ABSTRACT

Recently, a joint Swiss/Belgian initiative started a project to build a new generation airborne imaging spectrometer, namely APEX (Airborne Prism Experiment) under the ESA funding scheme named PRODEX. APEX is a dispersive pushbroom imaging spectrometer operating in the spectral range between 380 - 2500 nm. The spectral resolution will be better then 10 nm in the SWIR and < 5 nm in the VNIR range of the solar reflected range of the spectrum. The total FOV will be ± 14 deg, recording 1000 pixels across track with max. 300 spectral bands simultaneously. APEX is subdivided into an industrial team responsible for the optical instrument, the calibration homebase, and the detectors, and a science and operational team, responsible for the processing and archiving of the imaging spectrometer data, as well as for its operation. APEX is in its design phase and the instrument will be operationally available to the user community in the year 2006.

Keywords: APEX, imaging spectrometry, airborne imaging spectrometer, hyperspectral, environmental monitoring

1. INTRODUCTION

The Remote Sensing Laboratories (RSL) identified in 1996 the necessity to initiate a project that concentrates on the definition of an airborne imaging spectrometer which could represent a precursor mission to future planned spaceborne imaging spectrometers. This project includes the definition of an airborne dispersive pushbroom imaging spectrometer (named ‘Airborne Prism Experiment’ (APEX)) that will contribute to the preparation, calibration, validation, simulation, and application development for future imaging spectrometer missions in space, as well as to the understanding of land processes and interactions at a local and regional (or national) scale, in support for global applications. The APEX project is implemented through ESA PRODEX (European Space Agency PROgramme de Développement d’EXpériences Scientifiques), which aims at providing funding for the industrial development of scientific instruments or experiments proposed by institutes or universities, which have been selected by ESA for one of its programs in the
various fields of space research (e.g., Earth observation). ESA provides administrative, financial-management, and technical support\(^4\).

The APEX project started in 1997 by performing a feasibility study on the design of an imaging spectrometer\(^5\), which resulted in a first performance definition\(^6\), and a subsequent design phase\(^7\). Currently, various parts of APEX are being finalized in design, breadboarding and performance analysis of the processing chain\(^8,9,10\) and the subsequent construction of the instrument is planned to be final in 2006.

## 2. APEX SPECIFICATIONS

The APEX system has been specified as a combination of user requirements, which have been derived from a survey of imaging spectroscopy applications\(^11\) and a subsequently derived forward performance model based on these requirements\(^12\). Applications cover all varieties of environmental remote sensing targets and research, such as vegetation and soil. APEX’s performance will also enable to contribute to other major applications, such as coastal and inland water monitoring, atmospheric and alpine research.

<table>
<thead>
<tr>
<th>Specified Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of View (FOV)</td>
<td>(\pm 14^\circ) deg</td>
</tr>
<tr>
<td>Instantaneous Field of View (IFOV)</td>
<td>0.48 mrad</td>
</tr>
<tr>
<td>Flight altitude</td>
<td>4'000 - 10'000 m.a.s.l.</td>
</tr>
<tr>
<td>Spectral channels</td>
<td>VNIR: approx. 140, SWIR: approx. 145</td>
</tr>
<tr>
<td>Spectral range</td>
<td>400 – 2500 nm</td>
</tr>
<tr>
<td>Spectral sampling interval</td>
<td>400 – 1050 nm; &lt; 5 nm, 1050 – 2500 nm: &lt; 10 nm</td>
</tr>
<tr>
<td>Spectral sampling width</td>
<td>&lt; 1.5 * Spectral sampling interval</td>
</tr>
<tr>
<td>Center wavelength accuracy</td>
<td>&lt; 0.2 nm</td>
</tr>
<tr>
<td>Spectral sampling width accuracy</td>
<td>&lt; 0.02 * Spectral sampling width</td>
</tr>
<tr>
<td>PSF (Point Spread Function)</td>
<td>(\leq 1.75 \ast) Sampling interval</td>
</tr>
<tr>
<td>Spectral / Spatial Misregistration</td>
<td>&lt; 0.1 pixel</td>
</tr>
<tr>
<td>Scanning mechanism</td>
<td>Pushbroom</td>
</tr>
<tr>
<td>Storage capacity on board (on board)</td>
<td>&gt; 50 GByte / &gt; 200 GByte</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>12 … 16 bit</td>
</tr>
</tbody>
</table>

## 3. TECHNICAL DESCRIPTION OF APEX

APEX will allow for a flexible aircraft integration scheme. Therefore the instrument is subdivided into three major assemblies (Assy 1: Pilot interface, operator interface, computer (rack); Assy 2: APEX spectrometer including thermal enclosure and inertial unit; Assy 3: data and power harness). The APEX instrument itself is subdivided into the following components (c.f., Figure 1): An operator cockpit and pilot interface (OCI), a flight management system (FMS), the navigational subsystem (NSS), the central computer consisting of the control and data storage unit (CSU), a stabilized platform (STP), on which the opto-mechanical unit (OMU) is mounted and the type specific platform and aircraft interface (STPA-IF). The instrument is designed to be fully self-contained and is programmable using a software interface. Ground support equipment (GSE) is designed to integrate and remove the instrument for aircraft fuselage and store (or transport) the instrument from the airfield to the calibration home base and it’s permanent storage location.
Technically, APEX is designed to be a dual prism dispersion pushbroom imaging spectrometer using a common ground imager with a slit in its image plane. The spectrometer consists of a collimator that directs the light transmitted by the slit towards the prisms, where a dichroic beam splitter separates the two spectrometer channels into the VNIR (Visible/Near Infrared, 380-1000 nm), and SWIR (Shortwave Infrared, 930-2500 nm) wavelength range. Following the dispersion of the prism (two for the VNIR, one for the SWIR), the spatially and spectrally resolved lines are re-imaged on the detector arrays. The light is dispersed onto 1000 spatial pixels across-track for both channels, with 312 spectral rows in the VNIR and 199 spectral rows in the SWIR. Flexible, programmable on-chip binning will allow summarizing the spectral bands to about 300 spectral rows for both detectors. Figure 2 depicts to the left the OMU and to the right the dual prism pushbroom spectrometer design.

Figure 2: Left: APEX assembly of the opto-mechanical unit (OMU). Right: Optical base plate (OBP) with spectrometer details (right: SWIR detector, top: VNIR detector, top left: ground imager and filter wheel, bottom left: collimator, center: dual prisms).
An integral part of the spectrometer is a built-in ‘In-Flight’ Calibration facility (IFC), where a mirror will be shifted in the optical path to reflect the light of the internal stabilized QTH (Quartz Tungsten Halogen) lamp in the optical path of the spectrometer. The on-board calibration measurements are done using a filter-wheel, a fiber bundle and a diffuser (see Figure 3). The filter-wheel consists of filters to enable relative spectral and radiometric calibration. In the form of a secondary calibration standard, the IFC measurements will be performed just before and after the ground observation data is taken.

Figure 3: The in-flight calibration unit (IFC) enables relative spectral and radiometric calibration. The radiance of a stable light source is transferred via fiber to the optical path of the spectrometer.

The front end electronics of APEX are designed to support high read-out frame rates, and are located as close as possible to the detectors. After the analogue-digital conversion and the multiplexer of each spectral channel, the data is processed in an FPGA (Field Programmable Gate Array) to a stream of 16 bit words, which are then serialized and transmitted over an optical high-speed link at 700 Mbit/s. This link connects the APEX optical and mechanical structure to the operator’s console and computer.

The control and storage unit (CSU) of APEX is a dedicated rack in the aircraft, that hosts all the instrumentation required to operate APEX - in particular, the flight management system with an interface to the operator and the pilot, the inertial navigation system and the GPS (Global Positioning System) processor, and the computer that interfaces the optical unit (connected over the high-speed link) and the storage unit (c.f., Figure 4, right). Most of the components used in this setup are commercially available, apart from a dedicated PCI (Peripheral Component Interconnect) card, which is needed to connect the optical unit through a PCI-bus interface to the host system. The host system (c.f., Figure 4, left) is composed of a commercial Intel server board with a 2 GHz Intel Xeon CPU (Central Processing Unit), 2 GByte of RAM (Random Access Memory), a dual-channel ultra-320 SCSI (Small Computer System Interface) controller (64bit/133MHz PCI) and 6 x 72 GByte Ultra-160 SCSI hard disks. The data exchange between the incoming data from the PCI card and the hard disks are implemented using multi-threaded shared memory architecture to ensure data throughput. The maximum transfer rate of the system is limited by the PCI bus bandwidth, nevertheless breadboarding activities have demonstrated sufficient margin available.
The CSU is driven by control software that is composed of low level interfaces (e.g., the disk read/write interface, etc.), a middle tier that handles the logging and alerting, the configuration of APEX operating modes using a configuration data base, and the operator interface, where system configuration, status, and a waterfall image are displayed during data takes. The control software also includes the synchronization mechanisms of the various subparts.

4. APEX FACILITIES

APEX will be supported by four major external facilities. This includes the Science Center, the Operational Center, the Calibration Home Base (CHB) and the Processing and Archiving Facility (PAF).

4.1. APEX Science Center

The APEX science center is hosted at RSL in Zurich (Switzerland). One objective of the science center is to foster the use of imaging spectrometer data and the development of new scientific algorithms in close cooperation with scientific users, experts and algorithm developers. Another objective is to monitor APEX calibration, validation and long-term performance. Also calls for airborne/field experiments will be announced in the center. In this center the new interface between PAF and algorithm developers will be established. A documentation of all APEX related algorithms is provided in form of algorithm theoretical basis documents.

4.2. APEX Operations Center

The APEX operational center is located in Mol (Belgium) and hosted by VITO. All user interactions (flight requests, archived data search, flight planning, user support, etc.) are carried out from this location. A description of the infrastructure is given in Debruyn et al. [13].

4.3. Calibration Home Base (CHB)

The Calibration Home Base (CHB) with dedicated spectral, radiometric and geometric calibration facilities for full laboratory characterization and calibration of APEX. The calibration home base is located in Oberpfaffenhofen at DLR near Munich (Germany).
4.4. Processing and Archiving Facility (PAF)

The APEX Processing and Archiving Facility (PAF) manages the data from acquisition and calibration to processing and dissemination. The processing chain is based on analyzing in-flight acquired image data, housekeeping information (e.g., navigation data, temperature), and on-board calibration data (using the above mentioned IFC). Moreover, the CHB allows the characterization and calibration of the geometric, radiometric and spatial sensor parameters. Using the outcome of the sensor calibration, the raw image data are converted to at-sensor radiance in SI (le Système international d’unités) units, traceable to a certified standard (e.g., NIST, NPL, PTB).

It is expected that individual flight campaigns will collect data on the order of 100’s of GB that need to undergo an offline chain of data correction and characterization processes based on previously acquired laboratory and in-flight calibration parameters. This processing chain includes conversion of raw data values into SI units, bad pixel replacement, and corrections of smear, stray light, smile and frown anomalies. A simplified block diagram of the planned processing is illustrated in Figure 5. The data acquisition process produces the top four components on the left side in the Raw Data column. The lower two components are produced during inter-mission calibration of the instrument which takes place in the CHB.

![Figure 5: Generalized processing data flow from raw data until Level 1 B.](image)

Since the raw data is generated during the flight in the onboard computer, this data need to be transferred to the off-line PAF computer. During this data transfer, quick consistency checks are made, and some simple constant-time operations can be performed such as bad pixel detection as well as generation of a high-resolution composite RGB pseudo-color quick-look image. As a result, a calibrated at sensor radiance cube will be generated in the first processing step. This data will be channel wise corrected for spectral and spatial non-uniformities. Further processing steps will generate surface reflectance taking into account environmental conditions, such as the topography and atmosphere.

The PAF will generate three categories of products, i.e., standard, custom and research products. Whereas standard products are the result of automatic processing, they are generated for each flight/campaign. An example is the above mentioned Level 1b product. The second category of products are the custom products generated after special request and/or with user interaction. These products require semi-automatic processing of validated methods / algorithms. This is why they will be available upon user-request. An example would be an atmospherically and topographically corrected Level 1b product, where the user delivers correction measurements (in form of vicarious calibration results) or a special digital elevation model. The third category of products consists of research products, which will be processed by...
This kind of product is available to dedicated scientific users only. The goal is to test new methods / algorithms, which are under development and still need to be validated. This research product generation is supported by the PAF software using a flexible plug-in structure. Algorithm developers are able to provide their own algorithms, so that third party users are able to make use of new routines and scientific calculations. A documentation of the algorithms is provided by the developers in form of algorithm theoretical basis documents.

5. CONCLUSIONS

The APEX system is well defined and will be able to support a broad variety of application products for terrestrial ecosystems. But given the natural diversity of landscapes, the instrumented measurement and validation approach remains challenging. Earth observation from airborne or spaceborne platforms is the only observational approach capable of providing data at the relevant scales and resolution needed to extrapolate findings of in situ (field) studies to larger areas, to document the heterogeneity of the landscape at regional scale and to connect these findings into a global view. Recent development of Earth observation satellites and airborne platforms demonstrate that imaging spectroscopy is a valuable tool for the quantification of relevant parameters, supporting processes within the carbon cycle. Even though a number of imaging spectrometers are available in space (e.g., MODIS, MERIS, Hyperion, etc.), their performances rely on an integrated approach, including a sound instrument design, a well implemented calibration strategy and finally a processing chain capable of handling large amounts of spectral data. Only a wide and fast dissemination of spectrometer data and their products will guarantee the required scientific attention and their inclusion in operational Earth observation systems. The APEX system, to be available for operational use in summer 2006, will be a significant contribution to address the above said in a quantitative and qualitative manner.

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