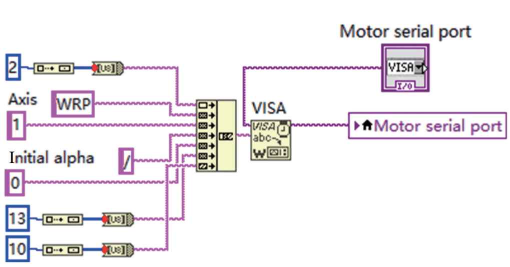

Fig. 11 Position control of multi-axis turntable (A4).

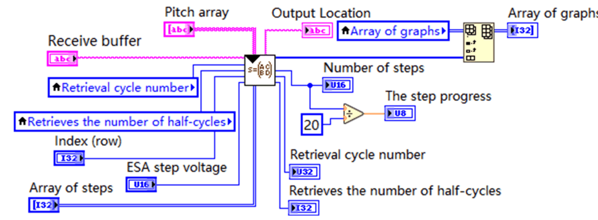

Fig. 12 Software module for feature information extraction (A5).

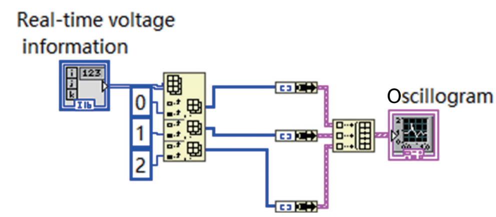

Fig. 13 Real-time display of instrument high voltage(A6).

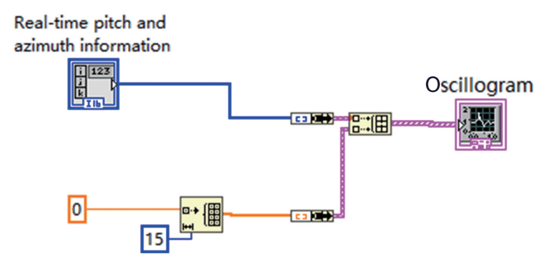

Fig. 14 Real-time display of pitch angle and azimuth angle (A7).

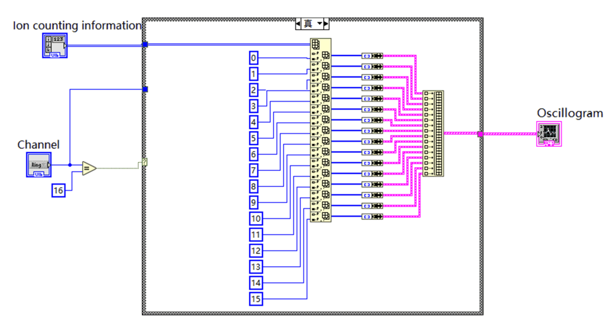

Fig. 15 Ion count display for each channel(A8).

Omni-directional Ion Analyzer, information readings such as the group number of the sweep voltages, the step numbers, the voltage value corresponding to the step, the pitch angle and the azimuthal angle, were assembled in module A5, shown in Fig. 12.

3.4.5 Displaying results of calibration experiments

In the ion analyzer calibration experiment, real-time monitoring can intuitively show the operating status and data, such as high voltage value, ion counts value, pitch angle and azimuthal angle of the analyzer. In Figs.13, 14, and 15, those modules were defined as A6, A7, and A8 respectively. Fig. 13 shows that the high voltage information can be displayed in the high voltage array in

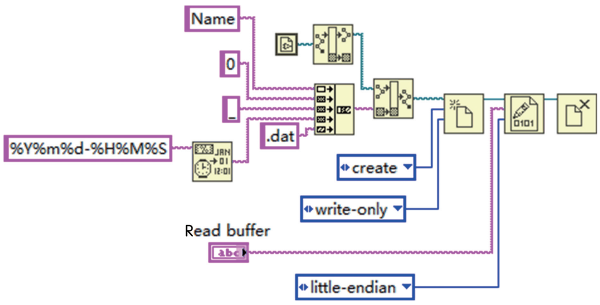

Fig. 16　Data storage program template (A9).

Fig. 17　Host computer interactive interface.

real time. The module in Fig. 14 can record the angles of the turntable. In Fig. 15, the ion counts information of any single channel was displayed.

Data storage module, A9, in Fig. 16, automatically saved the entire experimental data in one data file, which is convenient for further analysis.

3.5　Calibration experiment results

The interactive interface programmed by using LabVIEW is shown in Fig. 17, including parameter settings, and start/stop switches. Experiment results are also shown on this interface.

4　Conclusions

The software system has been developed successfully and applied in the ground calibration experiments of the Omnidirectional Ion Analyzer. This automated calibration system was developed by using the LabVIEW, which included the functions of controlling azimuthal and pitch angles of the multi-axis turntable, data acquisition, command sending, feedback receiving, real-time status display and data storage. When designing future ion analyzer calibration experiments, one may use those LabVIEW modules to quickly build a software system. The automated experimental system greatly simplified the manipulations of the experiment and ensures the accuracy of the experimental results.

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Conflict of interest

The authors declare no conflict of interest.

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基于 LabVIEW 的全向离子探测器地面标定实验的便捷设计和实施

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摘要: 全向离子探测器搭载在中国导航卫星上,对地球同步轨道附近空间中的低能段（5eV～25keV）离子进行探测.探测器在飞行之前,地面标定实验是理解空间中离子探测结果的关键步骤.根据对全向离子探测器的标定实验需求来设计特定的标定实验过程,实现复杂实验自动化进行,避免手动实验带来人为失误,并且提高实验效率.针对全向离子探测器的标定实验,给出了使用 LabVIEW 快速设计标定软件系统的方法和程序模板,为类似离子探测器标定的复杂实验设计提供参考,增加程序复用性.实验结果表明,该测试软件运行稳定可靠,减少了软件开发周期,提高了测试效率,能够精确控制多轴转台以及进行实时并且准确的信息处理.

关键词: 全向离子探测器；标定系统；LabVIEW；自动控制