USE OF A NIGHT-TRACKING CAMERA FOR REAL TIME CORRECTION OF THE POINTING OF THE SLR SYSTEM

E. Cordelli*, P. Schlatter, P. Lauber, T. Schildknecht

ABSTRACT

The continuous increase of the SLR targets requires a directly proportional optimization of the station performance in terms of target acquisition and tracking. If the station wants to maximize the number of observations and the number of observed objects, it has to minimize the time needed to acquire the target. Due to the small field of view of the laser system, the time needed to lock on a target depends on the accuracy of the predicted ephemeris of the target. This problem is even more evident when the telescope time is shared among different projects. The Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald owned by the Astronomical Institute of the University of Bern (AIUB) was developing a solution for the active tracking problem taking advantage of the experience acquired by multidisciplinary projects.

In this paper, we will show a way to shorten the time needed to lock a SLR target by using a high-resolution CMOS camera. In particular, we will show how this camera, whose main application is in the space debris domain, can be used as night-tracking camera for the real time correction of the pointing of the SLR system. After describing the steps needed for the hardware and software integration of the camera in the SLR system, we will present the different functionalities of the night-tracking camera, the procedure for the acquisition of the measurements, and the resulting improvement in the telescope performance.

1 INTRODUCTION

Currently there are about 90 satellites tracked regularly by Satellite Laser Ranging (SLR) stations of the International Laser Ranging Service (ILRS) community [1]. This amount of satellites, together with the use of the SLR telescopes for different projects, are already saturating the observations capacity of the telescopes.

Considering that the number of targets will increase rapidly in the future, several optimizations of the stations are required, among them one could try to shorten the satellite acquisition time by using a tracking camera. The employment of such of a camera will allow the assessment of the successful satellite acquisition, not only based on the laser returns but also, by visual inspection. It will allow the correction of the pointing direction of the telescope, shortening the satellite acquisition time, increasing the number of observations per normal point (NP) which finally will produce an increase of the pass observation rate.

In this paper, we will describe the integration of the night-tracking camera into the SLR system of the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald (SwissOGS), and we will show its performance.

2 HARDWARE INTEGRATION

The Zimmerwald Laser and Astrometry Telescope (ZIMLAT) is the telescope used for SLR observations at the SwissOGS. It is a 1-m aperture Ritchey-Chrétien with a Coudé path for laser observations and a Nasmyth platform with 4 focal stations which are used for astrometric observations. In order to not install any further hardware on top of the telescope we used as tracking

***Corresponding Author**
Cordelli, Emiliano. Email: emiliano.cordelli@aiub.unibe.ch

camera a Neo 5.5 sCMOS camera [2] mounted on an existing 8 m focal length station in the Nasmyth focus. Since (as can be seen later in Figure 4) the laser and the camera share the same telescope, a notch filter is installed in front of the camera to prevent laser light reaching the camera.

3 SOFTWARE INTEGRATION

After having integrated the camera hardware into the SLR system, it was also necessary to do the software integration. First, a software able to control the camera and calculate the pointing correction to be given to the telescope was implemented (see next Section 3.1); then, we needed to implement a communication server between the camera and the SLR observation software.

3.1 THE NIGHTCAM SOFTWARE

The tracking camera exploits sunlight reflected by the target, therefore we needed to implement a software that allows us to control the camera integration time to ensure the object visibility. The NightCam software whose functioning is briefly shown in Figure 1 and Figure 2 consists of two main components: the first allows the control of the camera settings like exposure time, binning, read out mode and speed, and shows the image on the display. The second is dedicated to the communication with the SLR observation system. It is possible to check the communication status with the telescope, to monitor the telescope parameters, send to the telescope the calculated pointing correction and resume the usual tracking optimization scheme. Finally, the NightCam software can be used for space debris applications. We introduced the possibility to store the acquired images which are including the telescope pointing position, and the accurate measurement epoch given by the SLR timing system. These data allow us to perform orbit and attitude determination studies of space debris.

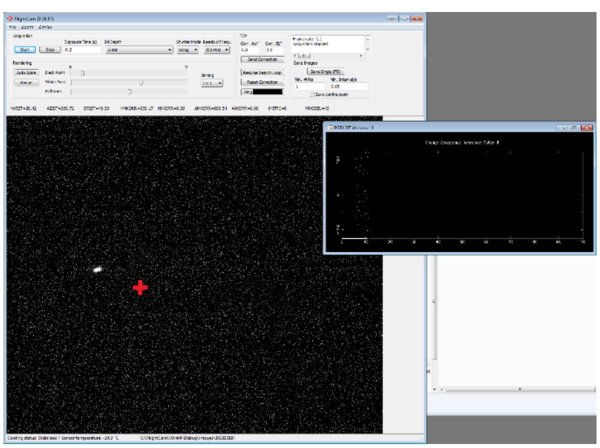

Figure 1 Screenshot of working tracking camera – unsuccessull tracking of target satellite

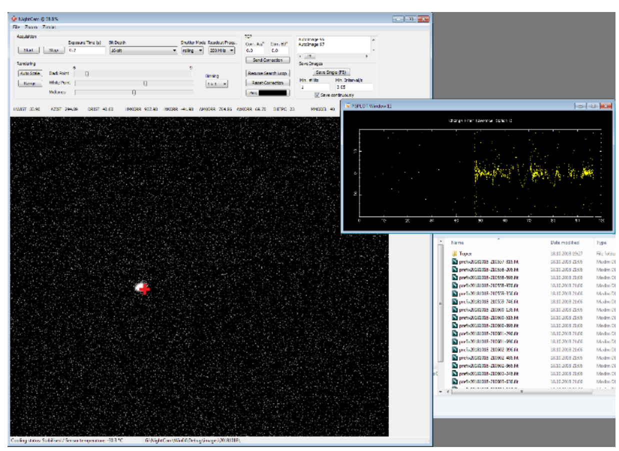

Figure 2 Screenshot of working tracking camera – successfull tracking of target satellite

3.2 THE POINTING MODEL

As can be seen in Figure 1 and Figure 2, the software is able to correct the error of the ephemeris allowing the successful tracking of the target. To be able to calculate this correction, it is necessary

to know where the pointing direction of the laser beam is located on the chip of the camera and how the chip axes are oriented w.r.t the azimuth and elevation direction.
The orientation of the chip axes was determined empirically acquiring and plate solving star fields for different azimuth and elevation positions with a fixed derotator position. We used 90° of interval for the different azimuth position and 25° for the elevation.
The determination of the laser beam position on the camera was also performed empirically. We stored the images acquired by the tracking camera during normal SLR observations only when we got echoes from the target satellite. In this way, we were able to find the position of the laser beam through the position of the object on the camera. This procedure was repeated exploiting different satellites in order to have a full coverage of satellite positions on the sky. The results of this procedure are reported in Figure 3. On the right plot, one can see the positions of the satellites in the sky; on the left, the corresponding satellites positions on the camera are shown. As one can see, almost all positions are within 6 arcsec rms from the average center position. The center of the laser position does not correspond with the center of the camera. There are two main reason for it: the complex structure of the telescope (see Figure 4), and the fact that the mount model for laser observation, optimized for the Coudé focus, is used while the camera is on a Nasmyth focus (see Figure 4).
Figure 5 shows the discrepancies of the object position w.r.t. the average center position as function of the pointing direction of the telescope. These differences are then used to model the changes of the position of the laser beam on the camera depending on the telescope pointing direction. A Nasmyth mount model described in [3] is applied w.r.t. the average center of the laser pointing allowing us to store more accurate pointing information that are then used for the orbit determination in the space debris studies [4].

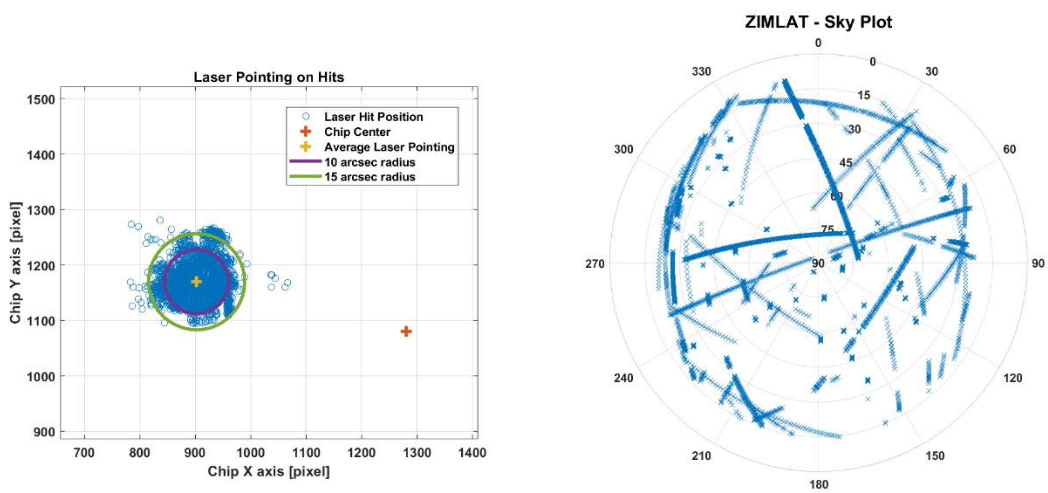

Figure 3 Derivation of laser pointing direction on tracking camera.

3.3 SOFTWARE OUTPUT

The outputs of the NightCam software are summarized in Figure 6. The left-side plot shows (from top to bottom) the difference between predicted and observed range expressed as time of flight difference (nanoseconds); the second shows the same difference but detrended to highlight the range changes due to attitude motion, and finally the bottom plot of Figure 6 shows the object magnitude obtained by the image analysis. On the right-side the sky plot shows the azimuth and elevation of the object which could be used for orbit determination.

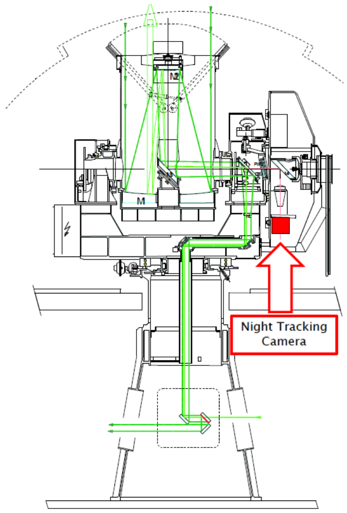

Figure 4 Telescope sketch and tracking camera position.

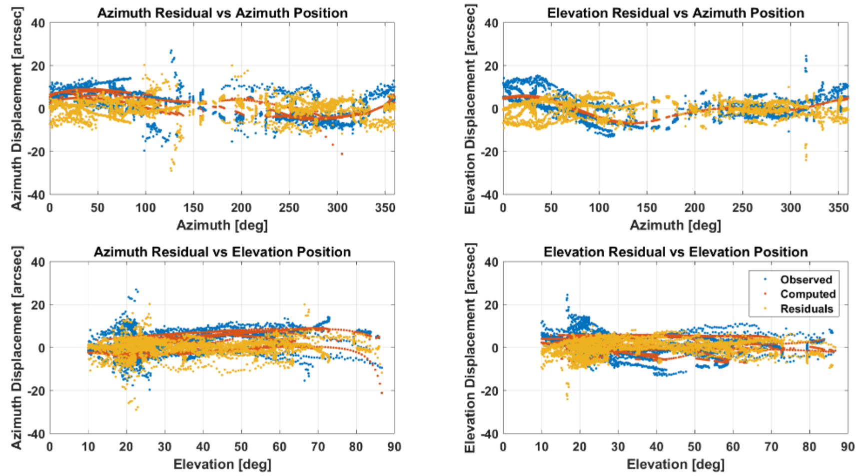

Figure 5 Modelling of laser pointing direction wobble on camera.

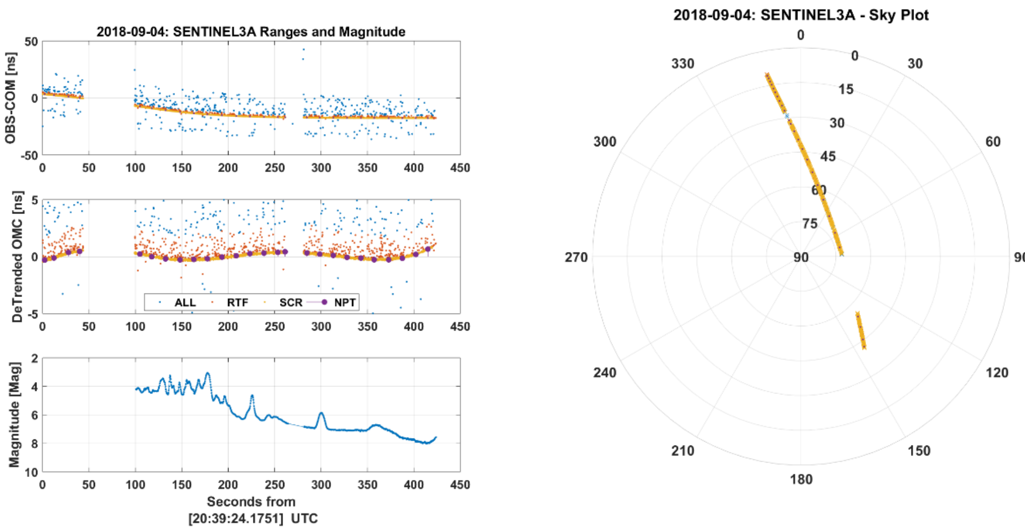

Figure 6 Night-tracking Camera output.

4 PERFORMANCE ANALYSIS

To evaluate the effects of exploiting the tracking camera for SLR observations, we focused our analysis on Global Navigation Satellite System (GNSS) satellites. This choice was made since the visibility window of these satellites is less sensitive to the time of the day when the observations are performed. In particular, being part of satellite constellations, providing a global coverage, roughly the same number and kind of satellite are visible from a certain station over a determined time window.

This preliminary analysis was carried out comparing 2 sessions of 4 hours with standard tracking and 2 sessions, lasting 4 and 5 hours, using the tracking camera. The results obtained during these

4 differents nights of observations are shown in Figure 7, Figure 8, Figure 9, and Figure 10 and are summarized in Table 1.

It is easy to notice how the employment of the tracking camera allowed us to acquire a higher number of targets, and allowed us to increase the number of observations from ~7 NP per hour to more than 10. Furthermore, the table shows that the increased number of acquired targets was obtained without losing data quality, in fact also the number of observations per NP was generally increased and we kept, on average, the same number of NP per satellite.

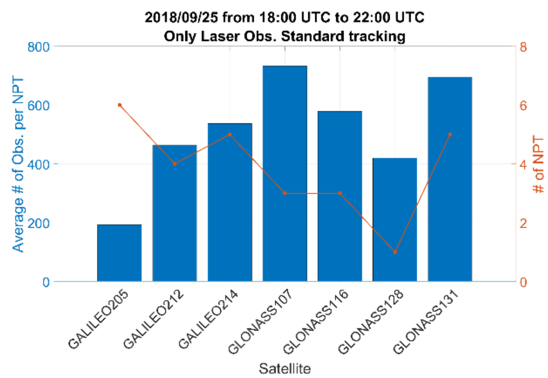

Figure 7 MEO observation summary for 2018/09/25 using standard tracking.

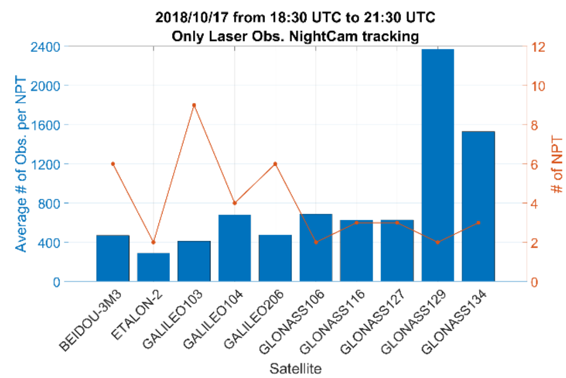

Figure 8 MEO observation summary for 2018/10/17 using tracking camera.

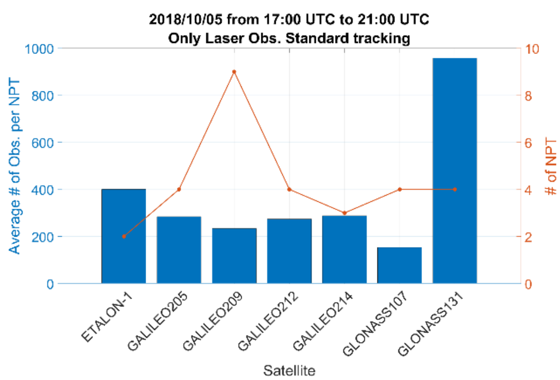

Figure 9 MEO observation summary for 2018/10/05 using standard tracking.

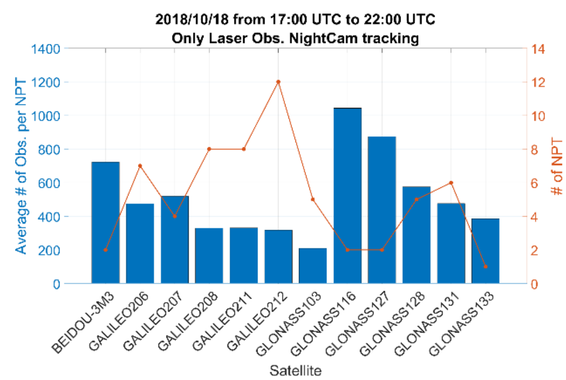

Figure 10 MEO observation summary for 2018/10/18 using tracking camera.

Table 1 Observation Summary comparing Tracking Camera and Standard Tracking.

Date	**Hour of Obs.**	**NP/Hour**	**Mean # of Returns/NP**	**Average NP/Satellite**
2018/09/25	4	6.75	517	3.86
2018/10/05	4	7.5	370	4.28
2018/10/17*	4	10	855	3.78
2018/10/18*	5	12.4	522	5.17

*Observation performed using the Night-Tracking Camera.

5 SUMMARY

In this paper we have described the integration of a night-tracking camera on the SLR system at the SwissOGS. After having described the hardware components, we focused on the steps performed for the software integration. We needed to adapt our SLR observation software to make it able to interact with the tracking camera and we have entirely developed a software able to control the camera, to calculate and send, in real time, the pointing corrections to the telescope; and finally, to store the image data which can be used for orbit and attitude determination studies. We showed how the problem of understanding the laser position on the camera was solved, and finally we performed a preliminary performance analysis based on the results of a real observation scenarios. The analysis has shown the improvement in the observation efficiency by using the tracking camera. The camera allows a faster satellite acquisition that produced an increase of the number of satellites and of NPs acquired during an observation session.

The camera can be already used to acquire difficult targets like newly launched satellites and, in the frame of space debris studies, defunct and re-entering satellites whose ephemeris accuracy is poor. Nevertheless, for the daily use of the tracking camera still automatization steps are needed. In particular, one could analyse the image and extract the object position in real time so that the pointing corrections could be calculated and sent automatically to the telescope. Another improvement which can be added is the change of the correction type from azimuth and elevation to along- and cross-track which will allow, in the case of poor ephemeris, the tracking of the object even once it is in the Earth shadow. Finally, one interesting aspect for which further investigations are needed is the possible application of the camera during day-time operations.

6 REFERENCES

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