The Hyperspectral Imager for the Coastal Ocean (HICO) on the International Space Station

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Abstract – The Hyperspectral Imager for the Coastal Ocean, launched to the International Space Station in September 2009, is the first spaceborne hyperspectral imager optimized for environmental characterization of the coastal zone. From the Space Station orbit HICO provides access to a variety of coastal types worldwide for scientific study and environmental product algorithm development, and HICO imagery is used to produce maps including coastal bathymetry, organic and inorganic matter in the water, bottom characteristics, and water optical properties. This article will discuss the performance requirements of the spaceborne imager, the design of the flight hardware, and show examples of the environmental products retrieved from HICO imagery.

Keywords: hyperspectral, coastal remote sensing, space

1. INTRODUCTION

Environmental characterization of the coastal ocean is a vital part of planning and executing naval operations in the coastal zone. The rapid and safe execution of operations ranging from military to humanitarian relief depends on accurate maps of bathymetry, water clarity, harmful blooms, and bottom characteristics. However, the coastal ocean is complicated, containing suspended and dissolved organic matter, suspended and dissolved inorganic matter, with a wide range of bottom types and depths, all of which can vary over tens to hundreds of meters. Spaceborne multispectral imagers such as MODIS and MERIS, which are successful at characterizing the relatively simple open ocean, generally do not provide sufficient information to characterize the complicated coastal environment.

Hyperspectral imaging has developed into a powerful tool for environmental characterization of the coastal ocean using remotely-sensed imagery. In contrast to multispectral imagers, a hyperspectral imager records a contiguous spectrum of the light received from each pixel in the scene. This extra spectral information can be exploited to produce the desired maps of environmental properties (Davis *et al*., 2006). More than two decades of research at the U.S. Naval Research Laboratory (NRL) and other laboratories has produced imaging system requirements and product algorithms to retrieve environmental information from hyperspectral imagers on aircraft platforms. A natural next step, building on this aircraft experience, is spaceborne hyperspectral imaging offering repeat access to the variety of coastal types distributed worldwide.

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2. HICO DESIGN AND PERFORMANCE

2.1 HICO Design and Performance

The Hyperspectral Imager for the Coastal Ocean (HICO), sponsored by the U.S. Office of Naval Research (ONR) as a component of ONR's Innovative Naval Prototype (INP) program, is the first spaceborne hyperspectral imager optimized for the coastal ocean. As an INP, HICO must satisfy two goals: demonstrate a new ability to satisfy unmet naval needs for coastal characterization and demonstrate ways to dramatically reduce cost and time to produce space instruments. HICO achieves the first goal by producing maps of coastal bathymetry, water content and optical properties, and bottom type, which are currently unavailable from spaceborne instruments.

HICO's performance requirements are tailored for coastal environmental imaging, based on the heritage of decades of airborne experience and product validation. A primary performance requirement is high signal-to-noise ratio when imaging coastal scenes from space. Water scenes have low albedo, and are imaged through the Earth's atmosphere which is significantly brighter than the underlying water scene due to scattered sunlight. This atmospherically-scattered light must be removed because it contains no information about the water scene. However, removing the atmospherically-scattered light inevitably degrades the signal-to-noise ratio of the water scene after removal, leading to the initial high signal-to-noise ration requirement. HICO is designed and tested to have a signal-to-noise ratio greater than 200 to 1 for water-penetrating wavelengths when imaging a 5% albedo scene. HICO images over all water-penetrating wavelengths, with spectral binning of 5.7 nm which is sufficient to capture the shape of coastal ocean spectral features. HICO's ground sample distance, which is the footprint of a single image pixel on the water surface, is approximately 90 m, providing sufficient spatial resolution for this proof-of-concept demonstration. HICO's primary performance requirements, derived from airborne coastal hyperspectral experience at NRL and other laboratories, are shown in Table A.

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Table A. HICO Performance Parameters

Parameter	HICO Performance
Signal-to-noise ratio	> 200 to 1 for water-penetrating wavelengths
Wavelength range	400 to 900 nm
Spectral bin width	5.7 nm
Ground sample distance	90 m
Image scene width	42 km at nadir
Image scene length	190 km
Cross-track pointing	45 deg left to 30 deg right
Scenes per orbit	1 maximum

2.2 HICO Imager Fabrication and Launch

The second HICO goal as an Innovative Naval Prototype is to demonstrate innovative ways to reduce the cost and time required to build a space payload. HICO satisfied this goal by using Commercial-Off-The-Shelf components wherever possible. The spectrometer, CCD camera and computer are COTS items. Because the camera and computer are not designed to operate in vacuum they are housed in hermetic enclosures filled with nitrogen gas. A particularly interesting use of COTS hardware is the rotary mechanism used to point the HICO line of sight to maximize imaging opportunities. The mechanism is a commercial motorized rotary stage intended for use in a laboratory vacuum system. The HICO flight imager is shown in Fig. 1.

Figure 1. HICO flight imager. The ruler in this picture is 0.5 m long. (NRL photograph).

HICO was launched from the Japanese Aerospace Exploration Agency's Tanegashima Space Center on September 10, 2009. On September 24, 2009 the payload module containing HICO and a second NRL instrument, the Remote Atmospheric and Ionospheric Detection System (RAIDS), was docked to the Exposed Facility of the Japanese Kibo module on the International Space Station.

3. HICO ENVIRONMENTAL PRODUCTS

A preliminary example HICO product is the relative bathymetry map of an area of the Yellow Sea off the coast of South Korea shown in Fig. 2. The left picture in Fig. 2 is a conventional color image made using three color bands (red, green and blue) from a HICO image of the scene. This picture shows extensive shallowly-submerged mud flats and channels formed by the tides. These mud flats and channels are dynamic, and safe navigation requires accurate bathymetry. The right image in Fig. 2 is a false-color

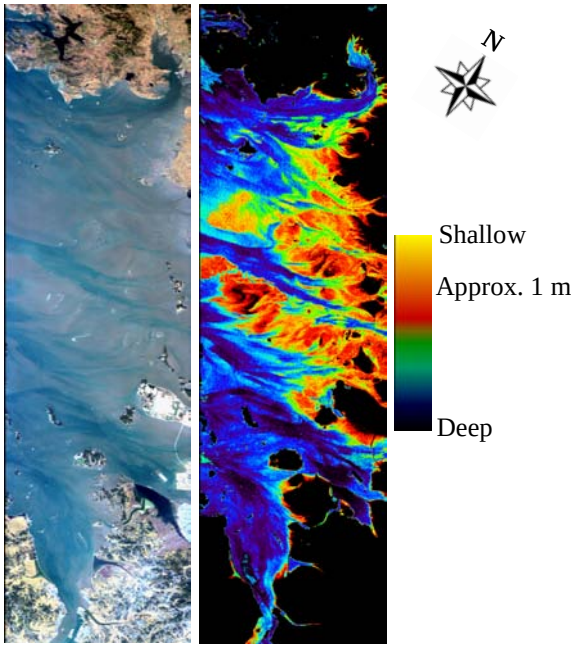

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Figure 2. Left: Color picture of an area of the Yellow Sea off the coast of South Korea constructed using three HICO color bands. The scene is approximately 42 x 190 km. Right: False-color relative bathymetry map retrieved from HICO image data.

relative bathymetry map produced using two selected HICO spectral bands. While this bathymetry map is qualitative and has not been validated, it does correspond well to the visible mud flats and channels in the picture on the left, indicating the potential of spaceborne hyperspectral imaging for environmental characterization of the coastal ocean.

4. CONCLUSION

The Hyperspectral Imager for the Coastal Ocean demonstrates the ability to produce coastal environmental products from spaceborne imagery. HICO and its products are pathfinders for future operational systems.

ACKNOWLEDGEMENTS

The relative bathymetry map in Fig. 2 was provided by C.M Bachmann at the Naval Research Laboratory, using the method of Bachmann (2008). HICO is launched and flown under the direction of the DoD Space Test Program.

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