Ground-Based Ultraviolet Absorbing Aerosol Monitor Electronics System Postprint

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Abstract

To utilize the UV-Vis continuous spectrum for aerosol observation, a ground-based UV-absorbing aerosol monitor based on passive remote sensing technology was developed. The electronic system of the instrument is described, which hardware-wise includes four components: telescope, controller, detector, and electronic control box. Software-wise, the instrument control system was designed based on LabVIEW, and CCD partial photosensing technology was employed to separately acquire UV-Vis spectra. Experimental results demonstrate that this electronic system can achieve automated observation of ground-based UV-absorbing aerosol monitors and obtain effective spectral data in the UV-Vis band.

Full Text

Electronics System of the Ground-Based Ultraviolet Absorbing Aerosol Monitor

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Abstract

To observe aerosols using continuous ultraviolet-visible spectroscopy, a ground-based ultraviolet absorbing aerosol monitor has been developed based on passive optical remote sensing technology. This paper introduces the instrument' s electronic system, which comprises four hardware components: telescope, controller, detector, and electric control box. The control system was designed using LabVIEW software, and the CCD’ s region-of-interest technique was employed to separately acquire ultraviolet and visible spectra. Experimental results demonstrate that this electronic system enables automated observations with the ground-based ultraviolet absorbing aerosol monitor and obtains effective spectral data across the ultraviolet-visible band.

Keywords: aerosol; ultraviolet-visible light; electronics system; control; region of interest

Passive optical remote sensing refers to a detection technology that utilizes natural light sources such as sunlight or starlight as optical signals to probe target information carried by radiation characteristics [1]. Currently, ground-based aerosol observations based on passive optical remote sensing have a development history of several decades both domestically and internationally. For example, NASA’ s AERONET (Aerosol Robotic Network), established using CE318 sun photometers worldwide, observes only a few discrete bands within the visible-near infrared region [2]. Meanwhile, the University of Bremen in Germany established a DOAS (Differential Optical Absorption Spectroscopy) ground-based observation network using MAX-DOAS instruments, which, although covering the continuous ultraviolet-visible band, can only detect sky-scattered light due to calibration challenges [3]. The ground-based ultraviolet absorbing aerosol monitor developed by the National Space Science Center, Chinese Academy of Sciences, is required to achieve continuous ultraviolet-visible spectral observations while simultaneously detecting both sky-scattered and direct solar radiation. Consequently, its electronic system must meet more stringent requirements.

1 System Hardware Architecture

The schematic diagram of the electronic system for the ground-based ultraviolet absorbing aerosol monitor is shown in Figure 1

. Based on the functional differences of each component, the electronic system can be divided into four main parts: the telescope electronic system, detector, controller, and electric control box. The telescope section is primarily responsible for selecting between the sky-scattered and direct solar radiation apertures. The detector component handles optical signal transmission, dispersion, and capture. The controller manages overall instrument operations, including sun tracking and sky scanning implementation, spectrometer control, CCD data readout, and processing of various sampling and environmental monitoring signals. The sampling circuits in the electric control box primarily acquire various raw signals, while the power supply module provides power to all instrument components. Peripheral equipment such as the sun tracking and sky scanning system employs the SOLYS Gear Drive sun tracker, and environmental monitoring devices include rain/snow sensors and anemometers.

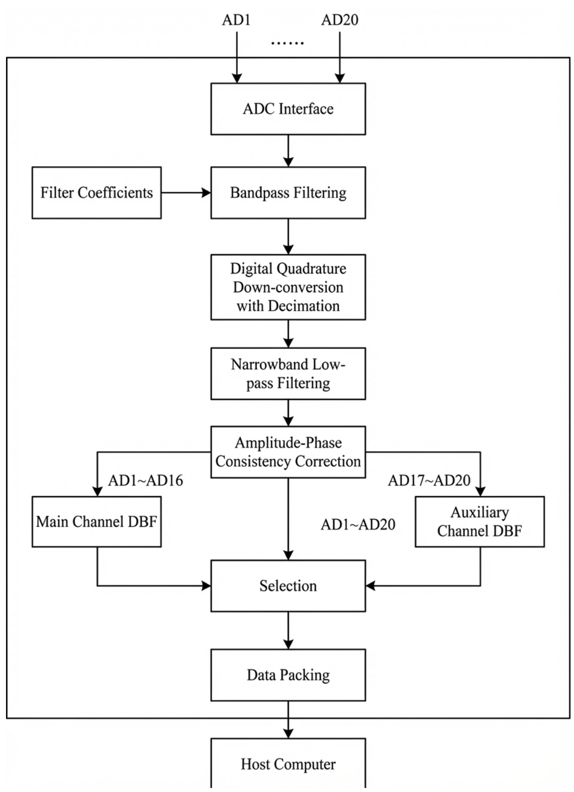

Figure 1: Figure 1

1.1 Telescope

The telescope electronic components include a stepper motor and its driver, integrating sphere, limit switch, Hall element and magnets, position detection unit, etc., with its internal structure shown in Figure 2

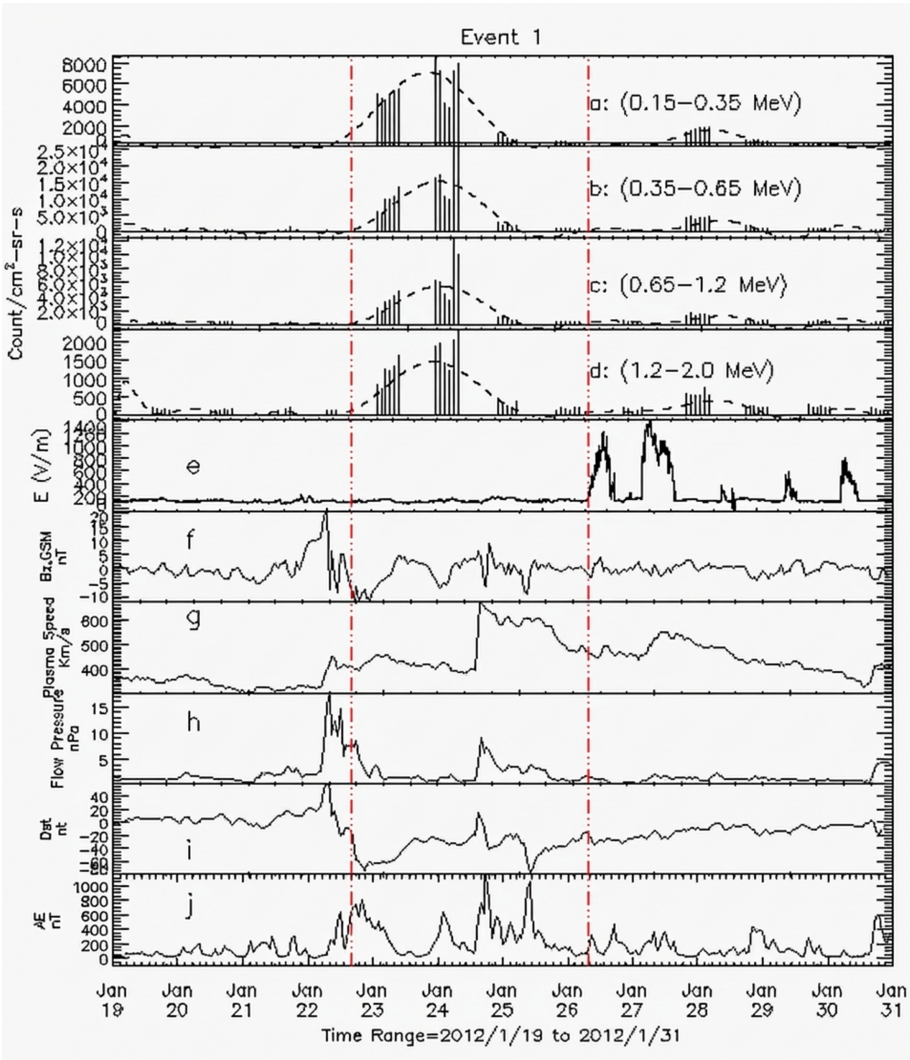

Figure 2: Figure 2

. Figure 3 [FIGURE:3] illustrates the motor driving the integrating sphere along the guide rail. Upon instrument startup, the stepper motor drives the integrating sphere to move rightward along the guide rail. The limit switch is located at the right end of the rail; when the integrating sphere contacts the limit switch, it activates and stops the sphere's motion, completing the reset operation. Magnets are mounted on both the left and right sides of the integrating sphere. When the Hall element senses the left magnet during sphere movement, the entrance aperture aligns with the sky-scattered light port; when it senses the right magnet, the entrance aperture aligns with the direct solar radiation port, thereby accomplishing switching between the telescope' s incident channels [4].

1.2 Detector

Optical signals exiting the telescope are transmitted via optical fiber into the spectrometer dispersion system. Considering the instrument' s operating wavelength range (300-500 nm) and spectral resolution requirements (0.6-0.8 nm), a planar grating spectrometer based on the Czerny-Turner structure was designed, covering 0-1400 nm with an accuracy of ±0.2 nm; wavelength band selection is achieved by setting the center wavelength. Since solar irradiance in the ultraviolet band (300-340 nm) is 2-3 orders of magnitude lower than in the visible band (340-500 nm) [5], a detector with high quantum efficiency in the UV region is required. The PI 2K series back-illuminated UV-enhanced CCD achieves 60%-70% quantum efficiency in the UV band, with a minimum cooling temperature of -70°C and low thermal noise, ensuring a high signal-to-noise ratio. Additionally, this CCD features a unique dual-ADC channel design with adjustable electronic gain for each channel, making it suitable for detecting optical signals with large dynamic intensity ranges [6]. Its main parameters are listed in Table 1 .

Table 1 Main Parameters of the PI-2KBUV Camera

Parameter	Specification
Pixel format	512 × 2048
Pixel size	13.5 m × 13.5 m
Readout rate	Slow (100 kHz), Fast (2 MHz)
ADC channels	High full-well, Low noise
Conversion gain (High full-well)	Low: 16 e /count, Medium: 8 e /count, High: 4 e /count
Conversion gain (Low noise)	Low: 4 e /count, Medium: 2 e /count, High: 1 e /count

Note: Conversion gain represents the relationship between pixel electrons and voltage readout counts; for example, 4 e /count means four electrons produce one voltage readout count, with a maximum count value (full-well depth) of 65,535.

1.3 Controller

The controller executes the overall instrument workflow, coordinating all components to operate in sequence. Based on the requirements for multi-device control, an NI industrial computer was selected. It offers a rich variety of interfaces including USB, serial port, Ethernet, digital I/O, and analog sampling inputs, with high flexibility allowing free configuration of expansion cards. The connection diagram of the controller composed of this industrial computer is shown in Figure 4 [FIGURE:4]. The data acquisition card includes 16 analog sampling inputs and 24 digital I/O channels, enabling multi-channel signal acquisition and device control through a terminal block. Control of the spectrometer and CCD data acquisition by the dual-core processor is implemented via USB 2.0 interface [7]. Additionally, by connecting the processor' s Ethernet RJ45 interface and the sun tracker' s Ethernet interface to different WAN ports of a router, and using the processor as the router' s management host to establish LAN communication, the processor can control the sun tracker through IP addressing [8].

1.4 Electric Control Box

The electric control box primarily houses the power supply module and sampling circuits. The power module connections are shown in Figure 5

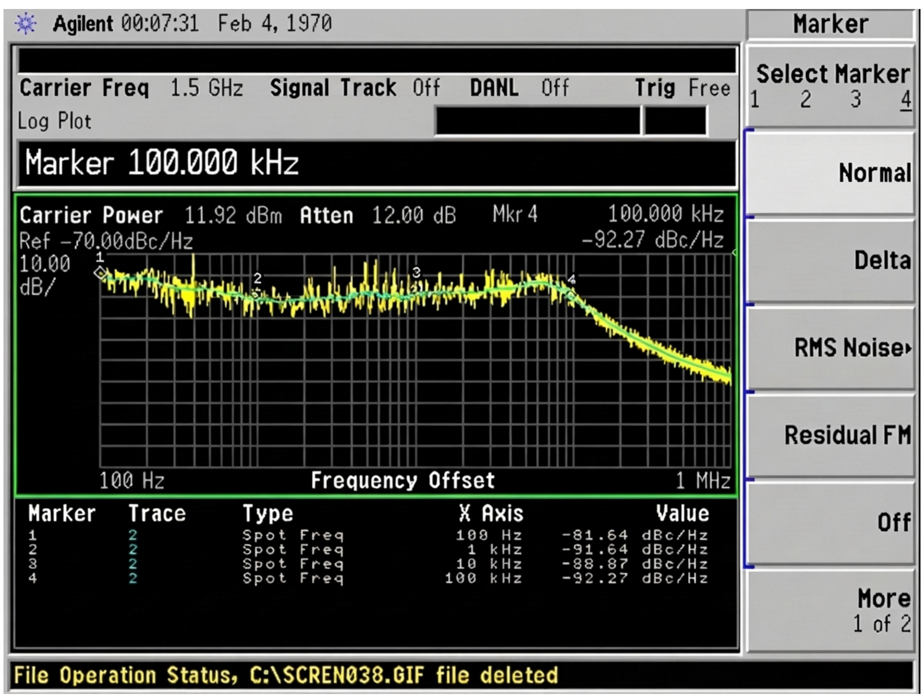

Figure 3: Figure 5

. The primary 220 V power supply remains continuously on, powering the industrial computer. During daytime operation, the industrial computer controls Relay 1 to activate the secondary 220 V power supply, which provides power to the spectrometer, CCD, and sun tracker, and is stepped down to 12 V for the sampling circuits. The computer also controls Relay 2 to step down 220 V to 24 V for environmental monitoring equipment. In adverse weather conditions, Relay 1 disconnects while Relay 2 remains engaged, allowing environmental monitoring to continue until weather improves, at which point Relay 1 reconnects and the instrument resumes operation. At night, both relays 1 and 2 disconnect, and the industrial computer shuts down.

The sampling circuits primarily acquire power module voltage and instrument temperature, with the basic unit shown in Figure 6

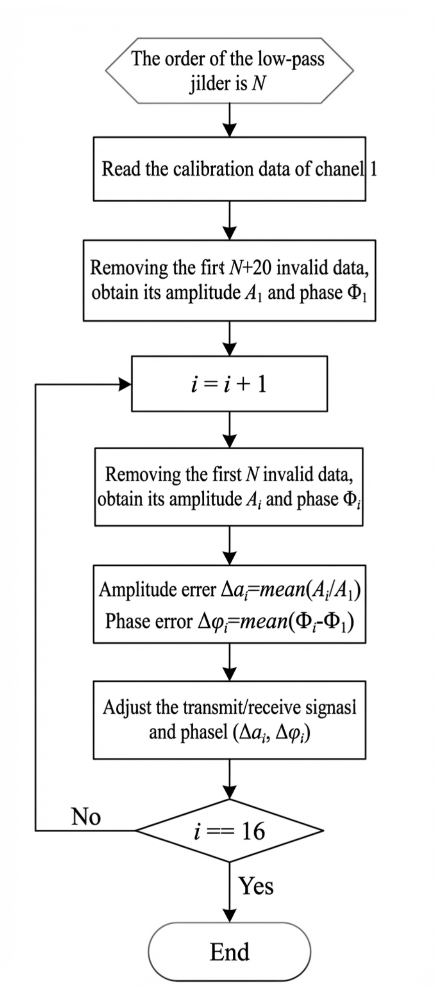

Figure 4: Figure 6

. Here, power supply VCC and resistor R2 are variable components: when

VCC represents the power module voltage with R2 fixed, it samples the power voltage; when VCC is fixed and R2 is replaced with a thermistor, it samples the instrument temperature.

The main instrument workflow is illustrated in Figure 7 [FIGURE:7]. Through BIOS settings on the industrial computer [9], automatic startup at a fixed daily time can be achieved. After startup, the power module activates and environmental monitoring begins, followed by initialization of all components. Upon completion, the instrument enters operational status, with the motor, sun tracker, and detector coordinating to perform measurements of direct solar and sky-scattered light. After the daily observation cycle completes, the instrument resets (including motor and sun tracker reset), then the power module shuts down and the computer powers off [10].

2 Software Design

The front panel design of the instrument control software based on LabVIEW is shown in Figure 8 [FIGURE:8] [11]. According to the functions of each instrument component, it is divided into several modules: the instrument status bar displays current time and power status; the working status bar shows voltage and temperature acquisition results along with current weather conditions; the telescope section displays the on/off status of components such as the motor, Hall detector, and limit switch, and indicates the current incident channel selection; the detector section primarily configures operating parameters for the spectrometer and CCD, such as grating selection, movement speed, center wavelength, CCD exposure time, and cooling temperature; the sun tracker section inputs IP address and TCP port to establish LAN communication between the sun tracker and processor [12], with various display controls showing the sun tracker' s current operational status, pointing position, sensor light intensity, etc.; data acquired by the software is stored in designated storage paths.

3 Experiments and Analysis

The instrument' s capability to measure both direct solar and sky-scattered light in the ultraviolet-visible band requires a large dynamic range and high sensitivity for weak UV signals [13]. To achieve this, the design utilizes the CCD' s dual-readout channels and different conversion gains, employing region-of-interest (ROI) technology to separately acquire UV and visible spectra. The UV and visible portions use different gains and readout channels, ensuring strong light signals do not saturate while maximizing signal-to-noise ratio for weak light [14]. After acquisition, the images are merged to obtain a complete image and count value spectrum, as shown in Figures 9-a and 9-b [FIGURE:9].

Comparison with theoretical simulation analysis demonstrates that using different CCD gains and readout channels for detecting direct solar or sky-scattered light preserves the fine structure of radiation intensity distribution in both UV and visible bands, indicating this approach can accommodate both weak UV signals and stronger visible light signals.

The electronic system of the ground-based ultraviolet absorbing aerosol monitor achieves alternating measurements of direct solar and sky-scattered light through hardware switching between different incident channels. The use of a UV-enhanced CCD combined with software-based separate exposure techniques for UV and visible bands effectively preserves spectral line information across both regions. After further radiance calibration [15], continuous solar spectra across the UV-visible band can be obtained for aerosol retrieval, particularly for ultraviolet absorbing aerosols.

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