

AUTOMATIC INTENSITY BASED IMAGE SENSING AS A MEANS TO AVOID ALBEDO ERRORS IN GNC SYSTEMS

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Abstract:

Sunsensors are core parts of most Satellite GNC systems because they are small, low power and highly resilient. Most of them are however plagued with albedo errors leading to significant errors in the attitude control system due to reflections of the Sun on the Earth or satellite parts.

True digital Sunsensors use 2D imaging to discriminate between direct Sun illumination and albedo signals. These sensors used to be complex and therefore costly with most of them having poor radiation tolerance.

More than 20 years of development has led to Lens R&D B.V. introducing a radiation hardened single chip true digital Sunsensor (dubbed IBIS) which uses intensity based imaging to lower power consumption and increase resilience to cosmic radiation.

The presentation will focus on the unique properties of this sensor and the development status

Abstract Category Research/Technology

Research Category GNC hardware

Technology Category Advanced Guidance Navigation and Control

References:

1. de Boom, C.W. et al, *ESA GNC. 2011, Mini-DSS: MINIATURIZED HIGH-PRECISION SUN-ANGLE MEASUREMENT*; 2. de Boer, B.M.. et al, *ESA ICSO 2012, MiniDSS: a low-power and high-precision miniaturized digital Sun sensor*

1 True digital Sun sensors

In order to understand what is meant with a true digital Sun sensor, one has to have some knowledge about the various types of Sun sensors that exist. In below paragraphs an attempt will be made to describe the distinctive properties of each type.

1.1 Analogue Sun sensors

Most Sun sensors used are passive Sun sensors either outputting an analogue current or a low voltage which is generated directly by the output current and an integrated shunt resistor. This type of sensor has been used for decades and has proven to be extremely resilient and reliable when properly constructed. The sensors have distinct advantages and disadvantages though.

Advantages:

- Don't require a power supply (with very few exceptions)
- Relatively simple construction
- Extremely high radiation tolerance possible if properly designed
- Very wide temperature range possible
- High signal to noise ratio
- High reliability when properly constructed
- Virtually unlimited readout speed.
- Remote readout electronics possible taking advantage of satellite body shielding and reduced temperature range for readout electronics.
- Wide angular measurement range (up to super hemispherical)
- Can be small.

Disadvantages:

- Analogue outputs requiring a significant amount of support electronics to readout the sensor
- Albedo sensitive

1.2 Digital Sun sensors

Most digital Sun sensors are actually analogue fine Sun sensors with a digital interface. This means they have a number of distinct advantages and disadvantages.

Advantages:

- easier to interface to the on-board computer
- analogue to digital conversion optimised for detector used

Disadvantages:

- Require a power supply
- Provide increased dissipation in unit on the outside of the satellite.
- Radiation sensitivity is linked to the most sensitive component
- Albedo sensitivity equal to that of analogue Sun sensors
- Readout speed limited by analogue to digital converter (ADC) and support electronics
- latency between sample moment and output moment.

1.3 True digital Sun sensors

True digital Sun sensors use either array detectors or 2D arrays to discriminate between signals generated by the Sun directly or signals generated by reflections. Again a number of advantages and disadvantages of this type of sensor can be listed.

Advantages:

- Easier to interface to the on-board computer
- Analogue to digital conversion optimised for detector used
- Albedo insensitive

Disadvantages:

- Require a power supply
- Provide increased dissipation in unit on outside of the satellite
- Radiation sensitivity is linked to the most sensitive component
- Latency between sampling moment and availability of data

2 Requirements and implementation

As mentioned in the previous paragraph there are two major issues that are expected to be the real discriminating factor for true digital Sun sensors:

- 1) The power supply and associated power dissipation
- 2) The radiation tolerance

The power supply and associated dissipation is mainly an issue in relation to three subjects:

- 1) Failure propagation potential
- 2) Electro Magnetic Interference (EMI)
- 3) Temperature control

Having a power supply always means there is a failure propagation potential. When a power line is short circuited, the remaining components connected to that power supply will also experience a power outage. Therefore, there is clearly a failure propagation potential that doesn't exist for most of the analogue Sun sensors (some need a voltage to readout the sensors but most don't).

Having failure propagation potential is never seen as a good thing even though it may be limited.

The same holds for EMI. Especially digital electronics can generate interference signals on data communication or power lines. Whereas analogue Sun sensors produce quasi-DC currents, analogue Sun sensors with a digital interface or true digital Sun sensors will cause ripple currents and switching signal lines that not only have the potential to generate radio frequency (RF) signals, but can also be interfered with by other RF signals, thus disrupting communication integrity.

Another serious issue is the power dissipation of the sensor which should be as limited as possible as the unit will be located on the outside of the satellite in vacuum facing

the Sun directly. As a result, there will be serious thermal control issues if the sensor dissipates too much power.

The above has led to the conclusion that if it were not for the errors produced by Earth albedo and reflections from satellite parts, there would be little to no incentive to change from simple and extremely radiation tolerant analogue Sun sensors like the BiSon and MAUS to a digital variant.

Adding the readout electronics on the outside of the satellite aggravates thermal control and radiation mitigation issues and adds failure propagation possibilities that are not there when using analogue Sun sensors. Therefore, this would probably not weigh up to the efforts required to integrate the readout electronics into either the on-board computer or a dedicated interface control box.

Albedo errors however are known to seriously degrade pointing accuracy and can even lead to the unwanted condition of Earth lock, where the attitude locks to the Earth instead of the Sun. Serious degradation means pointing errors in the 10° to 20° error in low Earth orbit where the core sensors are generally specified to 0.5° accuracy (for BiSon and MAUS) The reason for this is that analogue Sun sensors look directly at the sum of all optical signals reaching the detector and either compare this to the current expected when the sensor is perpendicularly illuminated by only the Sun (coarse Sun sensors) or the ratio's of currents generated in four quadrants of a detector (fine Sun sensors). Once combined at detector level, the relative contributions of Sun and albedo signal can never be retrieved again.

For true digital Sun sensors, the field of view is split in several segments and intensity measured in each of the segments. By looking at the signal intensity, it can be determined if the signal is generated by direct Sun illumination or by a reflection. This is the principle of intensity-based image sensing. Although in principle a specular reflection would have a similar intensity as a direct illumination that will only lead to a similar signal if the full angular extend of the segment is covered by the reflection. As a result, this is highly unlikely to occur with reflecting surfaces on Earth and only expected to happen when the Sun reflects off of spacecraft parts. Consequently, intensity-based image sensing is a highly reliable way of determining the Sun direction without the influence of Earth albedo especially if direct reflections from satellite parts can be avoided.

In general, it is quite easy to conclude that digital Sun sensors will never be able to reach the radiation tolerance levels as can be reached with analogue Sun sensors. This means that additional radiation shielding will need to be provided. For analogue Sun sensors, the readout electronics is generally located on the inside of the satellite causing the satellite panels to cause an additional level of shielding. External electronics will therefore require more shielding than internal electronics. This increases the overall mass budget for the Sun sensing functionality unless....

The major unless to be considered is the size of the volume that needs to be shielded. As material and component costs per unit are largely driven by the number of electronic components required. So is the size of the volume that needs to be shielded against radiation. Whereas most of the components are passive, using multiple active components, means a larger volume will have to be shielded and system mass will quickly increase. This leads to a preference to design a single chip Sun sensor.

3 Single chip true digital Sunsensor.

One of the main advantages of a single chip solution is the small volume that needs radiation shielding and consequently a much lower mass of the solution as compared to discrete implementations.

A second advantage of a single chip solution is the fact that all internal interconnects are very short and therefore low power. It should be realized that in most CMOS technology, the majority of power is dissipated charging and discharging internal capacitances. Therefore, power dissipation can be reduced by reducing clock speed and keeping capacitive loading low. The smallest capacitances are between the cells of a CMOS circuit and as soon as the signal needs to go off chip, current and capacitances get orders of magnitude higher. As a consequence, it is much easier to develop a low power chip than to develop a low power system.

A third advantage is that active high reliability chips are expensive and short in supply as they require extensive process and radiation verification before approval. As a consequence (despite several attempts) no company ever succeeded into developing a radiation hardened true digital Sunsensor and turn this into a commercial success.

A fourth (major) advantage of a single chip solution would be the availability of plenty of chips for each production run provided, leading to a very high repeatability of production and eventually lower cost per product.

A single chip radiation hardened true digital Sunsensor is therefore seen as the holy grail of Sun sensing.

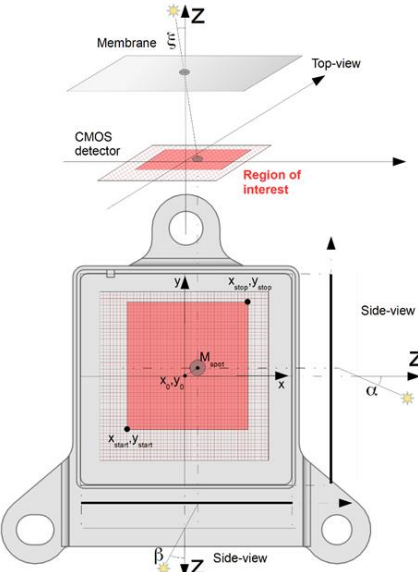
4 Intensity based image sensor (IBIS)

The IBIS is an image sensor that consists of a 384*384 pixel array in which each pixel is automatically evaluated to see if the incoming radiation within the pixels field of view exceeds 420W/m² or not. In order to save power this evaluation leads to a massive data reduction by turning the processed image basically into a yes Sun/ no Sun matrix. In this process all Earth albedo signals are automatically rejected.

Knowing the Sun intensity above the atmosphere is in the order of 1360W/m², the threshold means that only signals exceeding 1/3th of a solar constant are flagged as potentially being caused by direct Sun illumination.

Major Albedo contributors are reflections on ice clouds and surface waves, mountain tops or polar ice. Reflections on mountain tops and polar ice are largely diffuse so the intensity is high but will stay well below the set threshold. Reflections on surface waves are specular but part of the light will enter the water and only a small portion of the reflection will be in the exact direction of the satellite, so also this reflection will stay under the threshold. Perhaps the most critical reflections are from high ice clouds as they can be highly specular and well aligned to extensive layers in the atmosphere. Even if the generated signal would cross the threshold, this would only be for a very brief period and digital algorithms can (and have been for the LRD IBIS) be implemented that will automatically detect such a situation and flag to the user that the reading quality is expected to be lower than usual.

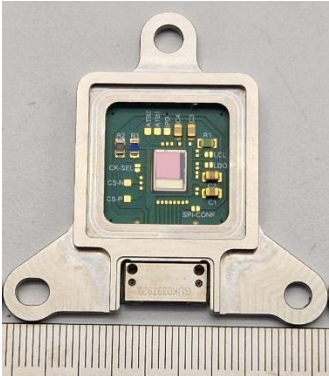
Leaves the risk of specular reflections on spacecraft parts. To mitigate this risk, LRD has asked Systematic to implement an exclusion zone that can be set by defining a start and stop coordinate as shown in below figure.



Pixels that are illuminated outside the zone which is set will not be evaluated. This feature (which can only be implemented on analogue Sun sensors by means of mechanical baffles) allows to avoid erroneous readings due to reflections on spacecraft parts. Expectations are, that having this feature will ease accommodation on the spacecraft significantly. It furthermore allows to create a programmable anomaly detector. (be it with a rectangular field of view) As the data provided includes a Sun presence detection flag, this flag in combination with the programmable field of view allows to create a very flexible anomaly detector.

5 Development status

Currently the second iteration of the chip is being tested. Unfortunately, this version of the chip is still not functional even though functionality of major parts of the chip has been confirmed.



An unexpected error in the digital part seems to be causing issues with the readout of the sensor and the root cause is still under investigation. A new design iteration will be needed to reach a functional chip, but once functional it is expected that the unique properties will lead to unique sensor that solves some long standing issues with analogue Sun sensors in an efficient way.