A Canadian Hyperspectral Spaceborne Mission – Applications and User Requirements[1]

K. Staenz [a] and A. Hollinger [b]

[a] Canada Centre for Remote Sensing, Natural Resources Canada, 588 Booth Street, Ottawa, Ontario, Canada K1A 0Y7; e-mail: karl.staenz@ccrs.nrcan.gc.ca

[b] Canadian Space Agency, 6767 Route de l'Aéroport, St. Hubert, Quebec, Canada J3Y 8Y9

ABSTRACT

This paper outlines the mission performance requirements suggested by the User and Science Team for the Canadian Hyperspectral Spaceborne Mission. This civilian mission focuses mainly on sustainability and environmental issues including the key application areas: forestry, agriculture, geology, coastal and inland waters, and environment (wetlands, climate change, etc.). The mission is currently in its conceptual stage (phase A) to define different mission and instrument scenarios taking into account the established user requirements.

Keywords: Hyperspectral space mission, user requirements, sensor performance, operational requirements.

1 INTRODUCTION

Over the last decade, hyperspectral remote sensing has become a powerful analysis tool for applications in environment and ecology, aquaculture, forestry, agriculture, and geoscience [1] - [6]. A hyperspectral imager's advantage over broad-band sensors, such as Landsat Thematic Mapper (TM) and the SPOT Haute Resolution Visible (HRV) sensor series, is its ability to detect molecular absorption and particle scattering signatures of constituents. The finer spectral resolution of a hyperspectral imager allows detection of surface materials and their abundances, as well as inferences of biological and chemical processes. This capability will also play an important role in addressing national issues on sustainability and environment. The Canadian Space Agency (CSA), the Canada Centre for Remote Sensing (CCRS) and industry are currently developing a hyperspectral spaceborne mission. A fundamental first step is to establish the user needs, which form the basis of the mission performance requirements. This is a difficult task, which requires a concentrated effort from the user and science community, including representatives from government, value-added industry and academia. The Canadian Hyperspectral User and Science Team was established in 2000 and tasked to define the requirements for a Canadian mission that will focus on sustainability and environmental issues encompassing the following key areas: agriculture, forestry, geology/soil, coastal/inland waters, and environment.

2 BACKGROUND

2.1 Hyperspectral Data

In Canada, hyperspectral imagers have been operated from aircraft for more than 15 years, for both commercial and public-good applications. Airborne instruments developed in Canada include the Fluorescence Line Imager (FLI) [7], the Compact Airborne Spectrographic Imager (casi) [8] and the Short-Wave Infra-Red (SWIR) Full Spectrum Imager (SFSI) [9]. The latest *casi* development encompasses a SWIR head designed and built by Itres Research.

Canada recently began involvement in satellite hyperspectral imaging, through ESA's Medium Resolution Hyperspectral Imager (MERIS), a synoptic imager, and the Hyperion targeted imager on NASA's EO-1 satellite that was launched in December 2000. In 1996, the CSA and Canadian industry began developing technologies for a future

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hyperspectral mission [10]. These activities, combined with applications development, led to a hyperspectral spaceborne program, which is currently in its conceptual stage (phase A) [11].

2.2 Applications

National Remote Sensing Advisory Groups provide guidance for the development of hyperspectral applications [12]. The objective is twofold: to utilize hyperspectral data for public-good usage (e.g., management of mine waste, assessment of environmental stress in ecosystems), and where possible to also facilitate the development of commercial products and activities (e.g., in exploration geology, forestry).

Government-led applications development activities have historically been carried out within the framework of larger government programs, such as the US/Canada Atmosphere Study (BOREAS), CSA's Canadian Expert Support Laboratory (CESL) for MERIS, CSA's Hyperspectral Imager Technology Assessment (HITA) program, Pacific Forestry Centre's Evaluation and Validation of EO-1 for Sustainable Development of National Forests (EVEOSD), and CCRS's Hyperspectral Method Development Program (HYSPEC). In addition, non-government organizations, such as the Centre for Research in Earth and Space Technology (CRESTech), several universities, and industry, have significantly contributed to the development of hyperspectral applications and data analysis technology.

3 CANADIAN HYPERSPECTRAL MISSION

The mission will consist of the space, ground, and applications segment [11]. The space segment consists of the payload (imager), the platform, and the launcher. The imager will operate in the Visible and Near Infra-Red (VNIR) and SWIR portion of the electromagnetic spectrum, approximately from 400 to 2500 nm. It will include an on-board calibration and data compression capability. Ground Motion Control (GMC) might be necessary in order to meet the signal-to-noise ratio (SNR) and/or spatial resolution requirements by the User and Science Team, as discussed in section 5. GMC requires pointing in the fore-aft (pitch) direction. Pointing in the cross-track direction is necessary to cut down the revisit time to the user requirement specification.

The functional elements of the ground segment include: mission control, satellite and payload control, data reception, quick-look facility, data processing (including calibration, atmospheric correction, etc.), data archiving, production of data products, distribution of data and/or data products to users, and order request functions.

The development of data preprocessing and information extraction algorithms and products is part of the application segment.

4 APPLICATIONS – USER REQUIREMENTS

Table 1 lists the applications and major product areas considered by the User and Science Team. Over 50 products in different application areas have been identified. Only those products were identified where hyperspectral remote sensing increases the accuracy of the information products or retrieves new information not possible with any other sensor. Table 2 summarizes the importance of the key hyperspectral application areas to the Canadian economy. Other areas, such as urban and snow and ice, are less developed. Nevertheless, there is the potential that hyperspectral data can help them to address important issues. The activities in the application area atmosphere concentrated on the atmospheric correction component of a potential hyperspectral sensor, which is important for the product quality. (Atmospheric correction is one of the most important steps in the data processing chain for the extraction of most information products.) This approach was felt to be more beneficial than pursuing purely atmospheric applications of a generalized hyperspectral sensor due to its competition with dedicated atmospheric sensors. The synergism between hyperspectral and SAR data was also considered, concentrating mostly on the fusion of different data sets, which can be combined for improvements for information extraction purposes.

Information from hyperspectral data to date is mostly from airborne sensors, where the spectral and especially the spatial resolution are generally finer than those of future satellite systems. Many studies have been carried out with the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS; 10-nm spectral resolution, 20-m spatial resolution, 20-km altitude) [1]. Therefore, the techniques to derive information are to some extent transferable to the spaceborne domain, though continued research and development is necessary to bring the information extraction procedures to a mature operational level.

Table 1. Applications and major product areas considered.

Application Area	Main Product Area
Agriculture	- crop stress mitigation and site specific management - crop productivity - soil quality and erosion - agro-environmental health monitoring and forecasting
Forestry	- inventory (forest attributes) - chemistry (health, precision forestry, environmental monitoring and assessment
Geology/Soil	- mineral exploration - lithological mapping - geobotanical mapping
Coastal/Inland Waters	- ocean phytoplankton biomass and large area productivity - coastal and inland water phytoplankton biomass and blooms, river plumes - ships, fishing activity, pollution events - coastline and shoal mapping, beach and sea-weed surveys, wetlands - water clarity and optical parameter assessment for defense applications.
Environment	- land cover mapping - climate change - wetlands and substrate mapping - land degradation - mine tailings rehabilitation - acid mine drainage mapping
Urban	- land cover mapping - air quality monitoring
Snow and Ice	- extend of snow cover (sub-pixel cover) - energy state (albedo, grain size, snow water equivalent, surface liquid water)

Table 2. Importance of the key applications in the Canadian economy.

Application Area	Economical Impact
Agriculture	- $ 118 billion industry - 89.9 million acres of cropland in 2001
Forestry	- $ 70 billion industry - 45 % (418 million hectares) of Canada's land area (10 % of world's forest)
Geology/Soil	- $ 27 billion (3.7 % of GDP) contribution by mining and mineral processing industries - 367,000 jobs
Coastal/Inland Waters	- 9 % of the world's renewable fresh water supply - world's longest ocean coastline
Environment	- one of the key issues of the Canadian and provincial governments (e.g., Kyoto protocol)

Sensor performance requirements were defined for each application area in Table 3 for the most stringent parameters. Obviously, a sensor that meets all the requirements in Table 3 would be technically difficult to build and enormously expensive. However, in many cases these requirements can be relaxed, and still satisfactorily retrieve the requisite information products. Key parameters are SNR, spectral resolution, spatial resolution, coverage, and revisit time. It should be noted that the retrieval of specific information requires dedicated bands, either located contiguously over a limited wavelength range or centred at specific wavelength positions. But, to address several applications, the full wavelength coverage is usually required between 400 and 2500 nm.

Table3. Most stringent user requirements for the key application areas.

Application Area	Requirements
Agriculture	- spectral resolution in the red-edge region: < 10 nm - spectral sampling interval in the VNIR: 5 nm - observation frequency: weekly
Forestry	- spatial resolution: 1 to 20 m - swath width: ≥ 60 km - spectral calibration accuracy: < 0.1 nm
Geology/soil	- spectral resolution: < 10 nm - peak SNR[1] in SWIR 2: 400:1 - spectral calibration accuracy: < 0.2 nm
Coastal/Inland Waters	- spectral coverage: from 370 nm - peak SNR[2]: >> 100:1 - observation frequency during critical periods: 1 to 3 days
Environment	- spectral resolution: < 10 nm - spatial resolution: 5 – 20 m - peak SNR[1] in the VNIR: > 800:1 - swath width (land cover): ≥ 50 km

[1] For a 30 % reflectance target viewed under a 30 ° solar zenith angle
[2] For a 5 % reflectance target viewed under a 30 ° solar zenith angle

5 SENSOR CHARACTERISTICS AND OPERATIONAL REQUIREMENTS

Table 4 shows the specification of a generalized hyperspectral sensor capable to meet most of the requirements in Table 3. Operational requirements are summarized in Table 5. A sensor that provides performance according to Table 4 will have significantly more to offer than broad-band sensors such as Landsat TM or SPOT HRV. It would enhance information products obtained using synoptic (broad area coverage) sensors such as MERIS and Resolution Spectroradiometer, by providing hyperspectral diagnostic zoom capability. Also the synergistic use of a hyperspectral sensor in combination with Radarsat will deliver products not possible before.

Table 4. Sensor performance requirements.

Parameter	User and Science Team Requirement	User and Science Team Goal
Swath width	at least 30 km	as wide as possible
Track length	200 km	
Ground sampling distance	20 m	
Spectral coverage	400 – 2450 nm	
Spectral resolution (FWHM)[1]	10 nm	5 nm in VNIR
Spectral sampling interval	one sample per FWHM	two samples per FWHM
Peak SNR[2] (VNIR)	600:1	800:1
Peak SNR[2] (SWIR1)	400:1	500:1
Peak SNR[2] (SWIR2)	200:1	400:1
Absolute Radiometric Calibration accuracy (TOAR)[3]	5 %	3 %
Absolute Spectral calibration accuracy	0.1 nm	
Radiometric quantization	12 bits	

[1] FWHM = Full Width Half Maximum
[2] For a 30% reflectance target viewed under a 30° solar zenith angle
[3] TOAR = Top Of Atmosphere Radiance

Table 5. Operational requirements.

Parameter	User and Science Team Requirement
Area coverage per day	as much as possible
Frequency of re-look	< 6 days
Roll angle off nadir of the satellite (from the centre of the swath)	30 ˚
Latency for tasking satellite	2 weeks; emergency: to be determined
Latency for data processing	1 week; emergency: to be determined
Maximum solar zenith angle acceptable for data acquisition	65 ˚ for arctic environments[1] 60 ˚ elsewhere
Acceptable cloud coverage with quick look	20 %
Satellite crossing time	10:00 – 12:00

[1]coverage includes July/August time frame between 10:00 and 12:00 local time for a 70º latitude (these months indicate usually the snow-free time)

6 NEXT STEPS

A concentrated effort of Canadian government, industry and academia will be required to come up with a preliminary mission design (phase B), which will meet the user's instrument and operation requirements. This effort includes also the evaluation of possibilities for international partnership. Besides the mission design activities, the objective is also to intensify applications development and to broaden the usage of hyperspectral data in Canada.

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