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LEO and the big blue marble, a bad combination for albedo errors

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ABSTRACT

Almost all satellites fly Sunsensors for launch and early orbit (LEOP) and safe mode operations. More than 90% of these are analogue Sunsensors with either an analogue or digital interface. The later are quite often referred to as digital Sunsensors but contrary to a true digital Sunsensor, analogue Sunsensors with a digital interface are still largely affected by albedo generated error signals.

Depending on the positioning of the sensor on the satellite, the satellites altitude, and the local node time, albedo errors can lead to significant measurement inaccuracies.

This paper describes some research into albedo induced errors in analogue fine Sunsensors as performed while using the data generated by the NAPA-2 satellite. This Satellite was built and is operated by ISISpace. This 6 unit Cubesat has one Auriga startracker and three MAUS Sunsensors on board allowing to compare the startracker determined attitude with the Sunsensor determined attitude.

Although the study results are far from complete, preliminary results shown a strong influence of the Earth’s albedo on the measurement accuracy of the Sunsensors

ANALOGUE SUNSENSORS

Most analogue Sunsors used on board of satellites are coarse Sunsensors that either use single photodiodes or a pyramid structure containing several photodiodes.

This type of sensor exhibits a very wide opening angle (up to >180° in both axis is possible for pyramid sensors) but also a very high albedo induced measurement error (errors up to 20° are not uncommon for satellites operating in LEO). Measurement accuracies are generally not better than a couple of degrees with exception of the center portion of the field of view for pyramide Sunsensors where accuracies down to 1.5° have been reported. (In absence of Albedo signal)

The Lens R&D MAUS Sunsensor as used on the NAPA-2 Cubesat is a so-called dual axis fine Sunsensor. The MAUS sensors use a radiation hardened four quadrant photodiode and a membrane to produce a two-axis device with an approximate ±60° FoV on both the X and Y axis. As depicted in Figure 1, the Sun shining through the aperture will create a Sunspot on the four detector elements. This in turn will cause the four-quadrant photodiode to generated four currents. When the height of the membrane with respect to the diode surface is known these currents can be used to calculate the Sun’s attitude.

The use of a membrane and four quadrant diode allows to take the ratio of the generated currents to calculate the attitude of the Sun, thus leveling out many artefacts that have influence on the accuracy of coarse Sunsensors. In essence all common mode effects are automatically balanced out by the principle of operation. This includes issues like common mode radiation effects and changes in the quantum efficiency due to temperature variations. Therefore, fine Sunsensors are generally much more accurate than coarse Sunsensors and they will be much more stable.

In addition to balancing out the vast majority of radiation effects, the generally fairly thick glass membrane that is used to support the membrane provides a significantly higher radiation shielding than the cover glasses commonly used on coarse Sunsensors. As a result, fine Sunsensors are very stable and robust to temperature variations, contamination, radiation and aging in general.

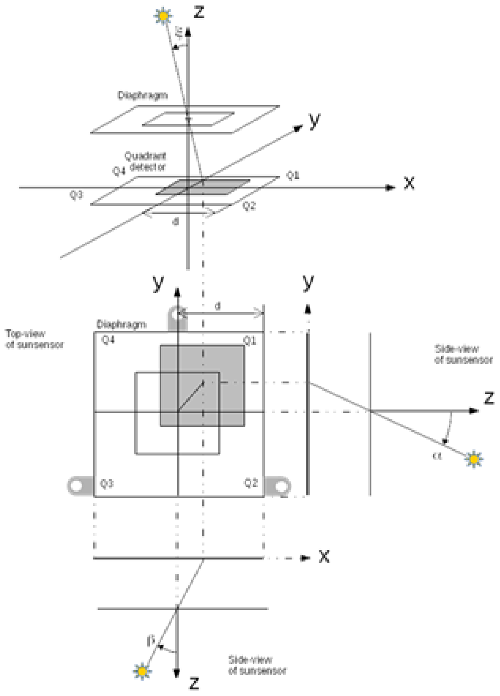

Figure 1: MAUS operating principle

Drawback of the fine Sunsensors is that the field of view is slightly smaller than for most coarse Sunsensors.

This on the other hand is an advantage when looking at albedo generated errors.

ALBEDO ERRORS

Not only the Sun will generate a light spot on the four-quadrant photodiode, but any other source of visible light that impinges on the sensor will cause a current in the diode segments. In the end the diode current is the sum of all currents generated and the algorithm will determine the centroid of received light. The sensor cannot discriminate against the direction the light is coming from, but the angle at which the received light reaches the sensor will determine the illumination of the four segments. As a result, reflections from the Sunlight on other objects (like satellite parts or the Earth) will cause a shift in the centroid of the light received and consequently a measurement error in the Sun angle.

Although the intensity of the Sunlight is much higher than the reflected light from the Earth, the angular extend of the Earth is a lot higher than the angular extend of the Sun. As a result, Earth Albedo can generate significant measurement errors. The magnitude of these errors strongly depends on the Size of the Earth within the field of view of the Sunsensor and consequently on a number of parameters:

- Field of view of the Sensor
- Satellites altitude
- Local node time

Coarse Sunsensors generally have a hemispherical field of view and consequently a very high albedo sensitivity.

Fine Sunsensors tend to have a more limited field of view (generally in the order of ±60° on axis) and therefore have a major advantage to that respect. Nevertheless, albedo errors on fine Sunsensors can still be very significant and in general an order of magnitude or more larger than the intrinsic accuracy of the Sunsensor.

It should be noticed that depending on the accommodation of the sensor, reflection on spacecraft parts will also cause albedo errors and in that sense both the angular extend of the Earth in the field of view and reflections on spacecraft parts will cause albedo errors. Below Figure 2 shows a poorly chosen location for a Sunsensor (if the sensor would have the same field of view as the picture) as both the Earth and various spacecraft parts are in the field of view.

Figure 2: Albedo generators

NAPA-2

ISISpace build the NAPA-2 6U Cubesat for the Royal Thai Airforce and it still operating the satellite. This Cubesat is of particular interest as it flies both a Sodern Auriga Startracker and 3 Lens R&D MAUS Sunsensors.

This allows to look at the attitude angel as determined on basis of the Sunsensors and compare this to the angle as determined by the startracker.

The three Sunsensors are positioned on the flight direction (FSS1), the anti-flight direction (FSS2) and Zenith (FSS3). The first two sensors will see a major portion of the Earth and the Zenith sensor is practically

Earth albedo free. As will be shown in below paragraphs this has a major effect on the generated albedo error and consequently the obtained accuracy.

NAPA-2 is flying at an altitude of 550km with a local time ascending node of 14:30h which means that some serious albedo errors are to be expected.

SUNSENSOR BASED ATTITUDE VERSUS STARTRACKER BASED ATTITUDE.

The most illustrative way to look at the differences between both attitudes is to plot them in the same graph.

For each of the sensors, the Sunsensor determined attitude is plotted in a solid line against the Startracker based attitude in a dotted line. This gives below three graphs.

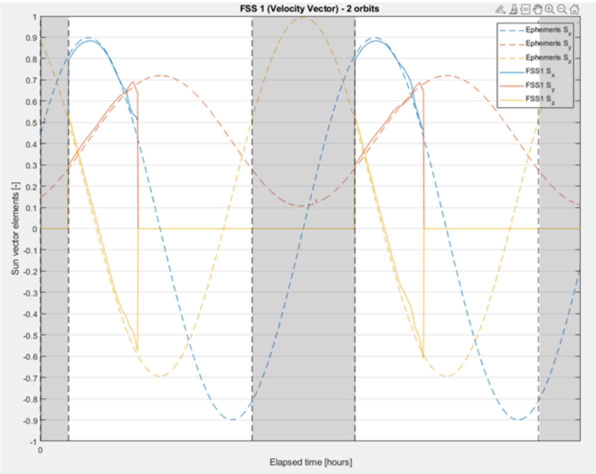

Figure 3 FSS1 signal vs Startracker

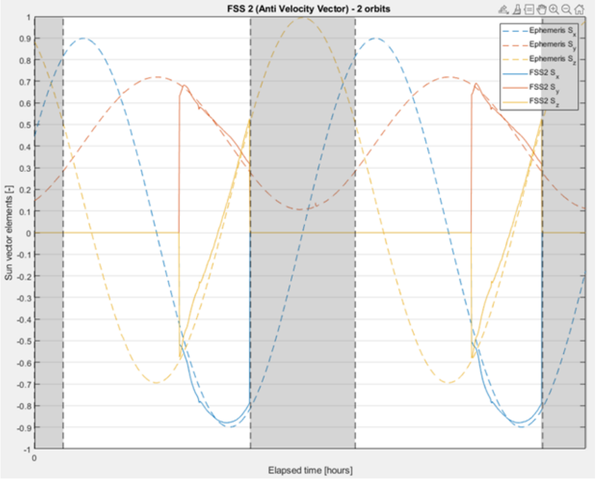

Figure 4 FSS2 signal vs Startracker

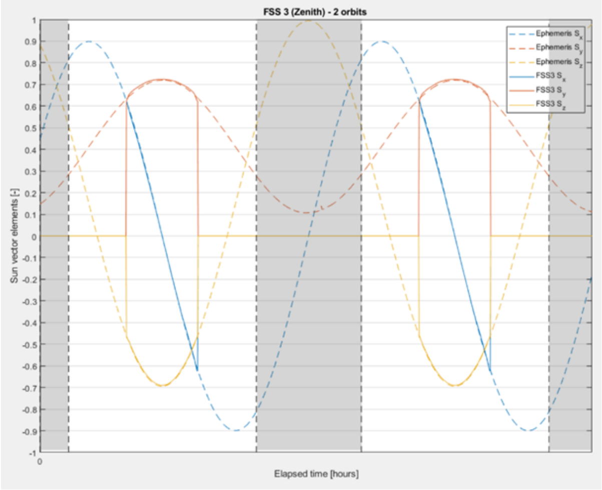

Figure 5 FSS3 signal vs Startracker

As can be seen from these graphs, the FSS3 based attitude follows the Startracker based attitude much closer than that of FSS1 and FSS2

Detailed errors

Amplifying part of the image shows the differences much clearer.

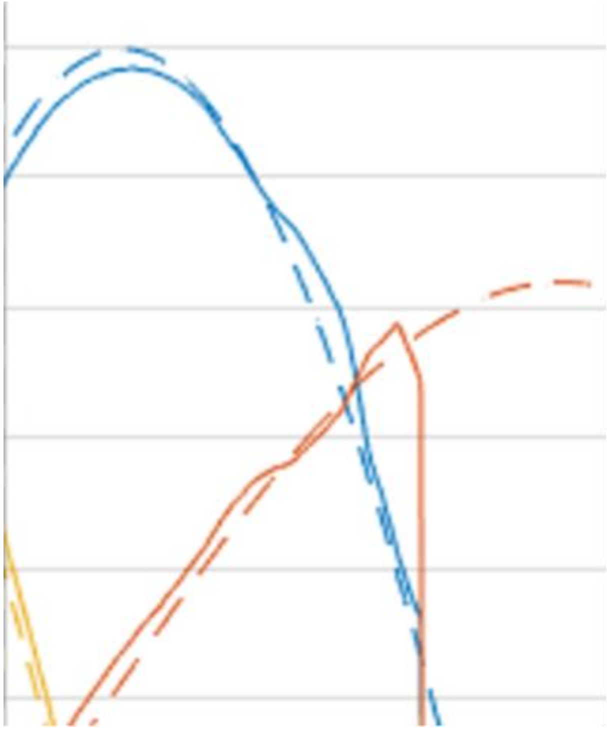

Figure 6 FSS1 error detail

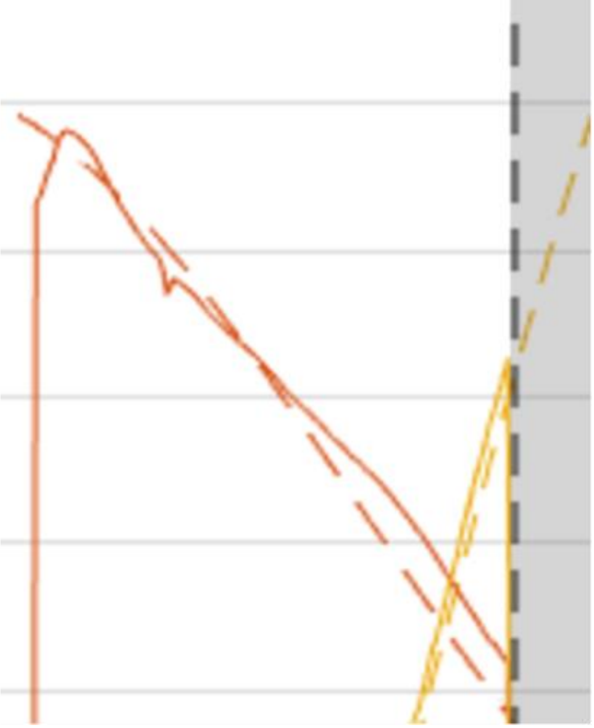

Figure 7 FSS2 error detail

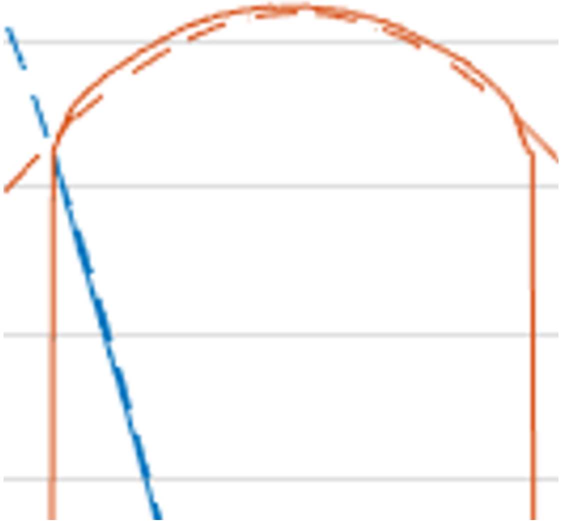

Figure 8 FSS3 based error

Looking at the actual error (in degrees) however provides the best insight into the actual errors.

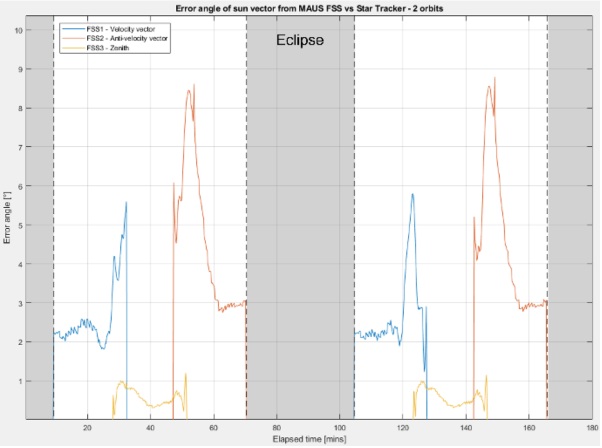

Figure 9 Sunsensor to Startracker errors

Magnifying these graphs shows a bit more detail

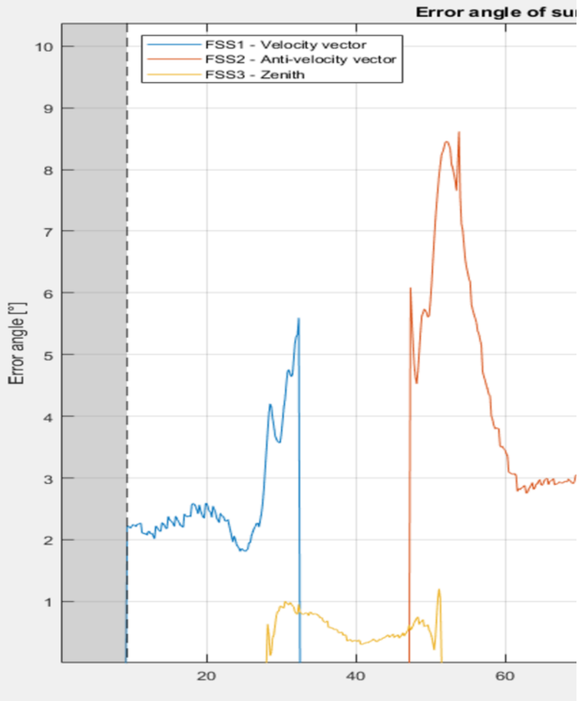

Figure 10 Magnified errors

The first thing that strikes the eye is the fact that FSS3 has a significantly lower error. The second is the fact that the other two sensors seem to have a significant bias error with extra errors in part of the profile.

The area's with the higher errors seem to have a significantly higher variability than the area's with the pedestal

This can be explained by the two types of Earth Albedo that are to be expected.

The most common one is due to diffuse reflection on the entire surface of the Earth. It should be obvious that green forests or black rock will generate relatively less signal than blue sea's and white clouds, but in essence everything contributes to diffuse albedo signal. As cloud cover and visible land cover change over the orbit, this signal varies, but not very fast or very strong.

The second one is called specular reflections and is caused by high reflectivity of certain surfaces like ice clouds, and waves. These specular reflections lead to a much higher albedo signal because much more of the available energy is reflected in the forward direction. Furthermore, the variability is much higher as specular reflection on waves for instance is depending on sea state and wind direction. Specular reflections of large areas of greenhouses for instance can lead to a flash-like phenomenon.

As specular reflection can only reach the satellite for certain parts of the orbit this is an explanation as to why part of the orbit shows a slowly varying pedestal with another portion that has a much higher error and a much higher variability.

Fortunately, the field of view of the sensors is limited to 57.5° on axis. This limits the Albedo error significantly. Still the error is far above the generic accuracy of the MAUS sensors. From the errors that are generated by FSS-3 it can be concluded that an albedo free sensor will give approximately an order of magnitude more accurate attitude information and consequently this sensor should be given preference in the AOCS system.

As the orbit of NAPA-2 is quite low and the LTAN unfavorable for albedo errors, using coarse Sunsensors for this type of mission is expected to lead to errors of a magnitude of 15 to 20 degrees. This magnitude of errors has been calculated before, but data on actual albedo errors is very sparse as most satellite builders avoid talking about this issue.

For digital Sunsensors that are actually analogue fine Sunsensors with a digital interface the albedo errors will be exactly the same as for analogue Sunsensors with an analogue interface. This is because the signals will be integrated at sensor level before digitization and albedo cannot be separated from Sun signal. Therefore, the only way to reduce albedo errors is to use a multi element detector and discriminate between direct Sun illuminated pixels and pixels that are only indirectly illuminated.

Such a sensor can be build using a dedicated CMOS circuit but would need to be radiation tolerant (as it is positioned on the outside of the satellite). As a consequence, this is a non-trivial development which is currently executed by Lens R&D in frame of an ESA advanced research for telecom systems (ARTES) contract

Until such time that a radiation hardened true digital Sunsensor is available, albedo effects will have to be taken into account while designing AOCS systems that rely on Sunsensors for their attitude determination. Careful positioning of the Sensors on board of the spacecraft and baffling if possible can largely reduce albedo induced errors and optimize the albedo free angular range

CONCLUSIONS

Albedo errors can significantly reduce the accuracy of a Sunsensor based AOCS system.

Fine Sunsensors have a significantly better performance with respect to albedo sensitivity than coarse Sunsensors due to the more limited field of view.

Analogue Sunsensors with a digital interface have the same albedo errors despite the fact that they are often called digital Sunsensors.

Carefull positioning of the Sunsensor and baffling can minimize albedo errors or mitigate them all together.

Only a true digital Sunsensor that uses a multi element detector and discriminate between Sun illuminated and indirectly illuminated pixels will be able to give albedo free Sun attitude measurements.