1.26-meter Infrared Telescope Photometric Processing Pipeline Design and Implementation Postprint

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Abstract

The 1.26m infrared telescope is a telescope system jointly constructed by the National Astronomical Observatories and Guangzhou University, where photometric observation represents one of its primary observational techniques. However, persistent issues include lengthy data processing cycles and fundamental dependence on manual intervention. To enhance the data processing capabilities of the Guangzhou University collaboration team, a semi-automated photometric processing pipeline for the 1.26m infrared telescope is proposed. Following raw data acquisition, this pipeline reconstructs FITS header information based on the day' s observation records; subsequently, the pipeline system automatically executes operations including image preprocessing, target star localization, and photometric calculation of target stars, ultimately yielding usable photometric data. This methodology is efficient and convenient, while simultaneously guaranteeing precision. By transferring the complex, repetitive steps inherent in current mainstream photometric modes to automated program execution, it saves time, markedly enhances operational efficiency, resolves the critical bottleneck in current optical photometry paradigms where image data processing fails to keep pace with data generation, and fulfills the requirements of the broader scientific research community.

Full Text

Design and Implementation of a Photometric Processing Pipeline for the 1.26m Infrared Telescope

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Abstract

The 1.26m infrared telescope is a joint facility constructed by the National Astronomical Observatories and Guangzhou University, with photometric observations representing one of its primary operational modes. However, the current data processing workflow suffers from long processing cycles and relies heavily on manual intervention. To enhance the data processing capabilities of the Guangzhou University collaboration team, we have developed a semi-automated photometric processing pipeline specifically for the 1.26m infrared telescope. After acquiring raw data, the pipeline reconstructs FITS header information based on the day' s observation log, then automatically performs image preprocessing, target star identification, and magnitude calculation, ultimately producing usable photometric data. This approach is efficient, convenient, and maintains high precision by automating the complex, repetitive steps inherent in conventional photometric processing. The pipeline significantly improves work efficiency, addresses the critical bottleneck where image processing cannot keep pace with data production in current optical photometry modes, and meets the needs of the broader research community.

Keywords: 1.26m infrared telescope; photometry; data processing; pipeline
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1. Introduction

The 1.26m infrared telescope, developed by the Nanjing Astronomical Instrument Center of the Chinese Academy of Sciences, was installed at the Xinglong Observatory in 1985 and has undergone comprehensive upgrades in recent years. The telescope now features both a near-infrared imaging system and a three-channel optical imaging system equipped with three CCD cameras corresponding to g, r, and i bands, with an f/8 focal ratio and a resolution of 0.117 arcseconds per pixel.

Currently, most observatories still rely on manual processing for photometric data, resulting in low efficiency that delays scientific progress and fails to meet researcher demands. The predominant approach uses the widely-adopted IRAF software, specifically the APPHOT or DAOPHOT packages [1]. This conventional workflow involves acquiring bias, flat-field, and dark frames, preprocessing target images, using the `imexa` command in IRAF to determine appropriate half-widths and standard deviations, setting relevant parameters, and finally performing photometry to obtain magnitude and flux information for a single image. These steps must be repeated continuously until all target images are processed, after which magnitudes from all images are compiled into a light curve. Throughout this process, both target stars and standard stars require manual selection, making the procedure extremely tedious and error-prone when processing dozens or hundreds of images.

To address these challenges, developing a dedicated photometric processing pipeline for a specific telescope system that can automatically complete data processing and deliver accurate results for subsequent scientific analysis represents a significant advancement. Such a system substantially reduces manual effort and accelerates scientific data production, offering clear practical value.

2. Related Work

Astronomical photometry, the measurement of celestial object brightness, utilizes CCD cameras to record brightness information as FITS images for subsequent research. Since their introduction in 1969 and widespread adoption in astronomical photometry in the early 1990s, CCD cameras have become fundamental tools. Reference [2] demonstrated that CCD flat-field correction accuracy is directly proportional to photometric precision, while reference [3] established the relationship between aperture parameter settings and instrumental magnitude errors when studying the BL Lac object 3C66A.

Photometric processing is a common function in astronomical data reduction. Over the years, astronomers have developed numerous photometric software packages, with the most popular being IRAF and IDL, both containing mature photometry modules. In recent years, as Python has gained prominence in astronomical software development, the Photutils package has been created and integrated into the Astropy ecosystem, further advancing Python' s adoption in astronomy.

Regarding specific photometric processing, researchers have investigated both efficiency and precision. Reference [4] compared internally designed software with IRAF' s APPHOT package when studying growth curves of star clusters NGC1664 and NGC2168, concluding that the custom software achieved slightly better internal precision for medium-brightness and faint stars. Reference [5] compared two fast star-matching algorithms, finding that vector-based methods are superior.

Batch processing and testing for various telescope systems have yielded promising results. For the Thacher Observatory, Michael developed the Photometry Pipeline [6], which offers high efficiency but suffers from precision limitations due to image preprocessing and star-matching factors. These existing programs provide relatively complete functionality for semi-automated data processing of specific systems.

Building upon these research achievements and leveraging existing software systems and packages, developing a comprehensive data processing pipeline tailored to the specific requirements of the 1.26m telescope jointly operated by the National Astronomical Observatories and Guangzhou University is both feasible and valuable.

3. System Architecture

The rapid development of internet technologies and software engineering over the past decade has created a solid foundation for astronomical software development. The difficulty of developing a practical photometric pipeline has decreased significantly, as functional components and algorithms are readily available. In addition to standalone software packages, numerous web-deployed astronomical applications now provide online data search, query, and processing services.

Consequently, the core challenge in developing the photometric pipeline for the 1.26m infrared telescope lies in effectively integrating these software resources through rational workflow design and key technology implementation to create a stable, reliable system.

3.1 Supporting Software and Environment To rapidly construct the data processing pipeline, we utilized the following software packages:

1. **Astropy**: The `astropy.io` module is essential for editing, reading, and storing FITS file information, while `astropy.wcs` (World Coordinate System) manages coordinate transformations within FITS files.
2. **ccdproc** [4]: Handles CCD image processing, including gain and read noise calculation, and image combination.
3. **SExtractor**: Part of the astromatic software suite, SExtractor detects light sources in astronomical images, calculates optimal half-widths and background deviations, and performs aperture photometry. With excellent resolution and deblending capabilities, it can quickly distinguish celestial objects from noise and separate partially overlapping sources [7], making it ideal for source extraction and photometry.
4. **SCAMP** [8]: Matches source extractions from SExtractor with existing star catalogs to determine the sky region covered by the FITS image (i.e., telescope pointing). SCAMP offers fast computation and high flexibility.
5. **Online Catalogs**: For rapid processing, we employ the GAIA catalog [5] for astrometry and SDSS-R9 for photometric calibration, accessing these through the `astroquery` package. To resolve issues with commonly used star names and different catalog designations, we utilize SIMBAD to extract target information.

3.2 System Workflow [Figure 1: see original paper] illustrates the data processing workflow for a single FITS file. The process relies on observation log files to determine required processing steps, with the entire pipeline depending on information contained within FITS headers.

4. Implementation Details

4.1 FITS File Preprocessing The 1.26m telescope operates with an observation assistant who manually compiles an observation log file after each observing session. This file, stored in the same directory as all observational data, must be formatted as shown in for pipeline compatibility.

TABLE:1 Observational Log File Format

```
1,10,bias,1,,
116,125,sky flat,1,,
126,135,dark,300,,
11,53,3C454.3,300,22:53:57,+16:08:53
55,94,PKS0235+164,300,02:38:38.9301,+16:36:59.275
96,114,OJ287,300,08:54:48,+20:06:30
```

This CSV-format log specifies start and end frame numbers, target name (or calibration type), exposure time, and telescope pointing coordinates (RA, Dec). Based on this information, rewriting the original FITS headers is essential, as they currently lack critical information required for automated processing, including telescope pointing (RA, Dec), observatory coordinates, and exposure time. This deficiency not only impedes subsequent data processing but also affects data archiving and collaborative research.

Our system uses `astropy.io` to read and modify FITS headers, filling missing fields and correcting unreasonable values after consultation. The specific header fields are listed in .

TABLE:2 Header Information Written to FITS Files

No.	Field	Value	Remarks
1	OBSERVAT	Observatory name	
2	LATITUDE	'+40:23:45'	Observatory latitude
3	LONGITUD	'117:34:38'	Observatory longitude
4	OBJECT	obj_name	Target name (e.g., OJ287)
5	RADESYS		Coordinate system
6	RA	ra_str	Telescope pointing (RA)
7	DEC	dec_str	Telescope pointing (Dec)
8	DATE-OBS		Observation date
9	TIME-OBS		Observation time
10	IMAGETYP	bias,dark,skyflat,object	Image type
11	WCSAXES	2	Number of WCS axes
12	EQUINOX	2000.0	Astrometry equinox
13	CTYPE1	RA-TAN	RA tangent projection
14	CTYPE2	DEC-TAN	Dec tangent projection
15	CRPIX1	(2536+1)/2	x-axis reference point (center)
16	CRPIX2	(3358+1)/2	y-axis reference point (center)
17	CRVAL1		Reference point RA
18	CRVAL2		Reference point Dec
19	CUNIT1	deg	Unit for x-axis
20	CUNIT2	deg	Unit for y-axis
21	EXPTIME	exp_time	Integration time
22	CD1_1	cdelt	x-axis scale (deg/pixel)
23	CD1_2	-cdelt	CCD x-axis tilt
24	CD2_1		y-axis tilt

| | 25 | CD2_2 | cdelt | y-axis scale (deg/pixel) |

This header information is critical for automated processing. For instance, CTYPE1 and CTYPE2 define the correspondence between the CCD and sky coordinates, while some parameters like CD1_1 are filled after precise astrometric matching.

4.2 Flat-Field and Dark Current Correction Flat-fielding and dark current correction significantly impact photometric accuracy. Using the `ccdproc` package, our program extracts two bias and two flat-field images from the day's data to calculate gain and read noise values. All bias images are combined and averaged to create a master bias. Flat-field images are bias-subtracted and then combined into a master flat. Finally, all target images are bias-subtracted and flat-fielded.

Notably, since the CCD's dark current is below 0.1 electrons/pixel/second, its effect is negligible, and dark frame correction is omitted.

4.3 Pointing Determination and Coordinate Refinement SExtractor employs moment analysis for centroiding, extracting pixel information for sources with signal-to-noise ratios exceeding 3 above the background based on approximate pointing and scale information from the FITS header. SCAMP then matches these extractions against the GAIA catalog via network access. Despite small telescope pointing offsets and rotations, SCAMP calculates precise telescope pointing and accurate CCD scale after successful matching.

[Figure 2: see original paper] shows the matching result, where red regions indicate catalog sources, green regions represent well-matched sources, the black frame shows dozens of FITS images from the test, grid lines represent celestial coordinates (hour angle on the vertical axis, declination on the horizontal axis). Successfully registered images are designated as "goodfits," while severely offset or double-exposed images that cannot be matched are labeled "badfits" and excluded from further processing.

Additionally, SExtractor calculates optimal half-widths for each image. For faint objects, the signal-to-noise threshold must be lowered to facilitate subsequent photometry.

This approach completely eliminates pointing and tracking errors. Given a target's RA and Dec, the system can always locate its precise position in the image without manual selection. Furthermore, standard stars in the field can be identified through catalog queries and located accurately by position.

4.4 Selection of Photometric and Standard Stars Based on the target star's designation, the program automatically retrieves its coordinates. Standard stars are selected as bright stars near the target (since image offsets and rotations cause different fields of view, distant stars may fall outside the frame while faint stars make poor standards). For the 1.26m telescope's CCD array

(2536×3358 pixels) covering a 4.51'×5.98'field, the system identifies stars present in both the first and last images of a sequence, then automatically selects standard stars (control_stars) based on catalog magnitudes. This mode leverages online catalog services to avoid manual selection and improve computational efficiency.

5. System Deployment and Performance

5.1 Deployment Thanks to significantly improved computing performance, our program does not require high-end hardware. Supported by the China Virtual Observatory and Alibaba Cloud, the pipeline is deployed on Alibaba Cloud with a 4-core CPU and 64GB RAM, running Ubuntu 16.04 LTS. All custom code is written in Python 3 using the Anaconda 3.0 distribution to simplify deployment.

5.2 Processing Performance Using data of OJ287 obtained on November 1, 2016, from the 1.26m infrared telescope as an example, the experiment processed 57 FITS images across g, r, and i bands with a total observation time of approximately 4.5 hours. The complete pipeline execution time was about 7.5 minutes, accomplishing FITS header reconstruction, source detection, optimal aperture calculation, and aperture photometry without manual intervention.

Key aspects of the processing include:

1. **Optimal Aperture Selection**: Based on the relationship between aperture radius and signal-to-noise ratio (SNR), the program selects the aperture with maximum SNR as optimal. As shown in [Figure 3: see original paper], this aperture (approximately 0.68×FWHM [9-10]) captures sufficient flux without including excessive background. While the optimal aperture does not encompass the entire source flux ([Figure 4: see original paper], red circle), aperture correction and photometric compensation are applied [9-10].
2. **Target and Standard Star Selection**: Target stars are identified from the OBJECT field in FITS headers, with coordinates retrieved via SIMBAD. Standard stars for differential photometry are automatically identified and processed. Results are shown in [Figure 5: see original paper], displaying magnitude variations over time for both standard stars and the target OJ287, with vertical error bars indicating measurement uncertainties.

5.3 Limitations and Discussion While the automated photometric pipeline is efficient and convenient, several limitations have been identified:

1. Using SExtractor and SCAMP for source matching provides accurate field center coordinates, pixel scale, and CCD rotation, forming a solid foundation for automated processing. However, this approach is computationally intensive and demands relatively high CPU resources.

2. Images with poor signal-to-noise ratios or severe pointing offsets cannot be processed automatically and require manual intervention based on observer requirements.
3. Current standard star selection is magnitude-based, but some applications may require a specific fixed standard star, creating potential conflicts that need resolution in future work.

6. Conclusion

We have successfully implemented an automated photometric pipeline that requires only an observation log from operators. The system completes FITS header enhancement and executes all photometric processing automatically, delivering scientifically valid results efficiently and accurately. Overall, the system meets its design requirements and demonstrates excellent operational performance.

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