THE HYPERSPECTRAL IMAGER FOR THE COASTAL OCEAN (HICO)- DESIGN AND EARLY RESULTS

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ABSTRACT

The design and early results of the Hyperspectral Imager for the Coastal Ocean (HICO) are presented. The performance requirements imposed on the sensor to measure the low signals and to differentiate the optically complex spectra of the coastal ocean are discussed. It is shown the as-built sensor meets or exceeds the design parameters. Further, environmental products from early retrievals of the HICO imagery are presented.

***Index Terms*—** Hyperspectral, space, ocean, coastal ocean

1. INTRODUCTION

The Hyperspectral Imager for the Coastal Ocean [1] was launched on September 10, 2009 and resides aboard the International Space Station (ISS) as part of the HICO-RAIDS Experimental Payload (HREP). It is the first spaceborne, hyperspectral imager optimized for environmental characterization of the coastal zone. From the ISS, which has an orbital inclination of 52° at an altitude of about 400 km, HICO provides access to a variety of coastal types worldwide for scientific study and environmental product algorithm development. HICO imagery is used to produce maps of maritime products including coastal bathymetry, bottom type and in-water optically active constituents. It was developed at the Remote Sensing Division of the Naval Research Laboratory and funded by the Office of Naval Research (ONR), as an Innovative Naval Prototype (INP). As an INP, HICO must satisfy two goals: demonstrate a new ability to satisfy unmet naval needs for coastal characterization as described above, and demonstrate ways to dramatically reduce cost and time to produce space instruments. For the latter, the sensor incorporates Commercial Off The Shelf (COTS) components similar to the ocean PHILLS [2], including a CCD camera, offner spectrometer, and lens. In addition to the sensor, the instrument includes a COTS rotation mechanism for pointing across track, and is controlled by a hermetically sealed computer constructed using PC104 based parts with little to no space tested legacy.

In the complicated coastal environment, where the water contains significant dissolved and suspended matter and the bottom is visible, hyperspectral imaging has demonstrated the ability to retrieve bathymetry, bottom type, and water inherent optical properties [3]. In order for this to be possible, maritime hyperspectral imaging must satisfy stringent requirements with respect to spectral resolution and signal to noise ratio (SNR). In general, both are not fully met by systems designed for land or open ocean applications. In terms of spectral resolution, systems require water-penetrating wavelengths from 04 to 0.8 microns, which must be divided into 0.01 micron or smaller spectral bands in order to separately identify coastal ocean features A high, 200:1, SNR is needed because like the open ocean, the coastal ocean is an optically dark environment, with an albedo of at most, several percent. As viewed from space, scattered sunlight makes the atmosphere significantly brighter than the water below it, and this atmospheric signal must be removed from the total signal. In addition, HICO must provide spectral image data from 0.8 to 1.0 microns in order perform accurate atmospheric removal and surface reflection.

The final design parameters required of HICO and their as-built values are listed in table 1. The required signal to noise ratio is based on a Modtran model using a 5% albedo as seen above the atmosphere for a sun angle of 45 degrees and a 23km rural aerosol model. Most of the other parameters are derived from the required ground sample distance and the spectral requirements as described above. Note that the high resolution (HR) spectral mode will be used as a diagnostic tool to check spectral registration and is not part of the requirements. Table 2 lists the required key optical design parameters that flow down from table 1.

2. PERFORMANCE

As previously presented [4], HICO was tested before launch using the Naval Research Laboratory's calibration and characterization facility. The measurements showed that the as-built sensor meets or exceeds most of the design requirements as shown in tables 1 and 2, and figure 1. The exception is the SNR at infrared wavelengths, but since this will be used only for atmospheric removal, the SNR can be increased by spectral binning. If HICO is used for land applications, the signal is much greater and spectral binning is not required. Recent on-orbit studies support the ground measurements and will be reported on later.

Some of the as-built values have been changed to reflect the on-orbit performance- most notably the GSD's are slightly smaller because the station's altitude is lower than 400 kilometers. Also HICO does saturate for some wavelengths at the tops of some bright clouds. It should be noted that even though HICO generates a signal in the as-built range, currently only data at wavelengths between 400nm and 900nm are being retrieved. There are two reasons for this. One is that the laboratory calibration sources provide a weak signal at short wavelengths. The second is due to a decrease in the sensitivity of the instrument for the shortest and longest wavelength ranges, which magnifies small retrieval errors. Currently there is a calibration/validation effort underway, and it is expected that the calibrated wavelength range should increase.

Parameter	Requirement	As-built Value
Off-nadir pointing	45 deg port, 30 deg starboard	45 deg port, 45 deg starboard
Spectral Range	400 to 860 nm (goal 380 to 1000 nm)	350 to 1070 nm
Spectral Channel Width (normal mode)	10 nm (goal 5 nm)	5.73 nm (11.46nm binned on the ground)
Spectral Channel Width (HR mode)	No requirement	1.91 nm
Signal to Noise Ratio	> 200 to 1 for a 5% surface albedo (10 nm spectral bins)	> 200 to 1 for a 5% surface albedo (11.46 nm spectral bins)
Polarization Sensitivity	< 5% (goal < 2%)	< 5% for most wavelengths
Crosstrack Ground Sample Distance	100 m @ 400 km alt.	94 meters @ 400 km alt.
Along-track Ground Sample Distance	100 meters	90 meters
Scene Size	(50 km wide)×(200 km long)	(42 km wide)×(190 km long)
vignetting	No vignetting	No vignetting
Saturation	Will not saturate when viewing 95% albedo cloud	Close (see text)
Image quality	MTF > 0.35 at Nyquist spatial frequency of 0.5 cycles/pixel	PSF about 1 pixel
Spectral stray light	< 1% albedo error	Not strictly measured
Jitter	< 0.2 IFOV per frame	Not significant
Long term stability	+/- 5% after calibration	Not fully quantified- appears to be within spec.

Table 1: HICO requirements

Parameter	Design	As-built Value
Focal Length	60 mm	68.1 mm
F#	3.5	3.5
Pixel Size	16 μ	16 μ
FPA Size, total: used:	512×512 512(spatial)×384(spectral)	512×512 512(spatial)×384(spectral)
Spectral smile	< 2 nm	< 0.3 nm (tilt only)
Keystone	< 3 microns	< 3 microns
Frame Time (normal)	13.7 ms	13.7 ms
Frame Time (HR mode)	30 ms	30 ms

Table 2: HICO optical design parameters

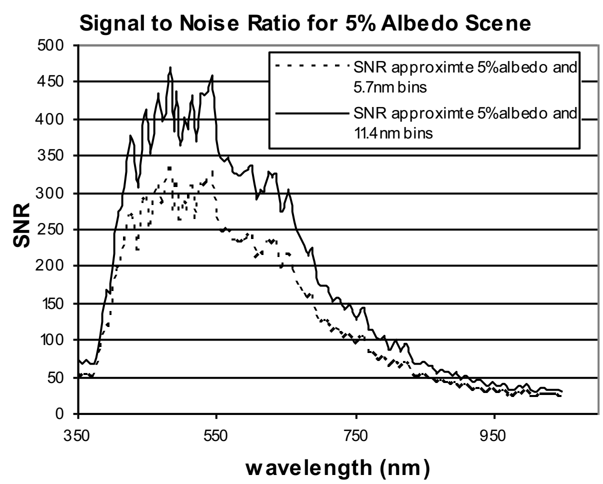

Figure 1: Measured SNR for a 5% albedo scene simulated by an integrating sphere consisting of a halogen lamp and a high pressure Xe lamp. The output of the sphere is too low below about 400nm to model the scene well.

3. DATA PRODUCTS

Figure 2 shows an image of Andros Island in the Bahamas along with a bathymetry map created using NRL's look up table (LUT) approach (see for example [3]). The LUT consists of a library of modeled remote sensing reflectance spectra produced using the radiative transfer numerical model HydroLight [5]. The spectral library is created by varying the inherent optical properties of the water, the water depth, and the bottom type inputs for approximately 100,000 HydroLight simulations. The spectra measured by HICO are then compared to the modeled spectra and the best match is determined using the minimum Euclidean distance as a metric. Results from these comparisons are shown in figure 2. The bottom depth inputs are plotted for each pixel to create the bathymetry map. This image shows HICO's ability to characterize a variety of optical conditions, from dark scenes like the deep water in the lower right side of the image, to bright shallow water areas in the upper left. As commented on in the caption, the results have not yet been validated, but are generally reasonable and demonstrate the potential for HICO to produce useful data products.

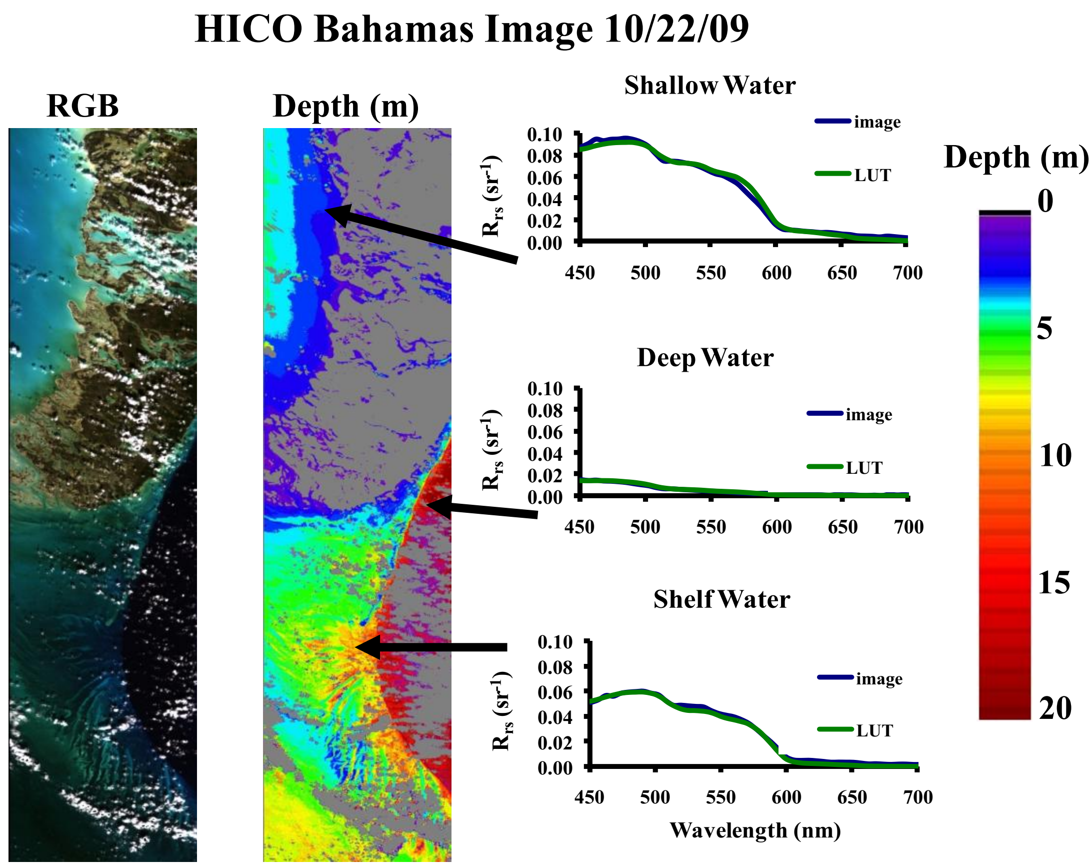

Figure 2: On the left is the RGB image of the southern end of Andros Island. Right is a bathymetry map and examples of measured and modeled spectra representing optically shallow to deep water. The grey areas are land and cloud masks, as well as optically deep areas. The scene is approximately 42x190km. Note that as of this writing, the depth has not been validated yet.

3. CONCLUSION

The design and examples of early data products for the Hyperspectral Imager for the Coastal Ocean are presented. The on orbit performance of HICO meets or exceeds the design parameters. The potential for producing useful data products when combined with NRL's Look Up Table approach is established. As an INP, it is shown to be successful and demonstrates that HICO is a pathfinder for future operational systems

3. REFERENCES

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