CENSSIS SEABED: DIVERSE APPROACHES FOR IMAGING SHALLOW AND DEEP CORAL REEFS

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ABSTRACT: The main task of the Center for Subsurface Sensing and Imaging Systems (CenSSIS), funded by the National Science Foundation, is to develop appropriate techniques to separate complex subsurface signals. This multi-university Engineering Research Center aims to revolutionize the existing technology for detecting and imaging objects under different layers, including underwater. The University of Puerto Rico at Mayaguez (UPRM), a main partner of CenSSIS, has created SeaBED for the development of improved remote sensing techniques for monitoring coral reefs. SeaBED includes both controlled laboratory facilities and a field test environment in the southwest coast of Puerto Rico that is being used to validate sensors, improve algorithms, understand physical models, and develop extraction tools and classification methods for underwater sensing. Multiple sensors with different spatial and spectral resolutions, such as TM, IKONOS, Hyperion, and AVIRIS, have been tested. In terms of image processing, different pattern recognition algorithms (e.g., image classification and spectral un-mixing) and time series analyses for change detection have been used. Bottom reflectance and remote sensing reflectance have been measured from several coral reef zones, different species, and coral health conditions with a submersible spectroradiometer. Furthermore, for optical imaging of coral reefs present below one attenuation depth (approximately 20 m in oligotrophic waters), which defines a practical limit for effective airborne and satellite remote sensing, we have used an autonomous underwater vehicle (AUV) as an *in situ* platform for acquiring measurements. High-resolution optical imaging from the AUV is used for mapping and characterizing deeper reefs present between 30 to 100 meters.

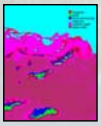
DESCRIPTION OF CENSSIS SEABED

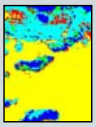
INDOOR TANK: It is composed of a small tank, light sources and hyperspectral imager and a spectrometer sensor. The hyperspectral imager consists of a 640x480 resolution CCD camera along with two tunable VariSpec filters. One filter covers the range from 400 to 720 nm, the other from 700 to 1100 nm. The spectrometer is a GER 1500 with a spectral range from 300 to 1100 nm and a FWHM of 2.8 nm. The primary light source for the tank are two halogen quartz lamps with fiber optic cables.

OUTDOOR TANK: It is located on Magueyes Island, the field station of the UPRM Department of Marine Sciences, located in southwestern Puerto Rico. The tank uses filtered seawater from two filters that remove organic and inorganic dissolved components. A SOC700 Hyperspectral Imager, which is a field portable imaging spectrometer, is utilized for this tank. The imager acquires 640 by 640 pixel images with 120 bands. The outdoor facility is a large tank illuminated by direct sunlight that provides an environment more similar to natural conditions while still retaining control over numerous variables.

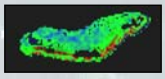
ENRIQUE REEF FIELD SITE: Enrique Reef is one of the many reefs located near the UPRM Marine Science Research facilities. An IKONOS image of the reef is shown in Figure 1c. Having an ocean based facility allows testing and validation of the developed algorithms and methodologies in a natural environment. Enrique Reef is a well-characterized system containing sand, coral and seagrass habitats.

IMAGE PROCESSING AND ANALYSES





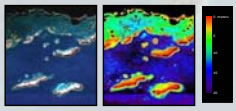
We have employed various remote sensing techniques to study the benthic habitats, including a comparison of the effects of spatial and spectral resolution using IKONOS (1 m; left images) and HYPERION (30 m; right images). Image processing of IKONOS included atmospheric correction, sun glint removal, water column correction, and supervised classification of the dominant benthic categories of seagrass, sand, and coral. HYPERION data analysis included atmospheric correction with ACORN, minimization of noise and determination of data dimensionality (Minimum Noise Fraction), location of the most spectrally pure pixels (Pixel Purity Index), extraction and identification of spectra with an N-dimensional visualization, and spatial mapping with a Spectral Angle Mapper classification. The results of the supervised classification after the images were processed are shown.



AVIRIS image collected during August 19, 2004 over La Parguera (left) and benthic composition of Enrique Reef after image processing (right).

NASA's Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS), operated by the Jet Propulsion Laboratory, is considered to be at the forefront of hyperspectral technology. Several AVIRIS flightlines over Puerto Rico were collected on August 19, 2004 covering much of the coastal areas of the island at 17 m spatial resolution, including La Parguera study site. Bottom types and bathymetry were obtained by processing the AVIRIS image.

AVIRIS composite with land mask (left image). Estimated bathymetry after image processing (right image).



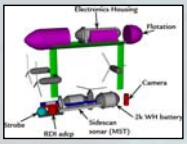
FIELD INSTRUMENTS AND ACTIVITIES

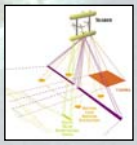
BIO-OPTICAL ROSETTE: This profiler consists of a SBE-19 CTD from Seabird that measures temperature and salinity a WetStar fluorometer from Wet Labs that measures chlorophyll fluorescence, an AC-9 from Wet Labs that measures transmittance and absorption at nine wavelengths, a HydroScat-6 from Hobi Labs that measures the backscattering coefficient at six wavelengths, and an OCR-200 submersible radiometer from Satlantic that measures upwelling radiance and downwelling irradiance Ed.

EXPERIMENTAL DESING: Field data collection for image validation is performed using standard methods of quadrants and transects. Twenty-meter-long transects are located at random on each Enrique Reef benthic habitats (coral, sand, seagrass). Each transect included ten quadrants of 1 meter separated by a distance of 1 meter. GPS locations and pictures are taken of each quadrant in order to locate ground points in the images and determine the bottom type.

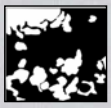
REFLECTANCE: The water-leaving radiance, Lw(λ), and the above-surface downwelling irradiance, Ed(0+,λ), are measured using a GER 1500 portable spectroradiometer. Rrs(λ) is calculated from the ratio between Lw(λ) and Ed(λ). The GER 1500 spectroradiometer is also used with a special housing for underwater spectral measurements to develop spectra libraries of reflectance for different bottom types.

AUTONOMOUS UNDERWATER VEHICLE





Remote sensing from airborne and satellite sensors becomes limited with increasing water depth due to the exponential attenuation of light. Therefore, autonomous underwater vehicles (AUVs), or other *in situ* platforms, are required to study the benthic habitat below approximately 20 m depth. As a leading instrument in this field, the CenSSIS Seabed AUV developed by Wood Holes Oceanographic Institution, has been successfully deployed for the imaging and mapping of the deep coral reef zones (30-100 m). The Seabed AUV is composed of two torpedo-shaped sections joined by vertical structural members. The main sensor on the AUV is a high resolution digital camera. The images acquired by the AUV usually have low contrast, can be noisy, and are extremely rich in both spectral variability and texture. A classification algorithm developed for this analysis uses the Local Homogeneity Coefficient Segmentation Algorithm to automatically segment each image. The classification results are validated with the results of a manual classification using Canvas.



CONCLUSIONS: As a core academic partner in CenSSIS, we are developing algorithms using hyperspectral, multispectral and other sensing modalities to extract subsurface information in aquatic environments. As part of this effort, SeaBED has been created as an algorithm validation testbed. SeaBED is composed of four different facilities: a lab based set-up, an outdoor tank facility, a field site located on a nearby reef in southwestern Puerto Rico, and an AUV for deep coral studies. SeaBED involves the collection of multiple levels of image, field and laboratory data needed to validate physical models, inversion algorithms, feature extraction tools and classification methods for subsurface aquatic sensing. In addition, the CenSSIS-developed AUV technology allows us to extend the study of coral reefs beyond the depth limit of effective airborne and satellite remote sensing. As SeaBED continues to evolve, we are working towards: (1) improving the indoor tank testbed using new illumination sources, (2) collecting new data sets for algorithm testing and validation using a SOC-700 HSI camera (3) developing a web-based interface for SeaBED to make it accessible to the general community, (4) organizing an airborne hyperspectral campaign over Puerto Rico, including La Parguera, to gather high spatial resolution hyperspectral imagery (<5 m) with well characterized underwater targets for spatial and temporal analyses, (6) assembling a spectral library describing the reflectance characteristics of specific targets (i.e., coral, algae and seagrass) and substrates (i.e., sand, rubble and mud) present in coastal Puerto Rico, (7) quantifying the spectral variability of water conditions (i.e., due to changing water constituents) in coastal areas, (8) continuing the field effort by CenSSIS students to perform a detailed field survey of habitat composition of Enrique Reef, and (9) expanding the current field work, image data collection, and algorithms development efforts to other benthic communities that are optically more complex.