Two 0.5-m robotic telescopes for Timau National Observatory in eastern Indonesia

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Abstract. Timau National Observatory will be the new Indonesia’s astronomical observatory in East Nusa Tenggara, planned for 2020. Besides the main 3.8-m optical telescope, it will host two 0.5-m “off-the-shelf” f/3.8 and f/8.0 telescopes, equipped with two CCD cameras and two filter wheels. The system will be controlled with a robotic system for autonomous operation. In this paper, we present the system description and current development progress, as well as the future plan for the facility, including its two potential scientific studies: near-Earth objects and exoplanetary transits.

Keywords: Robotic telescopes and Timau National Observatory

1. Introduction

Since 1923, Bosscha Observatory in Lembang (107°36'E, 6°49'S), West Java, is the only major astronomical observatory operating in Indonesia. It hosts a 0.6-m double refractor telescope (installed in 1928) and a 0.7-m Schmidt reflector telescope (installed in 1960), which are still operating, but no longer sufficient to keep up with the latest development and progress in modern astronomy that are made possible by bigger and more advanced telescopes and instruments. Moreover, the sky quality over Lembang, near Bandung, has deteriorated, with worsening air and light pollution decreasing the number of photometric nights suitable for observation. New observing facilities are needed, and the idea has come up within a framework of national observatory. Meteorological satellite data spanning over 15 years (1996-2010) suggested that Timau, in the region of East Nusa Tenggara, south-eastern part of Indonesia, could be the most suitable location for an astronomical observatory [1]. Compared to other sites, Timau has more photometric nights and drier climate, with yearly usable night sky fraction of ~70%. The main planned facility for Timau National Observatory will be a 3.8-m optical telescope, currently under development in cooperation with Kyoto University. Other smaller telescopes are also included in the planning, including two units of 0.5-m robotic telescopes for astronomical surveys. Robotic telescopes are useful to minimize operation costs and number of required personnel. Their system can be designed to manage complex observational schedules based on the most appropriate targets and switch immediately to observe sudden events that require fast response. One of the largest examples is the 2-m Liverpool telescope, designed for study of unpredictable phenomena, survey and follow up, and monitoring of variable objects. The next
generation of robotic telescopes includes the Liverpool Telescope 2, a 4-m telescope with the capability for faint-objects spectroscopy in the optical/infrared [2].

Here, we describe the 0.5-m robotic telescopes system to be established in Timau National Observatory (figure 1). We provide the description of the hardware (Section 2), system control (Section 3), preliminary testing (Section 4), plan for the weather system (section 5), and the scientific potential of the telescopes (Section 6).

Figure 1. The two 0.5-m telescopes with the dome opened, temporarily installed in Space Science Center LAPAN, Bandung.

2. Hardware
Here, we provide the general description of the hardware for the planned robotic telescopes system.

2.1 Dome
The two telescopes are currently enclosed in a 5-m Astrohaven clamshell dome. Such design is advantageous for rapid follow-up observations, since it is not necessary to rotate the dome to adjust with the telescope. The dome and the telescopes are currently installed in Space Science Center LAPAN, Bandung. The current major issue is the positioning of the two telescopes, which are aligned in north-south direction inside one dome, which is not adequate for observation since there is less space for pointing the telescopes. The reason for this were mainly administration and safety of the purchased equipment. We are currently planning to purchase a similar dome to be installed in Timau site, so each telescope will have its own enclosure. The primary power for the dome may be either 230 VAC three-phase or 230 VAC single-phase. The two shutters on each side are lifted by a pair of electric motors with a series of belts and pulleys. Each shutter requires 22 seconds to fully open or close.

2.2 Mounting
The mounts for both telescopes are Software Bisque’s Paramount Taurus Model 500 of equatorial fork design. It provides through-the-meridian tracking, with adjustable polar axis from 0° to 58°. The maximum slew speed is 3.5°/sec. for both axes. The factory default is 80% of the maximum; this may depend on the payload and the ambient temperature. The mount is equipped with an on-axis encoder, providing ≤ 10” RMS all-sky pointing accuracy. Theoretically, the pointing’s accuracy may reach the encoder’s limit under 1”. In practice, without the encoder, the achieved accuracy is ≤ 20” RMS and the periodic error for the RA gear is ≤ 7”. With correction, the periodic error is less than the local seeing.
2.3 Telescopes
The two 0.5-m OTAs (optical tube assembly) are off-the-shelf Officina Stellare’s RiFast 500 (f/3.8) and ProRC 500 (f/8.0), made of carbon and aluminium with low thermal expansion. Both OTAs are equipped with primary mirror heaters to prevent condensation, three ventilation fans for cooling the mirror, and four primary mirror shutters to protect the mirror. Each telescope’s mass is 85 kg. RiFast employs spherical primary mirror and aspherical secondary mirror, with three corrector lenses (two are spherical) near the focus to minimize chromatic aberration. ProRC is a Ritchey-Chrétien telescope. Both OTA’s secondary mirrors are motorized to adjust the focus. The linear obstruction of RiFast and ProRC are 55% and 47%, with back focus correction of 0.24 m and 0.3 m respectively. The telescopes use rotofocusers for the cameras.

2.4 CCD Cameras and Filter Wheels
The two CCD cameras are Finger Lakes Instrumentation’s (FLI) PL4240 Midband for RiFast and PL16803 for ProRC (figure 2). Both cameras utilize thermoelectric cooling system capable for working temperature of 55°C below ambient temperature. The detectors require ~15 minutes to reach the working temperature between -30°C and -20°C from the ambient temperature of 22°C. Both cameras are equipped with FLI CenterLine CL-1-10 filter wheels, employing two research grade 50S UBVRI and LRGB filter sets. The detailed specifications are shown in Table 1.

Figure 2. CCD camera with the filter wheel at the back plate of the telescope.
Table 1. CCD cameras specification.

| Spec.                     | PL 4240                                | PL 16803                             |
|---------------------------|----------------------------------------|--------------------------------------|
| Sensor type               | e2v CCD42-40-1-368                     | ON Semi KAF-16803                    |
| Sensor size               | 2048 x 2048 pixels;                    | 4096 x 4096 pixels;                  |
|                           | 27.65 x 27.65 mm²                      | 36.86 x 36.86 mm²                   |
| CCD type                  | back illuminated                      | front illuminated                   |
| Pixel size                | 13.5 micron                            | 9 micron                             |
| Full well capacity        | $10^5$ e$^-$                           | $10^5$ e$^-$                         |
| Anti blooming             | -                                      | > 100x saturation exposure           |
| Color                     | monochrome                             | monochrome                           |
| Pixel scale               | 1.47”/pixel                            | 0.46”/pixel                          |
| CCD field of view         | 49.8” x 49.8”                          | 31.8” x 31.8”                        |
| Readout mode              | 500 kHz & 2 MHz                        | 1 MHz & 8 MHz                        |
| Readout noise             | (“slow” & “fast” readout)              |                                      |
|                           | • Binning 1x1(e$^-$ & 8.42 e$^-$)        | • Binning 1x1(e$^-$ & 8.86 e$^-$)     |
|                           | • Binning 2x2(e$^-$ & 8.71 e$^-$)        | • Binning 2x2(e$^-$ & 11.40 e$^-$)    |
|                           | • Binning 3x3(e$^-$ & 8.94 e$^-$)        | • Binning 3x3(e$^-$ & 14.63 e$^-$)    |
| Dead time (“slow” readout)|                                      |                                      |
|                           | • Binning 1x1(11 seconds)               | • Binning 1x1(19 seconds)            |
|                           | • Binning 2x2(6 seconds)                | • Binning 2x2(10 seconds)            |
|                           | • Binning 3x3(4 seconds)                | • Binning 3x3(7 seconds)             |
| 100-s dark current (“slow”| < 10.0 e/pixel                          | < 2 e/pixel                          |
| readout at -30°C)         |                                      |                                      |
| Gain (from manufacturer,  | 1.38 e/ADU                             | 1.46 e/ADU                           |
| “slow” readout)           |                                      |                                      |
| Filter                    | CenterLine CL-1-10                     |                                      |
| Number of filters         | 2 (wheels) x 5 (slots)                 |                                      |
| Size of filter slot       | rectangular 50 mm                      |                                      |
| Filter set                | UBVRI and LRGB                        |                                      |

3. System Control

As for now, each subsystem is controlled using separate software. Images are grabbed using MaxIm DL Pro 5 in its Camera Control; the CCD and its filter are configured in this menu. Movement of telescope on its mounting is controlled from TheSkyX. Officina Stellare ATC Remote is used for controlling the primary mirror shutter, monitoring the status of primary and secondary mirror temperature, as well as backfocus control. Environmental data such as temperature, pressure, relative humidity, and dew point from the sensor attached on the OTA are also showed in the OS ATC Remote software. Images taken are focused using RotoFoc 3” V2 that can be controlled by RotoFoc Control Panel Software. RotoFoc focuser can be moved from zero position to 25,000 μm.

All of these systems are planned to be controlled from one integrated software such as ACP Observatory Control. This is a part of the integrated robotic system that will be implemented to the telescopes and is currently under development.
4. Preliminary Testing
This section describes the initial tests that have been conducted so far, mainly on the detectors used for the telescopes and the optical aberration of the telescope.

4.1 Cameras
The techniques used to characterize the CCD cameras here follow those of Abbott [3]. Bias and dark testing have been conducted for both cameras, while flat fielding analysis is still in progress.

A median of 9 bias images was taken for each camera in order to characterize the statistical and spatial distribution of the readout noise [4]. In figure 3 and 4, we plot the mean rows and columns to check the spatial distribution of the bias from PL4240 and PL16803. The count is represented in ADU (analog-to-digital unit).

![Figure 3](image_url)

**Figure 3.** The mean (a) row and (b) column of the unpinned (1x1) median bias image of PL4240, “slow” readout mode. Grey indicates the mean values in each row and column. Red curves are the binned mean values with their error bars. The overall mean and the 1-sigma are shown with blue solid and dashed lines, respectively.
It can be seen that the mean along the row direction for both cameras are relatively stable within ± 1 ADU. A gradient exists along the column direction for PL4240, with higher counts found at the “right” of the detector, but this is still within ± 1 ADU. Along the column direction of PL16803, the counts fluctuate within ± 1 ADU, with high jumps can be seen at both sides of the frame. We found similar patterns in each frame, irrespective of binning size and readout modes. Such patterns in both detectors were also found in previous testing and are relatively fixed, hence can be subtracted from the science image through debiasing.

Inspection of the statistical distribution of the bias for both cameras are shown in figure 5. The probability density functions were counted, as well as the mean (µ) and the standard deviation (σ), which is a good measure of the readout noise. Slight deviation can be seen in PL4240’s histogram, indicating the presence of systematics that may require further investigation. A skewed right distribution in PL16803 has been expected, considering the presence of significantly-higher counts at both sides of the frame. The readout noise increases with the binning factor and the readout rate as shown in Table 1. The gain, as provided by the manufacturer, decreases by only ~1.45% for faster readout modes for both detectors. We used the theoretical gain values to estimate the readout noises; further flat testing should provide a more realistic estimate for the gains, hence readout noises.

**Figure 4.** Same as Figure 3, but for PL16803.
Figure 5. Statistical distribution of bias counts for PL4240 (left) and PL16803 (right), “slow” readout mode. The probability density function is shown in grey, while red curves show the calculated normal probability density function.

The dark current were measured for unbinned frames at “slow” readout mode as functions of temperature (-30° – 20°C, 5-second exposure time) and exposure time (2 – 1800 seconds at -30°C). The dark variability of both cameras are shown in figure 6 and 7, showing exponential and linear profiles for temperature and exposure time variability, respectively. The values of 100-s dark current of PL4240 and PL16803 are shown in Table 1. Our measured value for PL4240 is lower than that given by the manufacturer, but slightly higher for PL16803. More data are still required and further analysis will be conducted.

Figure 6. Dark variability of PL4240 as a function of temperature (left) and exposure time (right).

Figure 7. Same as Figure 6, but for PL16803.
An important factor to be taken into account is the humidity inside the dome, which needs to be maintained below a safe observing limit [5]. Some initial images from PL4240 show the presence of ice crystals that begin to form below -20°C (figure 8), suggesting high moisture around the detector. Putting the camera into a dry cabinet is one way to solve the issue. We found no similar problems with PL16803 so far.

For now, the temperature and humidity inside the dome is controlled with a portable air conditioner. We found that it is necessary to cool down the detector and begin calibration before the dome is open, maintaining lower internal humidity before the system is exposed to outer environment. The whole preparation and calibration procedure should take no more than 35 minutes. With one simple try-out, we managed to reduce frost forming on the detector. For future operation, dehumidifier will be installed in the dome and integrated into the weather system.

Figure 8. Subsection of a frame from PL4240. Signs of condensation and ice crystals are clearly seen. Image is shown with SAOImageDS9, zscale, heat color.

4.2 Optics
RiFast’s optics is currently being investigated for off-axis aberration, particularly astigmatism. Such aberration is due to misalignments or residual aberrations and can be identified by defocusing punctual objects. The external contour of the defocused object is analysed to determine the equation of ellipse, in which the defocusing and astigmatism are represented by Zernike coefficients $Z_{20}$ and $Z_{22}$ [6][7].

One of the data taken from preliminary observation can be seen in figure 9, showing an out-of-focus image of Jupiter. Fitting can be done by measuring the gradual decrease of radial counts and fitting the outer border by an ellipse by least squares [8]. The position of the secondary mirror can be varied in steps to see how the geometry changes.

Figure 9. Defocused, off-axis image of Jupiter, taken with RiFast and PL4240, shown with SAOImageDS9, zscale, cool color.
5. Weather System
For the safety of the telescopes against bad weather, at least three weather stations are planned to be installed around the dome and the observatory site. The weather stations will monitor sky temperature, ambient temperature, humidity, rain clouds, and wind velocity around the area.

Currently, one available equipment is the AAG CloudWatcher. The sensor can be calibrated by using the cloud monitoring data from the same site. Similar device has been installed installed for pt5m telescope on La Palma, where it is calibrated with the images from the Gran Telescopio Canarias all-sky camera [5]. The other sensor being considered is the Boltwood Sensor II, which is able to send command to automatically close the dome when the weather is categorized as bad, even if the PC controlling the system is not functioning. This device is used for the Baker Robotic Autonomous Telescope in southern Missouri [9] and the Skynet Robotic Telescope Network at Dark Sky Observatory, USA [10].

6. Scientific Potential

6.1 Near-Earth Objects (NEO)
Observation of Near-Earth Objects (NEO) is necessary due to the threats and potential destruction posed by them. The challenges in observing NEO include their possible appearance and fast movement throughout the whole celestial sphere, and near real time inspection of the data is required. Short focal length Cassegrain and Newtonian telescopes with CCD cameras have been useful for NEO observation [11]. The two robotic telescopes for Timau have this potential, though further test for its adjustment is certainly still needed.

6.2 Exoplanets
Current examples of 0.5-m class telescopes for photometry of bright stars with transiting planets are DEMONEX [12], TRAPPIST [13], and pt5m [5]. DEMONEX is an f/8 Meade 0.5-m RCX400 telescope equipped with FLI Fairchild CCD3041 CCD camera (figure 8), while pt5m is an f/10 Officina Stellare ProRC 500 telescope with QSI-532ws camera. Both telescopes have been used for the study of hot Jupiters, which provides constraints on theories regarding planetary and disk formation, as well as planetary migration [14, 15]. TRAPPIST, as an f/8 0.6-m telescope, also conducts photometric search for transiting planets detected by radial velocity. The study of NIR emission from an extremely-irradiated planet that is blocked out during occultation is also one goal of this telescope.

![Figure 10](image-url)

**Figure 10.** Left: DEMONEX telescope at Winer Observatory in Arizona, USA [12]. Right: science example with DEMONEX, combined light curve from 7 transits of hot Jupiter XO-4b [16].
7. Summary and Future Work
We have presented the brief description of the planned robotic telescopes system for Timau National Observatory. The system is currently undergoing preliminary testing, primarily for the detector and optics. More comprehensive testing will be conducted in 2019, before its installation in Timau site, planned in 2020. Hardware testing will be the most important process of preparation, especially for the weather system and the dome control. The software control will be tested after the hardware tests, to make sure that the hardware and the software work properly. The integration of the entire system along with the preparation of the automatic image reduction and scheduling pipelines will be conducted afterward.

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