NVST Multi-Channel High-Resolution Observing System Software Design Postprint

Authors: Yuchao Chen, Jin Zhenyu, Yang Lei

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

Abstract

The 1-meter solar telescope multi-channel high-resolution imaging system is one of the critical terminal instruments of the telescope, currently comprising the H channel (line center 656. 283 nm) and the Ti0 channel (705. 8 nm). This paper primarily presents the design of the software for the multi-channel high-resolution observation system. Functionally, the observation system implements a multi-wavelength point-scanning observation mode for the H channel, a multi-temporal resolution observation mode for the Ti0 channel, and to accommodate future multi-channel development requirements, such as the addition of conventional observation channels and detector replacement, employs a loosely coupled distributed hierarchical architecture in its system framework.

Full Text

Software Design for the Multi-Channel High-Resolution Observation System of the NVST

Abstract

The New Vacuum Solar Telescope (NVST) is a 1-meter, ground-based telescope that offers unparalleled performance for solar observations. One of the important instruments in the NVST is the multi-channel high-resolution imaging system, which currently covers five main wavelength ranges including H , TiO-band, G-band, Ca II (854.2 nm), and He I (1083.0 nm). Up to now, the H and TiO-band channels are being used. The H channel is a narrow-band imaging system equipped with a tunable Lyot filter. The interpretation of narrow-band filtergrams is difficult due to crosstalk between brightness and Doppler-shift modulation; therefore, the observational system is required to perform multi-offband observation in the H channel to obtain a scanned profile in order to get meaningful physical information. The TiO-band is a broad-band imaging system and uses a high-cadence CMOS detector. To achieve much higher cadence for some specific observations, it should support decreasing the FOV to increase the acquisition speed of the camera. However, the software provided by the camera manufacturer failed to meet the observation need so that a new observational software system is constructed to satisfy the different observational needs in two channels. Taking into account the factors that another three channels will soon be added and high-cadence cameras will come into uses, the software architecture designed for NVST acquisition system should provide the scalability and the flexibility to adapt to changes in technologies throughout the lifetime of NVST. To achieve this goal, the distributed multi-terminal deployment and a loosely coupled system is adopted. The system is based on a tiered software architecture implemented as three primary systems that are the Observation Control System (OCS), the Instrument Control System (ICS) and the Data Handling System (DHS). The OCS interacts with our staff and coordinates the overall observational operations. The ICS manages the instruments and the DHS manages the data operation including saving, processing and transferring. For decoupling the logical systems they can be developed independently so that the software architectures are separated into the functional architecture and the technical architecture, patterned similar to that adopted by the ACS (ALMA Common Service). The technical architecture describes the underlying implementation of the technical aspect, such as threading and message broadcasting. The functional architecture, in contrast to the technical architecture, describes the functional behavior. Therefore, the container/component mode is adopted to achieve this separation of architectures. The container manages many components which provide functional behavior. This paper describes the deployment of acquisition system and the design of the software architecture on the top of the container/component mode to achieve the scalability and flexibility to adapt the changes in observational instruments and in observational methods.

Keywords: Observation System; NVST; High-resolution Observation

1. Introduction

The New Vacuum Solar Telescope (NVST) is currently the largest solar telescope in China and the world’ s largest vacuum solar telescope, primarily used for high-spatial-resolution imaging observations of the solar photosphere and chromosphere, as well as high-spectral-resolution spectroscopic observations [?]. High-spatial-resolution observations of the solar photosphere and chromosphere represent an important research direction in solar physics. The NVST has already implemented a dual-channel high-resolution observation system that uses high-resolution image processing techniques to eliminate the effects of turbulent atmospheric distortion, enabling simultaneous high-resolution observations of the solar photosphere and chromosphere. Based on this system, numerous frontier solar physics research topics can be investigated, such as the fine structures of solar flares.

While conventional astronomical observations can often be performed using software provided by detector manufacturers, such software cannot meet the more complex requirements of high-resolution observation systems. As observational demands increase, it becomes necessary to develop customized observation software. Many telescopes both domestically and internationally have implemented their own observation systems using different approaches. Since each telescope has different practical conditions and scientific objectives, the requirements for observation acquisition systems vary accordingly, leading to implementations with distinctive characteristics tailored to specific telescopes. Consequently, these systems cannot be directly adopted as control and observation systems for another telescope.

For example, the Remote Telescope System 2nd Version (RTS2) was developed for a small telescope to observe gamma-ray bursts (GRBs) [?], with the initial goal of enabling automatic control for rapid target switching in response to GRB events. This system uses a central scheduling server to manage various device processes, offering a simple structure that is easy to develop. However, when the system architecture becomes relatively complex, the load on the central scheduling server increases significantly, affecting overall system performance. Therefore, when developing its control and observation system, the Atacama Large Millimeter/submillimeter Array (ALMA) did not adopt the traditional client/server architecture. Instead, considering the need to coordinate multiple telescopes and the possibility of system expansion, ALMA used a container-component model [?], where multiple containers share the role of the central scheduling server, avoiding overload on any single server. This approach not only improves system scalability but also provides better reusability and offers an open-source, general software framework for secondary development, shortening the development cycle.

The NVST high-resolution observation system has many development plans, such as adding observation channels, upgrading to high-speed detectors, and implementing synchronous observation modes with spectrometers. Therefore, during the design of the high-resolution observation software, current requirements and future system developments must be considered comprehensively; otherwise, each change may require a complete software redesign, significantly delaying the development timeline. To ensure a short development cycle while meeting functional requirements, a software architecture similar to the ALMA Common Software (ACS) framework was adopted. Based on the Common Object Request Broker Architecture (CORBA) as the communication middleware, and considering component performance limitations and hardware support, the decision was made to develop the component container and underlying implementation of remote object invocation independently.

2. Overview of the Multi-Channel High-Resolution Observation System

2.1 Current Status of the Observation System

The NVST currently uses conventional observation channels at H (656.283 nm) and TiO (705.8 nm) for chromospheric and photospheric observations. Since the NVST does not use adaptive optics for routine observations, post-processing data reconstruction is employed to improve the spatial resolution of observational data. The NVST uses the speckle masking algorithm for multi-frame statistical reconstruction of images, which requires the acquisition system to collect a sufficient number of frames meeting the algorithm’ s signal-to-noise ratio requirements while ensuring the observed object structure remains unchanged.

The original data acquisition program provided by the detector manufacturer could only perform continuous acquisition and could not interact with other devices to implement more complex observation modes. Therefore, a new observation acquisition system was developed to meet the requirements of the reconstruction algorithm and to support various observation modes such as multi-wavelength point scanning and adjustable time resolution based on the characteristics of each channel’ s observation method.

2.1.1 H Channel The H channel uses a center-wavelength-tunable Lyot filter for imaging observations, enabling observations at different wavelengths. Single-point observations are often insufficient to interpret certain phenomena —for instance, low-temperature materials with certain line-of-sight motions can create false brightening effects. By leveraging the tunable center wavelength characteristic of the filter and observing multiple wavelengths, the system can obtain physical information equivalent to spectroscopic observations. On the basis of meeting post-reconstruction algorithm requirements, the observation acquisition system implements multi-wavelength point scanning observation mode, with single-wavelength point observation serving as a special case of this mode.

Due to the need to monitor flares during routine observations, scanning multiple wavelength points would reduce time resolution. The H channel’ s conventional observation mode is single-wavelength point observation at line center, requiring 42 seconds. The observation state diagram is shown in [Figure 1: see original paper], with the left panel showing the H channel and the right panel showing multi-wavelength point scanning observation mode.

2.1.2 TiO Channel The TiO channel observes dynamic phenomena with different evolution speeds. To meet observational requirements, it is equipped with a high-speed Complementary Metal-Oxide-Semiconductor (CMOS) detector capable of full-frame exposure at 100 Hz. Data must be transferred out within 1 second after exposure to prevent detector memory overflow. The main factor affecting acquisition speed is the CamLink transmission speed (250 MB/s). By reducing the exposure region to decrease data volume, the frames per second can be increased, trading field of view for higher temporal resolution.

For routine observations, the TiO channel focuses on monitoring and requires sufficient field of view. However, due to the slow speed of post-processing data reconstruction, the observation acquisition system must implement a large field-of-view, low time-resolution mode that pauses after collecting the required number of frames for reconstruction, thereby reducing data volume while ensuring reconstruction quality.

2.2 Future Development of the Observation System

Based on the existing dual-channel high-resolution imaging system, a five-channel imaging system will be built with parameters shown in .

Main Performance Parameters of the Multi-Channel High-Resolution Observation System

Channel	Wavelength (nm)	Bandwidth (nm)	Primary Observation Target
H	656.281 ± 0.4	0.025	Chromospheric magnetic structure dynamics
TiO	705.8	10	Photospheric small-scale bright points, fine structures of sunspots
G-band	430.0	0.4	Low photosphere small-scale magnetic structures
Ca II	854.2 ± 1	0.04	Chromospheric fine magnetic structure dynamics
He I	1083.0	1	Coronal hole or coronal base magnetic field dynamics

2.2.1 Increase in Conventional Observation Channels The upgrade of the multi-channel high-resolution imaging system includes two aspects. First, based on the original dual-channel system, three additional channels will be added: G-band, Ca II (854.2 nm), and He I (1083.0 nm) filters for chromospheric observations. These channels will adopt observation modes similar to the H channel, namely multi-wavelength point scanning observation, with single-wavelength point observation as a special case.

2.2.2 Use of Higher-Efficiency Detectors In the dual-channel observation system, the TiO channel detector acquisition frequency is limited by CamLink transmission speed, causing reduced temporal resolution. Therefore, detectors capable of using two CamLink interfaces for simultaneous data transmission will be selected for the multi-channel system.

2.2.3 Multi-Channel Synchronous Observation The increase in channels and use of higher acquisition frequency detectors will create greater data processing and reconstruction pressure. While the TiO channel reduces this pressure by lowering temporal resolution in routine observations, this approach is difficult to apply to other channels. Therefore, multi-channel synchronous observation will be adopted as a special acquisition method to reduce reconstruction pressure.

The synchronous reconstruction algorithm uses high signal-to-noise ratio broadband imaging system observation data to calculate the instantaneous transfer function for reconstructing lower signal-to-noise ratio narrowband channel observation data. This method offers several advantages [?]: (1) Faster reconstruction speed—synchronous reconstruction only needs to calculate the transfer function for the higher signal-to-noise ratio channel, reducing reconstruction time compared to traditional methods that require calculating transfer functions for all channels; (2) Improved temporal resolution—the speckle masking method typically requires many frames to ensure signal-to-noise ratio, while synchronous reconstruction needs fewer frames, yielding more results with the same number of frames.

The synchronous reconstruction algorithm requires synchronization trigger errors between different channel detectors to be within 1 ms. To meet this precision, one host computer controls multi-detector synchronous external triggering via Peripheral Component Interconnect (PCI) bus control card parallel ports. Tests have proven detector trigger precision at the nanosecond level, meeting synchronous reconstruction algorithm requirements. Although dual-channel synchronous observation experiments have been completed, they are not yet used for routine observations because the current detectors have vastly different acquisition frequencies (TiO channel at 100 Hz, H channel at 3.4 Hz in normal mode or 13 Hz in external trigger mode), which would greatly reduce the TiO channel' s temporal resolution in one-to-one synchronous mode. When building the five-channel platform, identical high-frequency detectors will be selected.

3. System Design and Implementation

3.1 Requirements Analysis

The main requirements for the NVST multi-channel high-resolution observation system are:

Functional Requirements: (a) H channel implements multi-wavelength point scanning observation (b) TiO channel has adjustable temporal resolution

Non-functional Requirements: (a) Short development cycle—functional requirements must be implemented immediately for actual observations (b) Good extensibility—the observation system must accommodate expansion or upgrades of the multi-channel observation system, and adjust pre-defined requirements based on usage experience

To submit software within a short development cycle, respond quickly to requirement changes during usage, and adjust implemented functions while adding new features during low-cycle iterative deployment, an agile development approach [**?**] was adopted.

3.2 Distributed Multi-Terminal Deployment Scheme

To meet the needs of multi-channel development, system coupling was reduced through both hardware deployment and software structure. Since each channel' s observation has a certain degree of independence and the NVST will add observation channels, a distributed multi-terminal observation acquisition deployment scheme was adopted, with each channel having its own control terminal. This approach offers several advantages:

1. Each terminal controls one detector, meeting detector bandwidth and other requirements
2. Commercially available computers can be used, reducing costs
3. When single-point failure occurs, it does not affect normal observation of other channels and facilitates troubleshooting

The deployment diagram of the observation acquisition system is shown in [Figure 2: see original paper].

3.3 System Architecture Design

Since the observation system is still evolving, the architecture must support loose coupling between functions and underlying computer technologies. There may be needs to replace detectors, adjust storage devices, or even change operating systems. Therefore, the system architecture is divided into functional architecture and technical architecture [**?**, **?**], as illustrated in [Figure 3: see original paper].

The functional architecture describes each component' s interfaces and functions, as well as relationships and interactions between components. The technical architecture describes underlying implementation details such as threading and transaction processing mechanisms. The container/component model was adopted to achieve this separation. Components are the smallest building blocks of the architecture, providing functional behavior and declaring architecture-related attributes through metadata, enabling independent component development. The container manages multiple independent components, providing external interfaces and controlling program startup, shutdown, and other functions to form the technical framework.

The separation of technical and functional architectures offers several advantages: 1. Reduced coupling between specific functions and software technologies—rapid software technology development would otherwise limit observation acquisition system performance 2. The NVST' s existing control system development is tightly coupled with communication technology; changing underlying communication would require rewriting the entire system, but loose coupling reduces this workload 3. Provides a platform for engineers to develop specific applications without concerning themselves with underlying technologies

3.4 GUI Design

For observer convenience, a graphical interaction interface was implemented with a minimalist design. The main interface only lists functions essential for observation, while rarely-used functions (such as modifying detector binning or AOI regions, exposure time, observation target information, or filter serial port parameters) are adjusted through configuration files. The interactive graphical interface is shown in [Figure 4: see original paper], with the left panel showing the H channel interface and the right panel showing the TiO channel interface.

4. Conclusion and Outlook

The multi-channel high-resolution observation acquisition system has implemented observation modes including H channel multi-wavelength point scanning, TiO channel adjustable temporal resolution, and different temporal resolutions for different observation purposes. The NVST multi-channel high-resolution observation system is still under development. To ensure good extensibility while implementing observation functions, the agile development approach was adopted during software implementation. Additionally, through distributed multi-terminal deployment and separation of functional and technical architectures similar to ACS, the system can adjust implemented functions and add new features during low-cycle iterative deployment, improving acquisition system scalability and extensibility.

In the next development phase, the system will expand from dual-channel to five-channel high-resolution imaging, replace detectors with higher speed, and add corresponding observation acquisition servers. Multi-channel synchronous external trigger acquisition mode will replace the current software trigger mode.

References

1. Liu Zhong, Xu Jun. Research in Astronomy and Astrophysics, 705-718.
2. Gu Bozhong. New vacuum solar telescope and observations with high resolution. Kubanek P. RTS2-the remote telescope system. Advances in Astronomy.
3. Schwarz J, Farris A, Sommer H. The ALMA software architecture. Proceedings of SPIE, 1-17.
4. Xu Zhi, Yang Lei, Xiang Yongyuan, et al. Astronomical Research & Technology—Publications of National Astronomical Observatories of China, 239-246.

5. Yao Huiling, Jin Zhenyu, Xiang Yongyuan. A study of influences of atmospheric dispersion on the multi-waveband synchronous high-resolution reconstruction applied to solar images. Astronomical Research & Technology, 189-195.
6. Shore J, Chiozzi G, Warden S. The art of agile development. New York: O' Reilly Media Incorporated.
7. Gustafsson B, Jeram B. CORBA-based common software for the ALMA project. Proceedings of SPIE, 43-54.

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

Source: ChinaXiv —Machine translation. Verify with original.