A NEW TIME ASSESSMENT METHOD FOR TELESCOPE CCD CAMERAS

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ABSTRACT

Most cameras provide timestamp to captured images, but not any accuracy information is provided about it, however, in some applications the accuracy is required to be known and verified. We present an end-to-end method to assess the time accuracy in any CCD cameras equipped with timestamp and settable exposure time.

The proposed method allows to evaluate the delay between the image timestamp recorded by the CCD camera and the shutter opening time. The method is standalone and offers a good temporal resolution, in according to the dynamic range and the signal to noise ratio of the CCD, moreover, it uses inexpensive, off-the-shelf components, requiring minimal assembly and no connections with the camera under test.

The HW is based on a GPS (Global Positioning System) receiver equipped with a PPS (Pulse Per Second) output, an Arduino board and a Light Emitting Diode (LED). In particular, by switching on and off the LED and by measuring the light with a CCD camera, is it possible to evaluate the discrepancy among the timestamp and the real acquisition time.

We applied this method to measure the accuracy of the timestamps in the images collected by the SPADE (SPAce DEbris) optical telescope, assigned to Space Surveillance and Tracking (SST) projects. Our result shows a delay of 40 ms for this sensor. This value well agrees with the results obtained by different methods based on calibration with GNSS satellites, provided in the SST contexts.

1 INTRODUCTION

The growing number of objects orbiting around the Earth has focused the attention of many space agencies on the observations and characterization of space debris and related issues. To this purpose, both optical and radar telescopes are used to collect data in different orbital regions (LEO, MEO, HEO, GEO). Within the framework of the European Union Space Surveillance and Tracking (EU SST), the Italian Space Agency (ASI) supports observational activities with SPADE optical telescope, located at the Geodesy Space Center "Giuseppe Colombo" (CGS) of Matera (Italy).

The SPADE configuration consists of a modified Harmer-Wynne astrograph of 400 mm aperture, f/3.8 (Officina Stellare 400 RiFAst Astrograph), with a motorized 3 m diameter Dome, an equatorial mount (Paramount ME II) and a FLI PROLine 16803 CCD with 4096x4096 pixels. The system is controlled by the TheSkyX software and synchronized with the time from a Network Time Protocol (NTP) server.

One of the main tasks of the SPADE data-processing pipeline is to measure the coordinates of space debris, tagged with a particular epoch. Usually, these coordinates are evaluated by considering the stars in the background, while the epoch is provided by the timestamp of the image. In order to measure the space debris orbit, both timestamps and coordinates are taken from several observing sessions. In this context, the accuracy of the timestamp is crucial for a high-quality orbit determination. To this purpose, usually, the assessment process consists in comparing the timestamps and coordinates of an observed GNSS satellite, with the reference values provided by the IGS (International GNSS Service).

In following paragraphs, we present an alternative method to estimate the delay (*time-bias*) between the timestamp of the images and the real acquisition epoch.

2 CURRENT PRACTICES

In most optical telescope in use today, the accuracy of the acquisition is estimated from comparisons with satellite's very precise ephemerides. For this purpose, precise ephemerides from GPS, Global Navigation Satellite System (GLONASS), International Laser Ranging Service (ILRS) or Federal Aviation Administration (FAA) are selected and used as reference [1].

The sensor configuration procedure consists in progressive fine tune in order to reduce the residuals between the measurements and the reference. There are a lot of aspect that can affect the accuracy of the measurement, but with respect to the time, the characterization of the shooting time and exposure time, compared to the timestamp, becomes of crucial importance. The timestamp, in turn, must be connected to a very precise reference. Most cameras for telescope rely on either GPS based time sources for fidelity to the Coordinate Universal Time (UTC), or use Network Time Protocol (NTP) as method to synchronize the

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timeserver through a link to the internet. Considering the measurements and references, the sensor model configuration is detected through a run of the estimator (the filter and smoother in Orbital Determination Tool Kit ODTK) and solve for the time tag bias first and then for measurement bias [2].

The current practice on one hand returns the system configuration model, which include all errors that affect the measure (also atmospheric and relativistic effects), on the other, is impossible to separate each error and lastly the single time errors. In order to characterize the system in terms of errors from different contributions, without the interaction of atmosphere, relativistic effects and the image processing accuracy, another approach must be considered.

Another possible approach was to disassemble the system actual configuration and mount the CCD camera on a tripod, then use a short focus lens to image the full window as displayed on a computer's monitor [3]. This method is similar to the one presented, but it requires HW disassembly from its operational configuration.

3 INSTRUMENTAL ASSET

The method uses a simple and inexpensive device to measure the timestamp of any off-the-shelf camera.

The HW is based on a GPS receiver, an Arduino, a constant current generator and a LED. This last is switched-on and switched-off for 0.5 seconds alternatively. The constant current generator ensures a stable LED intensity. This device is posed in front of the SPADE telescope in order to acquire images with an exposure time of 0.5 seconds.

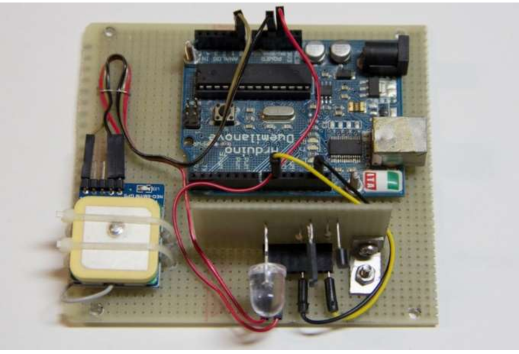

Figure 1. HW asset

Fig. 1 describes the device used for the test. Connections or synchronizations between the device and the camera under test are not necessary as well as the camera does not have to be disassembled from its original setup.

4 ANALYSIS

The Arduino synchronizes the LED lighting with the Pulse Per Second (PPS) of the GPS (with accuracy of about 100 nsec), in order that the LED is switched-on one time per second with a duty cycle of 50 %. This means that the LED is switched-on for 0.5 seconds from the start of the second, every second. It has been measured the Arduino processing time to lit the LED in order of about 10 µsec then it is negligible if compared to the ms of interest.

In SPADE system, TheSkyX software manages the CCD camera and applies the timestamp synchronized with the time of several NTP servers in less of 0.5 ms.

The CCD camera is set up to view the LED in the frame: in the SPADE system we directly pointed the telescope to the LED. In system with short focus distance this is readily done, but in system like telescopes or with high minimum focus distance will unavoidably lead to unfocused image. Unfocused images are as suitable as focused one for the analysis, it is enough that a part of the LED light is clearly visible, like in Fig. 2 where is possible to see the dark stripes of SPADE’s secondary mirror. The point of light is not circular in the bottom of the picture due to the presence of an obstacle immediately in front of the telescope.

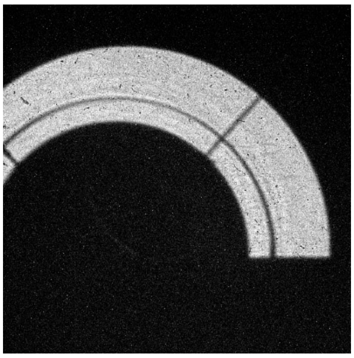

Figure 2. Unfocused LED image

While the LED is blinking the camera is taking a hundred photos to the LED without any synchronization. For a different overlap between the camera exposure time and the LED on phase, a possible result would be likely in Fig. 3.

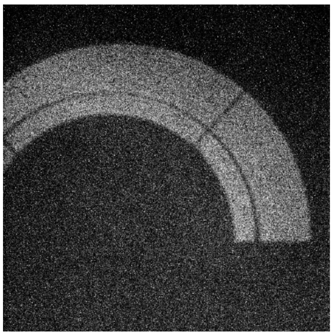

Figure 3. Darker image

In Fig. 2 and Fig. 3 is possible to note that only a part of total pixels in the image is illuminated by the LED light, depending by the distance between the camera and the LED, as well as by the focusing. Then, in order to obtain a realistic mean light intensity value for each image, is important to consider only those pixels which received the LED light. For this reason, we build a mask of pixels to identify and distinguish pixels with LED light from the background noise. The mask is shown in Fig. 4.

Figure 4. Mask image

Considering only the pixels in the mask, we obtained a mean light intensity value for each image where the bias subtraction was applied.

4.1 Analysis and results

The images acquired have been processed to evaluate the light intensity level (in ADU) versus the timestamp. In particular, the couples (timestamps; intensity values) have been sorted considering only the decimal representation of the timestamp, therefore the fraction of seconds, in ascending order. We plotted the measured light intensity versus the fraction of the time in Fig. 5. The accuracy of the timestamp is 1 ms.

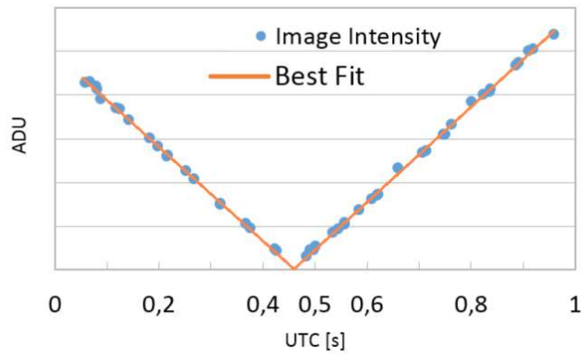

Figure 5. Light intensity plot figure. (ADU axis ranges from 0 to 60000)

We obtained a 'V' shape distribution, as expected. The maximum of intensity is situated near 0 sec when the integration time perfectly overlaps with LED-on phase. The minimum is near 0.5 sec, when the camera starts to expose at the time the LED goes off.

We have provided a linear regression analysis of the data with the least square method, minimizing the error on the time axis. The theoretical relationship between timestamp and light intensity (I) in ADU is given by Eq.1:

(1)

where I_{max} is the maximum light intensity achievable by the experimental setup, t is the time (expressed as the decimal part of 1 sec) of the image timestamp, t_b is the *time-bias* (delay between the timestamp and the real acquisition time). The free parameters are the maximum intensity (I_{max}) and t_b.

The value of the t_b is obtained by the difference between 0.5 sec and the time at the minimum value of the V-shape function. Our result shows a value of about t_b =40 ms.

We also estimated the t_b statistical error (jitter), by evaluating the Root-Mean-Square (RMS) as following (Eq. 2):

(2)

where t_i is the time of the timestamp, t_t is the expected theoretical time. In our case, we found a RMS value of 5 ms.

5 DISCUSSION

5.1 Literature comparison

We compared our results with independent literature values. In particular, the same CCD camera model was already characterized by German Aerospace Center (DLR) and University of Stuttgart [4] to evaluate the synchronization of the observing system for the surveillance of the Low Earth Orbit (LEO). In their study, the HW output trigger signal available on the camera has been compared with the PPS of a GPS receiver, leading to 40 ms of bias and 5 ms of jitter. These values well agree with our results. Note that the above method [4] requires physical connections between the instrumentation under test and is not applicable to cameras without a trigger.

We evaluate the impact of the time-bias in the case of observations of a GEO object. In particular, by considering a geostationary satellite moving with 15 arcsec per second, in order to obtain an uncertainty lower than 1 arcsec in its position, it is necessary to have an accuracy smaller than:

(3)

In the case of the SPADE telescope, the time delay of 40 ms is of the same order of the accuracy required to approach the telescope's pixel resolution (1.22 arcsec/pixel) and it need to be taken into account during the orbital determination. Note that when considering LEO satellites the required temporal accuracy is even lower. To this purpose, the SPADE data are analysed considering this time delay.

6 CONCLUSION

We presented an end-to-end method that allows to estimate the time delay introduced by the NTP server synchronization, the processing time and the camera management software that applies the timestamp.

The method can be applied to both focused and unfocused images, is very low cost, and requires minimal assembly and no connection with the camera under test. Moreover, the setup of the imaging system under test does not require changes to be adapted to the verification method.

We applied this method to the CCD camera of the SPADE optical telescope devoted to space debris observations, in the EU SST framework. We obtained a time delay of 40 ms and a RMS of 5 ms. These results well agree with literature values, obtained with different methods.

Note that to monitor the camera performance in time, the method need to be applied periodically.

7 SUPPLEMENTARY DATA

Source code for both Arduino and images processing is available upon request to the authors.

8 REFERENCES

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