IMAGE PROCESSING CHAINS FOR ALOS AND ENMAP DATA: SIMILARITIES AND DIFFERENCES

Tobias Storch [(1)], Peter Schwind [(1)], Gintautas Palubinskas [(1)], Rupert Müller [(1)], Mathias Schneider [(1)], Peter Reinartz [(1)], Christian Chlebek [(2)], Ferran Gascon [(3)]

[(1)] German Aerospace Center (DLR), Earth Observation Center, Münchner Str. 20, 82234 Weßling, Germany
[(2)] German Aerospace Center (DLR), Space Administration, Königswinterer Str. 522-524, 53227 Bonn, Germany
[(3)] European Space Agency (ESA), Via Galileo Galilei, 00044 Frascati, Italy
Email: tobias.storch@dlr.de

ABSTRACT

The Earth Observation Center (EOC) of DLR realizes processors for ALOS and EnMAP high-resolution optical remote sensing satellite missions. The functional and developmental similarities and differences of the DLR processors are analyzed. It turns out that despite or precisely because of pan-chromatic and multispectral versus hyperspectral imaging as well as the post- versus pre-launch establishment of the DLR processing chains, both activities strongly benefit from each other.

1. OVERVIEW

The Earth Observation Center (EOC) of DLR has long lasting experiences with the airborne and spaceborne acquisition, processing, and analysis of optical image data. Here, we investigate similarities and differences in the functionality of the DLR processors on the one hand and the development of the DLR processors on the other hand for the ALOS and EnMAP mission.

2. ALOS

ALOS (Advanced Land Observing System; www.eorc.jaxa.jp/ALOS/en/index.htm) was launched on 24 January 2006 and on 22 April 2011 a power generation anomaly caused an irreversible loss of communication. It had a target lifetime of five years.

ALOS is a Japanese satellite mission with two optical remote sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping and the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for disaster monitoring and precise land coverage observation. ALOS is part of the ESA third party mission program and in that context ESA has set up a ground segment using the JAXA operational processor. EOC is contracted by ESA to build an independent operational processor. Table 1 gives an overview of ALOS satellite, instrument, and processors [6].

From January 2008 to April 2009 EOC developed the prototype processors for ALOS optical data and from April 2012 to February 2013 the operational processors. Since February 2013, the processors are in Phase E.

For the prototype processor JAXA Level 0 data (raw data after restoration) served as input and products up to Level 1C (ortho-rectified including systematic and radiometric corrections) are generated for PRISM data and additionally to Level 2A (atmospheric corrections) for AVNIR-2 data. From these activities it was learnt, that apart from the fault-prone handing of a multitude of different inputs for JAXA Level 0 data, the systematic and radiometric corrections of the JAXA processors could not be improved by the DLR prototype processors. Therefore, for the operational processor JAXA Level 1b1 data (systematic and radiometric correction) that are also delivered to end users, serve as input and products up to Level 1C are generated. Furthermore, it was learnt, that apart from the absolute geo-location accuracy, the relative geo-location accuracy, which was independently validated to be within 10 m (linear root-mean-square-error) here, with respect to a standard reference image database is of major importance. Therefore, the application of a robust image matching technique is required for the operational processor. The Level 1B and Level 1C output formats are DIMAP for metadata including quality information and GeoTIFF for image data and the interfacing of the processor is compliant to that of the ESA multi-mission facilities [3].

3. EnMAP

EnMAP (Environmental Mapping and Analysis Program; www.enmap.org) is planned to be launched in 2017. It has a target lifetime of five years.

EnMAP is a German satellite mission with a Hyperspectral Imager (HSI) for measuring, deriving, and analyzing diagnostic parameters, which describe vital processes on the Earth’s surface encompassing agriculture, forestry, soil and geological environments, as well as coastal zones and inland waters. The imaging spectrometer consists of two 2-dimensional detector arrays, one for Visible and Near InfraRed (VNIR) and one for ShortWave InfraRed (SWIR). Jointly with the

German Space Operations Center the EOC is responsible for the establishment and operation of the EnMAP ground segment. EOC is contracted by DLR to build the operational processor for DLR. Table 1 gives an overview of EnMAP satellite, instrument, and processors [5].

Based on studies, since October 2008 EOC develops the operational processors for EnMAP data. Since August 2010, the processors are in Phase D.

Due to the fact that acquisitions cover up to 1020 km × 30 km, the Level 0 processor divides them into 30 km × 30 km tiles in order to simplify the data handling also on end users' site. However, information relevant to or based on the complete acquisition, namely to achieve consistency between neighbouring tiles, are annotated to each Level 0 product, that are long-term archived. These are information on dark current measurements, which are performed before and after each acquisition, to ensure the high radiometric accuracy, geometric sensor model improvements based on image matching techniques to robustly improve the pointing knowledge from 100 m (absolute) to 30 m (relative), as well as water vapour and aerosol optical thickness maps for an accurate atmospheric correction. The Level 1A/B processor inputs are Level 0 product together with corresponding valid calibration tables as well as orbit and attitude products, whereas for the Level 1C and Level 2A processor the input is solely the output of the previous processor [4].

4. SIMILARITIES AND DIFFERENCES

We first consider the functional and second the developmental similarities and differences.

4.1. Functional Aspects

For the functional similarities and differences of the DLR processors we analyze the combination of prototype and operational processors for ALOS with the processors for EnMAP.

We first consider an example concerning the co-registration in detail and afterwards the overall image processing chain as well as the Level 1A/B (systematic and radiometric correction), Level 1C (geometric correction), and Level 2A (atmospheric correction) processing.

4.1.1. Example

During the detailed design activities for the fully automatic processors for HSI it was learnt, that due to the short-term – in combination with the long-term – behaviour of the satellite an increased effort in geometric processing is necessary to achieve a co-registration accuracy of 0.2 pixels between the VNIR and SWIR bands. The design of the HSI leads to a time separation of approximately 86 milliseconds between the VNIR and SWIR bands and means that the SWIR scans the same area on ground about 20 lines delayed with respect to the VNIR.

To solve the HSI co-registration issue in the geometric sensor model, experiences based on a similar separation of about 5 lines between odd and even pixels for AVNIR-2 were proven to be useful. Figures 1 and 2 illustrate the co-registration issues for AVNIR-2 (real mission data) and HSI (simulated mission data).

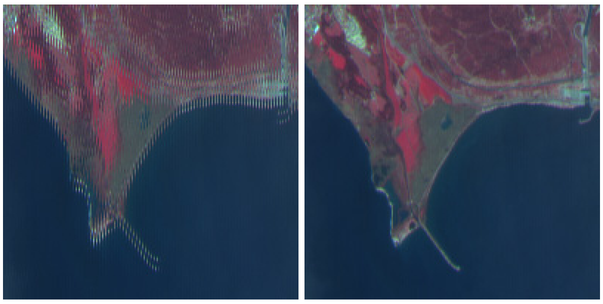

Figure 1. ALOS AVNIR-2 real mission data (left: no co-registered, right: co-registered)

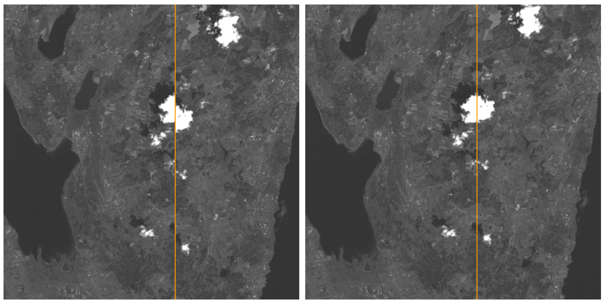

Figure 2. EnMAP HSI simulated mission data (left: no co-registered, right: co-registered)

To be more precise, the special co-registration procedure between odd and even image parts to be performed prior to the geometric correction of the AVNIR-2 data is very similar as between VNIR and SWIR images parts of the HSI data. Namely, let X and Y be the object coordinates (for example longitude and latitude or UTM coordinates) calculated for odd/VNIR and even/SWIR pixels using the sensor models and u the image column and v the image row. Then the mapping between pixels in image space and locations in object space can be approximated by a linear transformation.

For the odd/VNIR pixels:

$$u_{odd/VNIR}(X,Y) = a_1^1 + a_2^1 \cdot X + a_3^1 \cdot Y + a_4^1 \cdot X \cdot Y$$
$$v_{odd/VNIR}(X,Y) = b_1^1 + b_2^1 \cdot X + b_3^1 \cdot Y + b_4^1 \cdot X \cdot Y$$

And for the SWIR pixels:

$$u_{even/SWIR}(X,Y) = a_1^2 + a_2^2 \cdot X + a_3^2 \cdot Y + a_4^2 \cdot X \cdot Y$$
$$v_{even/SWIR}(X,Y) = b_1^2 + b_2^2 \cdot X + b_3^2 \cdot Y + b_4^2 \cdot X \cdot Y$$

The four sets of linear equations can be solved by least squares adjustment in order determine the unknowns. Therefore the mapping between the odd/VNIR image parts and the even/SWIR image parts can be described by the linear equations:

$$u_{odd/VNIR}(u_{even/SWIR}, v_{even/SWIR}) = c_1 + c_2 \cdot u_{even/SWIR} + c_3 \cdot v_{even/SWIR} + c_4 \cdot u_{even/SWIR} \cdot v_{even/SWIR}$$
$$v_{odd/VNIR}(u_{even/SWIR}, v_{even/SWIR}) = d_1 + d_2 \cdot u_{even/SWIR} + d_3 \cdot v_{even/SWIR} + d_4 \cdot u_{even/SWIR} \cdot v_{even/SWIR}$$

This means that the pixels of the odd/VNIR image parts can be mapped to the image space of the even/SWIR image parts. Because this linear relationship is not valid for the whole scene the image is subdivided in a grid of 100 × 100 pixels, where the linear relation holds with sufficient accuracy.

4.1.2. Overall Image Processing Chain

Figure 3 illustrates the overall processing chains of DLR. The interfaces are based on the ESA multi-mission facility interface and the XDibias file format and they are similar between the processors.

Since DLR is responsible for the complete EnMAP ground segment it is also in charge for the Level 0 Processor to generate for long-term archived Level 0 Products including the provision of catalogue information.

With only pan-chromatic data important correction parameters of the atmosphere such as AOT (aerosol optical thickness) and land-water or cloud coverage masks cannot be appropriately determined as well as advanced correction methods such as haze removal cannot be appropriately applied. Therefore, atmospheric correction is not applied to PRISM but to AVNIR-2 and HSI.

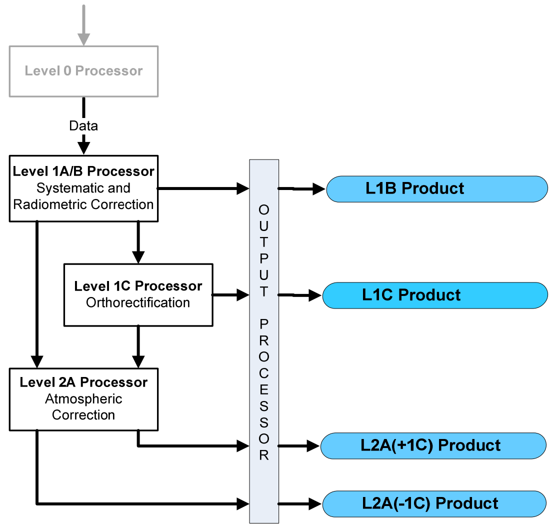

Figure 3. Processing Chain for ALOS AVNIR-2 and EnMAP HSI

4.1.3. Level 1A/B Processing

The systematic and radiometric correction steps are not comparable. This holds not only because PRISM and AVNIR-2 are based on CCD (charge-coupled device) technology and HSI is based on CMOS (Complementary Metal Oxide Semiconductor) and MCT (Mercury Cadmium Telluride) technologies but also the requirements concerning the spectral and radiometric accuracies including the calibration equipment at the satellite lead to differences in the correction approaches for pan-chromatic and multispectral compared to hyperspectral data. E.g. for HSI it includes the consideration of spectral and spatial straylight as well as a pixel based response non-linearity correction. And e.g. temperature variances of the detectors are taken into account for PRISM and AVNIR-2 and for PRISM also de-convolution methods to improve the image quality are applied.

4.1.4. Level 1C Processing

The geometric correction steps are comparable. The sensor modelling of PRISM, AVNIR-2, and HSI are similar since they all are push-broom sensors, have similar geometric resolutions and swaths, off-nadir pointing capabilities, both apply GPS (global positioning system) and STS (star tracker system), and image matching techniques to enhance the sensor model for an improved relative geo-location accuracy are used, e.g. necessary for change detection algorithms. The further steps such as DEM (digital elevation model) intersection, map projection, and resampling are equal.

Geometric correction is based on the DLR software ORTHO [1].

4.1.5. Level 2A Processing

The major difference in the atmospheric correction is that for the HSI different codes for applications over land and water are applied. However, concerning the atmospheric correction steps over land some aspects are comparable but with an improved accuracy for HSI making use of its wider spectrum and narrower bands compared to AVNIR-2. Such aspects are the determination of the AOT (aerosol optical thickness), haze removal, land-water or cloud coverage mask generation, or the surface reflectance estimation. And some aspects are not comparable because of HSI versus AVNIR-2 bands. Such aspects are the determination of the WV (water vapour) and cirrus removal. Atmospheric correction is based on the DLR software ATCOR [2].

4.2. Developmental Aspects

Beside the functional similarities and differences we consider the developmental ones. For DLR's ALOS processors the development is performed based on existing data and analyses since the satellite was in-orbit and therefore there were no possibilities to influence the interfaces. Whereas for DLR's EnMAP processors the development is performed based on simulated data and analyses since the satellite is realized in parallel with the processors including interaction between space and ground segment, and therefore with the possibility to influence the interfaces. Namely, the development of the processors benefited from each other, e.g. ALOS from EnMAP: high-quality documentation, consistent development methodology, and experienced efficient team – EnMAP from ALOS: experiences on other optical instruments and their algorithms, robustness of image matching in operations, and integration of processors to a processing chain.

5. CONCLUSIONS

We can conclude that even if there are differences in the functionalities of the ALOS and EnMAP processors, e.g. pan-chromatic and multispectral versus hyperspectral, and in the development of the processors, e.g. real mission data versus simulated mission data, there are various similarities, e.g. the co-registration correction, which result in benefits for each other.

6. ACKNOWLEDGEMENTS

Supported by the DLR Space Administration with funds of the German Federal Ministry of Economic Affairs and Technology on the basis of a decision by the German Bundestag (50 EE 0850).

7. REFERENCES

1. Müller, R., Krauß, T., Schneider, M. & Reinartz, P. (2012). Automated Georeferencing of Optical Satellite Data with Integrated Sensor Model Improvement. *Photogrammetric Engineering and Remote Sensing*, **78**(1), 61-74.

2. Richter, R. (2011). Atmospheric Correction Methods for Optical Remote Sensing Imagery of Land. In: *Advances in Environmental Remote Sensing Remote Sensing Applications*, Taylor & Francis, United Kingdom, pp 161-172.

3. Schwind, P., Schneider, M., Palubinskas, G., Storch, T., Müller, R. & Richter, R. (2013). Processors for ALOS Optical Data: Deconvolution, DEM Generation, Orthorectification, and Atmospheric Correction. *IEEE Transactions on Geoscience and Remote Sensing*, **47**(12), 4074-4082.

4. Storch, T., Bachmann, M., Eberle, S., Habermeyer, M., Makasy, C., de Miguel, A., Mühle, H. & Müller, R. (2013). EnMAP Ground Segment Design: An Overview and its Hyperspectral Image Processing Chain. In: *Earth Observation of Global Changes (EOGC)*, Springer-Verlag, Germany, pp 49-62.

5. Stuffler, T., Kaufmann, C., Hofer, S., Förster, K.-P., Schreier, G., Mueller, A., Eckardt, A., Bach, H., Penné, B., Benz, U. & Haydn, R. (2007). The EnMAP hyperspectral imager—An advanced optical payload for future applications in Earth observation programmes. *Acta Astronautica*, **61**(1-6), 115-120.

6. Tadono, T., Shimada, M., Murakami, H. & Takaku, J. (2009). Calibration of PRISM and AVNIR-2 Onboard ALOS "Daichi". *IEEE Transactions on Geoscience and Remote Sensing*, **47**(12), 4042-4050.

Mission	ALOS		EnMAP
Space Agency	JAXA, Japan		DLR, Germany
Target lifetime	2006-2011		2017-2022
Satellite (mass, dimension of main body)	4000 kg, 6.2 × 3.5 × 4.0 m^3		1000 kg, 2.0 × 1.8 × 1.7 m^3
Orbit (type, inclination, hight, period, local time at equator, repeat cylcle)	Sun-synchronous, 98.16°, 697 km, 5924 s, 10:30, 46 days repeat cycle		Sun-synchronous, 97.96°, 653 km, 5856 s, 11:00, no repeat cycle
Instrument name	PRISM	AVNIR-2	HSI (2 instruments)
Instrument type	panchromatic, triple view: 0° (nadir view), ± 23.8° (along-track)	multispectral: blue, green, red, near infrared	hyperspectral: Visible and Near InfraRed, ShortWave InfraRed
Off-nadir pointing in across-track	≤ 1.5°	≤ 44°	≤ 30°
Revisit frequency	≤ 46 days	≤ 46 days, ≤ 2 days (≤ 44° off-nadir)	≤ 4 days (≤ 30° off-nadir), ≤ 21 days (≤ 5° off-nadir)
Spatial resolution	2.5 m	10 m	30 m
Swath	35 km (70 km nadir view)	70 km	30 km
Spectral resolution	1 band	4 bands	228 bands
Spectral range	520-770 nm	420-500 nm, 520-600 nm, 610-690 nm, 760-890 nm	420-2450 nm (continuous)
Radiometric resolution	8 bit	8 bit	14 bit
Processing levels	L1A*, L1B, L1C	L1A*, L1B, L1C, L2A*, L2A w/o orthorectification*	L0, L1B, L1C, L2A, L2A w/o orthorectification
DEM	Global DEM based on ASTER data		
REF	Combination of EU37 REF based on SPOT and IRS-P6 data and Global REF based on Landsat data (Usage of Sentinel-2 data under consideration for EnMAP)		

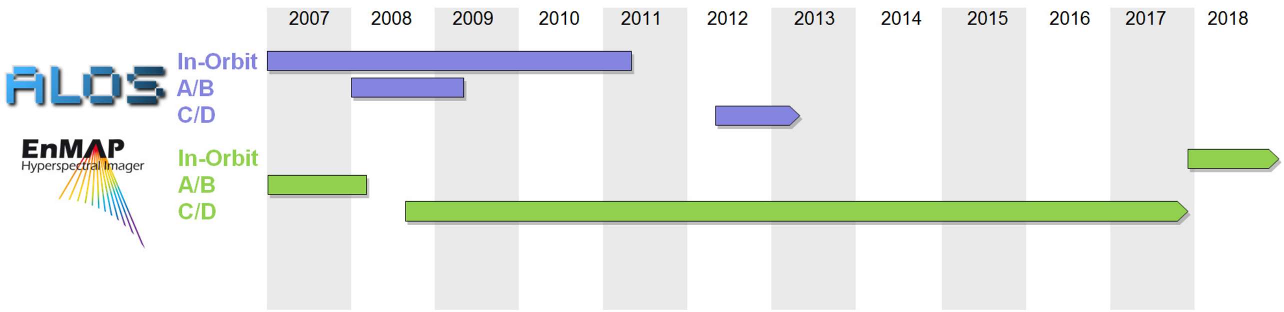

*Table 1. ALOS and EnMAP in a nutshell (*not part of operational processor but part of prototype processor)*