Low Cost Hyperspectral Imaging From a Microsatellite

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Abstract

A 100 kg class SSTL microsatellite platform accommodating the Sira Compact High Resolution Imaging Spectrometer (CHRIS) can perform high spectral resolution imaging over multiple wavelengths. Hyperspectral imaging data may be used within a wide variety of applications ranging from precision agriculture and land use, to ocean colour monitoring, coastal and atmospheric studies.

CHRIS operates in the 415 to 1050 nm wavelength band, with spectral sampling interval from 2 to 12 nm (depending on wavelength) and is programmable from the ground. Operating at 25 m ground sample distance the instrument can provide information over 19 spectral bands whilst at 50 m ground sample distance, for example, 63 bands can be imaged simultaneously. Flying CHRIS as the main payload on a SSTL microsatellite enables dedicated platform resources to exploit the huge potential of such a payload at low cost. The three-axis stabilised platform can off-point from nadir by ±30° to support accurate target selection. 48 Mbps payload data downlink rates, a 12 Gbyte data storage, and high efficiency GaAs panels for power provision all ensure a good payload duty cycle per orbit. The estimated spacecraft cost is 8.5 million GBP, resulting in affordable constellation options.

A constellation of hyperspectral satellites providing high temporal resolution in addition to high spectral resolution could also be used to enhance the infrastructure of the Disaster Monitoring Constellation (DMC). The DMC is currently under construction at SSTL and is due for launch in 2002. This may be implemented either singly, or in constellations, via a 'plug and play' constellation approach. This paper describes how low cost hyperspectral imaging may be effectively accomplished using a microsatellite platform and looks at the potential benefits of implementing a series of these microsatellites in a constellation.

Introduction

Earth Observation from space has traditionally been performed using large platforms, supporting large imaging payloads. The problem with this approach is that the instrument can only look at one place at a time, thus limiting operational use. This also limits experimental use and development of new applications of the instrument.

Small satellites have an important part to play as they are uniquely positioned to provide the opportunity to support niche payloads and, more specifically, a group of them can be used in a constellation by virtue of their low cost, and their small size allows multiple spacecraft to be launched on one launcher. The increase in temporal resolution which a constellation of small spacecraft provides can not be matched by large traditional spacecraft. The cost of putting 6 SPOT or TerraSat type spacecraft in one orbit at the same time would be prohibitive for any space agency.

The increase in capability of modern microelectronics means that certain technical aspects of a small satellite can be equal to a comparable large satellite. Sometimes a specific capability can even exceed that of a large platform, as the shorter development timescales allow the latest developments in microelectronics to be included..

SSTL has extensive experience with putting camera payloads on microsatellites, providing 50 metre ground sampling distance (GSD) multi-spectral Earth imagery from a 50 kg platform,

and 30 metre GSD, 600 km swath width, multi-spectral images, using a 100 kg platform.
There have been may multi-spectral imagers in space, imaging typically up to 6 optical bands in the visible to near infra-red wavelengths. The bands that are selected are typically the same for all spacecraft, often referred to as the Landsat bands. These are Near IR, Red-Edge, Red, Green, Blue and Pan-chromatic. These bands cover the most used applications of optical imaging e.g. vegetation monitoring and cartography.
The fact that many spacecraft use these same bands allows simple comparison between images, but it also limits development of applications that need information outside these bands.
Hyperspectral imagers have a function here, as they split the entire light spectrum in equally spaced bands, which allow any virtual filter to be applied to an image set later.

Hyperspectral Imager

The principle of a Hyperspectral imager is to use a slit in an optical imager to select one line of the image, and to split this line into its individual wavelengths using a prism. This then provides an image of the single line across a 2-D CCD sensor.

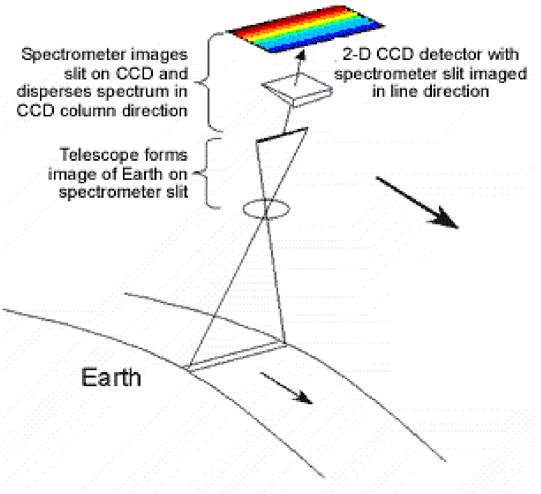

Fig. 1. Hyper Spectral Imaging concept

The amount of light per CCD pixel for the hyperspectral imager is small compared to a multi-spectral imager. This is because the bandwith of a typical filter used is up to 10 times wider than the bandwidth that is covered by a single pixel on the hyperspectral imager. This means that for a given optical camera aperture the ground sampling distance must be comparatively larger to provide enough signal to noise performance for good imaging.

The motion of the spacecraft is used to move the image line across the surface of the Earth, and the CCD is read out continuously to provide a complete hyperspectral dataset per line. This then can be combined for a complete area in the form of Data cubes, a set of images each containing information from one wavelength

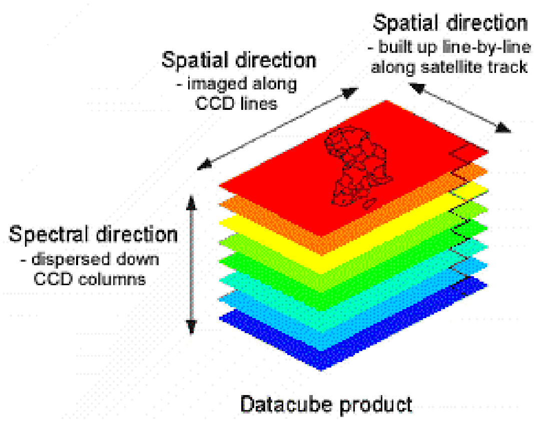

Fig. 2. Hyper Spectral Imaging data

The amount of data produced is vast compared to normal multi-spectral imaging, as each ground pixel is sampled once per band. The CHRIS sensor uses a 572 line CCD. Each CCD pixel is digitised to 12 bits, there are 6864 bits per ground pixel, 3.8 Gbit per square image, or 95 times as much as a 6-band multi-spectral image of the same area.

Limitations

The CHRIS hyperspectral imager is designed to fly on a small satellite. It has a mass of 15 kg, and it uses about 10 W of power when operating. It produces data at an effective rate of 18 Mbits/second using two 20 Mbps digital links.

Currently it is scheduled to fly on the ESA PROBA mission, where it forms but one of the payloads, introducing limitations to the operation of the instrument (1). The Proba mission is to support development of several space technologies, including On-Board autonomy and a range of sensors. It has not been designed specifically to support the CHRIS imager.

The 3.8 Gbit of data per image that the instrument produces far exceeds the data handling capability of the Proba spacecraft. CHRIS therefore includes a digital signal processing unit to extract up to 62 actual spectral bands of interest out of the 572 bands available. After initial processing, each square image contains only 131 Mbit of data, a compression ratio of almost 30:1.

Inevitably some information will be lost, and this requires a careful pre-selection of information and setting of parameters. One of the specific advantages of a Hyper Spectral Imager is that all spectral information can be extracted, such that novel applications can be developed. This requires a greatly increased data handling capability of the platform.

Operational enhancements

As with all optical Earth Observation systems there are only a limited number of days available for observation, and when the weather is good it is important to quickly observe as large an area as possible.

The CHRIS payload (2) is the only payload on the proposed SSTL Constella spacecraft bus, which means that the sub-system specification is optimised specifically to get the best performance out of the instrument.

Fig. 3. CHRIS instrument

The data storage capability takes advantage of the latest developments in computer memory, providing more than almost a hundred times the data storage capacity. This is complemented by a significantly higher download transmission speed, 48 Mbps X-band compared to 1 Mbps S-band.

The table shows the main differences in capability between the two missions (approximate figures):

	Proba	Constella
Data storage (for CHRIS)	1 Gbit (128 Mbyte)	96 Gbit (12 Gbyte)
Recording time available	56 seconds	91 minutes
Downlink rate	1 Mbps	48 Mbps
Downlink data per day (one groundstation)	0.5 Gbyte	25 Gbyte
Average operational time per day	4 minutes max.	3 hours max.
Orbit control	None	Yes

Per orbit there is about 40 minutes of suitable sun-angle for observation available, this means that two full orbits of continuous data can be taken before access to a groundstation is required, whereas Proba can record about one minute of data before downlinking is required to empty the memory for new data.

SSTL Constella microsatellite

The SSTL Constella spacecraft (3) is a 100 kg class microsatellite designed specifically for constellations: its solar panel layout is optimised for equal power generation in different or varying orbits, its structure is designed for mounting of multiple spacecraft on a single launcher, and its overall design is optimised for low cost and ease of manufacture and test.
The figure below shows a cut-away drawing of the Constella spacecraft with the CHRIS payload visible.

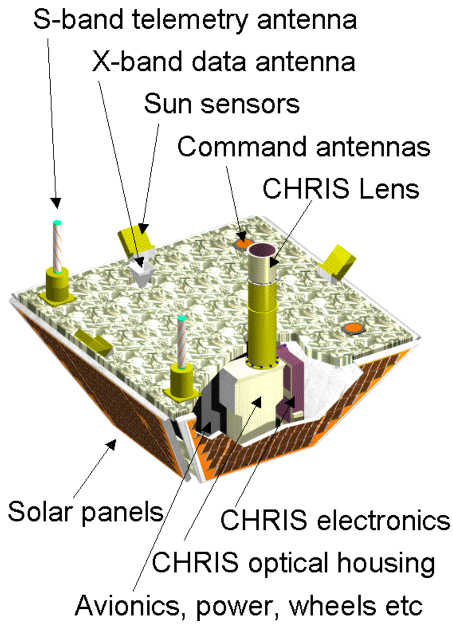

Fig. 4. Constella with CHRIS imager

The Constella platform has been designed to be launched in groups. The Dnepr launch vehicle (see illustration below) can accommodate up to eight spacecraft at once. In a typical constellation this is about the maximum number of spacecraft that are required in one orbital plane.

The orbit average power available on this platform is about 70 W, which is more than enough to support the payload and bus systems. Due to the optimised solar panel layout the power generation does not depend on the orbit, which makes this platform especially suited to constellations or non Sun-Synchronous orbits.

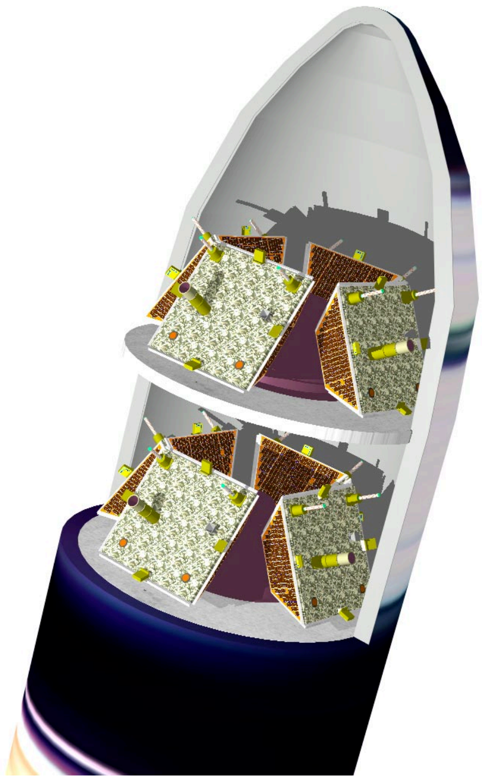

Fig. 5. Eight Constella spacecraft on Dnepr

The Constella platform provides on-board propulsion for constellation deployment and station keeping.

Additional capability

The platform can support two CHRIS instruments for an increase in swath width from 19 to 36 km. The data capability of the platform is easily enough to support two instuments.

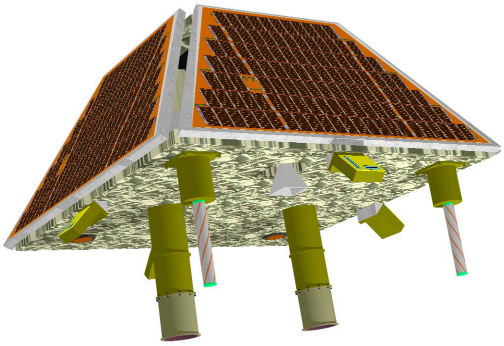

Fig. 6. Dual CHRIS instrument on Constella spacecraft

Alternatively the two cameras can be co-axial, this combination could be used to image a scene at two different ground sampling sizes at the same time, making the instrument even more versatile.

Conclusions

A hyperspectral imaging mission on an SSTL Constella microsatellite platform has been described. The performance of this platform is 50 times (downlink rate) to 90 times (data storage) better than Proba in supporting this particular payload.

The CHRIS instrument in this configuration on form provides a high performance combination that allows full use to be made of the capabilities of the imager, which will enable this to be launched as an operational mission, with enhanced research capability.

The projected cost of the platform allows a constellation of these spacecraft to be launched, which would provide an unprecedented capability for Earth Observation, and development of new applications.

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