Debunking Sunsensor specifications

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Abstract: Sunsensors are core components for most Launch and Early Orbit (LEOP) and Safe modes of operation for satellites. As such, these components are to be considered critical safety components. The core requirements for such sensors are related to reliability as well as pointing accuracy.

Based on comparison of many datasheets, evaluation of several technological implementations and measurements performed on several real implementations, both Lens R&D and ESA have concluded that datasheets ambiguity exists in terminology between different datasheets, and performance specifications are not uniformly used. Currently, no ECSS or other standard terminology exists yet to provide a definition of Sun sensor performance specifications.

Following the confusion on how to specify a Sunsensor properly it is advised to write a dedicated standardisation document detailing how to specify a Sunsensor in such a way that the performance values given are relevant, easily verifiable and defined properly so different sensors of different manufacturers can be readily compared.

This paper describes the application of *Sunsensors* and several issues that need to be considered in order to be able to derive an independent specification.

1. SUNSENSOR APPLICATIONS

A Sunsensor is an attitude sensor that can measure the attitude of a satellite with respect to the Sun. Although almost all satellites employ Sunsensors, their application is generally restricted to use during the LEOP and safe mode operations phases. This is mainly due to two reasons:

1) A Sunsensor cannot determine the rotation around the Sun-axis and consequently requires an additional attitude sensor to determine the full attitude of a spacecraft.
2) The accuracy of a Sunsensor is generally limited due to inaccuracies caused by albedo signals.

The reason why Sunsensors are still used, despite these drawbacks is the fact that the are generally very simple and therefore can be very robust. In addition to this, the Sun provides a very high signal to noise ratio signal that can be used to measure the attitude even at very high spin-rates. This allows to recover satellites that have gone into a high spin-rate mode due to an anomaly during orbit injection or due to a subsystem failure where star tracker-based systems lose the ability to provide a reliable solution. In general, this recovery means pointing the solar panels to the Sun so as to ensure a positive power balance during the anomaly recovery.

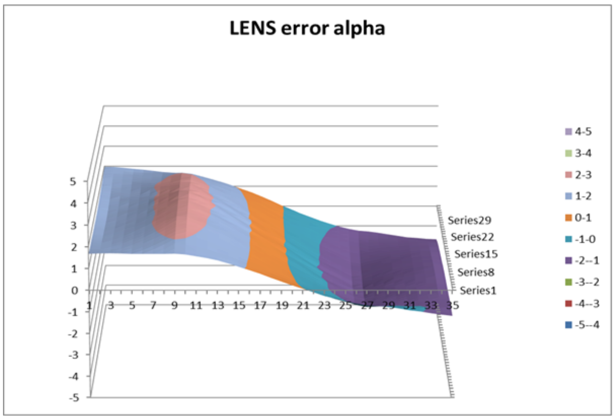
Only in very rare occasions a Sunsensor is used as the prime attitude sensor. In these cases, the attitude knowledge is generally driven by the sensor providing information about the third axis (most often an Earth-sensor or magnetic field sensor). This type of solution is only viable when an attitude error in the order of a few degrees is acceptable.

The last common application of Sunsensors is that of anomaly detector used to prevent the Sunlight from entering the aperture of sensitive instruments in case of an attitude failure. This again is a safe mode type of operation but generally used to shutter the aperture or in rare cases to directly activate the propulsion system so as to avoid satellite destruction (like in the case of the BepiColombo and Solo missions).

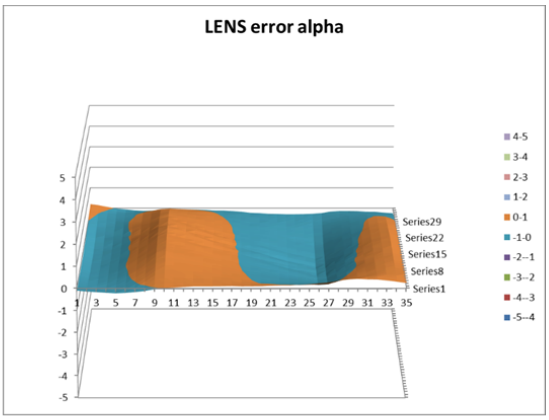
2. SUNSENSOR ACCURACY

According to the authors of this article, there is only one true definition of accuracy, and that is the difference between the true Sun aspect angle and the measured angle. Both of these angles shall be taken with respect to the mounting surface of the sensors or in case of availability to an optical reference plane provided (like a corner cube).

For an analogue fine Sunsensor, there are various effects that will lead to a deviation from the nominal value, like X/Y or Z diode-to-membrane displacements, component tilts and internal reflections. Many of these will also show some temperature dependence or aging due to thermal cycling and cosmic radiation effects. The specified accuracy of the sensors will have to take all of these effects into account. The errors caused by these effects can be in majority mitigated by adding offset and gain compensations in the formula used to calculate the actual pointing angle, but residual effects will cause a profile that can only be corrected by means of local interpolation and using error tables generated during calibration.



•Non calibrated



compensated

Above graphs show the error in degrees (Z axis) versus the error on the α angle (or X axis angle) measured over the two-dimensional field of view of a typical BiSon64 sensor (X/Y axis). As these measurements are BOL at 20°C, temperature and aging effects will have to be accounted for in the error budget while specifying overall accuracies. This means that either a correction value shall be provided, or multiple calibration tables. Providing calibration tables for aging or radiation effects however is not considered to be feasible because of the non-deterministic nature of the change. Therefore a budget allocation can only be made by an educated guess. The specified accuracy for the sensor however should be end of life and over temperature and aging

3. CALIBRATION ISSUES

There are several known serious issues related to the calibration of analogue Sunsensors especially when the source is an arc discharge lamp:

- Source flicker
- Bundle homogeneity
- Straylight
- Mechanical accuracy

Source flicker is a serious issue observed in arc discharge lamps causing the need for simultaneous samplers and averaging many measurements before a stable measurement is obtained. In general arc discharge lamps are driven by DC currents to avoid excessive electrode erosion but plasma oscillations, thermal runaway and localized electrode erosion cause significant intensity variations. Next to this many sources are poorly regulated, causing arc flickers at double the mains frequency. Therefore, it is in general necessary to take all samples at the same moment in time to minimize the effect of to the high variability of the momentary intensity (simultaneous sampling). In addition to this, it is generally needed to average thousands of samples taken before a measurement stability is achieved which is high enough to be confidently used as a measurement value.

As the arc of an arc discharge lamp is never at the same spot for a longer period of time, heating up the lamp for several hours does increase average output stability, but it does not increase the bundle homogeneity. This leads to errors in the calibration that will vary over time and will lead to non-repeatable measurements.

As an analogue Sunsensor merely determines the barry-centre of the impinging light, any straylight or calibration setup internal reflection will influence the outcome of the calibration. In order to have an accurate calibration, it is not sufficient to have a highly repeatable calibration, because reflections (causing straylight) can be very repeatable over time but still influence the accuracy to a much larger extend than the re-calibration repeatability would lead to believe.

Despite the fact that accurate rotation stages can be bought one has to be very careful during selection of the stages for a calibration setup. As for the Sunsensors themselves, it is easy to confuse resolution with accuracy and often the real performance of a rotation stage determined by the backlash in the driving system rather than the resolution. In order to demonstrate an accuracy of 0.5° for a Sunsensor it is good practice to limit the mechanical budget to less than $1/10^{th}$ of this. For high accuracy Sunsensors this leads to very stringent requirements on the mechanical setup which can only be obtained within a limited temperature range. For high levels of accuracy, settling of residual stresses and other relaxation effects can prove to be of influence and regular mechanical re-calibration is required.

Given the difficulty to perform a repeatable calibration, and the need to have a repeatable calibration before it can be accurate, it is obvious that people focus on producing stable calibration values first. From the quoted specifications however, it seems as often calibration repeatability is confused with accuracy when quoting sensor performance.

A lot of these uncertainties could be mitigated by asking the suppliers to specify a number of core properties independently (like accuracy, resolution, re-mounting accuracy, EOL and BOL accuracy) so as to be able to discriminate between accuracy and repeatability and see the aging effects taken into account.

4. RESOLUTION AND NOISE

For Analogue Sunsensors, (unless very small diodes are used or the sensitivity is spectrally limited) resolution and noise are seldom an issue. This is because the generated signals in general are relatively high in magnitude. A current of 1.6mA is equivalent to 10^{16} electrons per second which means the shotnoise limit is in the order of $1/10^{8}$ and consequently both noise and resolution are negligibly small.

Given the high signal to noise ratio, the resolution of the sensor is in general limited by the resolution of the readout electronics. An Adcole Maryland high accuracy fine Sunsensor (https://www.adcole-mai.com/high-accuracy-fine-sun-sensors) needs 100.000 bits to cover the 100° FOV at a resolution of 0.001°/bit or 17 bits. The quoted accuracy of 0.01° would require a 13 to 14 bit accuracy and despite the fact that there are electronic components that could reach this type of performance, and the noise generated by the sensor would allow for such performance, it is highly unlikely that a calibration can be performed where the straylight levels are below 1/10000th of the primary beam intensity. If the stray-light rejection of the calibration setup is not low enough the accuracy of calibration will not be high enough. At Lens R&D we have re-calibrated the same sensor ten times and every measurement taken in a 37x37 matrix over the 2-Dimensional field of view was within 0.0006° (which shows a very high degree of repeatability) yet we only specify a 0.5° accuracy.

SYSTEM REQUIREMENTS

As power production of the solar panels is ruled by the cosine law, in general a 3° to 5° accuracy is acceptable (cos(95°)= 0.996). The main reason for this is the fact that the sensors are inputting their data into an attitude control subsystem with a low bandwidth. As a consequence, any false inputs will lead to an error injection that can have an effect on the satellite attitude long after the wrong measurement has been taken. Bearing this in mind, one should be very careful in sensor placement to avoid albedo signals from providing a massive input disturbance. Even though it is generally preferred to have an as wide as possible field of view, it should be noted that Earth Albedo input significantly increases with the field of view. Consequently, a sensor with a baffle is generally preferred over a sensor without baffle and a sensor with a smaller field of view could eventually lead to a faster attitude acquisition due to the lower input disturbance.

Last but not least it should be realized that the sensor is used in closed loop. Generally, the gain factor is taken into account during loop design but the gain margin of the loop depends on the scale factor of the sensor. Therefore, the profile should be as smooth as possible and in no case the profile is allowed to become flat or reverse as this would lead to limit cycling or loop instability. In a similar way, too low a resolution on the Sunsensor data could lead to limit cycling (although a significant amount of filtering can be used to increase the actual resolution) and adding resolution to the output can be advantageous as long as the resolution is not such that the dynamic and integral non linearities become larger than 1 bit.

5. CONCLUSIONS

Without a proper definition of properties like accuracy, repeatability, resolution and long-term drift, it is very difficult to compare Sunsensor performances. Next to this, care should be taken that relevant properties are taken into account and not properties that are in actual fact more related to the properties of the test setup than to the properties of the actual sensor (like repeatability of calibration).