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Low Cost Hyperspectral Imaging from Space

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Abstract: This paper describes a concept for a low cost hyperspectral mission that will provide data for environmental and geological users. The instrument based on heritage from the Compact High Resolution Imaging Spectrometer (CHRIS) provides data across a spectral range of 450 to 2500 nm. The instrument is accommodated on a small satellite under 200 kg, which provides cost effective sub-systems that meet mission and instrument requirements.

Zusammenfassung: *Kostengünstige Hyperspektralmission.* Der Beitrag beschreibt ein Konzept für eine kostengünstige Hyperspektral-Mission, in deren Rahmen Daten für Nutzer auf dem Gebiet des Umweltschutzes und der Geologie gewonnen werden. Das Instrument, das auf der Grundlage des Compact High Resolution Imaging Spectrometer (CHRIS) entwickelt wurde, liefert Daten im Spektralbereich von 450 bis 2500 nm. Das Instrument wird auf einem Kleinsatelliten (unter 200 kg) platziert, der mit preisgünstigen Subsystemen ausgestattet ist, die den Missions- und Instrumentenanforderungen Rechnung tragen.

1 Introduction

Hyperspectral imaging (HSI) aims to maximise the spectral (as opposed to spatial) information recovered from an Earth observation system. Current multispectral systems can sense less than 10 different spectral colours or wavebands. This is enough, for example, to distinguish between broad classes of vegetation. Hyperspectral systems may have up to 300 contiguous spectral bands. This allows the much more complete reconstruction of the spectral reflectance curves of individual materials, giving insights into subtle details such as vegetation species mix, healthy or unhealthy growth, and different varieties of mineral types.

Historically, both scientific and commercial hyperspectral programs have been unable to secure the funding for a dedicated hyperspectral space program. However the availability of small and micro satellites provides an opportunity to develop a low cost system. Certain fundamental limitations need to be accepted before a practical small satellite system is considered. The available size power and volume are constrained, resulting in limited aperture, data storage, downlink capability, and orbit control.

In 2001, ESA's PROBA (Project for On-Board Autonomy) micro-satellite will be launched. PROBA will fly an advanced compact high resolution imaging spectrometer (CHRIS) on a 100 kg spacecraft. PROBA is primarily intended to demonstrate in-orbit autonomy through on-board navigation and calculation of manoeuvres to view desired imaging targets, but the CHRIS instrument gives an indication of the capability that can be obtained from the micro-satellite format.

PROBA is constrained by several of the limitations described previously – it will be launched as a passenger, so does not control final orbit. It has no propulsion, so must accept orbit evolution. It has limited power, and on-board storage. It uses an S-band downlink with a nominal 1 Mbps rate.

Based on the experience gained from PROBA, Astrium and Sira Electro-Optics have undertaken the development of the SPECTRE programme, using a derivative of the Advanced Microsatellite Mission (AMM) platform being developed for ESA

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by Astrium Ltd. and System Engineering and Assessment Ltd. The AMM platform represents a significant advance from PROBA, with a payload mass fraction $>45\%$, up to 200 W of payload power available, orbit maintenance, and a high rate data downlink.

2 Objectives

The main objective of the work was to determine the feasibility of a low cost hyperspectral system that could deliver data to meet the requirements of a range of user groups. For a low-cost mission, the launch cost becomes a major driver of the overall spacecraft characteristics. The spacecraft must be small and light in order to ensure compatibility with small low cost launchers, in addition to this the system must maintain feasible methods of meeting the instrument requirements for size, mass, power and thermal control.

3 Design

SPECTRE is designed to fly a high performance hyperspectral sensor derived from CHRIS, which will image the Earth in multiple spectral bands from the visible into the short wave infrared (450 nm to 2500 nm). This wide spectral range will allow broad range of requirements to be met, including: geological and land use surveys and vegetation and environment monitoring. Dual spatial resolution (15 m visible/near-IR, and 30 m short wave IR) is proposed to optimise the total product. The preliminary specifications defined for the mission are shown in the table below.

3.1 *Instrument Design*

The instrument requirements have been developed from the mission specification. The main emphasis is on commercial value, looking forward to the next generation of hyperspectral imagers that will provide large

Tab. 1: SPECTRE Mission Specification.

Requirement	**Mission Specification**
Spectral coverage and band spacing	Contiguous coverage from 450–2500 nm typically 15nm SWIR, less than 10nm VNIR
Band-to-band registration	10 % of a pixel between bands in SWIR and VNIR
Signal-to-noise ratio All for a 30 % albedo target at 450 latitude in spring with a solar zenith angle of 60°	typically over 400:1 across SWIR typically over 300:1 across VNIR $\geq$100:1 in the panchromatic band
Spatial resolution: for SWIR hyperspectral bands for VNIR hyperspectral bands for panchromatic bands	 $\leq$30 m at nadir $\leq$15 m at nadir $\leq$10 m at nadir
Swath Width	30 km
Positional accuracy: without GCPs with GCPs	goal 1 pixel at nadir ½ pixel at nadir
Revisit Time	6 days with 30° off-nadir viewing
Orbit	Sun-synchronous
Equatorial crossing time	10:30am
Design life	3 years
Key products	Mineralogical and vegetation maps and others to be defined
Spacecraft mass	$<$200 kg

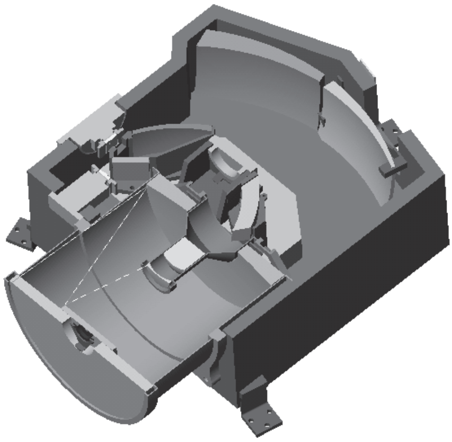

Fig. 1: Baseline Instrument Optical Design.

volumes of high quality data. The instrument design benefits from the CHRIS heritage, a key design philosophy of this being for a lightweight solution. The instrument is a conventional imaging spectrometer, with a telescope forming an image of the Earth onto the entrance slit to a spectrometer, and an area-array detector at the spectrometer focal plane. The instrument will operate in a push-broom mode during Earth imaging. The spacecraft will be required to provide pointing in the across track direction to improve the revisit time. The platform will also be required to provide slow pitch during imaging at higher spatial resolution, in order to increase integration time of the instrument. The optical design is shown in Fig. 1. The system comprises a catadioptric telescope and a dispersive imaging spectrometer.

The preferred basic design form for the spectrometer is similar to that of the CHRIS instrument. It will be based on the Offner relay, which can be extremely well corrected over moderate field areas and very wide spectral ranges. The Offner relay is turned into a spectrometer by adding curved prism (or wedged lens) elements.

For the telescope, two-mirror catadioptric systems are the preferred option, for CHRIS and also for SPECTRE. They provide a compact solution with a length typically less than the focal length. The mirrors for the telescope will be aspheric; however being used on a common axis they will have a relatively low cost (compared for example with three-mirror anastigmat mirrors) and will be relatively easy to align.

Two area-array detectors will be included. A special silicon CCD detector for the visible/near-IR band will provide 2000 spatially-resolved elements in the across-track direction (swath width), while a mercury cadmium telluride detector will provide 1000 spatially resolved elements at lower resolution in the short-wave IR. A separate telescope and a linear array detector will provide panchromatic imaging at higher resolution.

“Motion compensation” – use of slow platform pitch during imaging – will be used to increase the sensor integration time by a factor up to 2, and reduce data rates during imaging at higher spatial resolutions. However little or no motion compensation will be required during imaging at lower spatial resolution, which will typically be used to survey large land areas in long continuous strips.

3.2 *Spacecraft Design*

The instrument and the spacecraft solutions have been developed in parallel to achieve the required mission performance at minimal cost. Work carried out has shown that a low-mass spacecraft solution with image motion compensation and across track pointing is feasible. A 10:30 am sun-synchronous orbit at approximately 512 km height gives the necessary ground-track repeat cycle and signal to noise ratio. The revisit requirement is met by a $\pm 30^\circ$ off-track pointing capability.

Platform agility required for off-track pointing and motion compensation can be provided by a set of four reaction wheels. The attitude determination can be achieved using 2 autonomous star trackers; preliminary analysis shows that gyros are not needed for the required system performance.

To achieve the specified radiometric resolution the SWIR detector needs to be cooled to between 160 K and 180 K. Thermal analysis shows that a detector temperature of 180 K can be achieved passively by using the cold face of the spacecraft as a radiator and a baffle to block environmental fluxes from hitting the radiator. The implementation of a thermo-electric cooler between the radiator and the detector will further reduce the temperature and provide the required temperature stability.

The large amount of data generated by the hyperspectral instrument translates into a need for a high volume of on-board data storage and a high rate data downlink. To minimise the mass and power requirements the latest generation of low-mass, low-volume mass memory modules such as the 1.28 Gbit module from 3D-Plus Electronics can be used. A high rate X-band data downlink can be achieved without the use of expensive steerable antennas by utilising the agile platform capability in pitch and roll to steer the antenna towards the ground station.

The preferred mission platform is a derivative of the Advanced Microsatellite Mission (AMM) platform. The AMM development is aimed to be an agile platform, and will benefit from avionics allowing a high degree of autonomy. This closely matches the mission requirements.

4 Conclusions and recommendations for further work

From the work carried out to date it appears feasible to produce a low cost hyperspectral system that can provide commercial data to both the geological and environmental user groups. However there are critical technologies requiring further development.

The requirements on the SWIR detector for high performance and fast readout are challenging. Current development activities will demonstrate the technology required.

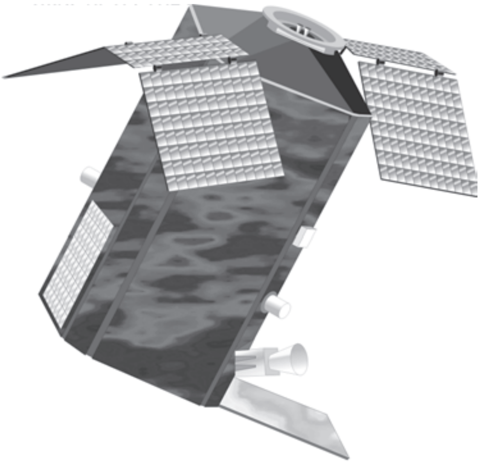

Fig. 2: Feasible SPECTRE Concept.

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