

# Hyperspectral projection of a coral reef scene using the NIST hyperspectral image projector

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## ABSTRACT

Improving the understanding of the optical scene components associated with coral reef imagery will advance the ability to map and monitor coral reefs using remote sensing. One tool that can aid in understanding the components in these scenes is the NIST Hyperspectral Image Projector (HIP). In this paper a hyperspectral scene is reformatted for projection using the HIP by first unmixing image spectra into endmembers. The abundance images representing each of the endmembers are then projected using the NIST HIP and collected by a hyperspectral imager. Since the scene is from a digital source, it can be used repeatedly without concern for changing measurement conditions. This work represents one of the first steps in developing scene projection capabilities that can be used for sensor characterization, algorithm testing or to have optical components changed independently in order to better understand the overall effects on the total observed scene.

**Keywords:** Hyperspectral, Remote Sensing, Endmembers, Coral Reef

## 1. INTRODUCTION

Coral reefs around the world are declining due to a variety of threats. Since coral reefs are expansive and are often located in remote areas, remote sensing is a critical tool in monitoring this natural resource. Remote sensing of coral reefs presents a number of challenges that can obscure the view of the reef. These include influences from the atmosphere, specular reflectance off the water surface and the spectral attenuation of the water column. The reefs also provide spatially and spectrally complex scenes which require a significant amount of image processing to accurately and fully classify the benthic composition. This makes coral reefs an ideal subject for examining complicated optical component interactions.

NIST has developed an instrument that is capable of projecting scenes of hyperspectral data cubes. The projected scenes appear normal when projected by a common projector, but instead of using only red, green and blue, the HIP provides the full spectral content for every pixel. This means the projected image is a close approximation to what an imaging spectrometer usually observes.

The HIP uses digital micromirror devices (DMD) to provide the spectral and spatial content of the data cubes. To efficiently provide the spectral content for each pixel, the HIP uses a compressive algorithm to match broadband spectral endmembers to the corresponding abundance images. This method conserves a significant amount of time over projecting the spectral content on a wavelength-by-wavelength basis. For an in-depth review of the HIP design, refer to Rice, et al [1-3].

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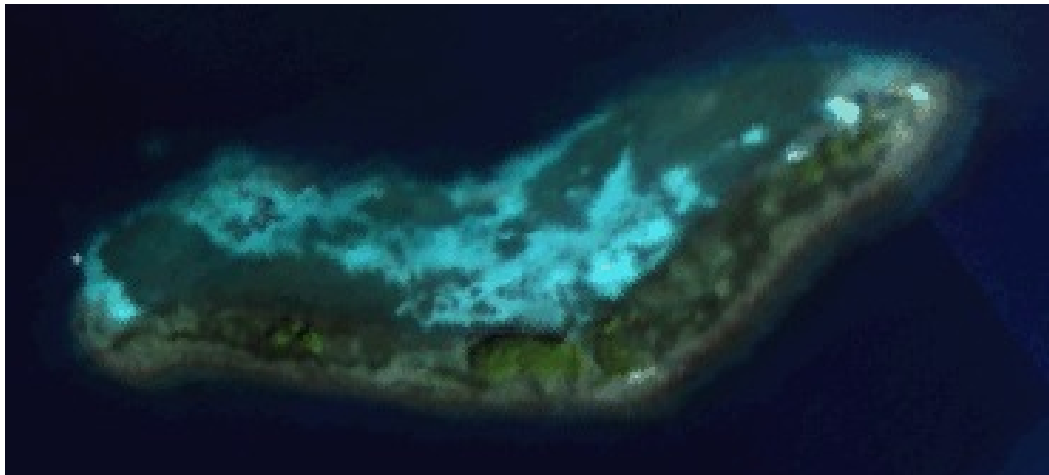
There are many potential uses for the HIP in relation to remote sensing. One application is for the testing of sensor performance in the laboratory using realistic scenes that have the spectral and spatial complexity that the sensor was designed to observe. This is a step beyond the standard method of using a lamp-illuminated integrating sphere, which is spectrally and spatially uniform. Beyond the testing of sensor performance, however, the HIP also has the potential to test algorithms and determine the sensitivity of remote sensing systems for detecting targets. Since the image is digital, it can also be manipulated to vary the components in the scene. For example, submerged objects can be projected at various depths in a water column while the sensor being tested records images from the different scenarios. Additionally, the field evaluation of remote sensing instruments can often be hampered by poor meteorological and/or environmental conditions, such as the presence of clouds and waves. This can cause significant delays in the testing of airborne-based sensors. Use of a system like the HIP for evaluation provides a means to project an image with full spectral content without concerns for changing conditions while the remote sensing system is under test.

## 2. METHODS AND RESULTS

### 2.1 Coral reef scene and collection

The coral reef scene of Enrique Reef used in this study was provided by the Center for Subsurface Sensing and Imaging Systems (CenSSIS) at the University of Puerto Rico at Mayagüez. Enrique Reef is located off the southwestern coast of Puerto Rico and has been well characterized with respect to bottom composition [4]. The reef is approximately 1.5 km long by 0.5 km wide with depths of 3 m to 4 m at the back reef and 20 m at the fore reef. Several areas have rocks and mangroves emerging above the water, while the bottom composition includes an often complex mixture of sand, sea grass, algae, and coral.

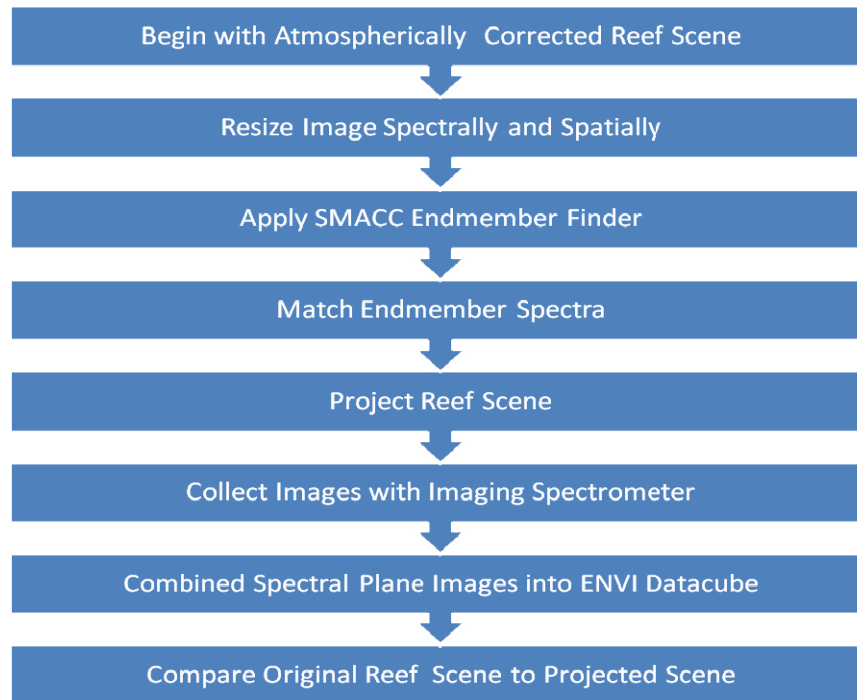
The image (Fig. 1) was collected by an AISA Eagle airborne sensor. The AISA Eagle is a pushbroom sensor with a 400 nm to 995 nm spectral range and a 3 nm spectral bandwidth. The radiometric resolution is 12 bit. The spatial resolution for this scene is 4 m at 2.97 km altitude. The image was captured on December 6, 2007 and consists of a mosaic generated from two parallel flightlines. A preliminary atmospheric correction was applied to the scene, but acquisition artifacts still remain (i.e., the stripe in upper right of image). These artifacts will be minimized in future applications using this image.



**Figure 1.** Color image of Enrique Reef using 649 nm, 550 nm, and 459 nm for red, green and blue, respectively. The back reef is towards the top of the image and the fore reef is near the bottom. Most of the scene is submerged with the exception of several groups of mangrove trees and a few small areas of rubble.

### 2.2 Image processing

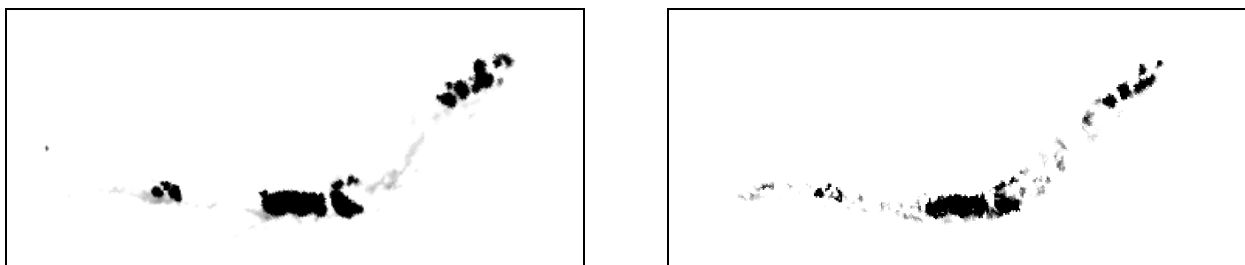
The process starts with the atmospherically corrected hyperspectral image (data cube) of Enrique Reef. The image is spectrally and spatially resampled to match the HIP configuration, image endmembers are identified, and the image is projected with the full spectral and spatial content. The projected image is then captured with an imaging spectrometer and compared to the original. The steps to this process are generalized in Fig. 2 with specific details provided below.



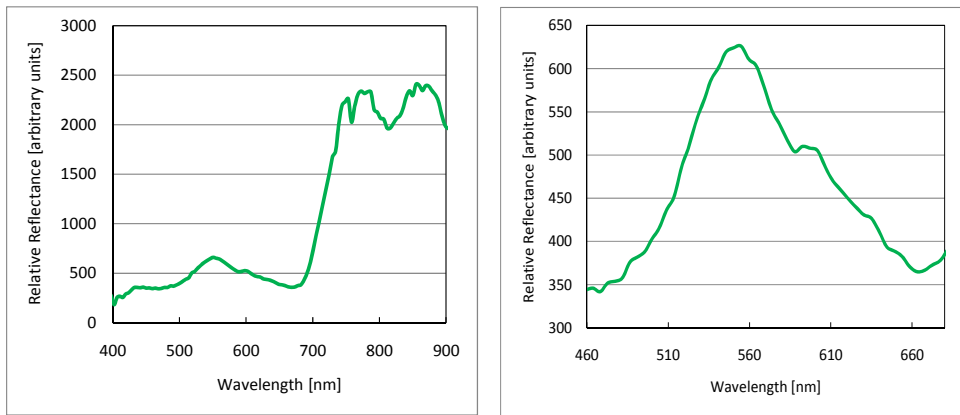
**Figure 2.** This general process flow diagram shows the steps involved in preparing the image for projection and re-imaging.

The image provided was in the Environment for Visualization (ENVI) standard file format and had been corrected for atmospheric effects using Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH). Statistics were reviewed for the image and no saturated pixels were found in the spectral bands of interest. The original image size was 372 by 167 pixels spatially and 397 nm to 995 nm spectrally. In order to adapt the image for the current HIP configuration, the image was resampled spatially to 1024 by 768 pixels and spectrally to 460 nm to 680 nm. The image was initially resized to 1024 by 460 pixels to maintain the original aspect ratio characteristics and black edges (i.e., zero values) were added to the top and bottom of the image during processing to fill the entire 1024 by 768 pixel frame of the HIP.

While this breadboard HIP only covers the visible part of the spectrum, the prototype version, which is under development, will cover the entire solar reflective region. To establish that the HIP wavelengths maintain the spectral integrity of the original image, a comparison was made between the full spectral content (397-995 nm) and the truncated visible subset (460-680 nm). Using ENVI's Spectral Angle Mapper (SAM), with the sensitivity set to 0.1 radians, the scene was mapped using a spectrum selected from a mangrove tree stand. The results show that even without the red edge the above surface vegetation is still spectrally distinct (Figs. 3 and 4).



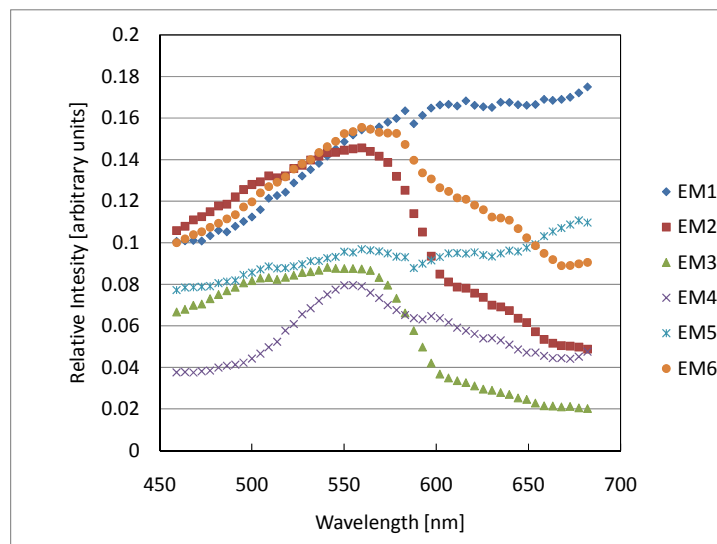
**Figure 3.** Results of the SAM unmixing comparison of the full spectral range (on the left) to the visible range (on the right). A contrast stretch has been applied to both images.



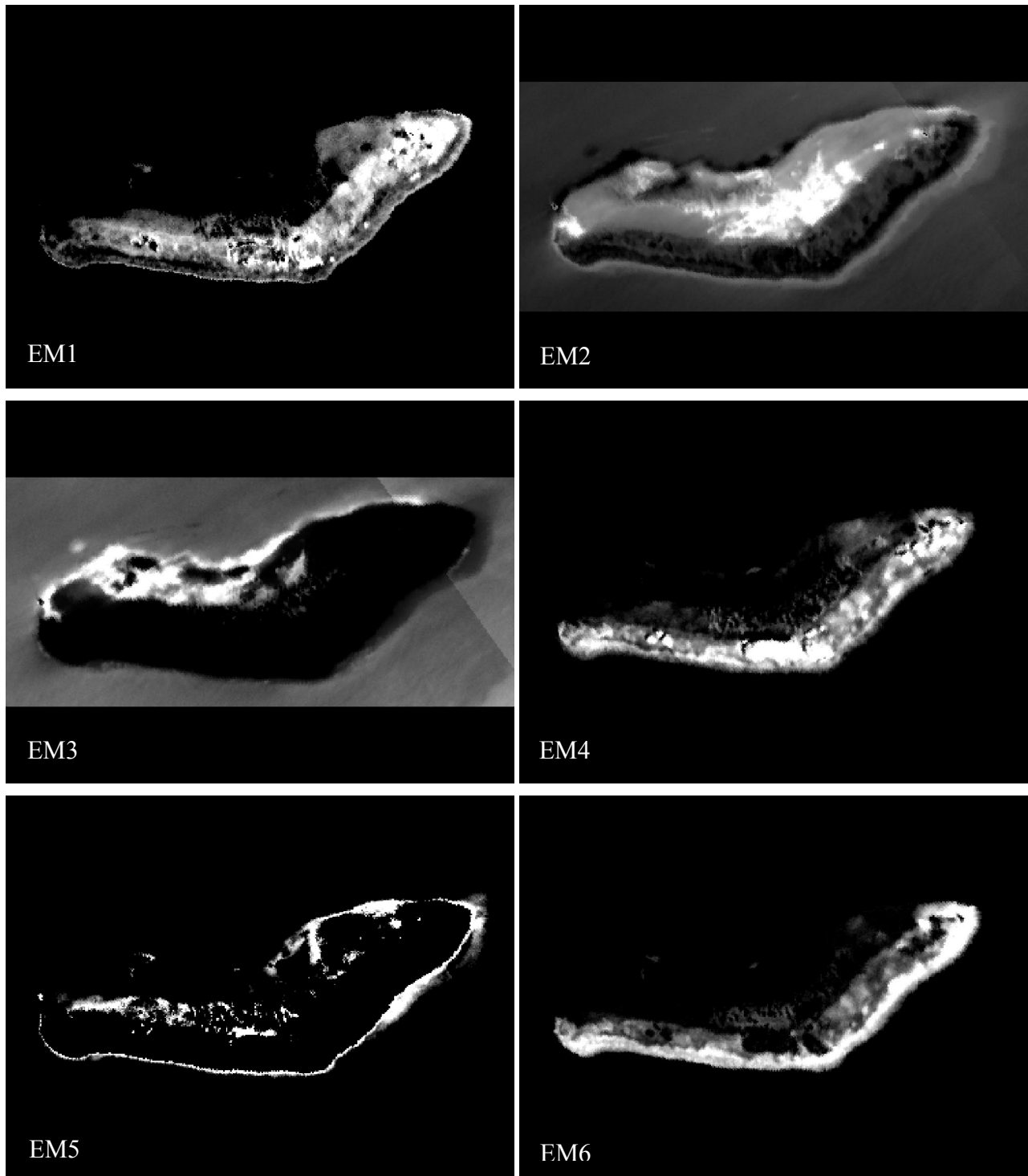
**Figure 4.** Results of the SAM endmember comparison of the full spectral range (on the left) to the visible range (on the right).

The HIP uses a compressive algorithm to represent the spectral components of the scene [2]. These components were identified by decomposing the scene into its major spectral endmembers, which was accomplished using ENVI's Sequential Maximum Angle Convex Cone SMACC endmember extraction routine. The SMACC routine provides both a set of endmember spectra (Fig. 5) and the associated abundance images (Fig. 6). The extracted endmembers are typically not the same endmembers that would be extracted to classify the bottom features, but instead represent the most distinct spectral features in the overall scene. The settings used for the SMACC implementation were: set the number of endmembers to six, sum to unity or less, coalesce redundant endmembers, and exclude the shadow band.

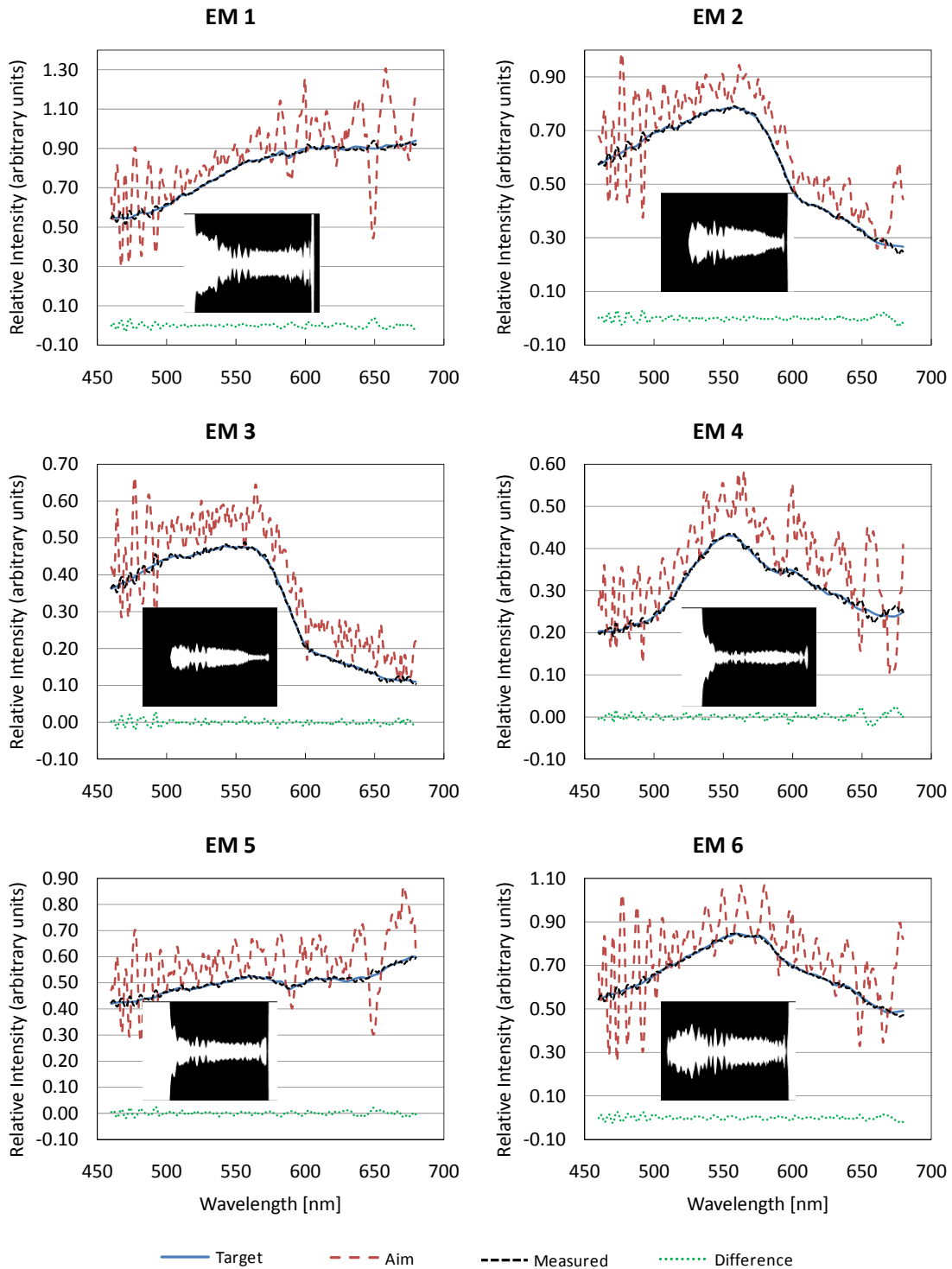
The endmember spectra were next resampled to one nanometer resolution and then the HIP software performed an optimization routine to match the spectra generated using the DMD with these endmember spectra. This matching method was performed with a constraint that the standard deviation of the difference between the target and the matched spectra is less than 1 percent, with a maximum of 100 iterations. During this optimization the 'aim' spectra were used to switch mirrors 'on' and 'off' to add or subtract light in selected parts of the spectrum. The result of this process (Fig. 7) was that the DMD generated spectra closely match the endmember spectra derived from the original image.



**Figure 5.** The endmember (EM) spectra are shown above for the SMACC results from the Enrique Reef image.



**Figure 6.** Abundance images derived from using the ENVI SMACC algorithm. The images have had a contrast stretch applied in order to make each image viewable.



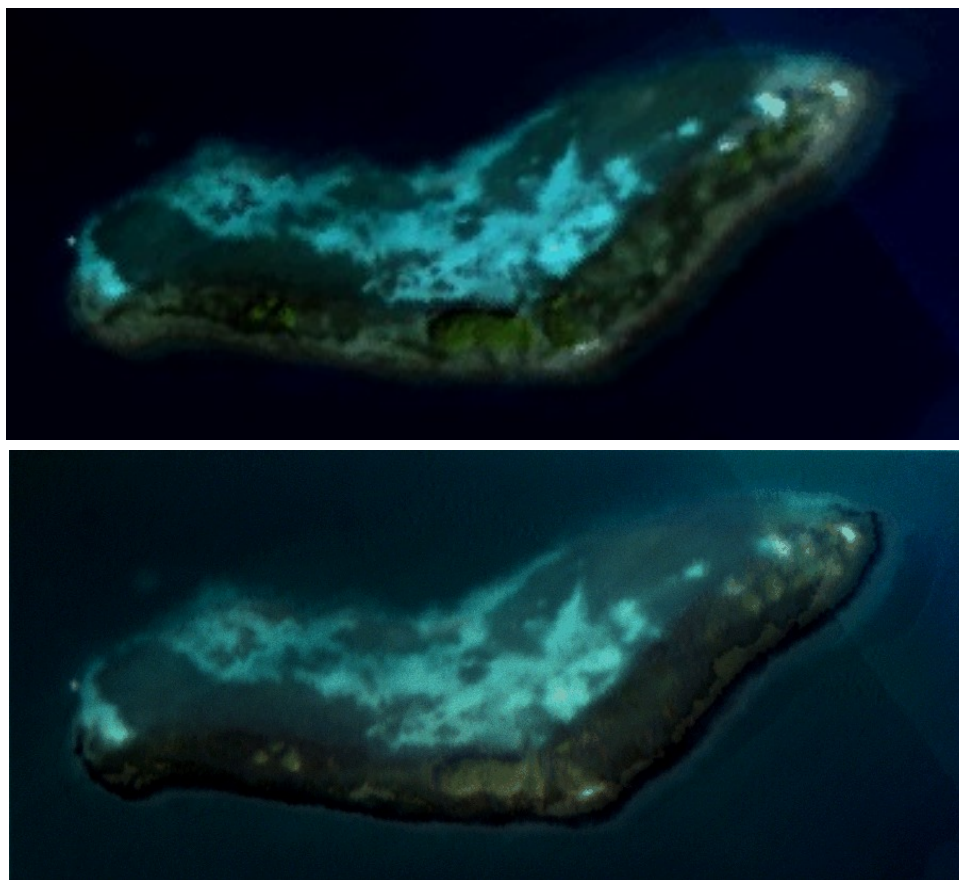
**Figure 7.** Endmember spectra used for matching are shown as the Target line. The Matched spectral lines obscure the target line in most cases in these plots due to a relatively good match. The difference between the two is shown as the Difference line at the bottom. The inset images show the position of the ‘on’ mirrors in white and the ‘off’ mirrors in black, as determined by the ‘Aim spectra’, which results in the Matched spectral lines.

The image was directly projected from the HIP using an optimized refractive collimator. To project the entire image, the six abundance images derived from the SMACC analysis, which were previously stored as individual Tagged Image File Format TIFF files, were sequentially projected at a rate of 6 per second, in sync with the corresponding endmember spectra and with the imaging spectrometer, within the 1 second integration time of the imaging spectrometer. The spectral intensity and shape of the broadband endmember spectra for the individual pixels within each TIFF were modulated by the spatial DMD mirrors corresponding to an 8 bit scene with 256 intensity levels for each abundance image.

### 2.3 Image cube collection and analysis

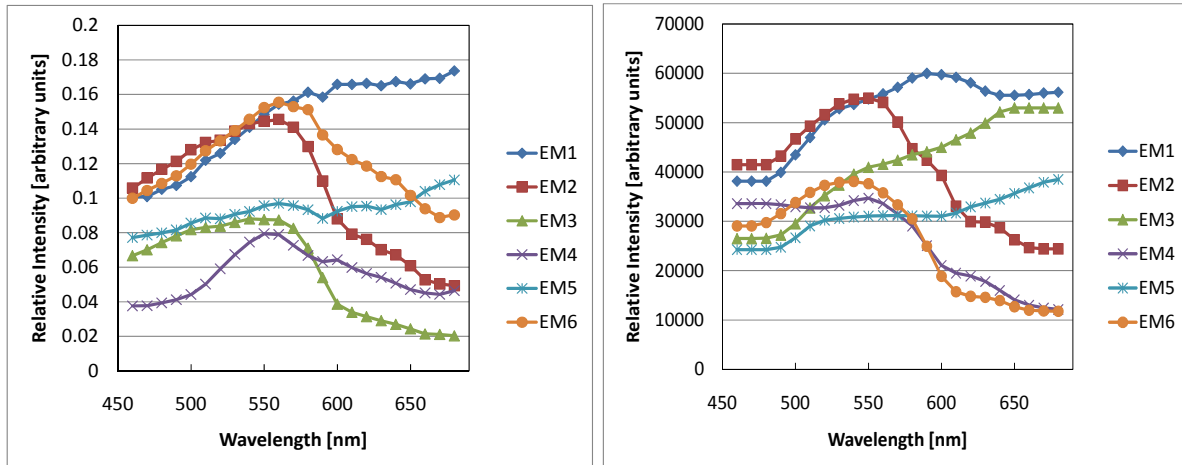
The hyperspectral imager used to capture the projected image was a Princeton Instruments PIXIS BR charge-coupled device CCD array camera with 1024 by 1024 pixels and 16 bit radiometric resolution. The detector array was cooled to a temperature of -70 degrees Celsius. The compound camera lens is set to f/8 and focused at infinity. In front of the lens is a VariSpec liquid crystal tunable filter (LCTF), which provides spectral measurements from 400 nm to 720 nm. The projected images were ultimately collected in the spectral range from 460 nm to 680 nm at 2 nm intervals with a typical spectral bandwidth of 7 nm. This produced a total of 111 TIFF images, one for each of the wavelength intervals.

The resulting images were then processed to convert the raw digital number DN values for each CCD pixel into radiance, taking into account the filter and lens transmittance and the responsivity of the CCD. The processed images were then opened in ENVI and saved as a standard ENVI image file as a single data cube. Once the new image was opened in ENVI a comparison could be made between the original image and the projected image.



**Figure 8.** The image on the top is of the original and the image on the bottom is the image that was projected by the HIP and recollected using the imaging spectrometer. The images are a composite using 650 nm, 550 nm, and 460 nm for red, green and blue, respectively.

For comparison, the SMACC algorithm was applied to the projected data cube using the same constraints as used for the original image. This analysis produced 6 endmember spectra that reasonably resembled the original set (Fig. 9). It is important to note, however, that, depending on the application, it is not necessarily of critical importance to reproduce the exact same spectra for sensor performance evaluation. Even if the spectra projected are not an exact match, they are still a known quantity and any subsequent analysis of the projected image will depend on the projected spectra rather than the original spectra.



**Figure 9.** Comparison of the original endmember spectra (left) with the projected endmember spectra (right).

### 3. CONCLUSION

We have demonstrated a method to unmix an image spectrally, project the broadband spectra using the HIP, and re-collect the image using an imaging spectrometer. The coral reef scene used for this demonstration provided a realistic example of natural complexity, both spectrally and spatially. The steps described here can be applied to any number of hyperspectral scenes. It is anticipated that the fully developed version of the HIP software will combine and automate some of the steps described above.

\*Note: References are made to certain commercially available products in this paper to adequately specify the experimental procedures involved. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that these products are the best for the purpose specified.

### REFERENCES

- [1] Rice, J. P. Brown, S. W., Neira, J. E. and Bousquet, R. R., "A hyperspectral image projector for hyperspectral imagers," *Proc SPIE* **6565**, 65650C (2007).
- [2] Rice, J. P. and Allen, D. W., "Hyperspectral image compressive projection algorithm," *Proc. SPIE* **7334** (these proceedings) (2009).
- [3] Rice, J. P., Brown, S. W., Johnson, B. C., and Neira, J. E., "Hyperspectral image projectors for radiometric applications," *Metrologia* **43**, S61-S65 (2006).
- [4] Goodman, J. A., Velez-Reyes, M., Hunt, Shawn, and Armstrong, R., "Development of a field test environment for the validation of coastal remote sensing algorithms: Enrique Reef, Puerto Rico," *Proc. SPIE* **6360**, (2006).