SHOC timing accuracy

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Abstract

The relative and absolute timing accuracy for the Sutherland High Speed Cameras (SHOC) was not tested during its commissioning phase, primarily because it required additional testing aids that were not yet available at that stage. In June 2013 a Light Pulse Generator (LPG) was fitted on the 1.9m telescope in Sutherland, that allows accurately timed second pulses to be inserted into an observation to allow testing the timing accuracy of the instruments. This report will elaborate on the results of the tests that have been performed to date.

1 Introduction

SHOC is capable of $\sim$ 10 ms (0.01 s) exposures when optimally sub-framed at maximum binning. While tempting to assume that the absolute timing is that accurate, there are a number of complicating aspects to be aware of.

1.1 Triggering modes

1.1.1 Internal

The SHOC control computer's system clock is used to trigger all frames.

- the computer clock drifts by $\sim$1 s per day and requires a sync to the GPS to be $\sim$1 s accurate
- the UT at the End of the first frame is written in the FRAME header of the fits cube, but commented incorrectly as 'Start of frame exposure'
- the number of decimals displayed in the FRAME header creates the impression that the item may be sub-second accurate, but it is **not**

1.1.2 External

All frames are triggered by the GPS and the time is not recorded in the fits headers by the Andor software. The user is responsible for correcting the FRAME and KCT/ACT/EXPOSURE headers with the exact UT start time and trigger interval.

If the SHOC data reduction pipeline is used, this process is facilitated and headers are updated with the values the user supplies in response to the on-screen prompts. According to the Andor specifications, the absolute timing of all GPS triggered frames have $\sim$10 microsecond accuracy. This is the appropriate mode to use if sub-second accuracy is required.

1.1.3 External Start

The first frame is triggered by the GPS, but subsequent frames are triggered by the Internal mode.

1.2 Exposure times

The kinetic cycle time (headers: KCT and ACT) reflects the chosen exposure time (EXPOSURE) plus the dead-time (0.00676 s). Both these items are limited to 5 decimals.

1.3 Time-stamps

SHOC creates data cubes with a single fits header. Time-stamps for each individual frame have to be calculated from the FRAME and KCT headers. The inherent uncertainty in both those values are therefore expected to determine the relative and absolute timing accuracy.

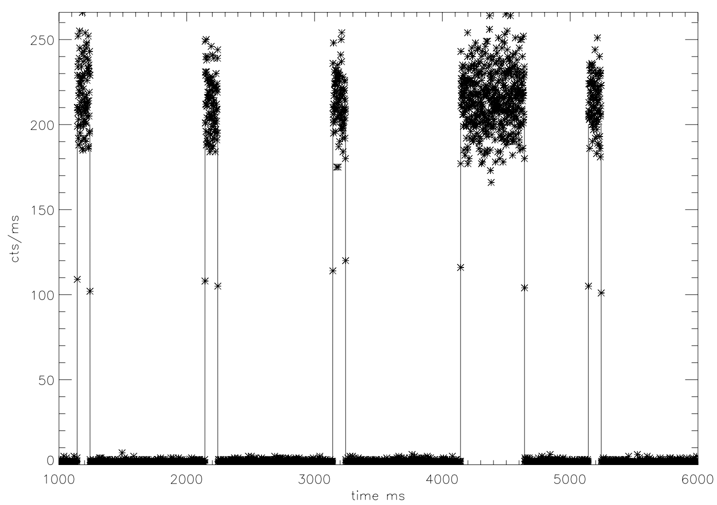
2 Light Pulse Generator (LPG)

The Electronics department (Geoff Evans) designed and built a device by which either millisecond or second and minute pulses received from the SAAO Time Service are used to flash a red LED that is positioned so that instruments mounted on the telescope may detect it.

Pulse-widths are 100 ms for second pulses and 500 ms for minute pulses. It was installed on the 1.9m in Sutherland during June 2013.

2.1 Testing the LPG

The accuracy of the LPG was tested by using HIPPO, which is fitted with photomultiplier tubes. Stephen Potter observed a sequence of light pulses generated by the LPG and binned the data to 1 ms integrations.



The plot shows 5 seconds of the data taken on 11 June 2013, which included a minute pulse. Each data point (star) is a 1 ms integration. The recorded flux levels line up with the expected edges (solid lines) of the LED light pulses.

2.2 Known discrepancies

Geoff Evans explained to me, Stephen Potter and Amanda Gulbis that the SAAO Time Service (STS) has a known offset with respect to the SALT GPS that ranges between ±100 ms and 0 ms. He has detailed logged datasets available for the size of that offset at any given time. However, such an offset would not present itself in the test of the LPG with HIPPO because they both get their time signals from the STS.

3 Initial SHOC timing tests

We had no reason to believe that timing would not work as described in the manual, so standard tests were done to verify if the timing works as expected. Several data cubes were taken on 10 & 11 July 2013 using the fastest possible integration times on SHOCnAWE, while the LPG generated second and minute pulses. See Table 1 for a summary of minute pulse arrival times detected.

Table 1: Detected minute pulse arrival times: The minimum exposure time is 0.00955 s (including the 0.00676 s dead-time) for maximum binning (42x42) and minimized sub-frame at the bottom of the CCD. Sub-frames on the CCD were located in the center at the bottom on 10 July 2013 and in the right bottom corner on 11 July 2013. POP intervals were 10 ms (0.01000 s) for External triggering.

Start UT hh:mm:ss	Cube	Mode	Minute Pulses UT[s]	
10-07-2013				
05:42:00	403	internal	13381.51560	
05:44:00	404	internal	13501.37235	
05:45:45	405	internal	13561.44915	13621.50910
05:47:34	406	internal	13681.51760	13741.57755
11-07-2013				
01:56:30	601	external start	7019.98700	7080.10425
01:58:45	602	external start	7139.96485	7200.08210
02:01:30	603	external start	7319.98700	7380.10425
02:05:00	604	external start	7560.05040	
02:07:20	605	internal	7680.49880	
02:09:10	606	internal	7801.30665	
02:11:11	607	internal	7921.33255	
02:35:00	608	external	9359.93000	
02:40:00	610	external	9659.93000	
02:45:00	611	external	9959.93000	
02:48:30	612	external	10139.93000	10199.93000

3.1 External

Minute pulses are consistently detected ∼70 ms too early. This is consistent with fact that the SALT GPS vs SAAO Time Service has a known offset of up to ∼100 ms. Unfortunately Geoff could not provide the exact offset of the SAAO Time Service to SALT GPS because of a power failure which affected the time service, but it was -35.7 ms on 08-07-2013 and -82.2 ms on 18-07-2013. The tests need to be repeated.

At least the minute pulses arrive exactly 60 seconds apart, indicating the relative timing is accurate to within the sampling rate (10 ms). But I need to confirm on more cubes, covering several minute pulses each.

3.2 Internal

Two cubes were taken with exposure time 10 s to verify that the FRAME header is in fact more consistent with the 'End of frame' rather than the 'Start of frame' of the first frame in the data cube.

Inaccuracy of minute pulse detections is consistent with the fact that FRAME header is not sub-second accurate. This adverse effect on the accuracy of the absolute timing is a known issue discussed in the SHOC manual, wherein users are advised to use the 'External' mode if they are concerned with sub-second or second(s) accurate absolute timing.

But the differences between minute pulse detections are >60 seconds, indicating inaccurate relative timing. Investigation revealed the error per frame to be ∼0.00001-0.00002 s, consistent with an uncertainty in the 5th decimal. The EXPOSURE, KCT & ACT headers and the input box for the 'exposure time' on the Andor Solis camera control interface, are all limited to 5 decimals. Furthermore, the 0.00676 s dead-time should also be more accurately known than 5 decimals, but it is also not currently available in FITS headers. After 100000 frames this error can accumulate to ∼2 s.

Further investigation will determine if the relative timing uncertainty originates from both the minimum exposure & dead-time and whether eliminating the uncertainty in the chosen exposure time gives consistent answers for an adjustment required to dead-time to improve accuracy. Either way, the fact remains that users should NOT rely on 'internal' triggering if they require (sub)second(s) accuracy.

3.3 External Start

Differences between minute pulse detections are >60 seconds and the arrival of minute pulses are not early by the same offset as observed for the 'external' mode. But since the relative timing for the 'external start' mode is determined by internal triggering, it should suffer the same inaccurate relative timing as identified for the 'internal' mode. That would also affect the absolute timing after a number of frames, explaining the inconsistent results for minute pulse arrivals between the 'external start' and 'external' modes.

3.4 Relative timing

Comparing the differences between minute pulse detections give us an indicator of relative timing issues. For that purpose the differences between pulse arrival times in 'external start' and 'internal' triggering modes may be expected to be the same, as they are both internally triggered for frames subsequent to the initial frame.

However, they are 60.05995 s (6289 frames) on 10-07-2013 (internal) and 60.11725 s (6295 frames) on 11-07-2013 (external start). Though the minimum exposure time doesn't appear to have changed for the different positions of the sub-frame between those dates, it was clearly different. This behavior is consistent with an uncertainty in the 5th decimal (per frame) accumulating over these frames.

4 More detailed SHOC timing tests

During an engineering week in January 2014, more detailed tests were conducted with SHOCnDISBELIEF using the LPG that has since been permanently mounted in the 1.9m. This time I ensured that Geoff has the offset between SAAO Time Service to SALT GPS before continuing with tests on 11 January 2014. He confirmed the offset was 0.00 ms on 10-01-2014 and the SAAO Time service has locked on to SALT GPS. See Table 2 for a summary of minute pulse arrival times detected.

Table 2: Detected minute pulse arrival times: The minimum exposure time is 0.00996 s (including the 0.00676 s dead-time) for 32x32 bins and minimized sub-frame at the right bottom corner of the CCD. POP intervals were 10 ms (0.01000 s) for External triggering.

Start UT hh:mm:ss	Cube	Mode	Minute Pulses UT[s]	
11-01-2014			First	Last
19:11:40	002	internal	69121.27260	70082.14368
19:45:00	003	external start	71160.11856	72061.84716
20:04:50	005	external start	72300.01976	73261.86692
20:27:30	006	external	73740.00000	74640.00000
20:49:10	007	external	75000.00000	75240.00000
20:55:40	008	external	75360.00000	75600.00000
21:02:20	009	external	75780.00000	76020.00000
21:10:00	010	external	76260.00000	76440.00000
21:20:00	011	external	76860.00000	77040.00000
23:10:00	014	external	83460.00000	83640.00000

4.1 External

Minute pulses are consistently detected on time and consecutive minute pulses arrive exactly 60 seconds apart, indicating that the absolute and relative timing are accurate to within the sampling rate of 10 ms. All cubes covered several minute pulses. This is undeniably the triggering mode to use if you require (sub)second(s) accuracy!

4.2 Internal & External Start

Results are consistent with the initial timing tests during July 2013. Fixing the exposure to an input value that eliminates uncertainty in the 5th decimal, did not lead to perfect relative timing. The relative timing uncertainty is therefore also related to the dead-time that is only known to 5 decimals.

Cubes taken in 'External Start' triggering mode all consistently show a relative timing error of 0.000019 s per frame, even at the different binning options of 42x42 (July 2013) and 32x32 (January 2014). But the relative timing error in the 'Internal' mode differs from that in the the 'External Start' mode.

While one may argue it warrants even further investigation, the fact remains that users should (and have always been advised to) use the 'External' triggering mode if they require (sub)second(s) accuracy.

5 Conclusion

The timing tests confirmed that the absolute and relative timing, when running SHOC in 'External' trigger mode, is accurate to within the minimum integration time of 10 ms when GPS triggering every frame. However, there are accumulating relative timing uncertainties in the 'Internal' triggered mode, which also compromises the accuracy of the 'External Start' mode and obviously also the absolute timing for both those modes.

Basically the 'Internal' triggering has relative timing uncertainty of $\sim$0.00001-0.00002 s per frame, consistent with the EXPOSURE and KCT/ACT (includes dead-time) fits headers only having 5 decimals.

For the 'External Start' mode, only the first time stamp has very high absolute accuracy but the subsequent frames are internally triggered and suffer the relative timing uncertainty associated with the 'Internal' triggering mode.

6 The new GPS web-interface

On 21 May 2014, SHOCnDISBELIEF was used in Cape Town to test the timing accuracy of the newly developed GPS web-interface with a new LPG (destined for the 1.0m). The LPG is tied into the Cape Town Time Service (which differs from the Sutherland Time Service), which is also offset to the GPS (albeit different). Offsets are not available on datasets, but is shown only on a screen close to the LPG controller.

Table 3: Detected minute pulse arrival times: Various POP repeat intervals from 5-40 ms (0.00500-0.04000 s) were used for 42x42 binned and minimized sub-frames at the right bottom corner of the SHOC2 CCD and a minimized sub-frame in the center was used for the POLA CCD.

Start UT hh:mm:ss	Cube	Repeat Interval	Minute Pulses UT[s]	
POLA (128x128)			First	Last
12:40:00	011	10 ms	45600.17000	45960.17000
12:46:30	012	10 ms	46020.17000	46320.17000
12:53:10	013	15 ms	46440.17500	46920.17500
13:03:30	014	5 ms	47040.17500	47460.17500
SHOC2 (1024x1024)			First	Last
13:30:00	101	10 ms	48600.17000	49020.17000
13:38:00	102	10 ms	49080.17000	49500.17000
13:55:45	104	40 ms	50160.16000	50340.16000
14:02:30	106	40 ms	50580.16000	50820.16000

Running cubes at 10 ms GPS triggering intervals gave us a 0.17 s offset in arrival of minute pulses using SHOC2. But running cubes at 5 ms GPS triggering intervals gave us a 0.175 s offset in arrival of minute pulses using the small Andor camera (probably POLA).

The known delay in the Time Service was ∼0.177 s on 22 May 2014, when we learned that the offsets were only available on the screen. The drift is normally ∼1 ms/day toward GPS lock. So it is reasonable to assume that it was ∼0.178 s on 21 May 2014. Independently triggered minute pulses are therefore detected on exactly the exposures where they are expected to be detected, all the way down to 5 ms sampling.

7 Testing for offsets

As previously described in my SALT SLOTMODE timing report [1], we can verify timing accuracy < the sampling rate (or exposure), as described in the section 'Confirming accuracy below $\frac{1}{2}\times$exposure'.

Pulse sequences can be used to determine absolute timing accuracy to lower than $\frac{1}{2}\times$exposure, by comparing all the predicted pulse times to observed pulse times. The UTC times of the pulses were predicted by adding integer increments of the pulse period to their accurately (within ms) known start times, assuming no lags or delays.

If pulse-widths are << sampling rate (exposure times), each pulse should be uniquely detected on a specific frame. Lightcurves may be extracted from the data, by using average counts over the entire frame, in which pulses can be detected as significant flux increases.

For each predicted pulse, one can determine whether it should have been detectable and also if it was detected. The former was achieved by testing if a predicted pulse occurred within an exposure from any of the UTC-OBS times from the FITS headers of the data. Detectable pulses were considered detected if they exceeded a limiting flux level.

Offsets to the observed timing of $-n\times$exposure to $+n\times$exposure were applied in increments of 1 ms. The resulting ratio of $\frac{(detected)}{(detectable)}$ pulses should be 100% when the correct offset is applied to the observed absolute timing. The value n is increased until all detectable pulses are considered detected, allowing us to determine an offset if there is one.

If the pulse-width is > sampling rate, we can detect the leading edge of a pulse (spreading over several frames), by only considering the pulse detected if the flux on the preceding frame was < limiting flux level (undetected). The analysis also immediately points out relative timing errors, since there would be no offset that could allow all detectable pulses to be detected. PYTHON scripts to facilitate this analysis has now been automated, requiring very little user interaction. By choosing a sampling rate that does not fit into a second (1 s) an integer multiple times, the offset can be determined uniquely to within 1 ms.

Results from this analysis run on all data obtained for timing tests, confirmed the offsets that were found by investigating the minute pulse arrival times.

[1] http://wiki.salt.ac.za/index.php/Timing_issues_with_Slotmode