Post-print of the Type II Multifunctional Astronomical Theodolite Image Acquisition System

Authors: Zhang Yigong, Su Jie, Yang Lei, Wang Jiancheng, Chen Linfei, Cheng Xiangming, Zhang Guanjun

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Abstract

The Type II multifunctional astronomical theodolite is a ground-based astrometric instrument developed by the Yunnan Astronomical Observatory, Chinese Academy of Sciences, to meet the need for monitoring local plumb line variation information at observation stations using a network of multiple instruments. In the image acquisition system of this instrument, three uncooled CCDs are employed as acquisition terminals, operating in external trigger mode, with camera acquisition triggered according to the observation sequence by external trigger signals provided by the telescope control system. The specific operating mode of the telescope is introduced, the workflow of the image acquisition system is described, and the hardware composition, software framework, and main programming methods involved in the acquisition system are presented. The software interface of the image acquisition system and the acquired images are provided, and a preliminary analysis of the imaging quality of the captured stellar images is conducted.

Full Text

The Image Acquisition System of the YNAO Multi-Function Astronomical Theodolite II

Zhang Yigong[1,2,3,4], **Su Jie**[1,2,3,4], **Yang Lei**[1,2,3], **Wang Jiancheng**[1,2,3,4], **Chen Linfei**[1,2,3], **Cheng Xiangming**[1,2,3,4], **Zhang Guanjun**[1,2,3,4]

[1] Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China
[2] Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming 650216, China
[3] Center for Astronomical Mega-Science, Chinese Academy of Sciences, Beijing 100012, China
[4] University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

The YNAO Multi-Function Astronomical Theodolite II is a ground-based astrometric instrument developed by Yunnan Observatories, Chinese Academy of Sciences, to monitor variations in the local plumb line through networked observations using multiple instruments. Its image acquisition system employs three non-cooled CCD cameras operating in external trigger mode, with the telescope control system providing trigger signals according to the observation sequence. This paper describes the telescope' s operational mode and the workflow of the image acquisition system, detailing the hardware configuration, software framework, and primary programming methodologies. The software interface and sample images are presented, along with a preliminary analysis of stellar image quality.

Keywords: Astronomical Instrument; Astrometry; Theodolite; Image Acquisition; Programming

0 Introduction

With advances in space science and technology, ground-based astrometric instruments have gradually been superseded in applications such as establishing celestial reference frames [1, 2] and determining Earth rotation parameters [3, 4]. However, these instruments remain important for geodetic measurements, as they can determine the orientation of a station' s plumb line in celestial coordinates through stellar direction measurements, enabling monitoring of local plumb line variations [5, 6]. Research teams worldwide have conducted astronomical latitude and longitude determinations using ground-based astrometric instruments. These measurements not only provide vertical deflection data [7, 8], but also reveal that anomalous fluctuations in time-latitude residuals—reflecting local plumb line variations—may serve as effective earthquake precursors [9, 10].

Given the increasingly severe earthquake situation in Yunnan Province, monitoring local plumb line variations using ground-based astrometric instruments to provide anomalous plumb line data as potential earthquake precursor information holds significant importance for earthquake-related departments and disaster prevention efforts. Against this background, Yunnan Observatories, Chinese Academy of Sciences, collaborated with domestic institutions to develop the Multi-Function Astronomical Theodolite for monitoring local plumb line variations. The first-generation instrument (Type I) was completed in 2012 [11, 12], followed by two Type II instruments in mid-2019. After commissioning, these instruments will conduct networked observations to monitor local plumb line variations.

The data acquisition system constitutes a critical component of astrometric instruments. Historically, data acquisition terminals have evolved from photographic plates [13] to photomultiplier tubes [14] and subsequently to CCD cameras [15]. Error measurement systems vary across different instruments: the

US Naval Observatory' s Flagstaff meridian circle employs a laser interferometer and video CCD configuration [15], the Low Latitude Meridian Circle uses a Reticon-based system [16], and digital zenith telescopes utilize high-precision inclinometers and tilt sensors as core error measurement components [17, 18]. The Type I Multi-Function Astronomical Theodolite's image acquisition system [12] used one digital camera and two analog cameras for error measurement and astronomical observations. However, the analog cameras offered only 8-bit pixel depth with limited dynamic range, high dark noise, and low quantum efficiency, making high signal-to-noise ratio imaging difficult. Additionally, using different camera models increased hardware maintenance and software development complexity. To address these limitations, the Type II system upgraded both the image acquisition hardware and accompanying software, with corresponding improvements in programming methodology.

This paper primarily introduces the hardware configuration and software implementation of the Type II Multi-Function Astronomical Theodolite' s image acquisition system, highlighting changes and improvements in programming methodology compared with the Type I system.

1 Operational Mode of the Type II Multi-Function Astronomical Theodolite

The Type II instrument employs the same trans-axis observation mode as the Type I system. For each target star in the observation program, exposure begins before the stellar image crosses the vertical meridian of the field of view. The main optical path CCD camera first acquires 50 artificial star images, followed by 100 target star images. Simultaneously with target star acquisition, the electronic leveler and axis collimator CCD cameras each acquire 100 images. The instrument then rotates 180° about the azimuth axis (vertical axis) while the tube rotates through twice the preset zenith distance angle, maintaining alignment with the same target star. Subsequently, 100 images each of the target star, electronic leveler artificial star, and axis collimator artificial star are acquired, followed by a final set of 50 main optical path artificial star images.

The telescope control system executes observations according to the prescribed program, controlling camera exposure via external triggers at specified timings for each target while synchronously recording GPS time, altitude axis encoder readings, and azimuth axis encoder readings. Integration of temperature and pressure monitoring modules into the telescope control system enables automatic recording of observatory environmental conditions before each star observation. The specific operational mode is illustrated in [Figure 1: see original paper].

2 System Hardware

The image acquisition system comprises three subsystems: the main optical path system for acquiring stellar and artificial star images to determine telescope pointing; the electronic leveler optical path system for acquiring electronic leveler artificial star images to measure telescope level error; and the axis collimator system for acquiring axis collimator artificial star images to detect errors caused by altitude axis wobble. All three subsystems use identical non-cooled digital CCD cameras.

The cameras are Imperx BOBCAT CLB-B1410M-SC000 area-scan cameras equipped with Sony ICX-285AL interline transfer CCD sensors measuring 2/3 . With a pixel size of 6.45 m × 6.45 m, the cameras achieve a frame rate of 23 fps at 1392 × 1040 resolution with 12-bit pixel depth[1]. Powered by 12 V DC, the cameras support multiple trigger modes including external triggering. The CameraLink Base protocol is used for data transmission, paired with Dalsa Xtium-CL_{MX4} frame grabbers capable of supporting two Base-configuration CameraLink cameras or one Medium/Full-configuration camera with data transfer speeds up to 1.7 GB/s[2].

The system operates in external trigger mode, with the telescope control system sending trigger signals to the frame grabbers according to the observation sequence. The frame grabbers convert TTL signals to LVDS signals to trigger camera acquisition. The system workflow is shown in [Figure 2: see original paper].

3 Software Framework

The image acquisition software was developed using Microsoft Visual Studio 2010 with Teledyne Dalsa' s Sapera LT 8.30 Release development kit. Sapera LT is a software development toolkit designed for Dalsa hardware, providing modules for image acquisition configuration, image capture, processing, and display. For the Type II system, CamExpert (Sapera LT' s camera configuration utility) was used to configure camera trigger modes, frame grabber memory allocation, and other parameters, generating configuration files. Additionally, since the cameras operate in external trigger mode, Imperx' s Bobcat Configurator CL software was required to set camera trigger parameters to match the CamExpert configurations, as shown in [Figure 3: see original paper].

All three subsystems employ the same software framework, differing only in allocated memory size. As shown in the operational mode diagram, the electronic leveler and axis collimator systems acquire 50 fewer images than the main optical path system before and after trans-axis rotation, requiring memory for 100 images versus 150 images for the main system.

4 Programming Methodology

The image acquisition system utilizes Teledyne Dalsa' s Sapera LT++ advanced C++ library, which includes Basic Classes for fundamental image processing functions and GUI Classes for graphical user interface components[3]. While the Type II acquisition workflow remains largely unchanged from Type I, two key improvements were implemented:

First, a memory clearing function was added to the custom image acquisition Save() function to prevent duplicate image storage. For the main optical path subsystem, the key implementation code is as follows:

```
m_{Buffers}->Next();
m_{StartFrame}=(m_{Buffers} == NULL) ? 0 : m_{Buffers}->GetIndex();//Get index number
m_{Buffers}->Save(FileName, m_{Options});//Save image
m_{Buffers}->Clear(m_{StartFrame});//Clear buffer
```

This function calls four SapBuffer class methods: GetIndex(), Next(), Save(), and Clear(). The Next() method locates the first image buffer, GetIndex() retrieves its index, Save() stores the image data in RAW format to the disk array, and Clear() resets the buffer memory.

Second, the Type II system implements automatic image data storage through a dedicated image storage thread. The method compares the image workstation time (calibrated using GPS before observations) with the program time to await the observation start time. For time comparison, the system uses the Win32 API GetCurrentTime() function to obtain the current system time in seconds, and the CTime class constructor CTime(int nYear, int nMonth, int nDay, int nHour, int nMin, int nSec, int nDST = -1) to create CTime objects from program file time information (year, month, day, hour, minute, second). This conversion to seconds avoids the "midnight crossing" issue encountered in the Type I system [12]. Time control is then implemented using the WIN32 API Sleep() function according to the observation sequence, enabling image data storage during trans-axis rotation and the waiting period between observations.

5 Test Results

The two Type II instruments have conducted over a year of follow-up observations, acquiring approximately 120 stars during four hours of observation on clear nights, generating about 250 GB of image data per night. All images are stored in the disk array of the image processing workstation and subsequently processed in batch using the project's dedicated image processing software. [Figure 4: see original paper] shows the software interface of the main optical path acquisition system.

[Figure 5: see original paper] presents a lunar surface image captured during the Type II instrument' s commissioning phase, clearly showing craters and indicating good optical system alignment. [Figure 6: see original paper] shows an enlarged artificial star image from the electronic leveler camera, consisting of a single spot. [Figure 7: see original paper] displays an enlarged image of a 5.01 mag star captured by the main optical path camera with 43 ms exposure time. The stellar intensity profile follows a Gaussian distribution with a flatness of 0.26 (indicating 26% of points fall outside the fitted circle). Non-circular stellar images result from factors including focal length variations, atmospheric seeing, and telescope tracking errors. Since the instrument' s observation principle requires fixed pointing during target acquisition, stellar motion relative to the telescope causes image distortion. Combined with atmospheric turbulence-induced random errors, this affects centroid measurement accuracy. The system mitigates these errors through continuous multi-frame image acquisition.

6 Conclusion

The Type II Multi-Function Astronomical Theodolite is a new astrometric telescope developed by Yunnan Observatories to meet the requirements of networked plumb line variation monitoring. Based on the Type I image acquisition system, the Type II system was developed with three digital cameras, matching frame grabbers, and image processing workstations as the primary hardware. The software was developed using Microsoft Visual Studio 2010 and Sapera LT 8.30 Release. The system has operated reliably for over a year on two Type II instruments, producing image data that meets subsequent processing requirements.

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