Design of the Spectral Scanning Observation System for the One-Meter New Vacuum Solar Telescope (Postprint)

Authors: Yang Changchun, Li Zhenggang, Chen Yuchao, Xu Jun

Date: 2017-10-20T00:00:00+00:00

Abstract

The 1 m New Vacuum Solar Telescope (NVST) is a large-scale scientific research facility in China dedicated to solar observation and research. To meet the spectroscopic observation requirements of solar active regions, a spectral scanning device has been designed based on the existing high-dispersion spectrograph and multi-band spectrometer, and an observation control system software has been developed using C# to implement motion control of the scanning device and acquisition of observation data. During spectroscopic scanning observations, the computer controls the stepwise motion of the scanning device and utilizes an image acquisition card to collect detection data from the CCD/CMOS camera via the Camera Link bus. Observation data is acquired based on multi-threading technology, the collected image data is stored as FITS (Flexible Image Transport System) files, and the spectral image data is processed into grayscale images for software interface monitoring. This software has been applied to spectroscopic scanning observations with the 1 m solar telescope, with test results meeting the expected functional requirements and providing good extensibility for subsequent upgrades to the observation system functionality.

Full Text

Design of a Spectral Scanning Observation System for the 1-meter New Vacuum Solar Telescope

Yang Changchun[1], Li Zhenggang[2], Chen Yuchao[1], Xu Jun[1]

[1]Yunnan Observatories, Chinese Academy of Sciences, Kunming, Yunnan
[2]University of Chinese Academy of Sciences, Beijing

Abstract

The New Vacuum Solar Telescope (NVST) is a large-scale research facility dedicated to solar observation and study. To meet the requirements for spectral observations of solar active regions, a spectral scanning device was designed based on the existing high-dispersion spectrograph and multi-band spectrometer systems. A complete observation and control system software was developed to achieve motion control of the scanning equipment and acquisition of observational data. During spectral scanning observations, the computer controls the scanning device to step the camera’ s detection field, acquires observation data using multi-line process technology through an image acquisition card, stores the collected image data as FITS (Flexible Image Transport System) files, and processes the spectral images into grayscale for software interface monitoring. This software system has been applied to spectral scanning observations on the NVST solar telescope, with test results meeting functional requirements and providing excellent scalability for subsequent system upgrades.

Keywords: NVST; slit scanning; spectroscopic observations; image acquisition; FITS

---

1. Introduction

Magnetic fields play a crucial role in the evolution of solar atmospheric structures and violent activities, typically producing phenomena such as sunspots, prominences, and coronal mass ejections [1]. Vector magnetic fields of the Sun can be measured using polarimetric imaging and spectroscopy [2], and magnetic field measurement represents an important scientific objective for many solar telescopes [3], including the Domeless Solar Telescope (DST), Swedish Solar Telescope (SST), New Solar Telescope (NST), and the New Vacuum Solar Telescope (NVST) [4]. As the primary facility of the Fuxian Lake Solar Observatory, the 1-meter NVST is a large-scale research instrument dedicated to solar physics research, with key scientific objectives including high-resolution polarimetric imaging and spectral scanning observations of solar active regions. Spectral scanning serves as an essential component of solar magnetic field measurements, enabling the NVST to conduct spectroscopic observations of the Sun using scanning methods.

2. System Design and Hardware Architecture

Based on the existing high-dispersion spectrograph and multi-band spectrometer systems, a slit scanning system was designed to enable spectral scanning observations. In the instrument structure of the solar tower, high-dispersion and multi-band spectrometer systems are orthogonally arranged behind the slit of the spectrograph’ s derotator platform. To obtain two-dimensional spectral information of solar images, a slit scanning system was developed utilizing an electric lifting platform and two pairs of plane mirror assemblies. By controlling the stepwise motion of the lifting platform to move the plane mirrors, the optical path is shifted through mirror reflection, causing the solar spot image to progressively pass through the slit and enter either the high-dispersion spectrograph or multi-band spectrometer system. The camera then collects spectral images, and the acquired spectral image data is stored for subsequent analysis.

The main hardware components of the spectral scanning system include the electric scanning equipment on the spectrograph derotator platform, CCD/CMOS camera detectors, and grating spectrometers. A slit window with adjustable width is designed on the derotator platform, allowing the solar spot image to gradually pass through the slit and enter the high-dispersion or multi-band spectrometer system. The scanning mechanism design draws on the concept of using plane mirror groups for optical path translation in spectral scanning from the New Solar Telescope [5].

[Figure 1: see original paper] Schematic diagram of the NVST terminal instrument structure

The scanning system employs an electric lifting platform and two pairs of plane mirrors to form an optical path translation mechanism. During spectral scanning, the computer controls the stepping motion of the scanning equipment, and the image acquisition card acquires observation data from the camera through the Camera Link bus. The collected image data is stored as FITS files, and the spectral images are processed into grayscale for software interface monitoring.

3. Scanning Mechanism and Motion Control

The scanning mechanism involves an electric lifting platform driven by a stepper motor. To achieve micron-level precision motion control and ensure high spatial resolution image data, a lifting platform from Zolix was selected, with a specially designed upper platform instrument conversion hub to mount the scanning system equipment and optical beam splitting devices.

[Figure 2: see original paper] Structure of the spectral scanning equipment: (a) scanning mechanism and motion controller; (b) working principle of scanning equipment; (c) relationship between scanning motion and optical path translation

During spectral scanning, the horizontal displacement of the optical path is twice the vertical movement distance of the lifting platform. The current slit width is 200 m, with scanning step size serving as an adjustable parameter. Preset values of 100 m and 50 m can be flexibly selected. Each step of the lifting platform translates the optical path by twice the step length. Image acquisition occurs when the step motion stops. The number of scanning steps is set based on the size of the image acquisition region, and the step size is also adjustable as a parameter. After completing one group of scanned images, the scanning device must return to the preset zero position to enable reciprocating scanning motion.

The motion components of the scanning mechanism are driven by a stepper motor, where the angular displacement is proportional to the number of input pulses. This can form an open-loop CNC system with the corresponding drive circuit or a high-performance closed-loop CNC system with appropriate feedback. In this system, the electric lifting platform is equipped with a linear grating encoder for position feedback, and the manufacturer-designed motion control driver is selected. The motion controller communicates with the computer via RS232 interface.

Basic performance parameters of the electric lifting platform

4. Software Control System Design

4.1 Serial Communication Control Given that the scanning equipment is directly controlled by its motion controller, which already implements low-level drive and control of the stepper motor, motion control can be achieved through upper-level computer program design. The controller and computer communicate via serial port based on the ASCII standard. For the motion control of scanning equipment, the observation system software was developed using Visual C# in the Windows environment, utilizing the SerialPort class from System.IO.Ports for serial communication control design.

The SerialPort class provides access to serial driver properties and pin/interrupt status [6]. The basic implementation flow of serial communication control is as follows:

First, configure serial port parameters and open the port. According to the serial communication parameters of the motion controller, a computer serial port is allocated for scanning equipment communication control. The serial port parameters are set to match, including port number, baud rate, parity, data bits, stop bits, and read buffer size. After opening the corresponding computer port, communication control can begin.

Second, send data to the serial port. After opening the serial port, motion commands can be sent to the controller for execution. For example, to control the lifting platform movement in the scanning mechanism, a Write() operation implements command transmission. A custom SendMsg(string Commands) function can be defined to convert all communication instructions with the motion controller into this function' s Commands parameter, improving the convenience of serial communication design.

Third, receive serial data. During communication between the computer and motion controller, the controller feeds back the motion status of the electric lifting platform to facilitate data processing and subsequent control execution. The feedback data is transmitted to the computer serial port' s allocated buffer. When reading serial buffer data, the ReadExisting method is primarily used to immediately obtain buffer data, based on the SerialPort.DataReceived event.

Finally, close the serial communication port. After scanning work is completed and the equipment is controlled to return to its home position, or when the control software exits, the opened serial port must be closed to release occupied resources. The port closing operation is relatively simple, directly using the SerialPort.Close() method.

4.2 Image Acquisition and Storage Design During spectral scanning observations, whenever the scanning device steps and waits for image acquisition, the camera captures one frame. The system selects PCO.2000/PCO.4000 series cameras and corresponding camera controllers, using Matrox series acquisition cards to collect image data via Camera Link bus. The acquired image data is stored as FITS files to meet astronomical data processing requirements [7].

The image acquisition program design utilizes the PCO.SDK wrapper provided by the camera manufacturer, which integrates camera control functions and improves development efficiency. The basic workflow of image acquisition is shown in Figure 4.

[Figure 4: see original paper] Schematic diagram of image acquisition process

The main steps of camera control programming are: first, declare data structures for camera status control and initialize structure sizes; second, open the camera using PCO_OpenCamera(); third, set camera parameters such as exposure time and image binning size; fourth, obtain the image size and allocate memory space for storage; fifth, perform single-frame or loop acquisition and image storage; finally, stop acquisition, close the camera, and release memory space.

When the telescope tracks the Sun, the solar image at the spectrometer slit plane rotates around the main optical axis over time. The spectrograph' s derotator platform must be used to counteract this effect for successful spectral scanning [8]. After the computer acquires the digital spectral image signal, the image data must be stored as FITS files. The FITS file consists of header information and data. The header stores file descriptions such as observation target and exposure time for later data analysis [10]. When storing images, the CSharpFITS class is used to flexibly create file storage paths and names, which can include current date and time information, with image files stored in automatically created folders.

5. Multi-threaded Implementation for High Temporal Resolution

The initial design implemented image acquisition and storage sequentially within a single control thread (Model-1). When the scanning device completed one step, the camera began image acquisition. After the computer obtained the image data, it stored the FITS file and displayed the current image on the software interface. Only after file storage completion would the next scanning step begin. Testing revealed this approach was very time-consuming, requiring approximately 3 seconds to complete one frame of scanning image acquisition, with FITS file storage being the primary time-consuming component. This scheme could not achieve high temporal resolution.

A second approach tested computer memory buffering (Model-2), where image data matrices were temporarily stored in computer memory during scanning, and multiple images were later transferred to hard disk. However, when allocating memory space for more than a few frames (with each PCO.2000 frame being 2048×2048 pixels), the program could not run stably. Although this scheme improved scanning temporal resolution, the limited space for large arrays in computer memory severely restricted the number of scanning steps. Additionally, transferring large amounts of image data to hard disk after scanning caused significant time consumption and software interface freezing, leading to this approach being abandoned.

The current system employs a multi-threaded approach for spectral scanning image acquisition and storage. Each sub-thread primarily implements: controlling the scanning mechanism to step once, controlling the camera to acquire one frame of spectral image, and immediately storing the image data before automatically ending the thread. Figure 7 shows the working sequence diagram of the multi-threaded implementation.

[Figure 7: see original paper] Schematic diagram of image acquisition timing sequence

After the scanning mechanism completes one step, the camera is controlled to detect the image. Following exposure completion, the analog signal is converted to digital image data via an ADC, which is then transferred to an array for subsequent processing. At this point, another thread is initiated to execute the next scanning step and image acquisition. After launching multiple threads at intervals, each acquisition thread executes independently and exits after storing the corresponding FITS file. During scanning, the acquired digital image data can be processed into grayscale and redrawn on the software interface. The program displays one frame at each scanning step and also shows images at the start and end of scanning for interface updating and monitoring. This scheme ensures higher scanning temporal resolution while enabling real-time storage of large FITS files.

6. User Interface Design

For this spectral scanning observation system, the software interface should be simple, user-friendly, and highly automated. The main interface design is shown in Figure 9, divided into several functional areas: "Instruments" for device management operations, "ScanSetting" for scanning parameter configuration, "Observation"for observation operations, "Current Setting"for displaying current settings and status, and "IntensityGraph" for image display.

[Figure 9: see original paper] The main interface of spectral scanning software

The IntensityGraph control displays acquired images after normalization and conversion to grayscale. This control, from National Instruments' Measurement Studio 2010, efficiently meets digital image data display requirements and provides better program design efficiency compared to GDI+ Bitmap approaches.

7. Field Testing and Performance

This scanning system has been applied to the NVST for spectral scanning observations. To verify the scanning mechanism' s stability, tests were conducted using a laser source and the telescope' s existing imaging system. The scanning device was controlled to capture one frame per step, and software analysis of all image trajectories confirmed the motion stability.

Meeting the requirements for solar tracking and spectral scanning observations, the current system uses a wide slit (200 m) with a scanning step size of 100 m. Field test images demonstrate successful spectral scanning observations of sunspots, obtaining the required spectral image data for analysis.

[Figure 10: see original paper] Field test of scanning software

8. Conclusion

Spectral scanning observation is an important scientific objective of the NVST. This paper designed a slit scanning device for spectral scanning and developed a complete observation software system in the VS2010 environment using C#. The software achieves motion control of the scanning mechanism and camera control, with images stored as FITS files. The SerialPort class provides good versatility for motion control programming, while the PCO.SDK wrapper improves camera control development efficiency. The CSharpFITS class enhances efficiency for FITS file storage programming, and the IntensityGraph control from NI efficiently displays images. The NVST' s scientific objectives also include polarimetric measurements of solar active regions, requiring simultaneous operation of the spectral scanning system with the high-resolution imaging system. The work described herein will provide a reference for subsequent system upgrades and related developments.

References

[1] Fang Cheng, Ding Mingde, Chen Pengfei. Solar Active Region Physics. Nanjing: Nanjing University Press. [2] Liu Zhong, Deng Yuanyong, Ji Haisheng, et al. Measurement of Sunspot Vector Magnetic Fields and Calculation of Radial Current Density. Science China: Physics, Mechanics & Astronomy, 1282-1291. [3] Deng Yuanyong, Liu Zhong, Xu Jun, et al. Ground-based Giant Solar Telescope of China. Science China: Physics, Mechanics & Astronomy, 1282-1291. [4] Liu Zhong, Xu Jun, Gu Bozhong, et al. New Vacuum Solar Telescope and Observations with High Resolution. Research in Astronomy and Astrophysics, 705-718. [5] Chae J, Park H M, Ahn K, et al. Fast Imaging Solar Spectrograph of the 1.6 meter New Solar Telescope at Big Bear Solar Observatory. Solar Physics, 1-22. [6] Wang Guosheng, Liu Pan, Ni Chunyu. C# Basic and Case

Development. Beijing: Tsinghua University Press. [7] Camera Link Specifications of the Camera Link Interface Standard for Digital Cameras and Frame Grabbers. [8] Liu Guangqian, Fu Yu, Cheng Xiangming. Image Field Rotation and Counter-rotation Control for the Spectrograph of the 1m Solar Telescope. Publications of the National Astronomical Observatories of China, 86-92. [9] Cheng Zuqiao, Deng Hui, Wang Feng, et al. Research on High-speed CCD Image Acquisition Techniques Based on Camera Link. Publications of the National Astronomical Observatories of China, 363-368. [10] (Reference appears incomplete in original text)

Note: Figure translations are in progress. See original paper for figures.