Improving Attitude Determination of a Satellite with Photodiodes for Sun Position Estimation using TRISAT data and Earth Albedo model

Nejc Kosanič[1], dr. Iztok Kramberger[2]

[1]*Laboratory for Electronic and Information Systems, Faculty of Electrical Engineering and Computer Science, University of Maribor*
E-mail: nejc.kosanic@um.si

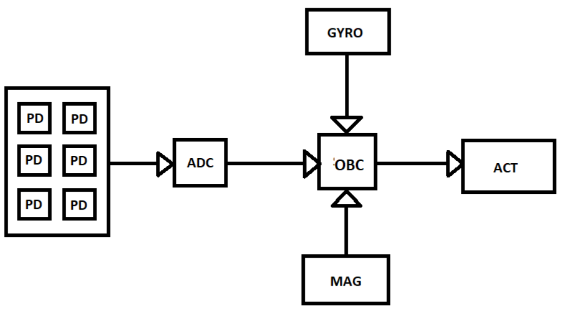

Figure 1: Block sheme of the ADCS onboard TRISAT functions during stabilisation period (PD - photodiodes, ADC - analog to digital converter, OBC - on-board computer, GYRO - gyroscope, MAG - magnetometer, ACT - actuators).

Abstract

In order to improve Sun-position estimation in low Earth orbits (LEO), an Earth albedo model [1] was designed, which helps to decipher the total solar and Earth-reglected current on solar sensors and improves Sun position estimation to a higher accuracy. In this short paper the method of improving the Sun position estimation with solar sensors is discussed.

1 Introduction

Satellite attitude determination and control systems (ADCS) are placed on satellites in order to be able to track the satellite and describe its movement. Positional estimation is usually done with the help of GNSS, while primary attitude control is done by a star tracker. During stabilisation periods, when GNSS and star-tracker are inactive, photodiodes serve as solar sensors and predict Sun position. Since light sensors are calibrated and have a strict linear response, data from three orthogonally-placed Sun-lit sensors results in a sun position estimation with a relatively high accuracy. The ADCS on board the TRISAT satellite uses photodiode data during stabilisation phase and accounts for a constant albedo factor of Earth reflected light. Currently an Earth albedo model is being built and tested, to provide for a better albedo factor estimation in regards to the satellite position in LEO.

2 Photodiodes and sun estimation

ADCS systems onboard TRISAT include a global navigation satellite systems (GNSS), a star tracker, a gyroscope, a magnetic sensor, and 6 photodiodes to record the amount of incoming light (Fig. 1). While star tracker returns high-accuracy satellite attitude it has to be offline when using magnetorques to correct satellite orientation. Photodiodes return values from which Sun vectors are being calculated to account for Suns position in relation to the satellite during that time.

The diodes on board TRISAT have been calibrated and have a strict linear power-to-current response, with best responsitivity around 360 nm (Fig. 3). Diodes have a viewing angle of about 160°.

As stated before, current Sun vector estimation takes into account a constant albedo factor, whereas data from TRISAT shows that abledo factor is much more complex to estimate. While the albedo constant is the correct time-average, the effect of a non-constant albedo factor is prominent (Fig. 4). The TRISAT satellite at the altitude of around 500 km takes several measurements at the same time (photodiodes, magnetometer, gyroscope). The measurement frequency is entirely dependant on the speed of change in rotation: the faster the rotation, the more data samples are acquired to increase the accuracy and validity of data, the lower the speed of rotation, the slower is the rate of data sampling. Keep in mind there is a maximum speed of data transfer to ground control and to increase the relevance of data sent, some threshold on rotation information is set in order to conserve the size of data.

The main problem in photodiodes lies in maximum values, where the maxime can not be properly estimated, which in turn translates to a discrepancy between actual Sun position and satellite-calculated Sun vector. Although the error between the real and calculated Sun position is small, even if the sun were 15° from the normal to solar panels, the amount of light that falls on panels is still above 95% of what it would be, had the Sun been on the normal.

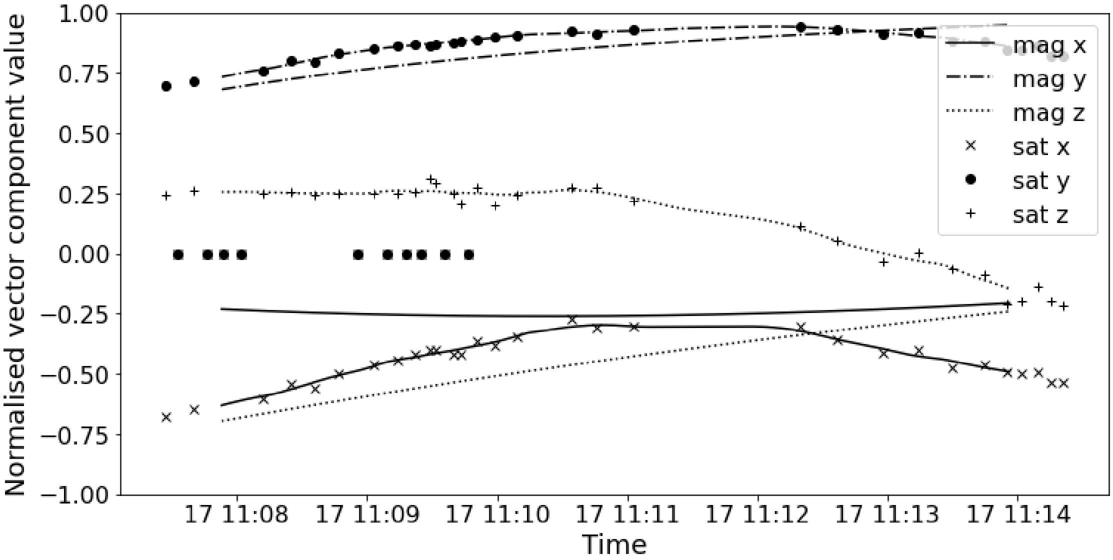

Figure 2: Recorded magnetic field vector (dots, 'sat') data interpolated (dashed lines through dots, 'sat') compared to WMM2020 prediction of magnetic field at the same trajectory (dashed lines, 'mag').

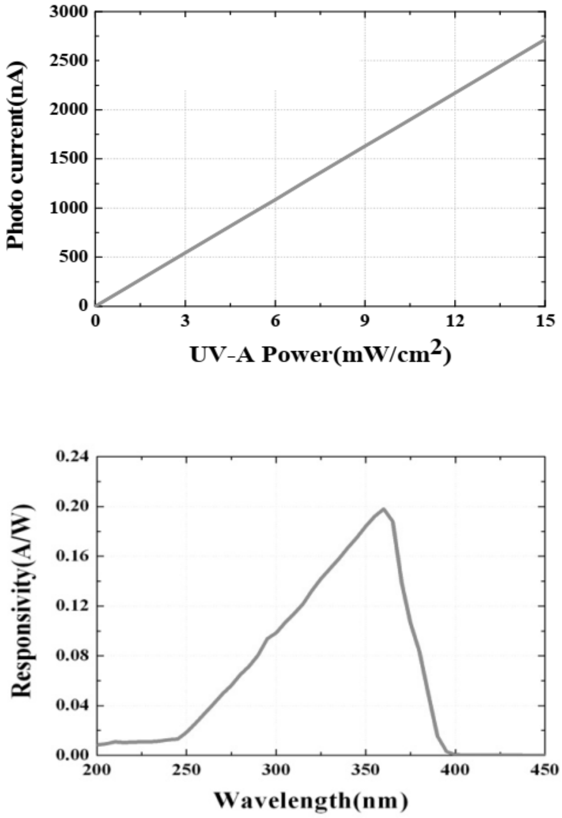

Figure 3: TOP: Photodiode responsivity in power spectrum, BOTTOM: photodiode responsivity in wavelength spectrum.

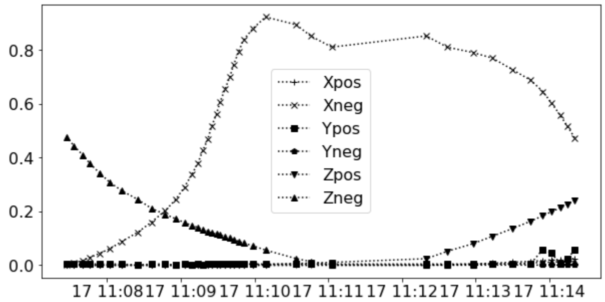

Figure 4: Normalised solar sensor values for a short data sample. It can be seen that satellite makes a nice rotation with "Zneg" values going to 0 and "Zpos" values starting to go up at roughly the same time.

3 Magnetic field data

Three orthogonal Sun sensors are needed to accurately predict Sun position, where an overshadowed photodiode results in an sun vector inaccuracy over a half-sphere around the satellite. To circumvent this problem we have turned our focus to other on-board sensors, specifically the magnetometer, which records the magnetic field vector around the satellite. With the help of an Earth magnetic field model - World Magnetic Model 2020 [2] - we can calculate the satellite orientation by comparing the recorded vector to that of the model.

As the magnetometer on-board the satellite has some unknown bias, the first step in checking the data validity was made by choosing a data sample that has little change in magnetic vector direction and then re-sampling and interpolating the data set over shorter, equal time intervals (Fig. 2). By doing this and subtracting zero-values from the data sample, we can assume to have gotten rid of some

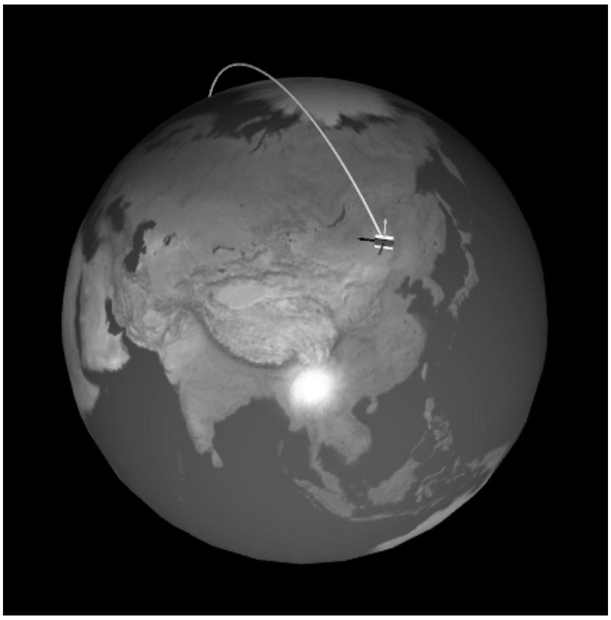

Figure 5: Visualisation of TRISAT path (with orientation vectors) over Earth.

of the data noise, while still maintaining quite an accurate dataset. Furthermore we have used the interpolated dataset to calculate the satellite rotation and compared it to the recorded rotation from gyroscopes (Fig. 6). There is some bias in the comparison, but the data is comparable, which shows that magnetic field data is accurate to a high enough degree that it can be used directly for satellite attitude estimation.

4 Earth albedo model

The main goal of the model is to properly account for the Earth reflected light and get an accurate estimate of the maximal Sun-only values on the solar sensors [3],[4],[5]. That way we can predict the Sun vector with a large accuracy and are ultimately able to rotate the satellite to get better Sun coverage over solar panels.

The model takes into consideration the surface of Earth in the form of a spherical albedo map. It then places the satellite above the surface and based on the telemetry data positions the Sun in respect to the satellite and the Earth (Fig. 5). On the first step the amount of satellite-visible Sun-lit Earth surface is estimated, where the lit surface is later divided to multiple smaller areas and integrated over to get the amount of reflected light. Then the viewing angles of all the photodiodes as well as all shadowing objects on TRISAT are taken into account (Fig. 7).

The model is being extensively tested and has shown great promise in providing useful data (Fig. 8). Based on comparing model data with satellite data, the basic ”satellite is lit/is not lit” function is accurate to within seconds, while the problems start with sensor orientation and longer time samples: while quaternions are used to rotate the satellite based on its recorded magnetic data, there are some inaccuracies in satellite attitude estimation.

One of the larger problems is also the WMM2020 inaccuracy over the magnetic poles, which makes the magnetic field data unusable for satellite attitude estimation over at least one third of the orbit.

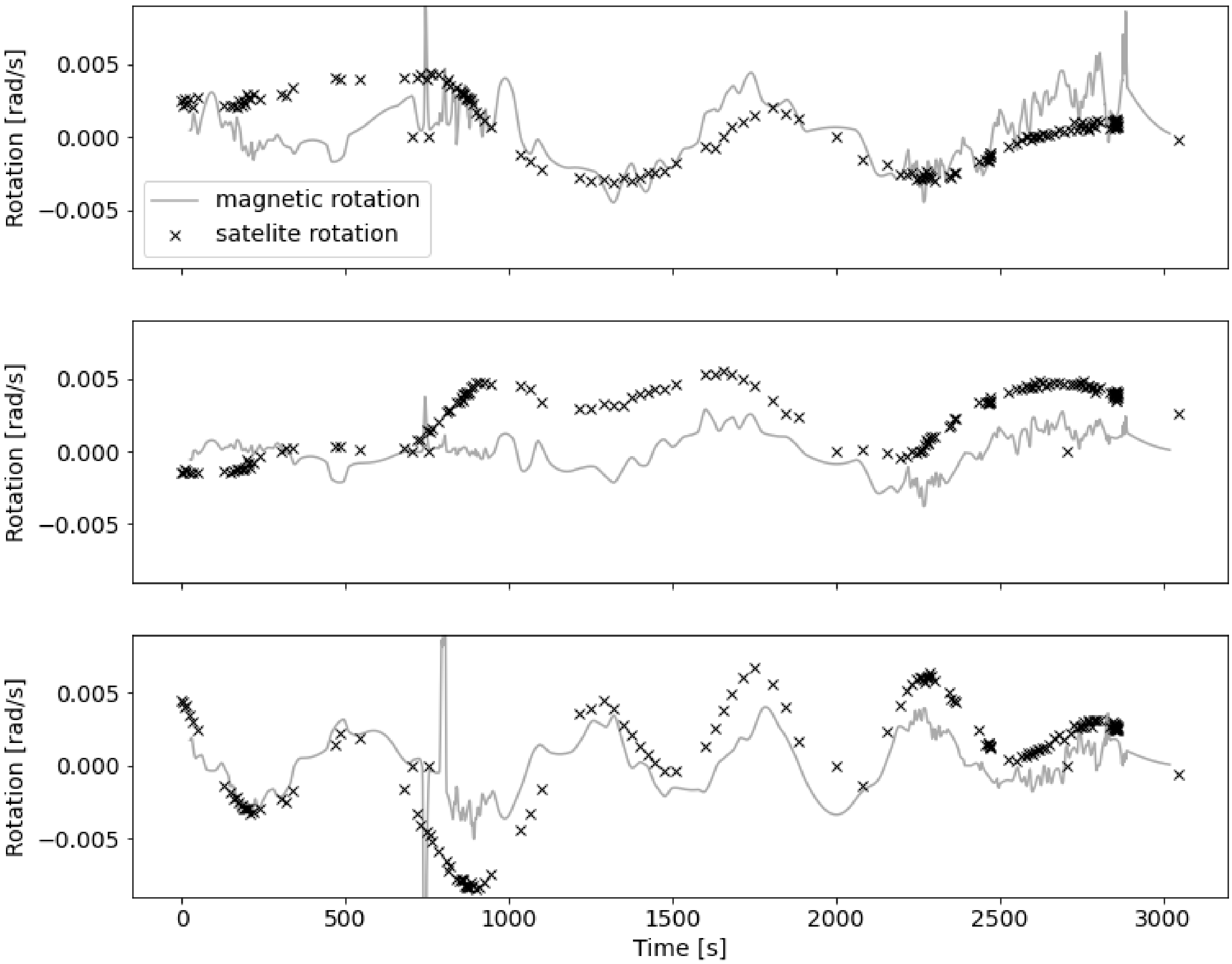

Figure 6: Recorded rotation (x, 'satelite rotation') compared to rotation from magnetic field data (ful line, 'magnetic rotation') for x-axis (TOP), y-axis (MIDDLE), z-axis (BOTTOM), different and longer time sample than on figures before.

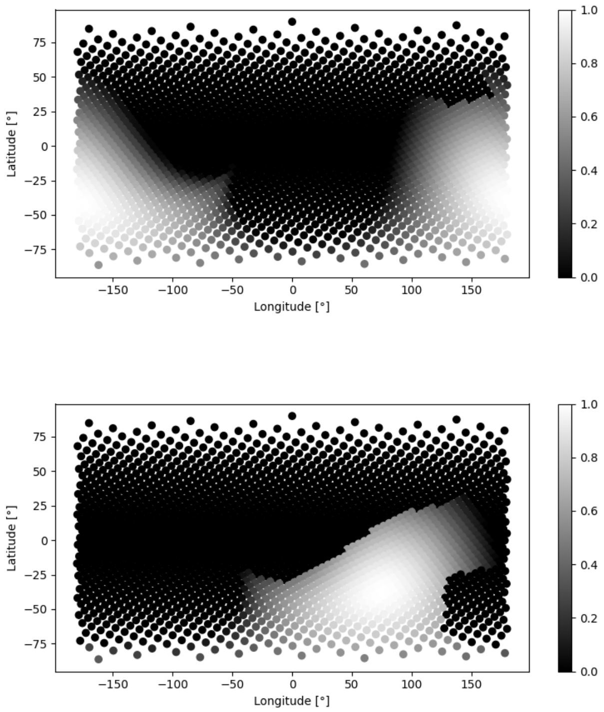

Figure 7: TOP: Modeled viewing angles for X+ solar sensor with recorded light intensity on the right. BOTTOM: modeled viewing angles for Z+ solar sensor with recorded light intensity on the right. Geometrical properties of the satellite which cause shading can be clearly distinguished in both figures.

Further work is needed to verify the model to account for the ever-changing albedo factor needed in the ADCS. Once the already collected data has been processed and verified with the albedo model, the plan is to implement the model on future TRISAT missions.

5 Conclusion

Since many (comercial) satellites are being produced to be flown in LEO, the need for a simple solution during satellite stabilisation period, when GNSS and star tracker are inactive, is needed. In this short paper we have shown that simple method with photodiode sensors and the help of an Earth albedo model in combination with real-time magnetic sensor and gyroscope data provides a high accuracy solution for Sun vector estimation. As the satellites in LEO are prone to Earth reflected light, the albedo model can account for reflected light and shine light on true Sun values thus providing accurate Sun vector estimations. Further testing of the model with more of TRISAT data is required for final model verification, with the end goal to produce an accurate model to be incorporated into ADCS on-board future TRISAT satellites.

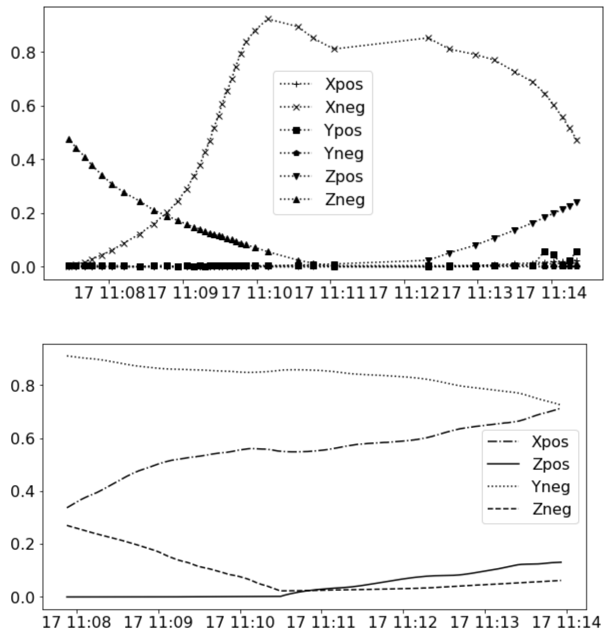

Figure 8: TOP: Normalised solar sensor values for a short data sample. BOTTOM: normalised solar sensor value for the same interval from albedo model. 'Yneg' line in bottom figure can not be seen in the top figure, because the solar sensor is blocked by a solar panel. Not all lines are drawn..

References

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