Daylight Space Debris Laser Ranging

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ABSTRACT

A precise knowledge of the orbit of space debris is essential for the implementation of removal strategies and for reentry predictions. Satellite laser ranging provides highly accurate distance and attitude measurements of tumbling objects. Due to inaccurate predictions it is necessary to optically identify space debris objects. Currently space debris laser ranging is limited to a few hours after sunset and before sunrise when the object is in sunlight and it is dark at the observing site. We present a method to visualize space debris targets in broad daylight which significantly extends the potential observation time. The gathered image of the space debris object is used to correct the inaccurate the orbit predictions in real time. After centering the target in the field of view the standard laser ranging search routine can be started.

1 SPACE DEBRIS LASER RANGING, CURRENT LIMITATIONS

Space debris laser ranging is currently limited to a few hours close to sunset or sunrise. Orbit predictions to space debris objects which are based on two line elements (TLE) and propagated using the SGP4 algorithm are usually only accurate to within a few kilometers. To be able to center space debris objects to the narrow field of view of the satellite laser ranging (SLR) telescope the object has to be optically detected with an additional telescope using a larger field of view. So far the detection of space debris was only possible close to the terminator period, when it is already dark at the SLR station and the object is illuminated by sunlight. The reflected sunlight can then be detected to correct the inaccurate predictions. To be able to extend space debris laser ranging times to daylight objects first have to be made visible during full daylight.

2 STAR AND SATELLITE OBSERVATION DURING DAYLIGHT

Optical observations of stars, satellites or space debris during daylight are strongly dependent on the contrast of the object relative to the daylight sky background. Contrast during daylight conditions is limited by three factors: the field of view per pixel, the Airy disc and the seeing condition at the station. The larger the field of view seen by each individual pixel the larger the relative fraction of background skylight collected.

On the other hand in theory the diameter of the telescope optics limits the minimal size (Airy disc, diffraction) of a point source object. A 4-inch telescope will already have an Airy disc of approx. 1.4 arc seconds. At Graz SLR station atmospheric seeing during daylight is in the order of a few arc seconds, so it can be concluded that large apertures are not necessary for daylight observations. We conclude that with respect to ideal contrast, telescope optics have to be chosen in a way that the light of the object (including seeing and airy disc) is concentrated on only one pixel. If the object is smaller than the field of view/pixel contrast is reduced. An object larger than the field of view/pixel will only have small impact on contrast but overall brightness will be reduced. If the seeing is larger than the field of view per pixel, the object will jump from one pixel to the other, which will also lead to decreased contrast.

Stars of different magnitudes were observed using a CMOS sensor sized 4.8 mm x 3.2 mm and a telescope with a focal length of 4800 mm in combination with a 780 nm edge filter to reduce the sky background. With this set up stars up to a magnitude of 8.4 were made visible (Fig. 1) during daylight. Using a larger CMOS sensor (17.7 mm x 13.4 mm) more than 40 different rocket bodies were observed during daylight (Fig. 2, Fig. 3).

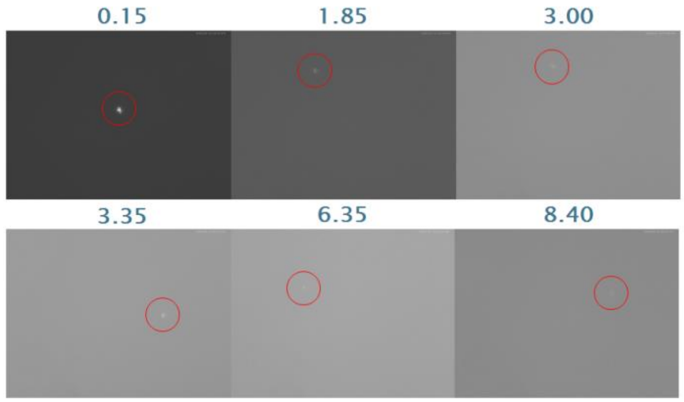

Fig. 1. Stars of different magnitudes (up to 8.4) observed with a 4.8 mm x 3.2 mm CMOS sensor and a telescope with a focal length of 4800 mm.

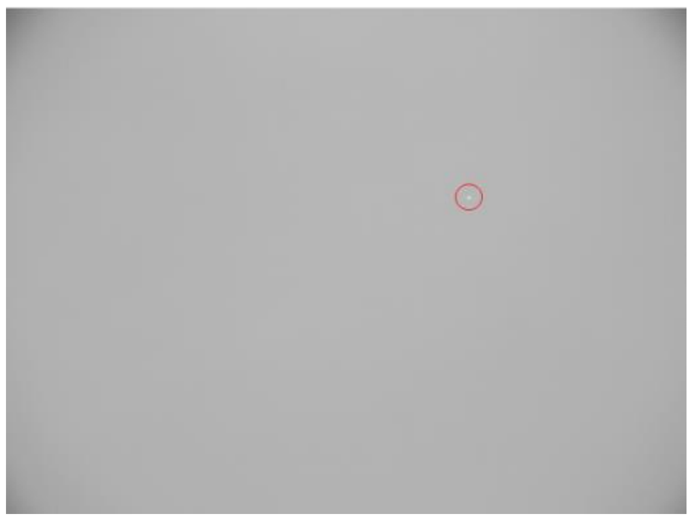

Fig. 2. Observation of an SL-12 rocket body (NORAD ID: 15772). The rocket body is highlighted with a red circle.

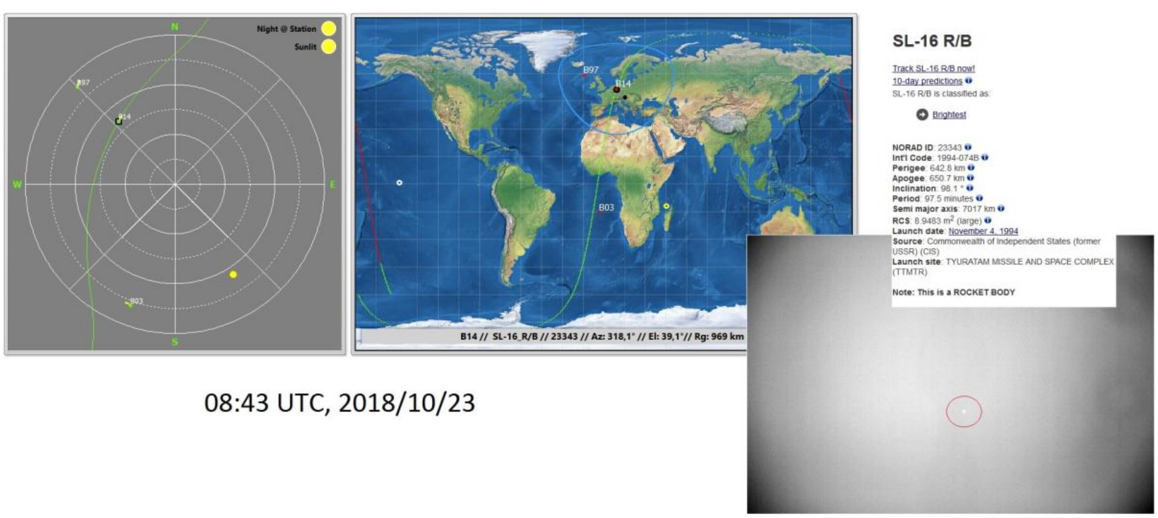

Fig. 3. Observation of an SL-16 rocket body (NORAD ID: 23343) while being plotted by Graz' SAT Tracer satellite tracking software. The rocket body is highlighted with a red circle.

3 SATELLITE AND TIME BIAS DETECTION SOFTWARE

To be able to correct time biases (along-track time offset of space debris objects with respect to the predictions) an image analysis software was developed. The object is automatically detected and highlighted within the image. With respect to the predicted path the time bias (in milliseconds) and the azimuth and elevation pointing offsets of the telescope are calculated. The calculated time bias is then used to modify the predictions introducing a time offset until the object is centered in the field of view. Within Fig. 4 an example of the software tracking the satellite Ajisai (NORAD ID: 16908) is presented. The red dots highlight the predicted path, the satellite is marked with a green circle. In the upper right corner the calculated time bias is presented. The relatively large time bias of 40-70 ms can be explained by a non-ideal mount model recorded during night time but used during daylight conditions. An additional error source to the image analysis based calculation of the time bias is the unknown range bias (offset to the predictions along the direction of the observer) which can influence the image analysis.

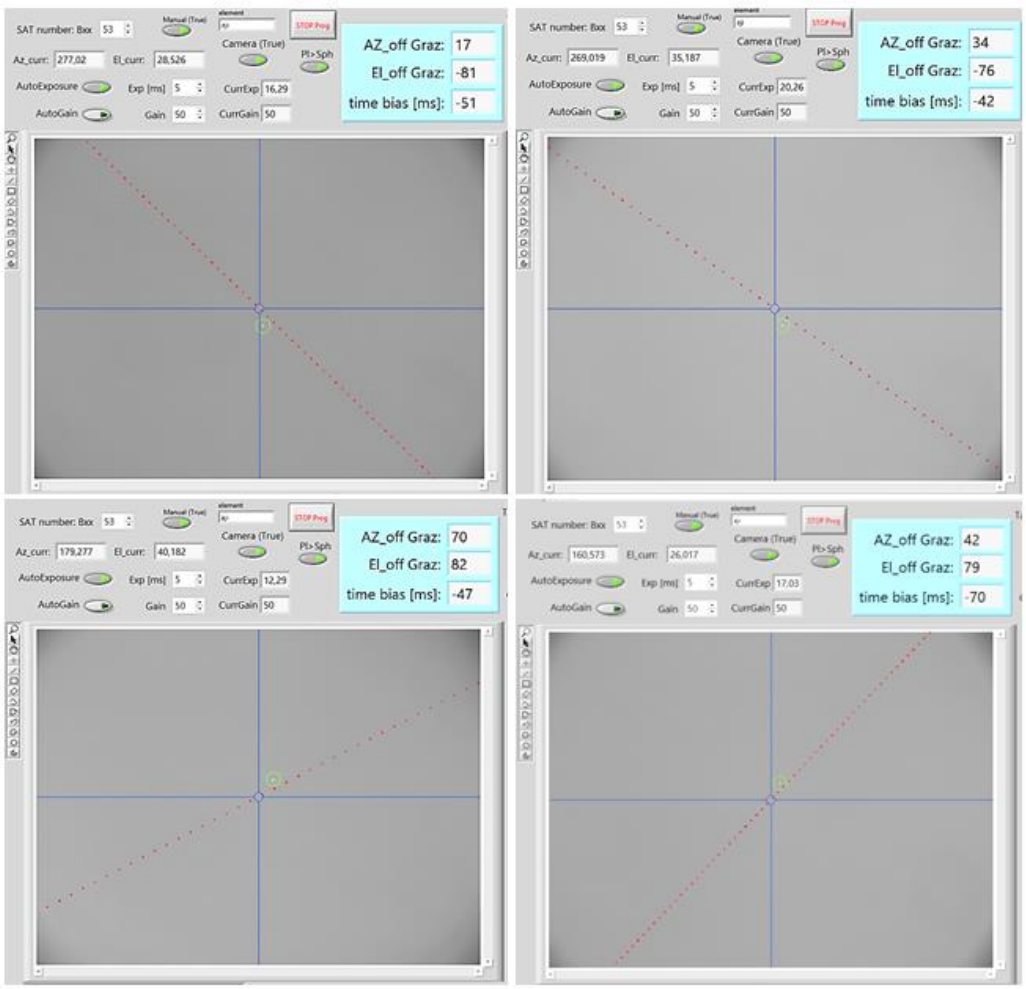

Fig. 4. Satellite detection and time bias calculation software is demonstrated while tracking the satellite Ajisai. The satellite is highlighted with a green circle and the predicted path by red dots which are separated by 30 ms. The four different images correspond to different times along the pass.

4 TOWARDS DAYLIGHT SPACE DEBRIS LASER RANGING

Single-photon avalanche diodes (SPAD) are usually gated: The detector is opened shortly before the reflected photon is predicted to arrive at the SLR station. On the one hand the detector noise depends on the repetition rate with which the detector is gated; higher repetition rates lead to an increase of detector noise. The noise distribution of a gated SPAD consists of a sharp Gaussian peak directly after opening the detector followed by an exponential decrease. This means that the probability of detecting a return photon within the noise significantly decreases the later the photon arrives after triggering the detector. From observations during the terminator period it was found that the range offsets relative to TLE-based predictions can be up to a several hundred meters. Hence, when searching for the target the triggering time of the detector has to be adapted to increase the chance to successfully detect return photons.

Via the image analysis software the time bias of the space debris object is detected. Time biases of space debris can be in the order of a few hundred milliseconds. The target is centered within the field of view of the SLR telescope by correcting the predictions with the determined value. However, a range bias cannot be detected via image analysis but it will influence the value of the time bias calculated by our software. Satellites detected with incorrect time biases will quickly move towards the outer parts of the noise distribution of the SPAD and at some point disappear within the noise. In addition to that, X/Y/Z coordinates of TLE predictions can oscillate with respect to the true orbit of the target. This leads to varying time and range offsets throughout the pass over the station.

The combination of large noise and inaccurate predictions makes daylight space debris ranging a challenging task. The above considerations highlight the importance of improved predictions with lower time and range biases; this paper guides the way to successful space debris laser ranging during daylight. First results will be presented at the conference and published in a scientific journal once data analysis is finished.

5 SUMMARY

In this paper the optical detection of stars and space debris during daylight is presented. Using filtering and image analysis techniques it is possible to visualize stars up to 8^{th} magnitude. More than 40 different illuminated upper stage rocket bodies were observed during daylight. Software was developed to automatically detect space debris and determine the time bias which was then used to correct TLE-based predictions. Furthermore a strategy is presented to conduct space debris laser ranging during noisy daylight conditions.