EFFECTIVE SMALLSAT CALIBRATION SERVICE: CALIBREO

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ABSTRACT

The rise of small earth observing satellites creates huge opportunities for creating useful information, but only if the image data is of high quality, for which it needs to be properly calibrated both geometrically and radiometrically. The small size however poses additional challenges endangering proper calibration and many different acquisition techniques increase complexity.

The necessity for consistent calibration across missions advocates a new way of working: instead of a custom calibration system for each mission, a generic solution can be used with minimal adaptations. With CalibrEO, we present such a solution which provides calibration as a service, targeted at calibration of optical earth observing instruments from small satellites.

The service builds on state-of the art vicarious calibration methods, which have proven to be successful in multiple missions. Apart from well-known methods like desert calibration, it supports lunar calibration, a technique which is very well suited for small satellites. It also provides a wide range of bundle adjustment techniques applicable for a large variety of sensors and imaging concepts.

CalibrEO is modular system which will be updated with new methods and tools to keep it performing with the best of its kind. It can be tailored to the need of specific missions, but is also offered in three predefined packages covering the most common scenarios. By offering reliable and accurate calibration services, the Cal/Val service will allow companies to reduce operating costs, shorten time to market and add value to their products.

1 INTRODUCTION: SMALLSATS

The field of earth observing small satellites is evolving fast. In the last decade, new levels of cost efficiency were pursued by miniaturization of instruments and platforms [1]. At first, many experimental designs consisting of custom developed components were used. More recently, these are being surpassed by more streamlined mission concepts, which are more efficient because they use standardized platforms and payloads [2].

The performance of such systems is not only determined by hardware, but equally by calibration and methods-and software solutions that convert raw measurements into data products. For instrument calibration, such consolidation is yet to take place. Currently, the development of a new mission very often encompasses the development of a new custom calibration solution. However using a standardized solution instead can bring clear advantages.

The primary advantage is that such solutions can bring important quality and consistency improvements. The demand for consistent and dependable solutions from EO community is strong. Users acquire analysis ready EO data from multiple sources and suppliers, and expect this data to be consistent across sources. Secondly, it is more efficient than to develop a new calibration solution for each new mission. For missions which share key components, this is evident. Still, even for missions with very specialized hardware, many software component can be reused.

2 SMALLSAT CALIBRATION

2.1 Challenges

Smallsat inflight calibration faces multiple challenges. Smaller platforms have less mass, and therefore thermal stability is more difficult to achieve. Similarly, the platform attitudes are generally less accurately controlled, and smaller attitudes measurement may yield to less accurate results, which result in larger geo-pointing deviations.

Unlike for most larger missions, there are usually no onboard calibration devices present. This implies that inflight calibration relies completely on vicarious calibrations methods. Many radiometric vicarious techniques require dedicated acquisitions to be made, which can reduce nominal imaging time, and require large downlink capacities, which are limited.

Companies deploying a small satellite missions operate under strict time and cost constraints and want to deliver results early on, especially for shorter missions. Some of them put only limited resources into the preparation of orbit calibrations. Such a minimal approach can be insufficient to tackle the full complexity of problems arising during missions operation.

2.2 Instrument conceptual variety

Many innovative solutions are being implemented to generate unique and powerful earth observation data within the platform limitations. This has led to a surprisingly wide variety of imaging concepts in use. Especially for instruments aiming at hyperspectral imaging, many different setups to acquire spectral information (Figure 1)

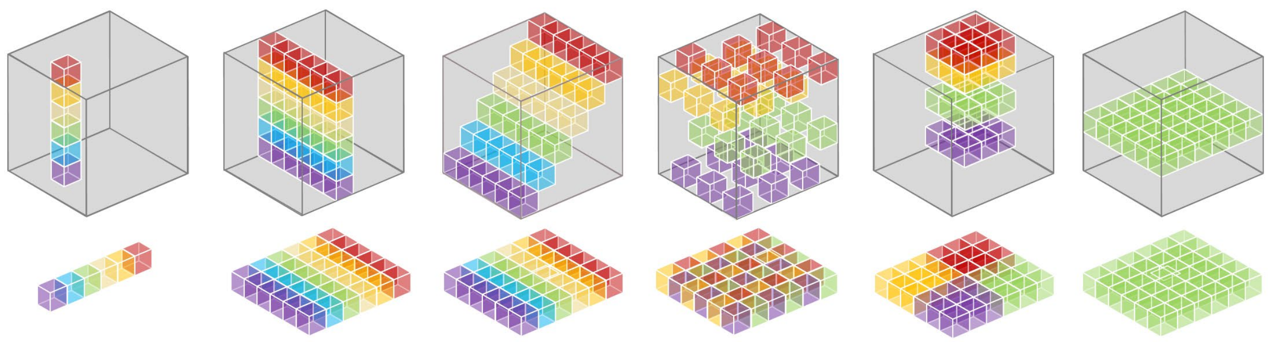

Figure 1: Hyperspectral acquisition principles (from [3]).

We illustrate this by reproducing a schematic drawing from [3]: the top drawings show the part of a hypercube sampled in a single acquisition, bottom drawing the acquisition on the sensor. From left to right it shows: whiskbroom, pushbroom, pushframe, mosaic and tiled snapshot, sequential imaging. Also less conventional concepts find their way into missions. E.g. pushframe system are used in the Skysat satellites by Planet [4] which capture multispectral images, as well as by the Hyperscout and upcoming CSIMBA missions [5].

2.3 Calibration as differentiator

Given the challenges and the limitations explained in section 2.1, many small satellite missions experience quality issues and cannot guarantee the same quality and reliability as customers have come to expect from established missions. This has made the scientific community sceptical about relying on data from small satellites.

To be valuable for space science, SmallSats must meet the quality requirements set by the science community. Otherwise, the rapid growth in SmallSats will create massive amounts of data which is not only diverse in terms of products specifications, and validation approaches, but also inconsistencies in the used measurement practices and in the associated quality information [6]. To avoid creating a deluge of uncalibrated, a top level inflight calibration solution is a key part of any SmallSat Earth observing mission, essential for its success.

Progress is being made for many missions towards introducing better calibration methodologies. At the same time, stricter requirements are being put on data consistency. ESA is putting great efforts towards this, not only for its own missions but also for third party missions [7]. To this effect they are elaborating a strategy for establishing guidelines and common protocols for the calibration and validation (Cal/Val) of optical land imaging sensors [6]. The goal is to enhance user confidence in satellite based data and characterize inter-sensor inconsistencies, starting from at-sensor radiances and paving the way to achieving the interoperability of current and future land-imaging systems. This is definitely a much welcomed evolution, but as a side effect, it will also decrease the willingness of users to tolerate and cope with less good data.

3 A NEW CALIBRATION PARADIGM

The technical complexity and the necessity for consistent calibration across missions advocates the use of another way of working: instead of deploying a custom in-house developed inflight calibration system for each mission, a more generic solution by a provider specializing in calibration. With CalibrEO, we propose a calibration as a service, dedicated to SmallSats and CubeSats. This Cal/Val service will allow companies to reduce operating costs, shorten time to market and add value to their final products.

CalibrEO will offer radiometric and geometric inflight calibration of optical passive multispectral and hyperspectral imagers covering the visible to shortwave infrared spectral range. It will be able to handle a large variety of sensors and imaging technologies as listed in section 2.2.

It is built is a modular way. This allows it to maximally reuse common workflow components, guaranteeing a consistent approach across missions. For this, it builds on state-of the art vicarious calibration methods, with a proven track record. At the same time it is fully customisable so it can be tailored to meet specific requirements of a mission. This makes it more efficient as efforts can be concentrated on mission specific aspects.

4 CALIBRATION EXPERTISE

4.1 On vicarious calibration

The PROBA-V mission marked a turning point in development of vicarious calibration [9]. The mission aimed at a radiometric and geometric accuracy and consistency to match that of the SPOT-Vegetation mission for which it provided data continuation. However, as a clear break from traditional calibration, it did not include an onboard calibration devices. To make this possible, a calibration system was built up from the ground up, based solely on vicarious calibration methods. The approach used a broad set of vicarious methods. These are used not only to collect complementary information, but also allow to perform validation using independent sources [10]. It included facilities for temporal modelling and time series analysis.

This set of Cal/Val methods and tools has been expanded and updated with new state of the art methods over the year, and is now the basis of the CalibrEO toolset. It is based on solid tools developed by VITO, including OSCAR (Optical Sensor Calibration with simulated Radiances tool) for radiometric calibration and a block bundle adjustment tool for geometric calibration.

Its core is a set of vicarious calibration methods, based on different types of targets whose radiometric signal is accurately known or can be modelled. The most common widely used are pseudo-invariant desert sites [11]. Calibration using targets on earth also relies on a Radiative Transfer Model such as iCOR [12] to simulate the at-sensor signal. The results are compared to the sensor values to establish the radiometry, and to monitor the variation over time. As such, it is aligned with the vicarious approaches are used by ESA for radiometric assessment and intercalibration of S2 and S3 optical sensors, using the DIMITRI tool [6].

4.2 Mission expertise

To ensure successful calibration, the right tools need to be complemented with human expertise, ideally gathered by calibration scientists in similar missions. At VITO, since PROBA-V we have acquired associated Cal/Val expertise was collected in many past current and future ESA missions. For Hyperscout-1, the first calibration of a hyperspectral Cubesat was achieved. Currently, we contribute to the mission performance centre activities of the Sentinel-2 and Sentinel-3 missions, including commissioning of S2C and S3C/D, SYN-VGT Validation and radiometric calibration using lunar, sun glint and Rayleigh calibration for S3-OLCI/SLSTR.

4.3 Lunar calibration

A special case is lunar calibration. Using celestial targets as vicarious references brings important advantages. They provide references which are independent of the earth and thus not influenced by atmospheric variations, which are a major source of uncertainty for other targets [13]. The moon is the preferred target not only because of its proximity, but because its variations can be accurately modelled. ROLO was the first lunar irradiance model. More recently, a major advancement has been made with the LIME model which offers improved accuracy [14]. We show an illustration of the phases of the moon, as captured by the PROVA-V satellite in the course of one month. It clearly demonstrates the variability over the month, illustrating the need for a very accurate lunar irradiance model.

Using the moon as vicarious target has proven to be very successful in many missions including MODIS; Landsat-8, PROBA-V and Sentinel-3, but also for small satellites including Planet Doves [15][16].

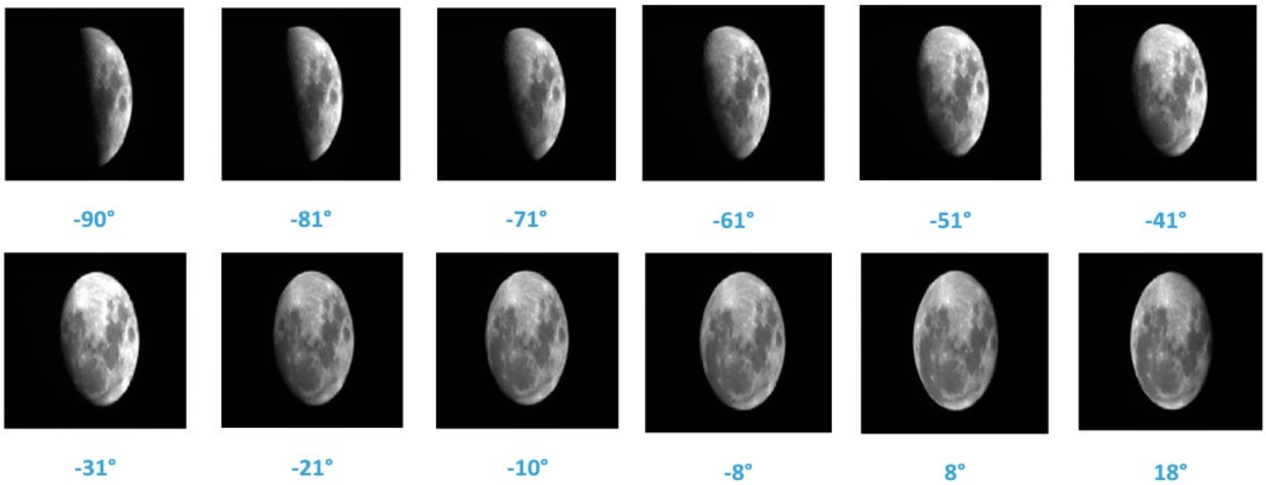

Figure 2 lunar phases as captured by PROBA-V, November 2020

4.4 State of the art geometric calibration

Despite efforts to precisely determine the camera alignment before launch, on-orbit geometric calibration is mandatory as alignment may have changed after launch by launch shock, outgassing, zero gravity, thermal effect, etc. Consequently, it is common for EO satellite programs to calibrate the alignment during the commissioning period. The geometric calibration of a sensor is essential to 1) assess the initial post-launch geometric accuracy which could have been affected by the satellite launch and 2) update the in-flight geometric calibration parameters (exterior and interior) based on regular images taken from space co-registered with a set of global reference images.

CalibrEO offers a set of geometric calibration tools already applied to PROBA-V and HyperScout satellites to refine the geometric sensor model and correct for the geometric biases in the line of sight model. These tools are further adapted and refined to be applicable to a large variety of satellite imaging concepts as listed in section 2.2.

CalibrEO geometric refinement is based on the usage of Ground Control Points (GCPs) and a geometric sensor model. GCP are used to provide an external positional reference coordinate. This allows the internal geometry of the image (line of sight model) to be matched with the real terrain coordinates for the area that is imaged by the sensor. Template matching technique, which is based on locating a known reference image in the newly acquired sensor image is used to estimate pixels/lines distortions. Finally, bundle adjustment technique based on collinearity equation is performed to determine the updated geometric correction parameters.

5 THE CALIBREO APPROACH

Our proposed CalibrEO service offers an **affordable** and **universal/generic** solution dedicated to SmallSats and CubeSats. The CalibrEO service is backed by a flexible toolset, which can offer different levels of service depending on customer needs. The service can be tailored individually to meet specific needs, but to cover the most common situations, three predefined levels of support have been defined:

- **Entry level quality** verification: suitable for complementing a custom solution.
- **Express calibration**: focuses on achieving industry standard accuracy in a short time.
- **Premium calibration**: aims to achieve and maintain optimal accuracy over the mission.

The three service levels are summarized in Table 1. The menu of services can cater for missions with very different scope, which do not all require the same level of calibration effort, depending on:

- the goal of the mission and the intended users,
- the intrinsic properties of the instrument(s)
- the presence or absence of alternative calibration activities

Table 1 CalibrEO levels of service

<table>
<tr><th></th><th>Aspect</th><th>Entry level quality verification</th><th>Express data calibration</th><th>Premium data calibration</th></tr>
<tr><td rowspan="8">Radiometry</td><td>Absolute radiometric</td><td>accuracy check</td><td>calibration</td><td>calibration</td></tr>
<tr><td>Dark current</td><td></td><td>calibration</td><td>calibration</td></tr>
<tr><td>Inter-band</td><td></td><td>verification</td><td>calibration</td></tr>
<tr><td>Interpixel</td><td></td><td>verification</td><td>calibration</td></tr>
<tr><td>Spectral</td><td></td><td>verification</td><td>calibration</td></tr>
<tr><td>constellation cross-calibration</td><td></td><td></td><td>calibration</td></tr>
<tr><td>multitemporal stability monitoring</td><td></td><td></td><td>monitoring</td></tr>
<tr><td>SNR</td><td>evaluation</td><td>evaluation</td><td>evaluation</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="6">Geometry</td><td>Absolute geolocation</td><td>check</td><td>correction</td><td>correction</td></tr>
<tr><td>Band to Band co-registration</td><td>check</td><td>correction</td><td>correction</td></tr>
<tr><td>Refinement of satellite Line of sight</td><td></td><td></td><td>correction</td></tr>
<tr><td>RPC model bias correction</td><td></td><td></td><td>correction</td></tr>
<tr><td>Correction of satellite attitude data</td><td></td><td></td><td>correction</td></tr>
<tr><td>MTF</td><td>analysis</td><td>analysis</td><td>analysis</td></tr>
</table>

6 PRESENT STATUS AND FUTURE STEPS

The CalibrEO service based calibration solution can be used to perform calibration activities of small satellite missions, with the aim of bringing product quality and consistency to a higher level. At this point, we are reaching out to potential partners to bring the system into practice. Early adopters will be valuable to the finetuning of the system, and to facilitate this, they will receive an increased level of expert support.

In parallel, the solution is being streamlined to bring software components into an optimal shape, which will make it more performant and more automated. This will improve the timeliness and free up time for experts to detect and look into any potential issues early on.

The calibration tools are continuously refined and extended, also for supporting the upcoming VITO-led IOD small platform hyperspectral mission CSIMBA. CalibrEO is not a fixed solution, but a dynamic toolset which is ready to incorporate new methodologies. These can include methods emerging from the scientific community, including AI approaches where they bring value. In parallel, we are also developing new and improved calibration methods within the AQUALIS project [17]. There we explicitly take into account the specific challenges for small mission (e.g; thermal and attitude stability), and focus on improvement which focuses on quality improvements

Overall, the CalibrEO Cal/Val service has everything it needs to become a valuable tool for bringing SmallSat product quality and consistency to a higher level.

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