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Review of a Small Satellite Hyper-spectral Mission

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ABSTRACT: This paper describes a low cost hyper-spectral mission based around the CHRIS instrument that has been developed at Sira Technology Ltd. The CHRIS instrument is flying on the ESA PROBA platform, a small agile satellite of the 100kg class, which was launch in October 2001. The instrument typically acquires more than 300 hyper-spectral images each year via two European ground stations. Today this instrument provides the highest sampling capability of any space-borne hyper-spectral instrument. The main purpose of the instrument is to provide images of land areas, although the applications have extended to include coastal monitoring. The platform provides pointing in both across-track and along-track directions, for target acquisition and slow pitch during imaging (motion compensation). An observational mission has been developed around the facility and this is catering for some 40 or so Principal Investigators (PI) around the world, including Europe, North America, Australia and China with around 100 observational sites.

INTRODUCTION

The CHRIS instrument was developed by Sira Technology Ltd (formerly Sira Electro-Optics Ltd) principally to provide remote sensing data for land applications, although currently it is being used for a wide range of applications including coastal zone monitoring. It is the main instrument payload on the European Space Agency (ESA) small satellite platform PROBA (Project for On-Board Autonomy). PROBA was launched from the Indian PSLV on the 22nd October 2001. The platform orbits the Earth with an apogee of 673km and a perigee of 560km. PROBA is a highly manoeuvrable small satellite, capable of large, rapid rotations on pitch and roll axes, with fine control over pitch and roll rates.

CHRIS provides a ground sampling distance of 17m, at perigee, over typical image areas 13km square. It has a spectral range from 400nm to 1050nm, at spectral resolution <11nm. The instrument provides sets of images of selected target areas, at different pointing angles, forming a maximum of 5 images of each target in a single overpass. The five "nominal" pitch angles are 0°, ±36° and ±55°. To access the targets the platform can provide roll angles up to ±25°. The data is being used to analyse directional effects in the radiance of targets, with particular emphasis on vegetation targets.

The CHRIS instrument and the PROBA platform development programmes were initiated as part of a technology demonstration programme. The interest in the utilisation of the CHRIS instrument has led to the formation of an "operational" programme to fully exploit the capability of the instrument and the opportunity to acquire space-based hyperspectral data sets. The ground station infrastructure includes the ESA ground stations in Redu, Belgium and at Kiruna, Sweden.

MISSION OBJECTIVES

The mission objectives for the CHRIS instrument are both scientific and technological.

The scientific objective of the mission has been to provide data on Earth surface reflectance in the visible/near-infrared (VNIR) spectral band, at high spatial resolution. The instrument uses the PROBA platform pointing capabilities to provide Bi-directional Reflectance Distribution Function (BRDF) data (variation in reflectance with view angle) for selected scenes on the Earth surface. The instrument is used mainly to provide images of land areas, and is of interest particularly in recording features of vegetation. One aim is to validate techniques for future imaging spectrometer missions, particularly with respect to precision farming, regional yield forecasting and forest inventory. The high resolution of the instrument has also found application in coastal region monitoring.

To evaluate the scientific benefits of the mission an observational programme was established, initially for the one-year design life. However, the encouraging results from the first year mission and excellent health of the platform and payload encouraged ESA to extending the mission life. We are now in the fourth year of operations and both the platform and payload are still performing well.

Currently there are 42 Principal Investigators (PIs) and approximately 100 sites. The European Space Agency (ESA) through various Announcements of Opportunity (AO) has managed the selection process on behalf of the CHRIS Steering Group. The 100 sites are spread across, Europe, the USA, Canada, Australia and elsewhere.

The technological objective of the mission was to evaluate the performance of the compact design form. There is particular interest in instrument sensitivities and the methodology for calibration, since options for on-board calibration systems are limited on a small satellite platform. Use of the platform agility to provide pointing and motion compensation also required evaluation. Experience gained from this mission will feed into the design decisions of hyperspectral systems for future small satellite missions and, hopefully, provide some pointers to design of more demanding systems.

CHRIS INSTRUMENT CONCEPT

The CHRIS instrument is an imaging spectrometer of basically conventional form, with a "telescope" forming an image of Earth onto the entrance slit of a spectrometer, and an area-array detector at the spectrometer focal plane. The instrument operates in a push-broom mode during Earth imaging.

The spectral waveband covered by the instrument is limited to the band 400m to 1050nm, which can be achieved using a single CCD area-array detector. However, the current optics coatings limit performance below 450nm.

Optical Design

The optical system comprises a telescope and an imaging spectrometer. The system has no moving parts.

Telescope

A catadioptric design for the telescope provides the required spectral range and spatial resolution. The focal length of the system is set at approximately 746mm, and the aperture diameter at 120mm (f/6). The telescope is axially symmetrical and has only spherical surfaces, so that conventional construction methods can be applied.

Spectrometer

The spectrometer is a design patented by Sira. It uses "prisms" with curved surfaces integrated into a modified Offner relay. The design has only spherical surfaces, and uses only fused quartz for the prisms. The dispersion of the spectrometer varies from 1.25 to 11nm across the spectrum, with the highest dispersion at 400nm and the lowest in the near infrared at 1050nm.

Instrument Electronics

The instrument electronics enables:

- programmed CCD line integration and dumping for spectral band selection
- CCD pixel integration on chip for spatial resolution control
- noise reduction circuit
- gain switching for optimum ADC usage
- 12 bit ADC
- DC-DC converter
- two parallel data interfaces to the platform

There is considerable useful flexibility in operation of the payload. It offers the facility to sum sets of CCD row-signals in the shift register, before read-out, providing users with a facility to compose spectral bands of optimum widths. Signals can also be integrated in pairs at the output CCD port, relaxing across-track spatial resolution by a factor 2, and CCD integration time can be increased over a wide range to provide control of spatial resolution along-track (in combination with control over the platform pitch rate). The system also allows images to be restricted to half swath widths to increase the number of spectral bands that can be read out.

It is possible to read out 18 spectral bands at the highest spatial sampling and the full swath width, plus one band for smear/stray light calibration in each frame. However, it is possible to read out much larger numbers of spectral bands with relaxations of spatial resolution and/or swath width. Current user configurations are listed in table 1.

Mode	No. of bands	GSD (m)	Swath width	Application
1	62	34	Full	Aerosols
2	18	18	Full	Water
3	18	18	Full	Land
4	18	18	Full	Chlorophyll
5	37	18	Half	Land

Table 1 CHRIS Nominal Operating Modes

Relaxed Ground Sampling Distance (GSD) (associated with increased integration periods) provides enhanced signal-to-noise ratios.

The flexibility of the instrument and observation programme has enabled specific trials to be undertaken on special modes to evaluate detection of features of specific interest to PIs, including measurement of the Photochemical Reflectance Index (PRI).

Calibration

The small platform provides limited scope for on-board calibration facilities. Consequently, calibration is provided by a mixture of on-ground and in-orbit measurements.

On-ground measurements included:

- full aperture radiometric calibration,
- stray light calibration,
- spatial resolution,
- spectral and spatial registration assessment,
- wavelength characterisation
- linearity and saturation
- noise measurements

In-flight measurements included:

- DC offset measurements
- relative gain measurements,
- linearity and saturation measurements,
- spatial resolution
- wavelength calibration
- solar calibration
- power consumption

Vicarious calibration has also been undertaken using data recorded in dark and bright scenes of known effective radiance.

Data for absolute response measurement is gathered in flight by use of a solar calibration device (SCD). This device comprises a small reflecting prism, with one lens surface, which is located at the outer end of the instrument external baffle. When the platform is over the Antarctic region, on the dark side of the terminator, imaging a dark Earth area at nadir, the SCD receives direct sunlight. The platform is manoeuvred so that the device reflects sunlight into the field of the instrument, with spread provided by it's lens power. The SCD fills the field of the instrument at a nominal radiance equivalent to albedo 0.25 in direct sunlight. The SCD is not moved; it is fixed in the main instrument aperture area, but occupies (and samples) only a small fraction of the instrument aperture area. The field of the device for receiving sunlight is limited to 2° x 4°, and this field is fully sampled, in pre-flight calibration and in orbit, to check for non-uniformities in transmission of the device and instrument optics over a small area and thus to detect signs of local optics contamination.

Wavelength calibration is checked in flight using atmosphere absorption features, particularly the oxygen absorption band at 762nm.

Physical Characteristics

The CHRIS instrument has an envelope of approximately 200 x 260 x 790mm, a mass of less than 14kg and a power consumption of less than 8W.

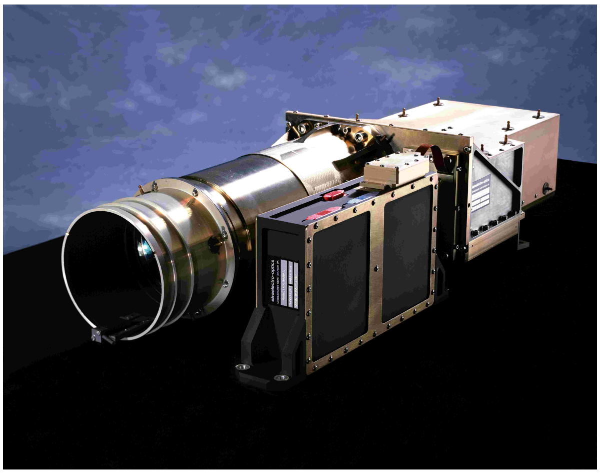

Figure 1 CHRIS Instrument

An illustration of the instrument, comprising the telescope, spectrometer and the electronics box, is shown in Figure 1.

MISSION ASPECTS

Observation Programme

Observations requests for the science mission are selected by the CHRIS Steering Group, scheduled and prioritised. These observations are then compared with a UK Met Office 48 hour cloud predictions before selection of the preferred image acquisitions for each day. Instrument configurations files and target coordinates are then transmitted to the platform from Sira via the ESOC ground station in Redu, Belgium. The platform implements the request and downloads the data to either Redu or Kiruna in Sweden. Data is then transferred via FTP servers to Sira for Level 1a processing. The processed data is placed on an FTP server for rapid access by the investigators. Quick-look images are also placed on a PI accessible website (http://earth.esa.int/missions/thirdpartymission/proba.html) , where other details such as the observational programme can be found. The data sets can be viewed and accessed via the ESA Multi-mission catalogue, details of which can be found on the above website.

The daily imaging capacity of CHRIS-PROBA is limited to two to three image sets (i.e. two to three sites) of five images every 24 hours. A further geographical limitation is placed on the location of the selected sites since they must be sufficiently apart, in terms of orbit time, to enable the data from the previous acquisition to be downloaded before new acquisitions are made. Three overpasses are needed to download a five-image set.

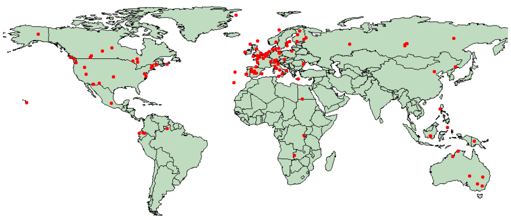

Fig. 2. Location of sites in the 2005 Acquisition Plan

CHRIS observation sites for the science programme are largely located in Europe and North America, although, as indicated in the above figure, a smaller number of sites are distributed around the globe.

For 2005, the user community has expanded and includes projects that are conducting research into:

- land vegetation and forests
- estimation of crop types and state
- water run-off and soil erosion
- carbon flux measurements
- changes caused by biological soil crusts
- water resources management in Africa
- absorption of heavy metal waste in trees
- vineyard phenology in Italy
- solid waste classification in landfill sites
- detection of meteorite impact craters
- inland & coastal water quality assessments

CHRIS has also been used to support the International Charter (www.disasterscharter.org) on major disasters, an international agreement for the rapid provision of Earth Observations data to civil protection agencies responding to disaster situations. The Charter has been activated more than 70 times since 2000.

CONCLUSIONS

The CHRIS Mission is now into its fourth year of operation and continues to provide some exceedingly good images for the scientific applications. The limited calibration facilities on-board have proved useful in complementing the on-ground calibration measurements. Whilst the overall cost of the mission is low, compared to conventional mission costs, the benefit to the users has been high enabling them to acquire valuable data to evaluate algorithms that can be explored in more depth on future missions. An example image is shown below in figure 3.

ACKNOWLEDGEMENTS

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Figure 3
Bromo Volcano, East Java (19 June 2005)