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Long-Term Variation of the Shutter Delay Time of Y4KCam of the CTIO 1.0 m Telescope[†]

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Abstract: We investigate the long-term spatial drift of the center and the temporal variation of the shutter delay time map of Y4KCam mounted on the CTIO 1.0 m telescope. We have collected shutter delay time maps over eight years as a part of our long-term survey program. We find that the center of the shutter delay time map can drift up to 450 μm, equivalent to $\approx$ 30 pixels, on the CCD. This effect can result in a small amount of error in integration time without the proper shutter delay time correction, but it does not appear to cause any significant problems in photometric measurements. We obtain a mean shutter delay time of 69.1 ± 0.8 ms and find no temporal variation of the shutter delay time of Y4KCam over eight years, indicative of the mechanical stability of the shutter. We suggest that using a master shutter delay time correction frame would be sufficient to achieve high precision photometry, which does not exceed photometric errors $\approx$ 1.7 mmag across the CCD frame for exposure times longer than 1 s.

Key words: telescopes — instrumentation: shutter

1. Introduction

Charge coupled devices (CCDs) have played a critical role in the field of astrophysical research over almost three decades. The important features involved in CCD astronomy are low-noise readout properties and high quantum efficiency (e.g., see Howell 2006). Furthermore, the small field of view of the old-fashioned CCD cameras is no longer a drawback thanks to the emergence of the modern large-format CCDs or mosaic CCD cameras.

The accuracy of photometric measurements using CCDs depends on several factors. Putting aside the errors introduced during the photometric measurements and transformations into the standard photometric systems, achieving an accuracy of the milli magnitude level, which is often claimed by observers, is a demanding task.

The most important procedure in astronomical image processes involves obtaining a correct flat field (e.g., Tyson & Seitzer 1988). Although the method to obtain the correct flat is still under debate, an ideal flat field should remove the pixel-to-pixel variations of the detector, the large-scale gradient of the optics and the color effect in the illuminating light (e.g., see Sterken 1995; Marshall & DePoy 2013). Since the presence of the scattered light can produce the large scale gradient on the CCD frame, the scattered light should also be well controlled (Grundahl & Sorensen 1996).

Any mechanical shutter used in modern CCD cameras has finite opening and closing times. Unlike the sliding door-type shutter, the shutter delay time of an iris-type shutter across the CCD frame is not uniform and imprints a complex shutter delay time pattern on the CCD frames, causing a significant effect in exposures with short integration times.

The first author of this paper has been performing a long-term extended Strömgren photometric system (Strömgren *by* plus the *Ca* filter) survey program of Galactic globular clusters and the Baade's Window using the CTIO 1.0 m telescope (Lee et al. 2009a,b; Lee 2015). The trouble with the extended Strömgren photometry is that the most of photometric standards by Twarog & Anthony-Twarog (1995) and Anthony-Twarog & Twarog (1998) are too bright even for the CTIO 1.0 m telescope. Although defocusing is frequently used to observe isolated bright stars in the field, such as photometric standards, the most of the standard stars are still too bright to be observed with an integration time longer than $\approx$ 10 s. It is known that defocused observing is not in general recommended since it introduces a systematic error at some level between the out-of-focus standard stars and the in-focus program star frames (Sterken 1995).

Without any viable options, science frames with a short integration time ($\lesssim$ 10 s) are often necessary to secure wide ranges in colors of photometric standards. Therefore, the shutter delay time correction should be well understood to achieve high precision photometry for short exposure frames.

In this short paper, we investigate the long-term spatial drift of the center of the shutter delay time map

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[†] Based on observations made with the Cerro Tololo Inter-American Observatory (CTIO) 1.0 m telescope, which is operated by the SMARTS consortium.

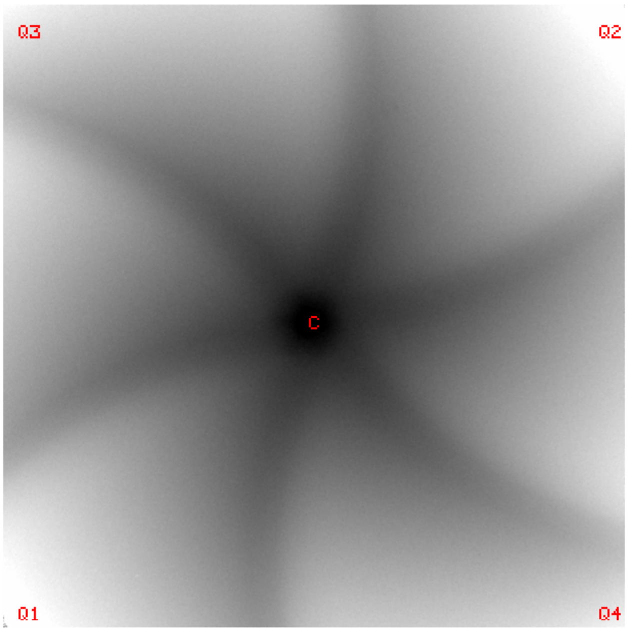

Figure 1. The shutter delay time map of Y4KCam for the May 2014 run. We measure the counts in the center (denoted by C) and four outskirt regions (denoted by Q1 – Q4) to derive the mean shutter delay time. Note that the mean shutter delay times for the Q1 and Q2 sections are about 9 ms longer than those of the Q3 and Q4 sections.

on the CCD frame and the temporal variation of the shutter delay time of Y4KCam mounted on the CTIO 1.0 m telescope, in order to help design the optimal observing strategies with the CTIO 1.0 m telescope and similar instrument setups, and to understand the propagation of errors due to the variation of the shutter delay time across the CCD frame. As mentioned above, it should be emphasized again that the accuracy of the final photometric products depends on many aspects, such as obtaining correct flat fields for each passband and correct transformations into the standard photometric system, and these are beyond the scope of our current work.

2. THE PRONTOR MAGNETIC E/100 SHUTTER

The CTIO 1.0-m telescope was equipped with a STA 4k×4k CCD camera (Y4KCam), providing a plate scale of 0.289 arcsec pixel^{-1} and a field of view of about 20×20 arcmin. The shutter mounted inside the Y4KCam filter wheel is a Prontor Magnetic E/100 shutter. Basic specifications of the shutter provided by the manufacturer are as follows:

1. 100 mm diameter (round aperture) with a 6-blade iris-type;
2. opening time: 22-33 ms;
3. closing time: 22-34 ms; and
4. minimum time between exposures: 1 s.

The shortest exposure time using Prontor's metric is about 60 ms, which was measured as the FWHM of the profile for snap open-and-close by hitting the shutter electronics with the minimum 50 ms control pulse (24 VDC). For Y4KCam, however, the shortest exposure time is 0.3 s (300 ms), which is set by the shortest shutter pulse this particular camera controller electronics can send.

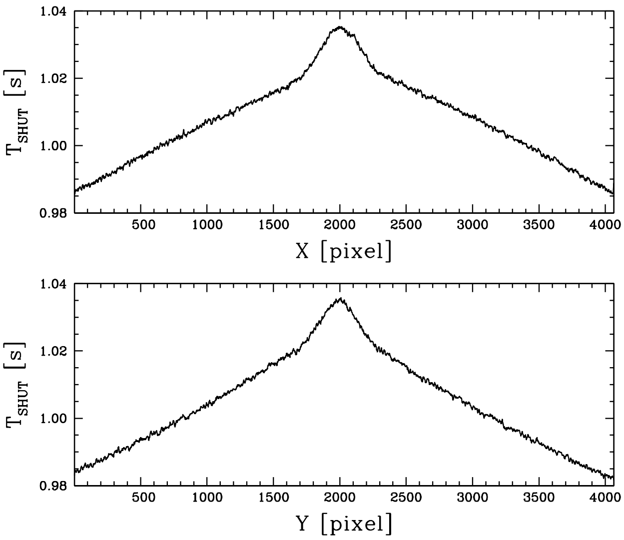

Figure 2. The shutter delay time, T_{SHUT}, for the X and Y axes passing through the center of the central ellipsoid of the shutter delay pattern.

The lag between the time reported in the FITS headers as "start of exposure" and the actual time the shutter is fully open is not known precisely. Unfortunately, there is no means to measure this independently and any event the CCD controller is not configured for high-precision timing (Pogge & Subasavage 2010).

3. DATA AND REDUCTIONS

We have collected the shutter delay time correction frames, series of 30 × 1 s and 1 × 30 s white spot images using the FOCUS mode exposure without a pixel shift. For most cases, we intended to obtain the white spot images during the cloudy nights in order to prevent the scattered sunlight coming through the dome.

As described by Lee et al. (2014) and Lee (2015) in detail, the raw data were processed using the standard IRAF.[1] The raw image frames were trimmed and bias-corrected.

By comparing the 30 × 1 and the 1 × 30 s white spot images, we derived the shutter delay time map across the CCD frame. In Figure 1, we show the shutter delay time map for the May 2014 run as an example and we show the shutter delay time against the X and Y axes passing through the center of the central ellipsoid of the shutter delay pattern in Figure 2. Being an iris-type shutter with six blades, the shutter delay time map of Y4KCam is not uniform across the CCD

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[1] IRAF (Image Reduction and Analysis Facility) is distributed by the NOAO, which are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation of the U.S.A.

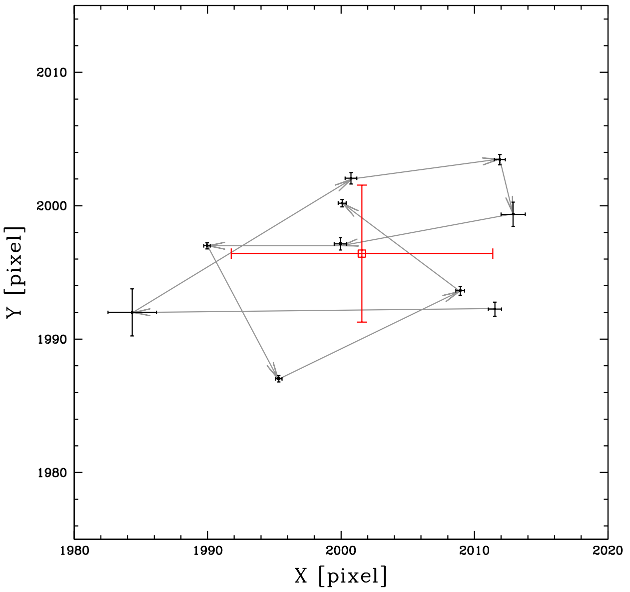

Figure 3. The distribution of the centers of the shutter delay time map. The grey arrows show the time sequence. The mean values of the center are X = 2001.6 ± 9.8, Y = 1996.4 ± 5.1 pixels and they are denoted by a red symbol.

frame and shows a starfish-like complex pattern. As a consequence, a simple analytic correction term can not be applied and a more robust pixel to pixel correction method should be performed to achieve the high precision photometry with exposure times of less than $\lesssim$10 s.

4. Results

4.1. The Drift of Center of the Shutter Delay Time Map

We derived the center of the shutter delay time map on the CCD frame using the ellipse fitting method. As shown in Figure 2, the central part of this map appears to be a well-behaved ellipsoid and the ellipse fitting method can be used to determine the center of the shutter delay time map. For this purpose, we used the ELLIPSE task in the STSDAS.ANLYSIS.ISOPHOTE package. We visually inspected the positions of the center on the individual frames returned from the ELLIPSE task.

In Table 1, we show our results for the center of the central ellipsoid of the shutter delay time map in the units of pixel in both axes. Note that one pixel on the CCD frame corresponds to 15 μm (Pogge & Subasavage 2010). The mean values of the center from ten data points are 2001.6 ± 9.8 and 1996.4 ± 5.1 pixels on the X and the Y axes, respectively.

We show the distribution of the centers in Figure 3. In this figure, we also show with grey arrows the time sequence of the drift of the center in the shutter delay time map. As can be seen, the drift in the position of the center of the shutter delay time map appears to be much larger than the ellipse fitting errors reported by the ELLIPSE task, with a typical measurement error of less than one pixel in both axes as shown in Table 1. As mentioned above, we visually inspected the center of the map returned from the ELLIPSE task and the drift of the center of the map can not be attributed to the ill-measurements by the ELLIPSE task. The largest difference in the positions of the center among data points is 29.8 pixels (between the December 2009 run and the August 2011 run), equivalent to 447 μm on the CCD. Although small, it is believed that the spatial drift of the center of the shutter delay time map is real.

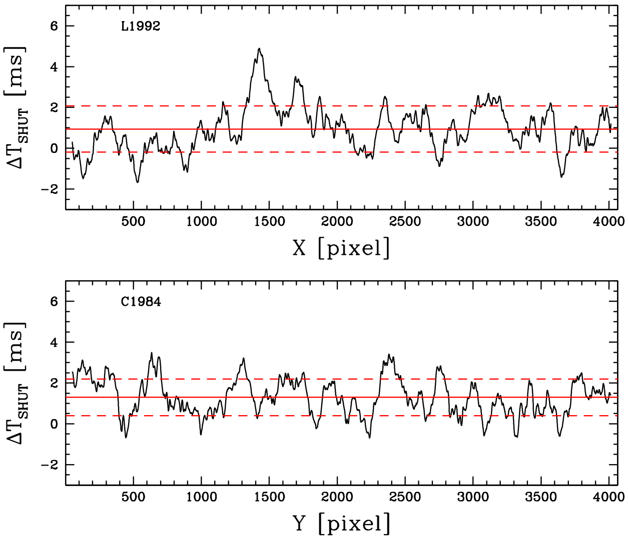

Figure 4. The difference between the shutter delay time map of the December 2009 run and that of the August 2011 run. The red solid lines are for the mean differences and the red dashed lines are for the standard deviation of the difference. The mean values are 0.9 ± 2.9 ms and 1.3 ± 2.9 ms for the line 1992 and the column 1984, respectively.

To understand the effect of the drift of the center of the map on photometric measurements, we compare the shutter delay time correction frame of the December 2009 run and that of the August 2011 run. In Figure 4, we show the differences in the shutter delay time along the X and the Y axes, passing through the center of the map of the December 2009 run. The mean differences in the shutter delay time between the two runs are 0.9 ± 1.1 ms and 1.3 ± 0.9 ms for the line 1992 and the column 1984, respectively (see also Figure 5). This additional error due to the drift of the center of the map is not expected to cause any serious problems in the photometric measurements. For example, this can result in the uncertainty in the photometric measurement of less than 1.5 mmag for the exposure time of 1 s and it is considered to be negligible.

4.2. Temporal Variation of the Shutter Delay Time

We measured the shutter delay time by comparing the the mean count values at the center and the four outskirt regions of individual CCD frames as shown in Figure 1. For our calculations, we used the mean count values for squares with a length 50 pixels. The four out-

Table 1
The positions of the center of the shutter and the shutter delay time.

Run	Center [pixel]		T_{SHUT} [ms]		HJD
(yy/mm)	X	Y	(Q1 – Q4)	(Q1 & Q2 only)	(day)
07/02	2011.53 ± 0.50	1992.25 ± 0.53	65.4 ± 5.1	69.8 ± 0.8	2454142.30
09/12	1984.35 ± 1.81	1992.01 ± 1.76	65.4 ± 4.6	69.3 ± 1.2	2455175.26
11/03	2000.75 ± 0.44	2002.06 ± 0.43	63.8 ± 4.8	67.9 ± 0.9	2455651.34
11/08	2011.90 ± 0.41	2003.46 ± 0.39	65.7 ± 4.9	69.9 ± 0.7	2455799.73
12/02	2012.90 ± 0.90	1999.36 ± 0.91	66.3 ± 4.9	70.5 ± 0.5	2455975.49
12/10	1999.96 ± 0.47	1997.14 ± 0.46	64.1 ± 4.8	68.2 ± 0.8	2456210.31
13/04	1989.96 ± 0.24	1997.00 ± 0.23	64.5 ± 4.7	68.6 ± 0.9	2456388.29
13/07	1995.34 ± 0.24	1987.03 ± 0.24	64.3 ± 4.7	68.4 ± 1.0	2456499.54
14/05	2008.94 ± 0.33	1993.63 ± 0.33	65.0 ± 5.0	69.2 ± 0.5	2456800.65
15/10	2000.08 ± 0.30	2000.20 ± 0.28	64.6 ± 4.8	68.7 ± 0.7	2457304.51
Mean	2001.57 ± 9.80	1996.41 ± 5.14	64.9 ± 0.8	69.1 ± 0.8	

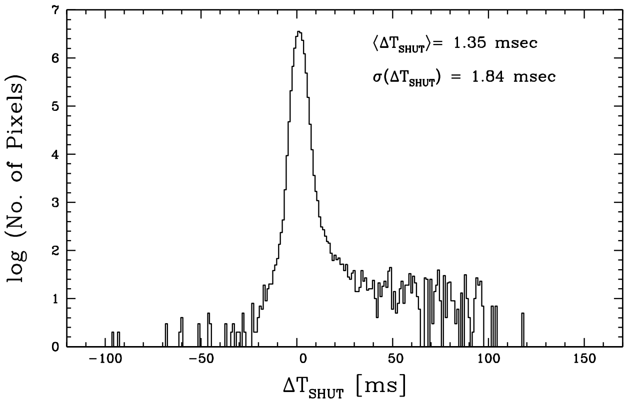

Figure 5. Histogram of differences in the shutter delay time in each CCD pixel between the December 2009 run and the August 2011 run. The mean values is 1.4 ± 2.9 ms and the peak value is 1.0 ms.

skirt regions were chosen to have offset values of ±1900 pixels from the centers of the shutter delay time map in both axes. Note that the mean delay times in Q3 and Q4 sections are about 9 ms shorter than those in Q1 and Q2 sections. Therefore, we rely on the difference in mean count values between the center and the mean of Q1 and Q2 for our definition of the shutter delay time in our study.

We obtain the mean value of the shutter delay time of 64.9 ± 0.8 ms from all four quadrants and 69.1 ± 0.8 ms from Q1 and Q2 sections. We show our results in Table 1 and Figure 6. It is thought that our results are consistent with the slowest end of the shutter delay time reported by the manufacturer of the shutter, ≈ 67 ms, as described in Section 2. Figure 6 clearly shows that there are no temporal variations of the shutter delay time of the Y4KCam over eight years. The absence of the temporal variation indicates that the performance of the Prontor Magnetic E/100 Shutter has been very stable.

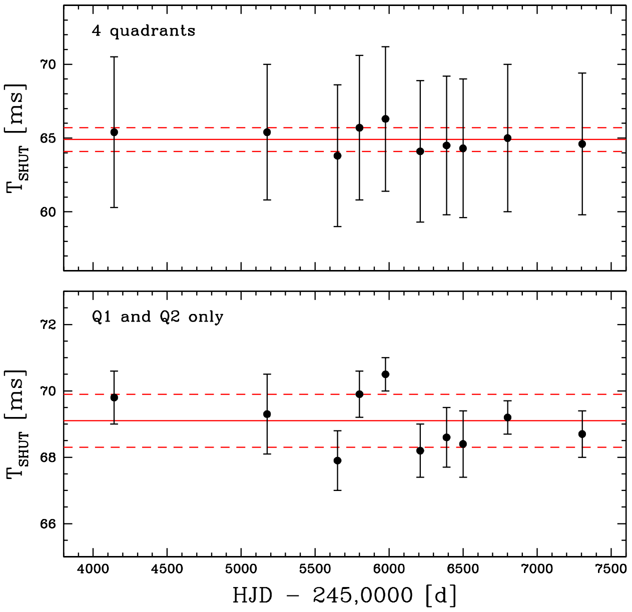

Figure 6. The shutter delay time against the HJD based on 4 quadrants (upper) and the Q1 and Q2 sections (bottom). The mean values are 64.9 ± 0.8 ms for 4 quadrants and 69.1 ± 0.8 ms for Q1 and Q2 sections. Note the absence of the temporal variation of the shutter delay time.

Based on the results of our investigation, it is thought that using a master shutter delay time correction frame is sufficient to achieve high precision photometry. The combined effects from the spatial drift of the center and the temporal variation of the shutter delay time results in an uncertainty in the photometric measurement of less than 1.7 mmag for the exposure time of 1 s. Again, this error is considered to be negligible.

5. SUMMARY

We have systematically investigated the long-term spatial drift of the center and the temporal variation of the shutter delay time map of Y4KCam mounted on the CTIO 1.0 m telescope, based on our long-term survey program. We found that the center of the shutter delay time map can drift up to 450 μm, equivalent to $\approx$ 30 pixels, on the CCD frame. However, this effect does not appear to cause any significant problems in photometric measurements.

By comparing the the mean count values at the center and the outskirt regions of individual CCD frames, we derived the mean value of the shutter delay time of 69.1 $\pm$ 0.8 ms, consistent with that reported by the manufacturer of the shutter. We found no temporal variation of the shutter delay time of Y4KCam for over eight years, indicating that the performance of the shutter has been very stable.

We suggest that using a master shutter delay time correction frame would be sufficient to achieve high precision photometry and this remedy does not add up errors more than $\approx$ 1.7 ms across the CCD frame. Also importantly, since the error related with the shutter time delay will decrease as the the integration time increases, the shutter delay time is no longer a serious problem once the proper shutter delay time correction has been taken care of.

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