CALIBRATION CONCEPT FOR THE AIRBORNE PRISM EXPERIMENT (APEX)*

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ABSTRACT

The development of the Airborne PRISM Experiment (APEX) has been supported by the European Space Agency (ESA) in view of an appropriate data simulator of the future LSPIM mission. The calibration of the APEX instrument will be performed using a standardized laboratory calibration procedure, where spectral response, geometric response, as well as gain and offset values will be determined. Additionally, an in-flight calibration consisting of built-in means and vicarious calibration approaches will be performed. All calibration related parameters are stored in a database for later reconstruction of the calibration process as well as for drift and trend analysis. A processing chain is defined for appropriate data preparation which allows an efficient generation of all the calibration parameters and a fast processing of all acquired data from raw format to calibrated radiances. Sensor simulation, standard quality control procedures, and in-flight validation campaigns finally give a characterization of the accuracy of the calibration, its trends, and the reliability of the delivered image data products.

1.0 INTRODUCTION

From 1997 the Airborne PRISM Experiment (Itten et al., 1997) was supported by the European Space Agency ESA. The instrument will be an airborne hyperspectral simulator for the planned PRISM instrument (Posselt et al., 1997), the payload on one of ESA's planned Earth Explorer Mission, the Land Surface Processes Interactions Mission (LSPIM). APEX will scan the earth's surface using a 'pushbroom' imager with up to 300 spectral bands between 400 and 2500 nm at a flight altitude of 4 to 10 km. The ground pixel size will be 2-5 m with approximately 1000 pixels per scan line at a spectral resolution of 5-10 nm. The sensor will be completed by the year 2002. During this period (Phase B and C/D), the Processing and Archiving Facility (PAF) will be set up and implemented simultaneously to the hardware construction of the instrument.

The first major step to be performed in the PAF before the data can be processed consistently is the downloading and segregation routine, where the data are registered and converted to appropriate data formats. Second, the raw digital numbers as measured by the imaging instrument have to be calibrated to physical units. The whole calibration process consists of the laboratory and optional in-flight comparison of the instrument output to known sources, the creation of standard calibration files, and the subsequent transfor-

* Presented at the Fourth International Airborne Remote Sensing Conference and Exhibition, June 21st - 24th, 1999, Ottawa, Canada

mation of the image data to physical units. The following sections give details about all necessary processing steps between the imaging spectrometer hardware and the delivery of level 1D calibrated image data.

2.0 CALIBRATION STRATEGY

Based on the inherent flexibility of the APEX instrument to integrate it into the aircraft within less than three hours, frequent laboratory calibration cycles are foreseen to monitor the stability of the instrument. The key requirement for it is a total radiometric accuracy of ≤ 2% at any time, traceable to a primary standard. This requirement may result in supporting in-flight calibration means. Pushbroom scanners do not have the ability to scan a reference source for each detector element and scanline such as whiskbroom scanners. The calibration strategy therefore needs special attention as long as the instrument is on its carrier.

2.1. LABORATORY CALIBRATION

The laboratory calibration setup of APEX includes radiometric, spectral (or wavelength), and geometric calibration. The radiometric calibration is performed using an integrating sphere which is traceable to NIST. This sphere will also be used to intercalibrate a sphere that is built into the instrument itself by establishing it as a secondary standard. The traceability of the instrument sphere is in the range of ≤ 2% to the laboratory sphere.

The spectral calibration aims at a center wavelength accuracy of 0.2 nm and the combination of geometric and spectral calibration will result in the knowledge of the spectral sampling width at a relative accuracy of 2% (see Schaepman (1998) for details on spectral and radiometric calibration).

Finally, the geometric calibration of the instrument will resolve the frown and keystone effects of the sensor that will be in the magnitude of 0.1 pixels.

2.2. IN-FLIGHT CALIBRATION

In the aircraft, the instrument is operated in a closed housing where pressure and temperature are kept constant. Before an image run is acquired (a run here typically indicates a continuos recording of up to 80’000 scanlines), the internal depointing mirror is directed into a built-in integrating sphere. This sphere is cross-

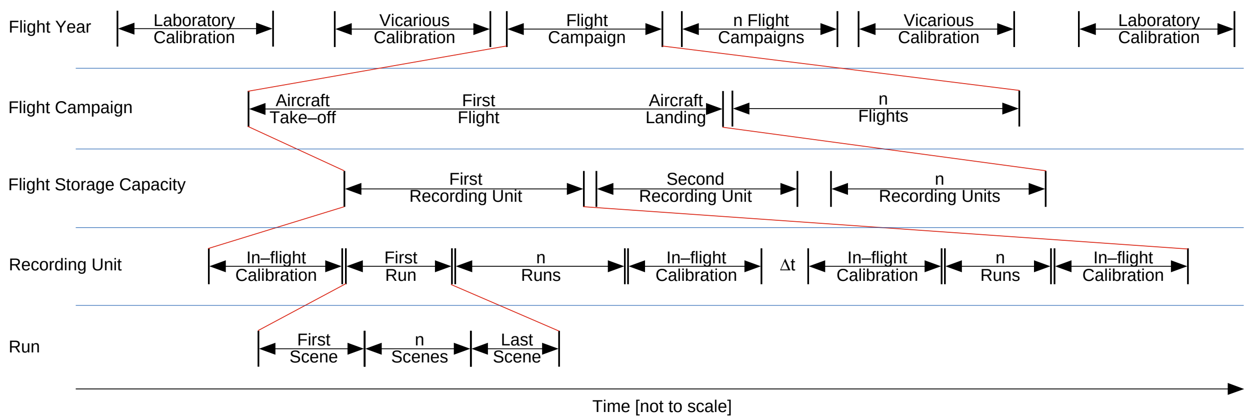

Figure 1. Data Acquisition and Calibration Terminology for APEX

calibrated with the laboratory devices and from the point of view of the APEX seen as a secondary calibration source. The terminology of the data acquisition and the schedule of the calibration tasks during a flight season are depicted in Figure 1.

After the scanning of some lines of dark signal and looking into the built-in integrating sphere, the instrument will acquire the normal scene radiances. Before the recording devices are being shut off again, the integrating sphere and the dark signal are scanned again. This process will allow to reconstruct possible drifts of the instrument calibration during the data acquisition.

During the flight year, vicarious calibration experiments will help to support the evaluation of the expected performance in the aircraft as well obtaining an estimate for operating the instrument in two different environments.

3.0 RAW DATA PROCESSING AND CALIBRATION

3.1. IMAGE DOWNLOAD AND SEGREGATION

The APEX sensor data acquired during any data take is originally stored on high capacity discs in sequential order (BIP, Band Interleaved by Pixel). The readout to the Processing and Archiving Facility (PAF) is done by hooking up the discs directly to the PAF computing hardware. The download includes a segregation process, where in a first step recording units (e.g. physical hard drives with data) are read from the discs and split into two entities: in-flight calibration data and runs. The runs again are subdivided into scenes, where

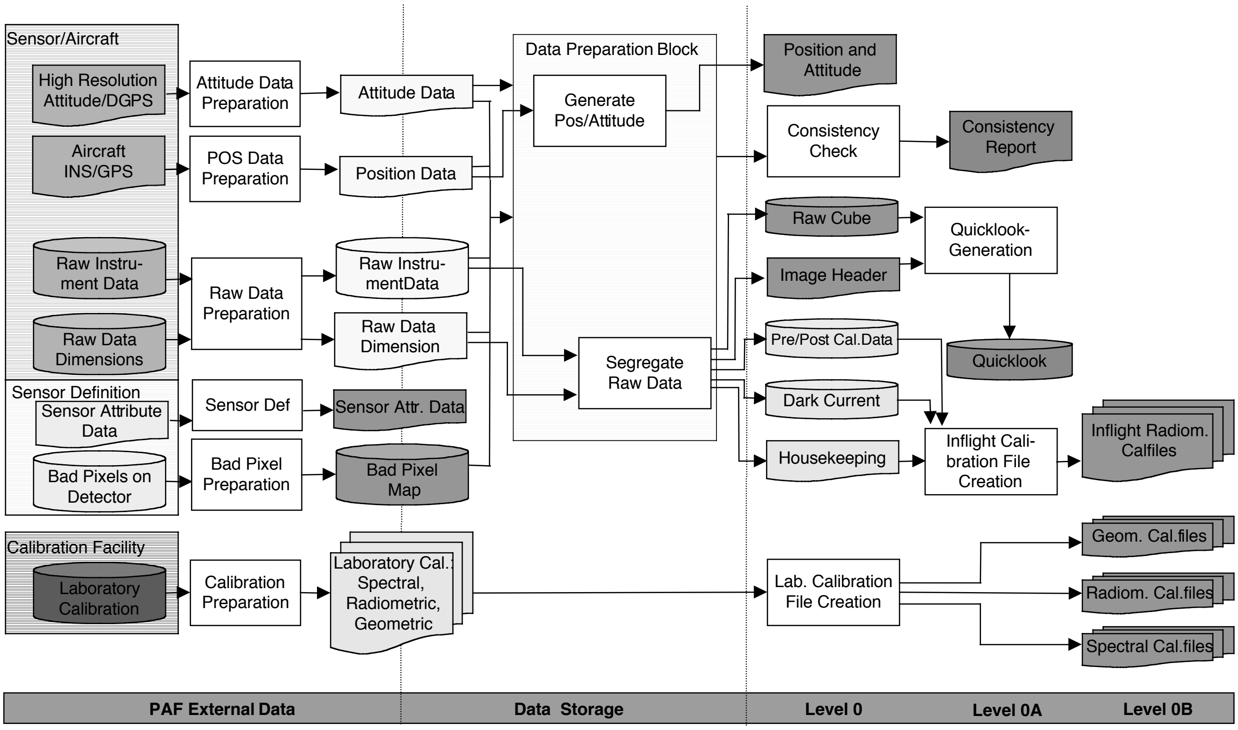

Figure 2. Level 0 Data Preparation Process

the first n scenes will have 1500 scanlines each and the last scene will complete the run. A scene is then not subdivided anymore. All coregistered spectral channels of one scene are then represented in a data concept called ‘data cube’ or ‘cube’ (see Figure 2).

The image header data is stored into the PAF database for each scene. All subsequent access to any type of data is then administrated through the PAF database.

The main task of the data segregation and download is the preparation of the file formats and scene related information for the further processing. The radiometry remains unchanged throughout the level 0 processing. After the segregation the following information is available in distinct data entities (compare Figure 2):

- Raw image cube: max. 16 bit digital numbers of the original measurements of the sensor in unchanged byte interleaved representation (BIP),
- Image header: header information related specifically to the cube, containing dimensions and basic attribute data (e.g. date, sensor, channel interleave, description),
- Pre/post run calibration data: data taken by the sensor shortly before and after the scene scan process. These data are registered on shutter closed and by looking at a sensor internal calibration source,
- Dark current: measurements on the obscured part of the detector (up to 50 pixels on each side of the detector) for dark current drift monitoring, and
- Housekeeping: synchronization information, temperatures of the detectors and further status reports per scanline.

The position and attitude data is processed in a separate data stream. It therefore has to be prepared in a dedicated module and is concatenated to one file per cube containing all positional and angular data per scanline.

General sensor attribute data such as the field of view, the PSF characteristics, and the amount and distribution of bad pixels on the detector are initially known from the manufacturer and are not subject to change during normal instrument operation. They are therefore stored within the database in quasi-permanent tables, which are updated whenever the sensor or the detector is upgraded or changed in its characteristics.

3.2. LEVEL 0 DATA PREPARATION

After downloading and segregation some preparations have to be made to most of the data to allow a consistent further processing.

Two final data products are generated automatically for control purposes:

- A consistency report is automatically created from the raw image data to register missing data elements and possible recording failures.
- A quicklook file is processed for the visual assessment of the acquired scene. The quicklook will be immediately available for download to the end users.

The second preparation process deals with the creation of standardized calibration files. Three types of calibration files can be stored within the APEX PAF: spectral response information, the geometric PSF, and radiometric calibration constants.

Spectral response and geometric PSF calibration can only be measured in the laboratory. The corresponding files contain information about the detector response functions (spectral and geometric across track) and the geometric footprint of the sensor along track.

The radiometric calibration files may origin from two different sources. Quasi-continuous gain characteristics can be measured in the laboratory. They are parametrized to obtain calibration gain and offset values and a linearity measure of the response. The second source for radiometric calibration are the in-flight measurements. Only two radiance calibration levels are measured in-flight (shutter closed and built-in calibration source). Thus, no result on response linearity can be validated from these measurements. These values are transformed directly to calibration gain and offset values per detector element. This information will be used in conjunction with a calibration drift model and compared to the laboratory measurements and is used for validation purposes.

3.3. LEVEL 1 CALIBRATION PROCESS

All system calibration steps are performed in the Level 1 processing chain as depicted in Figure 3. They include the calibration of position and attitude data to absolute angles and coordinates of the airplane on a separate track.

The main task is the calibration of the scene from digital numbers to radiances [W/(m^2 sr nm)] by applying the corrections for spectral, spatial and radiometric distortions (as given above).

3.3.1 Radiometric Calibration

The raw digital image numbers are transformed to image radiance values L_{im} using a simple calibration gain/offset model:

$$L_{im} = \left((\mathrm{DN} - \mathrm{DC}_{x,\lambda})\frac{1}{g_{x,\lambda}}\right)s, \tag{1}$$

where $\mathrm{DC}_{x,\lambda}$ is the dark current estimated at detector level and $g_{x,\lambda}$ is the calibration gain. The scaling factor s is introduced to fit the whole dynamic range of radiance into a 2 byte integer word. Both constants are provided per detector pixel, resulting in 1000 x 300 x 2 different calibration constants for the sensor. Non-

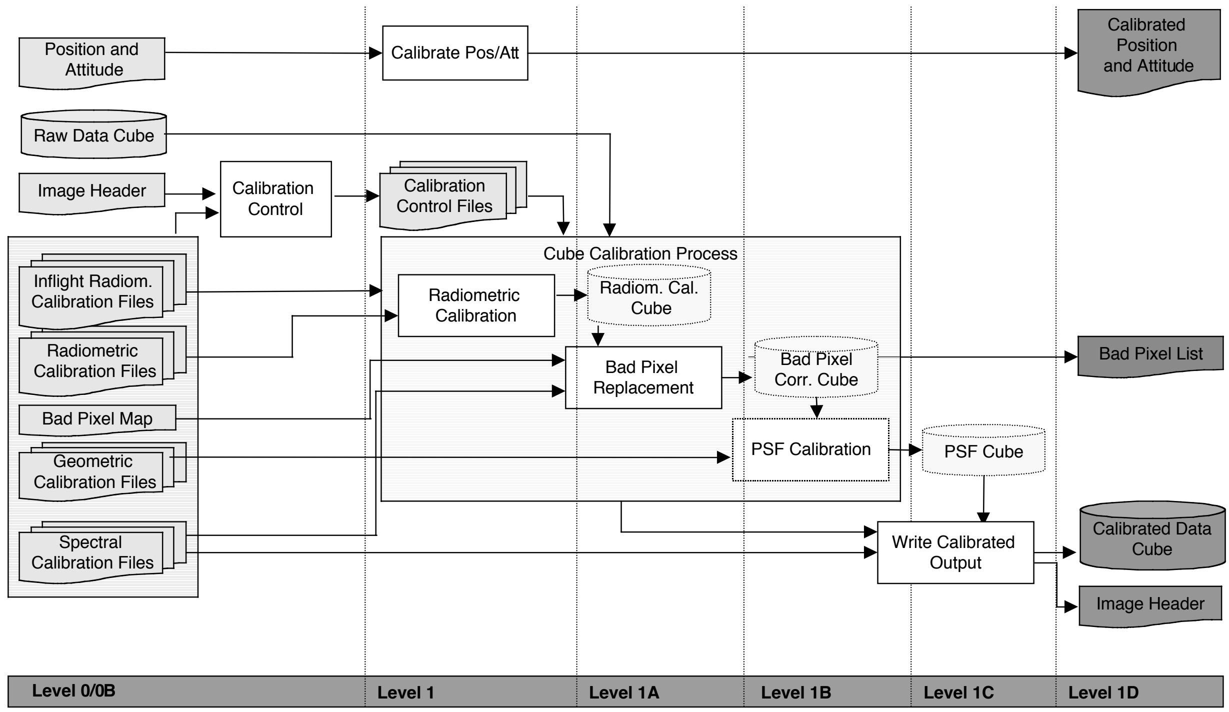

Figure 3. Level 1 Processing Concept

linear gain responses are not considered here, because the sensor specifications exclude nonlinearities.

3.3.2 Bad Pixel Replacement

The bad pixel requirement for APEX is defined at the electronics level and assumes no bad pixels on the detector. Anyhow, bad pixels will be present (approx. 0.5 – 2 % of all detector elements may be malfunctioning) and this effect is considered using two different strategies.

A complete replacement has to be done if bad pixels produce missing or wrong data elements. Spectral interpolation is preferred for that process since natural spectra usually are highly correlated in the spectral domain, while they often vary with discrete features present in the spatial domain. The replacement may be repeated after atmospheric correction to avoid the effects of sharp atmospheric features. The process is based on the bad pixel map supplied by the manufacturer.

Spectral resampling may have to be done if spectral binning is used on the detector to avoid missing data elements. If some of the binned pixels are bad, the center wavelength of the binned measurement is shifted substantially away from the intended center wavelength. It therefore has to be resampled using the signal of the spectrally neighboring channels, preferably by a resampling procedure similar to the one proposed by Schläpfer et al. (1999).

3.3.3 Point Spread Function Correction

The overall point spread function (PSF) describes the blurring of the spatial information by the electro-optical parts of the system and the movement of the airplane. It can be described as a convolution function and influences the image quality significantly. This effect can be corrected with filter techniques using the laboratory calibrated PSF together with movement models at some point.

Because of the enormous data amount to be processed for each scene, only a simple deconvolution algorithm can be applied, otherwise processing time will exceed user expectations by far. Detailed information of deconvolution and its associated performance issues are discussed in Janssen (1997).

4.0 SENSOR SIMULATION AND QUALITY CONTROL

4.1. SENSOR SIMULATION

There are three general methods to model a new sensor based on existing remote sensing instruments: The first one is to use simple mathematical/physical approaches to describe the interactions between the observed object and the sensor specific behavior. The second is the optimization of the instrument (or parts of it) in a laboratory, and the third one is to combine all the knowledge about the sensor, the object, its environment and the processing software into a computer model and to describe it as one system. All of these approaches have their own advantages and disadvantages. The last approach is best suited for calibration purposes in order to test the performance of the processor using modelled input data.

4.1.1 The SENSOR Model

The simulation tool SENSOR (Software ENvironment for the Simulation of Optical Remote sensing systems) is built in cooperation between the German Aerospace Center and the Remote Sensing Laboratories. The following problems could be solved with SENSOR (Börner et al., 1999):

- Optimization of sensor parameters and observation conditions for a certain scientific/commercial task,
- Adaptation and evaluation of the processing algorithms such as calibration,

- Testing of the processing chains, and
- Error and accuracy estimations.

SENSOR is used to substantiate the APEX specifications, to check the system parameters suggested by the industrial partners, to test the processing and archiving facilities (PAF), and to evaluate software for the final data processing.

SENSOR consists of two big parts. The first one describes the sensor environment, the second one the remote sensing system itself. The environment model includes the observed object (e.g. the physical surface), the source of the radiance (e.g. sun) and the atmosphere. Using the knowledge of the sensor design and a flight path the geometrical relations between object and sensor are described with the help of a ray-tracing algorithm. Furthermore, the influence of the atmosphere is considered using pre-calculated MODTRAN lookup-tables to determine the at-sensor-radiance for a representative set of atmospheric parameters. The next part simulates the sensor itself the optics and the electronics. Pre-calculated lookup-tables are used to model effects like distortion, shading, attenuation etc. The electronic part will be described by modules which deal with the most important noise sources, the analogous signal processing chain and the digitization of the signal. It results in a simulated APEX data cube.

The result of a simulation should be a configuration of the sensor-environment system, which is optimal to test a specific calibration problem.

4.2. QUALITY CONTROL PROCEDURES

Another way to evaluate the calibration quality is based on the image content itself. It includes standard statistical image analysis to obtain channel by channel quality control values. Such procedures are e.g. the creation of cross correlation matrices, the comparison of histograms, the automatic search for physically impossible data values, or image based SNR estimation. The latter will be made based on the most homogeneous areas in an image in comparison to the average signal. Furthermore, procedures are defined which allow the detection of bad pixels in addition to the sensor description files.

Validation campaigns (Strobl et al., 1997) are planned for acceptance tests and for regular monitoring of the instrument in-flight reliability. Spectroradiometric field measurements are compared to image derived reflectance values to obtain results on the quality image data preprocessing and calibration. Such validation describes the overall accuracy of the radiometric calibration combined with the level 2 processing chain (as shown for APEX in Schläpfer et al., 1998). Level 2 includes the correction of the at sensor radiance values to ground reflectance by considering most of the atmospheric and geometric effects.

5.0 CONCLUSIONS

A proof-of-concept has been given in order to include the whole calibration process from laboratory to the APEX sensor calibration as well as the treatment of the image data within the processing and archiving facility. It includes the consideration of radiometric effects, geometric optical PSF distortions as well as spectral misregistrations. All these effects can be determined and will be fed into the overall uncertainty estimation of the calibration stability and accuracy, and can finally be given to the end users in a quantitative form. However, it is currently not possible to correct all sensor related effects in an efficient way through the standard calibration process chain because of restrictions in computing power and troughput considerations. It is therefore planned to provide the alternative correction methods of e.g. spectral deconvolution to the end users as precompiled code (e.g. in Java or similar platform independent technologies) together with the appropriate attribute data such as the calibration files.

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