Overview of the Hyperion Imaging Spectrometer for the NASA EO-1 Mission

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***Abstract* – The New Millennium Program (NMP) is an initiative to demonstrate advanced technologies and designs that show promise for dramatically reducing the cost and improving the quality of instruments and spacecraft for future space missions. The EO-1 platform hosts the Advanced Land Imager (ALI), the Hyperion Imaging Spectrometer and the LEISA Atmospheric Corrector (LAC) payloads. It was launched on November 24, 2000 and is now in an orbit one minute behind Landsat 7. Hyperion has a 7.5km swath width, a 30 meter ground resolution and 10 nm spectral resolution. The initial mission for Hyperion is to measure and characterize on-orbit performance as thoroughly as possible and to compare with ground acceptance test data. This will be followed by activities of the EO-1 Science validation team to assess the utility of space-based hyperspectral data. This paper gives an overview of the technical innovation and on-orbit characterization scope for the EO-1 Hyperion Instrument and planned operations.**

I. Introduction

The primary EO-1 mission is to validate new instrument technologies in flight and to provide science data to the user community for utility assessments. The three primary instruments are the Advanced Land Imager (ALI), the Hyperion hyperspectral imager and the Linear etalon imaging spectrometer array Atmospheric Corrector (LAC). An overview of these three instruments is given in Table 1. This paper focuses on the Hyperion instrument and addresses the instrument characteristics, the pre-launch calibration and the post launch check out and calibration.

II. Hyperion System Description

The Hyperion instrument provides high quality calibrated data that can support evaluation of hyperspectral technology for Earth observing missions. The Hyperion is a pushbroom imaging instrument. Each image taken in this configuration captures the spectrum of a line 30m along-track by 7.5Km wide perpendicular to the satellite motion.

Hyperion has a single telescope and two spectrometers, one visible/near infrared (VNIR) spectrometer and one short-wave infrared (SWIR)) spectrometer. The Hyperion instrument consists of 3 physical units: 1) the Hyperion Sensor Assembly (HSA); 2) the Hyperion Electronics Assembly (HEA); and 3) the Cryocooler Electronics Assembly (CEA). The HSA includes the optical, cryo-cooler, and inflight calibration systems and the high-speed focal plane and its electronics.

TABLE I
SUMMARY OF PRIMARY EO-1 INSTRUMENT CHARACTERISTICS AND COMPARISON WITH LANDSAT 7

	MULTISPECTRAL		HYPERSPECTRAL	
	Landsat 7	EO-1	EO-1	
Parameters	ETM+	ALI	HYPERION	LAC
Spectral Range	0.4 - 2.4* µm	0.4 - 2.4 µm	0.4 - 2.5 µm	0.9 - 1.6 µm
Spatial Resolution	30 m	30 m	30 m	250 m
Swath Width	185 Km	37 Km	7.5 Km	185 Km
Spectral Resolution	Variable	Variable	10 nm	2-6 nm
Spectral Coverage	Discrete	Discrete	Continuous	Continuous
Pan Band Resolution	15 m	10 m	N/A	N/A
Number of Bands	7	10	220	256

The Hyperion Sensor Assembly (HSA) shown in Fig. 1 includes subsystems for the telescope, internal calibration lamps, the two grating spectrometers and the supporting focal plane electronics and cooling system. The Hyperion telescope (fore-optics) is a three-mirror astigmat design. The telescope images the Earth onto a slit that defines the instantaneous field-of-view which is 0.624° wide (i.e., 7.5 Km swath width from a 705 Km altitude) by 42.55 µ radians (30 meters) in the satellite velocity direction. This slit image of the Earth is relayed at a magnification of 1.38:1 to two focal planes in the two grating imaging spectrometers. A dichroic filter in the system reflects the spectral region from 400 to 1,000 nm to the VNIR spectrometer and transmits the region from 900 to 2500 nm to the other SWIR spectrometer. The HEA contains the interface and control electronics for the instrument and the CEA controls cryocooler operation. These units are placed on the deck of the spacecraft with the viewing direction along the major axes of the spacecraft as shown in Fig. 2. The visible/near-infrared (VNIR) spectrometer has an array of 60 µm pixels created by aggregating 3x3 subarrays of a 20 µm CCD detector array. The VNIR spectrometer uses a 70 (spectral) by 256 (spatial) pixel array, which provides a 10 nm spectral bandwidth over a range of 400-1000 nm. The

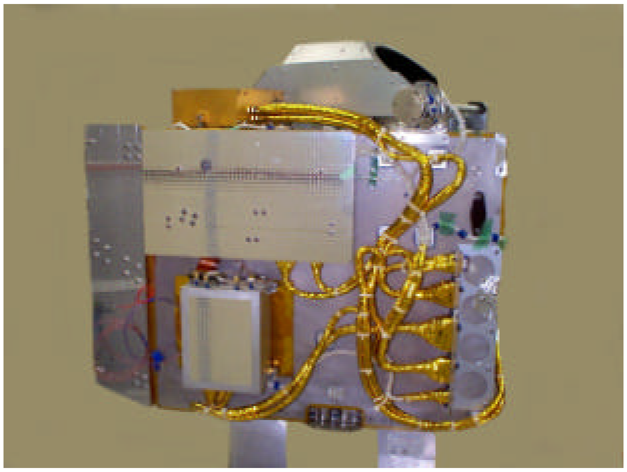

Fig. 1. Hyperion Sensor Assembly includes the telescope, internal calibration lamps, the two grating spectrometers and the supporting focal plane electronics and cooling system.

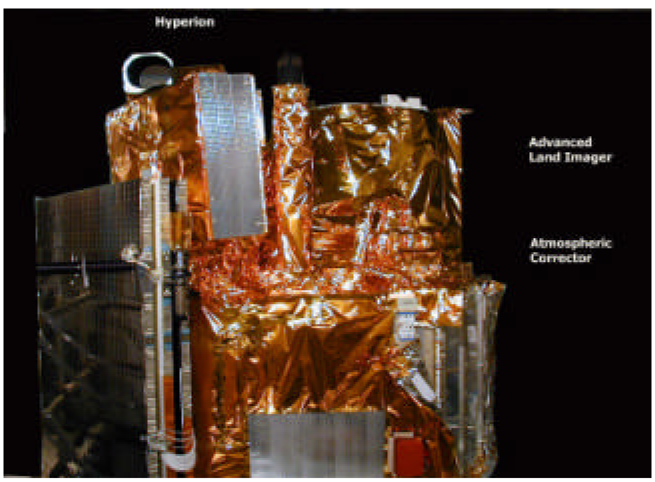

Fig. 2. Hyperion shown installed on the EO-1 spacecraft (upper left in photo)

shortwave infrared (SWIR) spectrometer has 60 μm HgCdTe detectors in an array of 172 (spectral) x 256 (spatial) channels. Similar to the VNIR, the SWIR spectral bandwidth is 10 nm. Thus, the spectral range of the instrument extends from 400 to 2,500nm with a spectral resolution of 10nm. The HgCdTe detectors, cooled by an advanced TRW cryocooler, are maintained at 110 K.

A common calibration system is provided for both the VNIR and SWIR spectrometers. The solar calibration utilizes a diffuse reflector on the backside of the optical cover to provide uniform illumination across the focal plane arrays. The cover is set at a 37° angle and the spacecraft is oriented such that the sun enters the solar baffle in a direction normal to the normal viewing angle at a nominal angle of 53° angle of incidence to the cover normal. Solar data are used as the primary source for monitoring radiometric stability, with ground site (vicarious) and lunar imaging treated as secondary calibration data. The internal calibration subsystem is used for field flattening and as an additional source of calibration cross check.

III. Hyperion Performance and Characterization

A. Pre-Launch Charaterization

The instrument was extensively characterized to provide a performance baseline for the collection of radiometric data for use by the Hyperion science team. This characterization has been previously described by Liao [1] and Jarecke [2]. A hyperspectral characterization facility (HSCF) provides test target inputs to Hyperion while it is in a test vacuum chamber. The HSCF consists of a monochrometer with an output used in one of two optical configurations: either the radiant energy illuminates a pinhole, slit or knife edge which is at the focus of an off-axis parabola reflector or it illuminates a spectralon panel from which the diffuse reflectance is collimated by the same off-axis parabola. A transfer radiometer is used to characterize the radiance output from the monochromator. The light from the steering mirror is directed onto the transfer radiometer or into the Hyperion aperture through a vacuum window.

The measured signal to noise agreed to better than 10% with a system model based on measured optical and focal component data. The image quality characteristics of the radiometer were measured with the HSCF. The cross-track spectral error requirements of <1.5 nm (VNIR) and <2.5 nm (SWIR), spatial co-registration of spectral bands < 0.2 pixel and absolute radiometric accuracy of < 6% were all met during acceptance test performance characterization. The cross-track MTF ranged over spatial and spectral dimensions from 0.35 to 0.47 at Nyquist frequency. Both the center wavelength and the bandwidth were determined for a selected number of pixels across the VNIR and SWIR focal planes.

B. On-Orbit Characterization

Following launch, the initial, on-orbit instrument performance was characterized and compared with pre-launch measurements. The first images were taken one week after launch and were VNIR only. The SWIR FPA cryocooler was turned on three weeks after launch and the full imaging operations for characterization was started a few days later. The characterization was carried out over a four month period.

Specific sites were targeted and data collected for use in measuring the instrument image quality parameters of MTF, spatial and spectral co-registration and VNIR-SWIR FPA alignment. Fig. 3 shows the Mid-Bay Bridge near Denton, Florida an example of a site used for MTF measurements.

Spectral wavelength calibration was checked using telluric and solar spectral features as well as ground truth sources of spectral band edges. The on-orbit measurements produced the same results as the pre-launch characterization.

Absolute radiometric calibration and pixel to pixel relative response performance were directly addressed using the internal calibration system and the solar irradiance. Solar calibration data collections were made every three days from February 16 to March 7, 2001 and then once a week to track both the relative pixel to pixel calibration stability and the long-term repeatability of the radiometer. Successful lunar observations were made and data sets collected on February 2 and February 8, 2001. A comparison of Hyperion pre-launch and post-launch calibration results are given in Figure 4.

Lake Frome in southeastern Australia was characterized by COSSA[3] and used as a prime site for cross-calibration of Hyperion. Measurements at the site in December 2000 were correlated with the instrument data for January 5, 2001 and top of the atmosphere radiances were compared. The first step in the process was to test geometric accuracy of the image for overlaying ground sites. This was done using corrected Landsat data as a reference. A set of 26 ground control points were identified in both the January 5 2001 Hyperion and the geo-rectified (UTM base) January 21 2001 Landsat images.

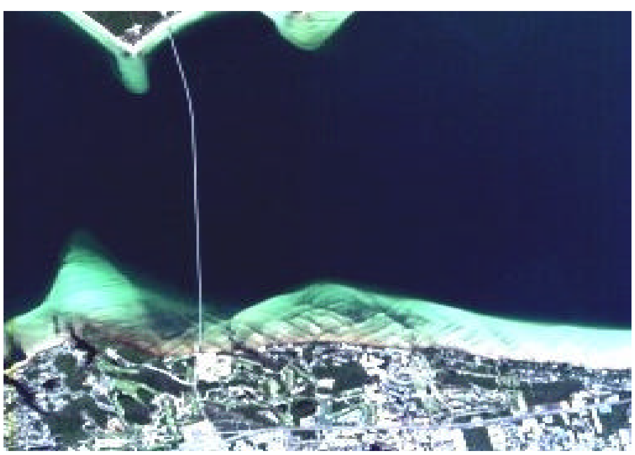

Fig. 3. This is a Hyperion image of the Mid-Bay Bridge near Denton, FL used for MTF characterization

Six other papers, five in Special Session (SS40MO) and one in the Hyperspectral Application (C27BTU) Session, discuss the on-orbit characterization results in detail.

III. Mission operations

EO-1 data collections can be done 8 times per day or more,

Characteristic	**Pre-launch Cal**	**On-orbit Cal**
GSD(m)	29.88	30.38
Swath (km)	7.5	7.75
No. of Spectral Channels	220	200 (L1 data)
VNIR SNR (550-700nm)	144-161	140-190
SWIR SNR (~1225nm)	110	96
SWIR SNR (~2125nm)	40	38
VNIR X-trk Spec. Err	2.8nm@655nm	*
SWIR X-trk Spec. Err	0.6nm@1700nm	0.58
Spatial Co-Reg: VNIR	18%@Pix#126	*
Spatial Co-Reg: SWIR	21%@Pix#131	*
Abs.Radiometry(1Sigma)	<6%	3.4%
VNIR MTF@630nm	0.22-0.28	0.23-0.27
SWIR MTF@1650nm	0.25-0.27	0.28
VNIR Bandwidth	10.19-10.21	*
SWIR Bandwidth	10.08-10.09	*

*similar to pre-launch values within measurement error.

Fig. 4. Summary of Pre-launch and On-orbit Characteristics

depending on the type of collection and the availability of ground stations. Lunar calibration is performed about once per month; solar calibration is performed about once per week. The standard image cube for Hyperion consists of 660 frames of data (19.8 Km long by 7.5 Km wide) and takes about 3 seconds to collect; an image equivalent to a Landsat scene is nine cubes, and takes 27 seconds. The spacecraft is capable of a ± 22 degree roll angle that permits viewing a Landsat swath adjacent to the ground track swath.

IV. Conclusions

The EO-1 Hyperion Instrument accomplished a very successful mission, meeting all the goals for levels of on-orbit radiometric performance and for characterization of those levels. As such, it will provide hyperspectral imagery with of excellent radiometric quality the science community for further use in establishing the value for this technology in remote sensing of the earth's environment.

References

[1] L. Liao, P. Jarecke, D. Gleichauf and T.Hedman, "Performance Characterization of the Hyperion Imaging Spectrometer Instrument", *Proc. of SPIE*, Vol. 4135, pp. 264-275, August 2000.

[2] P. Jarecke, K. Yokoyama, "Radiometric Calibration of the Hyperion Imaging Spectrometer Instrument From Primary Standards to End-to-End Calibration" ", *Proc. of SPIE*, Vol. 4135, pp 254-263, July 2000.

[3] David Jupp and Dean Greatz, private communication.