Status of the Airborne Dispersive Pushbroom Imaging Spectrometer APEX (Airborne Prism Experiment)

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***Abstract*—Over the past few years, a joint Swiss/Belgian initiative resulted in a project to build a new generation airborne imaging spectrometer, namely APEX (Airborne Prism Experiment) under the ESA funding scheme named PRODEX. APEX is designed to be a dispersive pushbroom imaging spectrometer operating in the solar reflected wavelength range between 400 and 2500 nm. The spectral resolution is designed to be better than 10 nm in the SWIR and 5 nm in VIS/NIR range of the spectrum. The total FOV is on the order of ± 14deg, recording 1000 pixels across track, and max. 300 spectral bands simultaneously. The final radiance data products are well characterized and calibrated to be traceable to absolute standards. APEX is subdivided into an industrial team responsible for the optical instrument, the calibration home base, and the detectors, and a science and operational team, responsible for the processing and archiving of the imaging spectrometer data, as well as its operation. APEX is in its design phase with partial breadboarding activities and will be operationally available to the user community in the year 2005.**

Keywords-imaging spectrometer; hyperspectral; pushbroom; calibration; validation; sensor design; data processing; imaging spectroscopy applications.

I. 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 these 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. The APEX project is funded through ESA PRODEX (PROgramme de Développement d'EXpériences Scientifiques), which aims at improving the relations between scientific and industrial circles and to provide funding for the industrial development of scientific instruments proposed by institutes.

The project started in 1997 by performing a feasibility study on the design of an imaging spectrometer [1] and resulted in a first performance definition [2] and a subsequent design phase [3]. Currently, various parts of APEX are being finalized in design, breadboarding and performance analysis of the processing chain [4], and the subsequent construction of the instrument is planned to be final in early 2005.

II. TECHNICAL DESCRIPTION OF APEX

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/NearInfraRed, 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 195 spectral rows in the SWIR. Flexible, reprogrammable binning on-chip will allow summarizing the spectral bands into a maximum of 300 spectral rows for both detectors.

An integral part of the spectrometer is a built-in 'InFlight' 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 / integrating sphere combination in the optical path of the spectrometer using a filter-wheel, a fiber bundle and a diffuser. The filters will be a set of quartz filters with rare earth doping components for spectral calibration and another set with different transmission properties without distinct spectral absorption features for radiance calibration. This setup will be used just before and after a regular data take in the form of a secondary calibration standard.

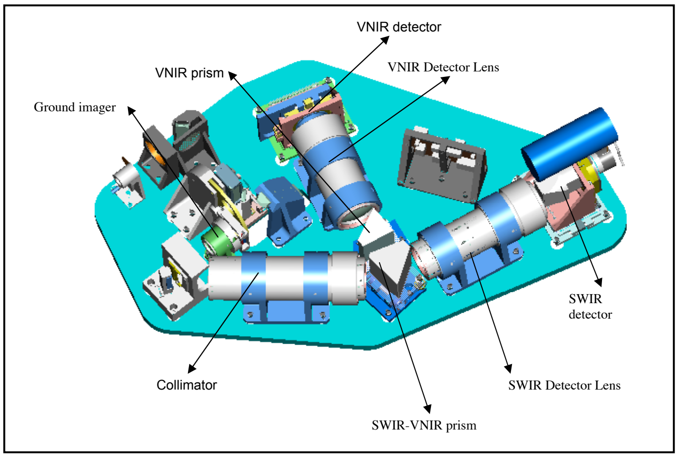

Figure 1. APEX spectrometer layout.

The front end electronics of APEX are designed to support frame rates up to 43.4 Hz, 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 processor, and the computer that interfaces the optical unit (connected over the high-speed link) and the storage unit. Most of the components used in this setup are commercially available, apart from a dedicated PCI card, which is needed to connect the optical unit through a PCI-bus interface to the host system. The host system is composed of a commercial Intel server board with a 2 GHz Intel Xeon CPU, 2 GByte of RAM, a dual-channel ultra-320 SCSI 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 a 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 level that handles the logging and alerting, the configurations of the operating modes of APEX 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 includes also the synchronization mechanisms of the various subparts.

The CSU racks will also host a power distribution unit, that acts as an interface between the aircraft power supply and the different APEX subsystems. The optical system will also be supported by a stabilized platform and a thermal control that maintains constant temperature while operating the instrument.

The technical details are a result of the initial APEX specifications as listed in the following Table 1.

TABLE I. APEX SPECIFICATIONS

Specified Parameter	Value
Field of View (FOV)	± 14˚ deg
Instantaneous Field of View (IFOV)	0.48 mrad
Flight altitude	4'000 - 10'000 m.a.s.l.
Spectral channels	VNIR: approx. 140, SWIR: approx. 145
Spectral range	400 – 2500 nm
Spectral sampling interval	400 – 1050 nm: < 5 nm, 1050 – 2500 nm: < 10 nm
Spectral sampling width	< 1.5 * Spectral sampling interval
Center wavelength accuracy	< 0.2 nm
Spectral sampling width accuracy	< 0.02 * Spectral sampling width
PSF (Point Spread Function)	≤ 1.75 * Sampling interval
Smile	< 0.1 pixel
Frown	< 0.1 pixel
Bad pixels	None (requirement after electronics)
Scanning mechanism	Pushbroom
Absolute radiometric calibration accuracy	≤ 2%
Storage capacity on board (online / offline)	> 50 GByte / > 200 GByte
Dynamic Range	12 … 16 bit
Positional knowledge	20% of the ground sampling distance
Attitude knowledge	20% of IFOV
Navigation system, flight line repeatability	± 5% of FOV
Positional and attitude data	Recording of data onto a housekeeping channel.
Reliability	99% successful data acquisitions for all flights

III. EXTERNAL FACILITIES TO APEX

APEX will also be supported by three major external facilities. This includes a 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 Oberpfaffenhoffen at DLR near Munich (Germany).

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.

Finally 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 calibration of the geometric, radiometric and spatial sensor characteristics. 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). The second major step derives surface reflectance under consideration of the environmental conditions. Optional HDRF (Hemispherical Directional Reflectance Factor) correction algorithms are later used to convert the directional reflectance values into nadir-normalized reflectance. The derivation of scientific data products is supported using a flexible plug-in structure in the PAF and documented in standard ATBD's (Algorithm Theoretical Basis Document).

There are three noteworthy features of the PAF software development process - an iterative prototype-based development model, the amount and method of multi-environment integration, and the accommodation of mixed-level domain development contributions.

A large application with so many stake-holders is often subject to design and implementation setbacks resulting from 'specification by committee'. Two approaches have been taken to actively counter these risks and to ensure the coherency of the overall design. First, a prototype-based, iterative development model has been selected. The first iteration consists of simulating program flow using high level prototyping languages and subsequent iterations involve refining the simulated steps by gradually replacing them with more realistic modules - more realistic first in terms of data size and shape and then in terms of processing resource requirements. The PAF is expected to continually undergo such additions and refinements but at every iteration a coherent understandable design and a realistic working process will be given highest priority. In addition, it is planned to take a modified SPID (Statistically Planned Incremental Deliveries) approach during the planning for each iteration, where the planned tasks are reviewed and statistical estimates are upgraded for the best, most-likely, and worst case scenarios to help prioritize and re-align the project plan for that iteration.

It was determined that if the control logic of the PAF is developed in a high level meta-programming environment, then this environment could be used to access and integrate the strengths of many other special purpose rapid prototyping environments. The direct affect of providing a highly "multi-lingual" development environment is the ability to enable mixed-level domain application development. The development team for such an application can consist of spectroscopy experts developing core algorithms with IDL (Interactive Data Language) and possibly other mathematical modeling languages; database experts developing data models and queries in SQL (Structured Query Language); user interface experts developing graphical (graphical user interface toolkit (Tk), widget based) and web (HTML- HyperText Markup Language) front ends; software architects analyzing overall program and data flow to maximize not just efficiency but flexibility - for example allowing calls to special-purpose CORBA-based (Common Object Request Broker Architecture) services in the processing chain; and finally software engineers which ensure that everything glues together and can help find and re-work bottlenecks.

IV. CONCLUSIONS

Terrestrial ecosystems have been identified as being a critical component of the variability of the global carbon cycle. 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 addition to 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 performance relies on an integrated approach, including a sound instrument design, a well implemented calibration strategy and finally a processing chain capable of handling large amount 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 presented APEX system will be a significant contribution to address the above said in a quantitative and qualitative manner.

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