Transient Optical Sky Survey Automated Telescope System

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ABSTRACT

We describe the optical design of a sky survey system comprised of small aperture telescope tube assemblies mounted on a common semi-equatorial frame with a single polar axis. It is the first ground-based instrument to create a map of transients down to optical m=17 by imaging a fixed-declination strip of the sky on a nightly basis. The system is fully remotely automated and physically robust. The mount tracks the sky using a motion controller, drive motor, and a laser rotary encoder. The prototype configuration is suited to house up to 6 telescopes on the current mount and is easily expandable to accommodate up to 30 telescopes which would enable full sky coverage if one system each were placed in the Northern and Southern Hemispheres[1].

Keywords: sky survey, small aperture telescope, transients

1. TOSS OVERVIEW

The Transient Optical Sky Survey (TOSS) is a system of optical telescopes designed to survey the sky to a limit of 17th magnitude, and to catalog transients by analyzing time-series luminosity measurements of detected objects from nightly observations[2]. We describe the optical system, focal plane cameras, and electromechanical pointing system used to achieve the science objective. The proof of concept system currently consists of two telescopes, as shown in Figure 1.

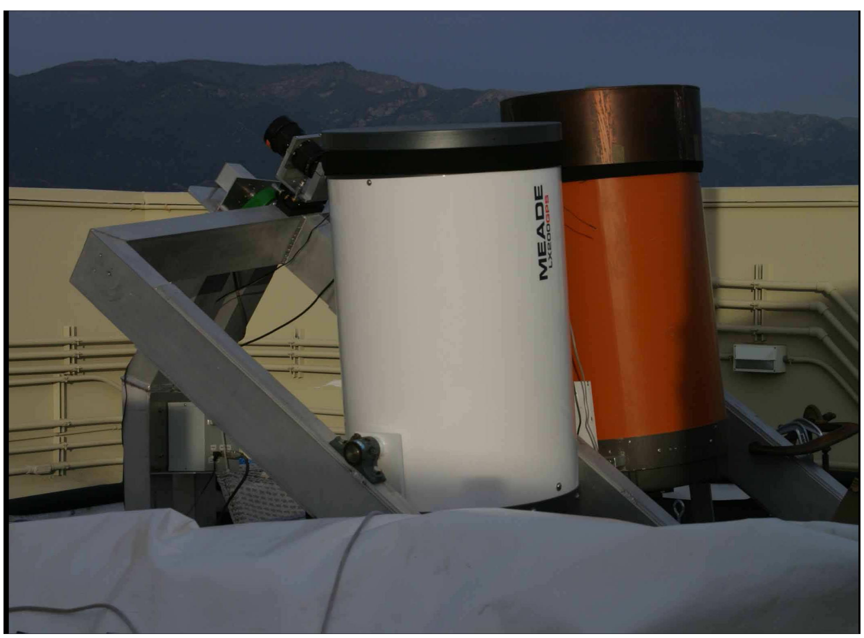

Fig. 1. Celestron (14 inch aperture, f/11) and MEADE (16 inch aperture, f/11), on aluminum mount.

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2. CHARACTERISTICS

Successful operation of TOSS required integration of several subsystems, including the cameras, telescopes, optical hardware, and mechanical motion control elements. The performance specifications of these components is listed in Table 1. In addition, several items not listed aid in the calibration and data collection during various weather conditions. These items include a polar alignment telescope, electronic focusers, dew shields, and dew heaters.

Table 1. Characteristics of the TOSS system and its components.

Parameter	Value	Units	Notes
TOSS System			
Limiting Magnitude	18	Mag	
RA Field	1800	arcsec	Per camera
Dec Field	1200	arcsec	Per camera
Cameras			
Tint	120	sec	Integration time
Plate scale	0.667	arcsec/pixel	
Pixel size	7.4 X 7.4	μm^2	3 colors
Camera Format	3072 X 2048	pixels	
Read Noise	14	e-	
Well size	250000	e-	
Gain	4.0	e-/ADU	
Resolution	16	Bits	Per color
Filter	RGB Bayer		
Meade Telescope			
Optical System	Catadioptric		
Aperture	40.64	cm	
Focal Length	406.4	cm	
Celestron Telescope			
Optical System	Catadioptric		
Aperture	35.56	cm	
Focal Length	355.6	cm	
Focal Length Reducer			
Reduction	0.63		
Mechanical System			
Pointing Stability	±1	arcsec	Over 120 sec integration time
Range of motion	±10	degree	Allows for calibration

3. SYSTEM BLOCK DIAGRAM

The telescopes are mounted on a robust aluminum frame which is free to rotate in the right ascension direction only. Its RA axis is fixed to a horizontal triangular frame, which has a jackscrew in each corner. The three jackscrews allow precise alignment to the celestial axis. Both telescopes are pointed at the zenith, and offset from each other in declination. To achieve the pointing stability required, an electromechanical system is used. It consists of a Galil motor controller, DC motor with encoder, and an optical encoder with a sine wave interpolator. The system's position encoder has a resolution of 0.5 arcsec. Setting stable values of position, integral and derivative allows accurate tracking through the 120 sec integration time. The Galil is also used to control the exposure time of the cameras. A computer controls the system, which is shown in Figure 2.

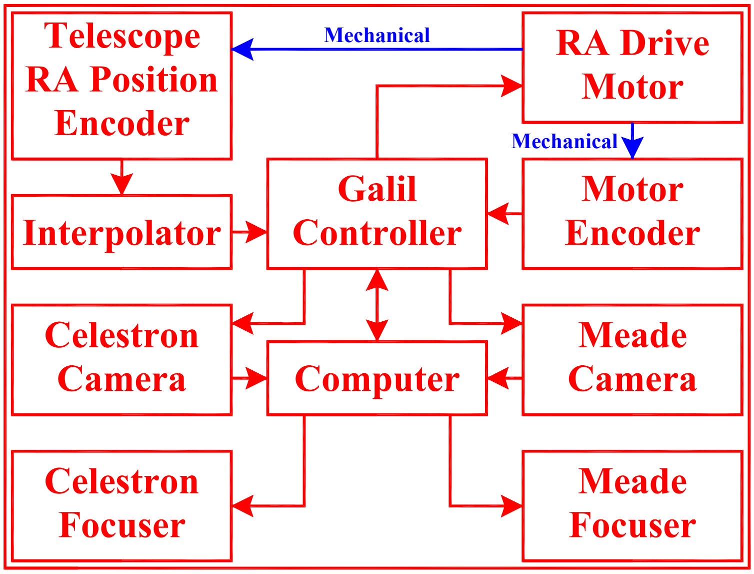

Fig. 2. TOSS electromechanical system.

4. OPTICAL SYSTEM

The optical system is shown in Figure 3. It consists of a Meade 16” aperture telescope and a Celestron 14” telescope, followed by a focal length reducer, and an automatic focuser. The camera is mounted to the focuser. A dew shield is used to reduce the condensation of dew and to block stray light from entering the telescope. In addition, a dew heater maintains the temperature of the corrector plate at just above the dew point. This allows optimum performance in the often high relative humidity found on site. The focuser is designed to compensate for its own thermal expansion and contraction with temperature, and it has additional control to eliminate temperature effects on focus from the rest of the system. The focal length reducer allows optimization of the focal length of the telescope to the pixel size of the camera.

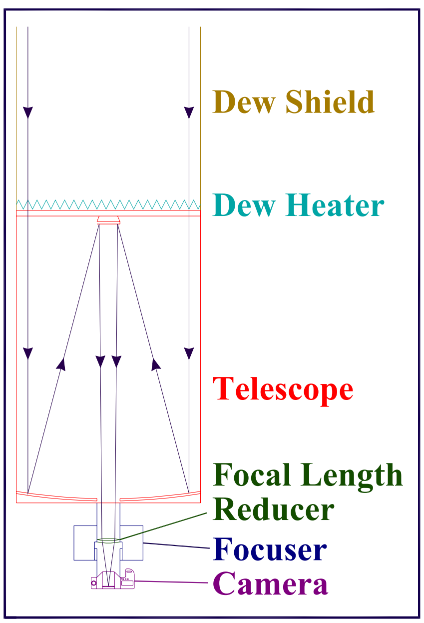

Fig. 3. TOSS optical system.

5. CAMERA READ NOISE AND GAIN

The read noise and gain of both cameras were measured with a uniform, constant intensity light source, and varying the integration time. The variance was plotted against the standard deviation of the central 100 X 100 pixels. The slope of the resulting data produces the gain in electrons/ADU, and the zero intercept is the read noise in electrons. This is shown in Figure 4. The noise and gain of the two cameras is listed in Table 2. Both cameras were at 22C temperature, and the ISO was set to 400. The ISO sets the relative gain on digital cameras.

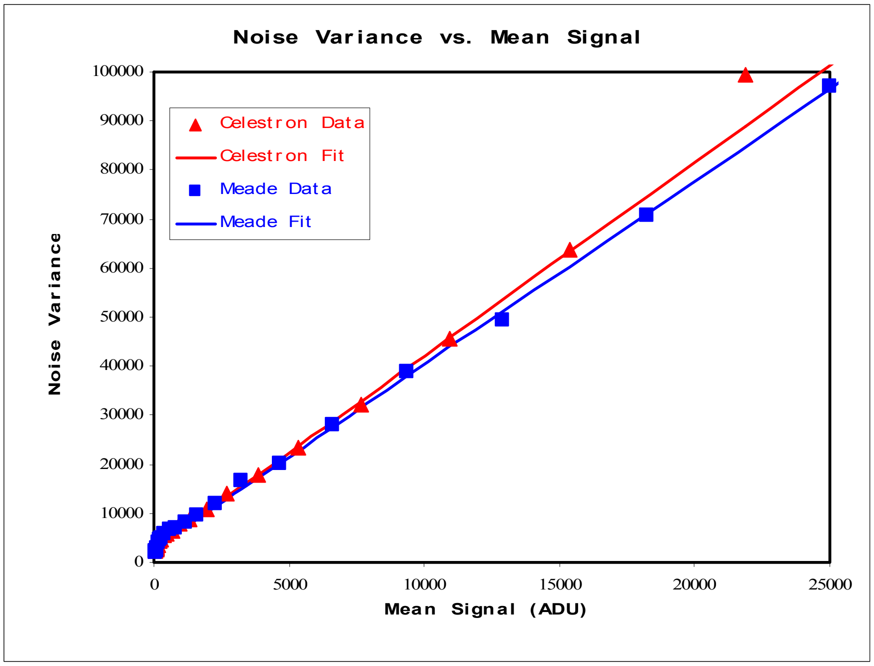

Fig. 4. Noise variance vs. mean signal plot for the two cameras..

Table 2. Noise and gain for the two cameras.

Parameter	Celestron	Meade
Noise (e-)	13.17	14.18
Gain (e-/ADU)	3.94	3.75

6. CAMERA SPECTRAL RESPONSE

The spectral response of each camera was measured using an Optronics spectrometer. Data was taken every 10nm from 350 nm to 1200 nm. A standard detector with calibration traceable to NIST was used to determine relative spectral quantum efficiency. The relative spectral quantum efficiency for the Meade and Celestron cameras is shown in Figure 5.

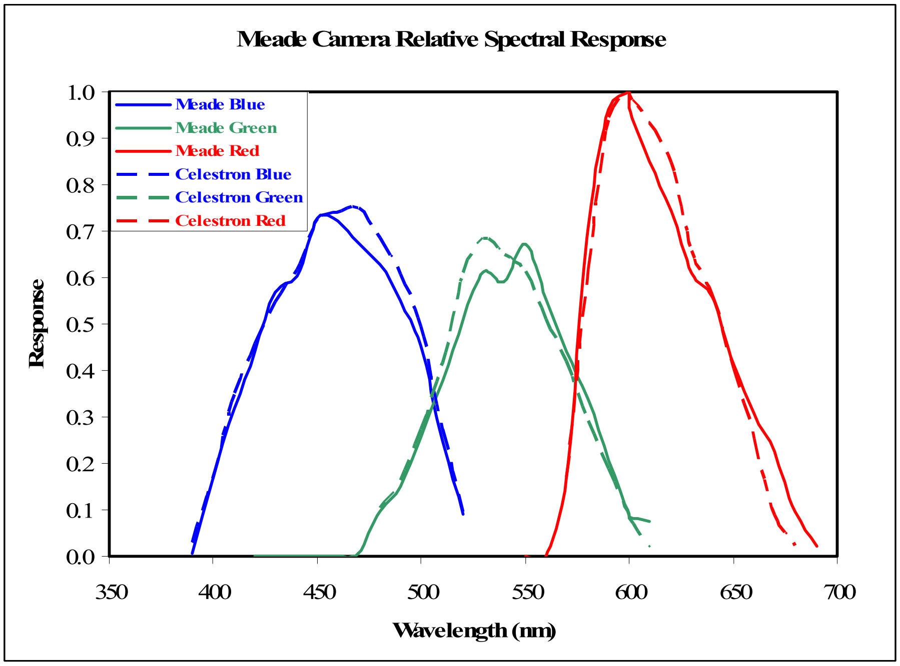

Fig. 5. The relative spectral quantum efficiency for each color for the Meade and Celestron cameras.

7. DARK FRAME AND FLAT FIELD CHARACTERIZATION

The dark frame corrects for camera array anomalies, while the flat field corrects for optical deformations. The dark frame is shown in Figure 6, and the flat field is shown in Figure 7. The dark-frame offset is just a few hundred counts out of 65535 maximum counts. The dark field data was taken at each of seven temperatures for each camera. Sixteen frames were taken and averaged at each temperature, to reduce the dark field noise contribution when subtracted from the image frames. All data was taken with 120 sec exposure. The dark field subtraction also eliminates "hot" pixels from the resulting image. An average of sixteen dark field exposures is shown in Figure 6.

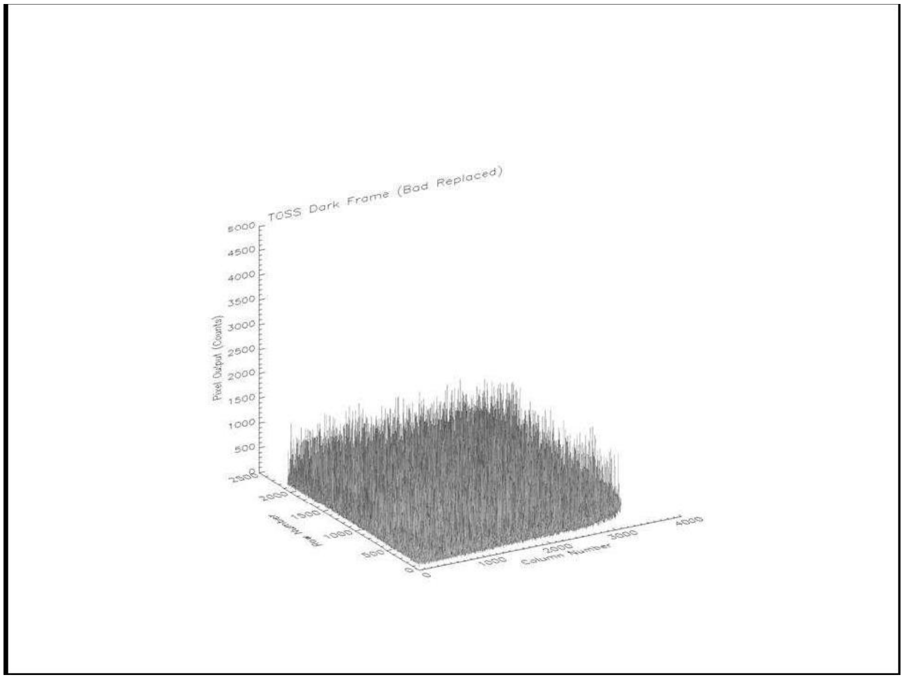

Fig. 6. Dark field data for the Meade camera.

The flat field frame is used to correct for the optical effects in the system. The image data is divided by this frame to correct the gain, which varies over the field of the camera mainly because of the focal length reducer. A flat field frame is shown in Figure 7.

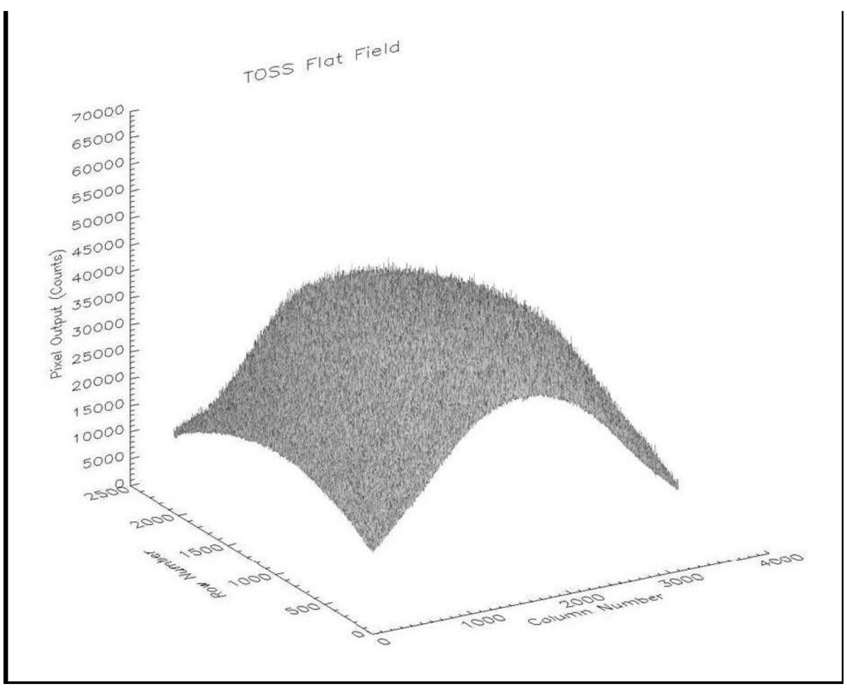

Fig. 7. Flat field data for the Meade camera.

8. LIMITING MAGNITUDE CALCULATION

The limiting magnitude achievable with the TOSS system was calculated using data from a known star. After allowing for the air mass, less than ideal focus of the telescope, and the short integration time (30 sec vs. 120 sec), the limiting star magnitude is at least 17.5. The seeing conditions were average when the data was taken. A signal to noise ratio of 1.5 was assumed, as this is the lower limit at which the analysis software can reliably detect objects. The calculations are shown in Table 3.

Table 3. Limiting magnitude calculation.

Star	GSC 1266:11	Limit Star	Unit
Magnitude	10.28	17.53	Mag
Exposure Time	30	120	sec
ISO	400	400	ratio
Air Mass	1.06	1.00	ratio
FWHM X	9.9	3.0	pixel
FWHM Y	6.1	3.0	pixel
Noise Floor	77	154	e-
Signal	6101.22	231	ADU

9. DEW SHIELD CALCULATION

Dew shields provide multiple advantages. Most importantly, the dew shield reduces the tendency for the telescope optics to reach thermal equilibrium with the air above it. Since our telescopes are pointed at the zenith, the optics attempts to reach a temperature of -40C, which is the average temperature of the air above us. Long before the optics reach that low temperature, however, condensation of moisture in the air occurs on the corrector plate. This limits the cooling process, but it makes the telescope unusable. A dew shield works by limiting the thermal field of view of the optics (which is much greater than the optical field of view), and thus limiting the amount of heat the optics can radiate to the air above. The solid angle and reduction in heat loss for our telescope are shown in Figure 8. A dew heater with a thermocouple temperature feedback provides additional heat to further prevent condensation.

The dew shield also greatly reduces stray light from entering the optical path of the telescope, and it reduces the collection of dust and contaminants on the collector plate. The dew shield was constructed of aluminum sheet with optically absorbing black felt lining its inside surface.

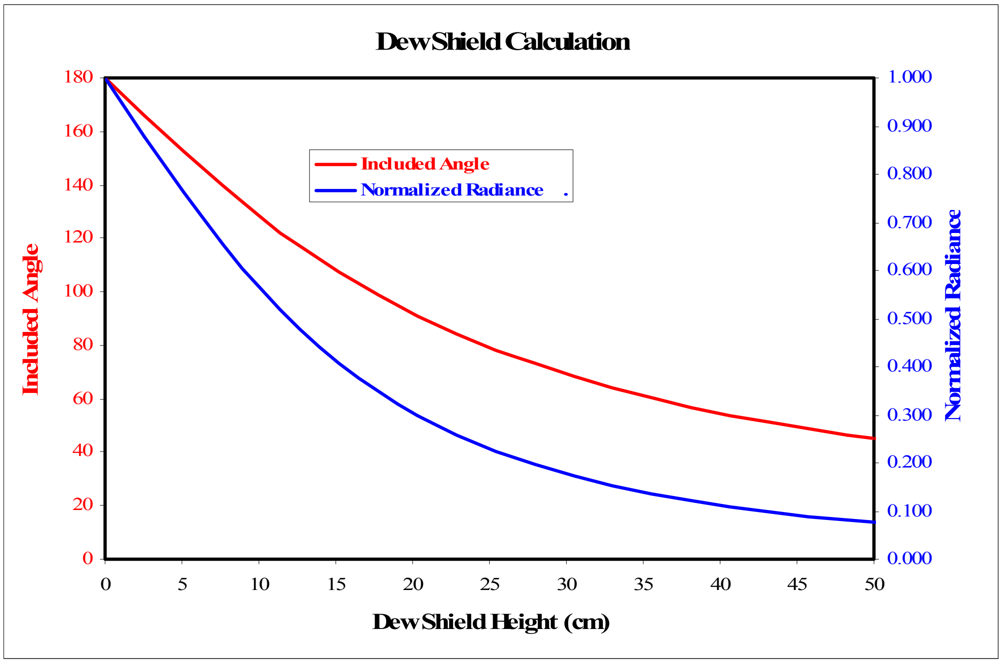

Fig. 8. Dew shield included angle and normalized radiance at the corrector plate vs. height in cm.

10. CONCLUSION

The Transient Optical Sky Survey system was developed to provide a low cost, automated solution to conducting an extensive search for transients. A large number of such systems could result in a very substantial quantity of transients reported in a timely manner. Accurate calibration of a commercially available digital camera, coupled with the long exposure times possible, greatly extends the magnitude range possible.

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