ENMAP RADIOMETRIC INFLIGHT CALIBRATION

Harald Krawczyk[1], *Birgit Gerasch*[1], *Thomas Walzel*[1], *Tobias Storch*[2], *Rupert Müller*[2], *Bernhard Sang*[3], *Christian Chlebek*[4]

[1]Earth Observation Center (EOC), German Aerospace Center (DLR)
Rutherfordstr. 2, 12489 Berlin, Germany
[2]Earth Observation Center (EOC), German Aerospace Center (DLR)
Münchner Str. 20, 82234 Weßling, Germany
[3]Kayser-Threde GmbH
Perchtinger Str. 5, 81379 Munich, Germany
[4]Space Administration, German Aerospace Center (DLR)
Königswinterer Str. 522-524, 53227 Bonn, Germany

1. INTRODUCTION

EnMAP (Environmental Mapping and Analysis Program; www.enmap.org) is a German hyperspectral satellite mission with the declared goal to investigate the Earth's surface with a so far surpassing quality. The main scientific goals are the ecological assessment of vegetation for agriculture and forestry, of water bodies for coastal zones and inland waters and of land surfaces for geology and soil applications. Hyperspectral remote sensing is an efficient method to obtain the desired environmental information for relative large areas in regular time intervals. This is very useful to produce long term data series for the analysis of climatological behavior of the areas of interest. The satellite operates in a sun synchronous orbit in 650km height with a local time of descending node set to 11:00 h and with an across tilt opportunity, to improve the local revisit time. The instrument foreseen for the hyperspectral remote sensing is the so called **H**yper**s**pectral **I**mager (HSI), consists of two pushbroom spectrometers, covering the optical and near-infrared part of the electromagnetic spectrum. The 232 spectral channels range from 420nm to 2450nm with a resolution of 6.5nm in the visible up to 10nm in the near-infrared. The ground nadir pixel size is 30m, what generates a swath width of 30km with 1000 valid pixels per spectral channels. This relative good pixel resolution makes the instrument very attractive for a lot of local geo-ecological researches. All these data are operationally processed on-ground to standardized products and delivered to the international user community [1].

2. RADIOMETRIC CALIBRATION – GENERAL CONCEPT

The general approach of passive remote sensing in the optical part of spectrum bases on the concept, that the sun as a natural light source emits electromagnetic photons, which are interacting with matter by absorption, reflection and scattering processes in a specific way dependent of the kind and properties of the illuminated object.

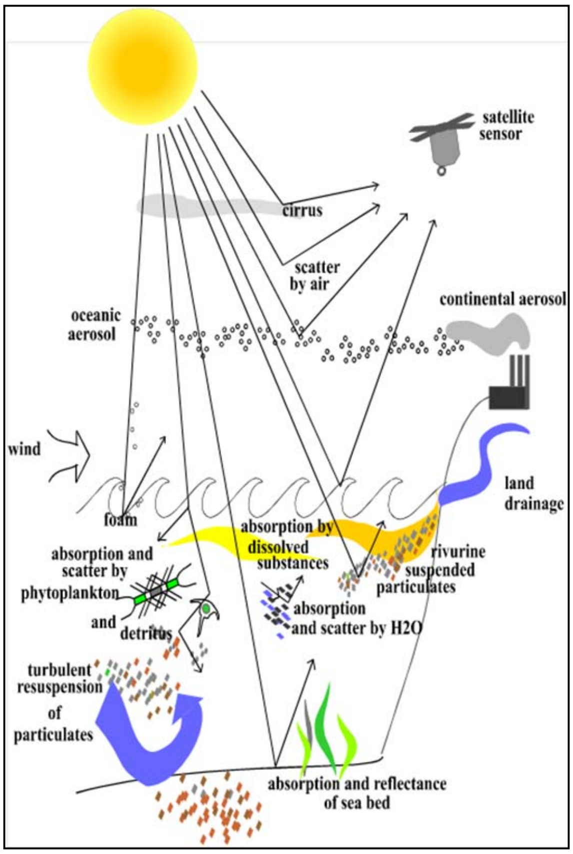

Figure 1: light – environment interaction (absorption, scattering, reflection)

The spectrally specific absorption and reflection properties of different objects transform the "white" spectrum from the sun into a "coloured" one at the recipient, e.g. the human eye or like in our case the detector in the spectral instrument. The higher the spectral resolution of the signal, the better the interpretation possibilities of the topic. An example from ocean colour remote sensing - a large number of spectral channels increases the number of discriminable water constituents (algae species), but also the interpretation accuracy. The sun light falling onto the 2-dimensional CMOS (Complementary Metal Oxide Semiconductor) detector in the HSI, induces voltages which are A/D-converted into counts. These simple numbers are the primary product (level-0) from the instrument. For any further interpretation now the relation between the measured counts C and the causal radiances L (spectral radiance densities) must be known. This mapping between the two sets Counts → Radiance is the so called radiance calibration rule. Due to the individuality of pixels, the calibration must be performed for every pixel on the CMOS detector array. The electronic and optical design of the HSI is so complex, that it is very hard to deduce the radiance to count transformation rule on a purely theoretical way. Therefore the approach to derive the information is much more heuristic. Since the desired radiometric calibration accuracy is below 5%, it very important to obtain a very high preflight characterization of the device, which will be performed under controlled laboratory conditions. The instrument will be illuminated with absolutely calibrated “etalon lamps”, changing their intensities. This can be done in different ways, e.g. varying the voltages or distances from lamp to instrument. The former can be distorted by nonlinear effects between voltage and brightness, so the second is often preferred, because the $1/r^2$ distance law holds very accurately. For every pixel one gets a data massive with corresponding counts and radiance levels, what on principle already gives the information about the calibration, with possible interpolation between the supporting points. Since this very uncomfortable due to the large data massive (1000 pixels in 232 spectral channels, with ~ 10-100 radiance levels) one aim of the instrument developer and engineers is to design the entire optical-electronic complex in such a way, that the dependence is linear. This drastically reduces the amount of information necessary for the radiometric calibration. It then leads to a simple linear calibration relation

$$L_{ij} = (C_{ij} – C_{ijdark})\, K_{ij} \qquad (1)$$

where L_{ij} and C_{ij} are the radiance and digital count in pixel (i,j) on the matrix, C_{ijdark} is the corresponding dark value, which occurs, when if no light is present). K_{ij} is the linear calibration coefficient matrix. In the case there are nonlinear residual effects exceeding the 5% accuracy request, additional corrections must be applied, e.g. in form of extra correction look-up-tables.

3. IN-FLIGHT CALIBRATION OF ENMAP

Although the preflight calibration has established the high radiance calibration accuracy, it is necessary to perform a regular in-flight check of the radiometric properties to achieve the product requirements during the complete mission lifetime. Due to air-vacuum transition and gravity release most significant effects are expected at the start of the mission. Therefore the frequency of calibrations is planned relatively high at this stadium. During routine operations aging effects are playing a more important role and therefore, calibration measurements will be performed with lower frequency [2]. For EnMAP are foreseen two on-board calibration concepts, allowing an absolute assessment of the radiometric values, another following relative change in the radiometric calibration properties.

The most frequent calibration measurements are the dark value measurements to obtain the actual C_{ijdark} in formula (1). They are carried out at begin and end of each data take and as an integral part of any calibration measurement. There are two kinds of dark measurements for HSI, one by closing the entrance shutter mechanism of the instrument and so blocking any incoming light. The second method is achieved by looking into deep space with opened shutter and instrument in normal measurement mode. This method will be used for comparison with closed shutter measurements and, in particular in the SWIR domain, to determine residual signals caused by emissions from the shutter mechanism.

For relative radiometric performance measurements there is used a main sphere with 100mm diameter, coated inside with white Spectralon® and equipped with a set of different light sources (halogen lamps and LEDs). All light sources are duplicated as cold redundancy. They are realizing a broadband homogeneous illumination covering the entire spectral range of EnMAP. The flux level may be adjusted by applying different currents to the lamps and LEDs. The sphere output port through the calibration optics and the shutter-calibration mechanism is imaged to the entrance slits of both VNIR and SWIR spectrometers. Regularly recording these measurements, comparing the values with pre-launch measurements and analyzing the trends, gives useful information about the relative radiance performance changes of the instrument during the mission. The values cannot be used for absolute calibration purposes, because the radiance properties of the lamps dependent from the electric currents are not known in adequate accuracy, since they are not absolutely calibrated etalon lamps. The seen doped sphere will be used for spectral calibration assessments.

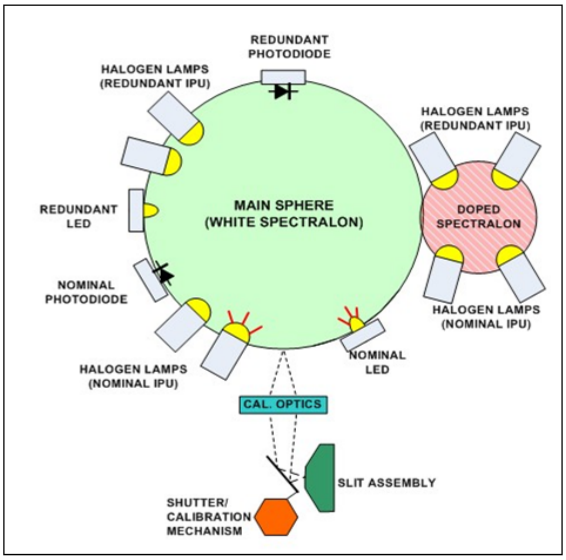

Figure 2 HSI in-flight calibration means (drawing © Kayser-Threde)

For an absolute assessment of the radiance accuracy the so called sun calibration is used. There is a large advantage to use the sun as the calibration source. The sun is also the light source for the aimed earth observation. For laboratory measurements one must know the spectral characteristics of the calibration lamp with high precision. Using the sun as a common source for calibration and observation measurements one can build a higher accurate reflectance value, $R = L/E0$, where E0 is the extraterrestrial sun irradiance. The precision of this value is higher than the (although small) uncertainty inherent in the sun irradiances.

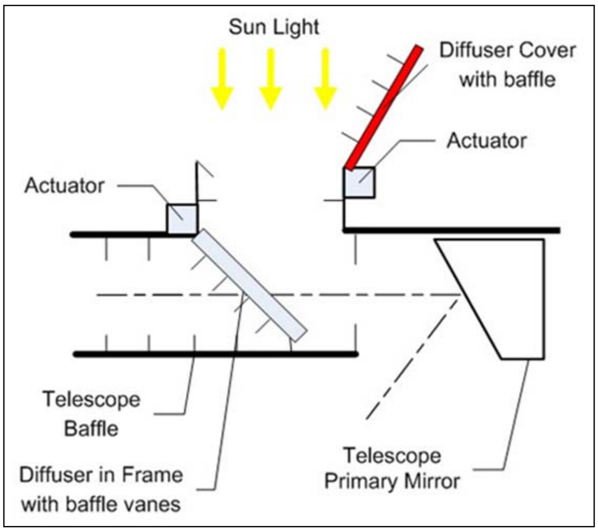

Figure 3 Solar diffuser setup for Sun calibration (drawing by © Kayser-Threde)

The extraterrestrial Sun irradiance reflected by the diffuser will be used for the absolute radiometric calibration in orbit. The diffuser material is a space proofed Spectralon®. Except for Sun calibration, the diffuser is stored in the frame of the entrance baffle system and the Spectralon® side is shielded by an additional cover to avoid exposure to radiation or particles. For Sun calibration measurement (see Figure 3) the cover is opened and the diffuser is moved into the entrance aperture of the telescope. To perform the recording, the satellite is working in precise orientation mode and pointing with the Sun calibration aperture towards the Sun. The analysis of sun measurements allows a recalculation of the calibration coefficients. If the desired radiometric accuracy will be overstepped, the actual calibration tables will be exchanged. A special question always rises regarding diffusor aging. This is difficult to monitor on-board without having a second redundant diffusor or trying to apply "vicarious calibration", what is completely different from on-board calibration philosophy. Experiences have shown that the main reason for aging is ultraviolet radiation appearing during the sun calibration cycle. To extend the life-time of the diffusor, there was developed a concept to dynamically control the time between successive sun calibration cycles. The available data base allows an estimation of the expected reliability time for actual calibration through trend analysis. So the mission control can decide to perform the measurements with higher frequency, if degradations are expected or to extend the time to the predefined maximal time gap.

4. REFERENCES

[1] T. Stuffler, H. Kaufmann, S. Hofer, K.-P. Förster, G. Schreier, A. Müller, A. Eckardt, H. Bach, B. Penne, U. Benz, R. Haydn, "The EnMAP hyperspectral imager – An advanced optical payload for future applications in Earth observation programmes," *Acta Astronautica*, 61(1-6), pp. 115-120, 2007.

[2] M. Schneider, R. Müller, H. Krawczyk, M. Bachmann, T. Storch, V. Mogulsky, and S. Hofer, "The Future Hyperspectral Imager EnMAP: Its In-Flight Radiometric and Geometric Calibration Concept," *ISPRS Congress 2012*, Melbourne, Australia, pp. 267-272, 2012.