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SPOC Mission Overview

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Revision Table

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Mission Overview

The Spectral Ocean Color (SPOC) Satellite shall acquire moderate resolution imagery across a wide range of spectral bands to monitor coastal ecosystems and ocean color. SPOC will acquire image data between 433 and 866 nm to monitor 1) coastal wetlands status, 2) estuarine water quality including wetland biophysical characteristics and phytoplankton dynamics, and 3) near-coastal ocean productivity. SPOC shall use multispectral remote sensing techniques to quantify vegetation health, primary productivity, ocean productivity, suspended sediments, and organic matter in coastal regions.

Mission Objectives

1) SPOC shall acquire moderate resolution imagery of coastal ecosystems and ocean color
2) SPOC shall acquire image data between 433 and 866 nm
3) SPOC shall use multispectral imaging products to monitor coastal wetlands status, estuarine water quality including wetland biophysical characteristics and phytoplankton dynamics, and near-coastal ocean productivity
4) SPOC shall train students in STEM related fields by having them investigate optimal data transmission techniques, geo-reference imagery for mapping, conduct photogrammetric processing of images acquired from the satellite, develop community outreach programs, and learn general aerospace manufacturing/testing/designing skills

Mission Success Criteria

Minimum Success

1) Image one coastal target. The images shall have a minimum spatial resolution of 240m.
2) Acquire images with band spectral resolution of 50nm.
3) 30 students shall be directly involved in SPOC Satellite development for at least two semesters over the lifetime of the project.
4) The SPOC project shall give five community outreach presentations, mentor two local high school students, and five space news/educational podcasts.

Full Success Criteria

1) Scan the same coastal target 5 times. The images shall have a minimum spatial resolution of 150m.
2) Acquire images with band spectral resolution of 10nm.
3) 75 students shall be directly involved in the SPOC satellite development for at least two semesters over the lifetime of the project.
4) The SPOC project shall give twenty community presentations, mentor five local high school students, host two workshops, release ten satellite related instructional YouTube videos, and twenty space news/educational podcasts.

Background

The Spectral Ocean Color (SPOC) mission will develop and operate a moderate resolution coastal ecosystem and ocean color CubeSat and acquire imagery of these ecosystems across a wide range of spectral bands. This mission directly supports NASA's current strategic goals and objectives, including Strategic Goal 2 (to "*advance understanding of Earth and develop technologies to improve the quality of life of on our home planet*") and Objective 2.2 (to "*advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet*") (NASA 2014 Strategic Plan 2014). Data collected by the SPOC mission shall leverage ongoing coastal research efforts within the University of Georgia and shall be shared with relevant actors within coastal communities through presentations, publications, and data releases.

Coastal ecosystems, which include salt marshes, mangroves, wetlands, estuaries, and bays, are uniquely important to global economic and environmental health - yet are uniquely threatened. The US Environmental Protection Agency estimates that in the eastern United States, coastal wetlands are being lost at twice the rate they are restored (Dahl 2011). Top threats to coastal environments include development, overexploitation, pollution, eutrophication, altered salinity and sedimentation, and climate change (Crain et al. 2009). This is despite the estimated tens of billions of dollars that coastal ecosystems add to the US economy each year, through erosion control, recreation, commercial fishing, and tourism. In addition, wetlands have innumerable benefits for our nation's ecological health, as they provide habitats for thousands of species of birds, fish, and mammals (Pendleton and Rooke 2006). Monitoring changes in coastal ecosystems can help enable effective responses through conservation, recreation, development, planning, and safety.

An adjustable multispectral imager represents an effective medium for studying ecological change. Sensors that are multispectral in nature will detect, quantify, and record electromagnetic energy across many non-contiguous spectral bands. Since the bands they detect tend to be narrow, multispectral sensors are said to have high spectral resolution, which is useful for environmental monitoring and thus the purposes of this mission. Improvements in spectral resolution yield more precise reflectance curves, which can then be measured and compared to study wetland productivity, estuarine water quality, and suspended sediment over time. In addition, the SPOCeye payload, with its adjustable bands, will be able to effectively detect a wide range of environmental phenomena. Examples of multispectral sensors that have been used for remote sensing purposes include NASA's MODIS sensor and DigitalGlobe's WorldView3. With SPOC's targeted focus on coastal ecosystems, the team shall expand on the work done by previous multispectral imaging platforms and use it to better understand the way our coastal ecosystems are changing.

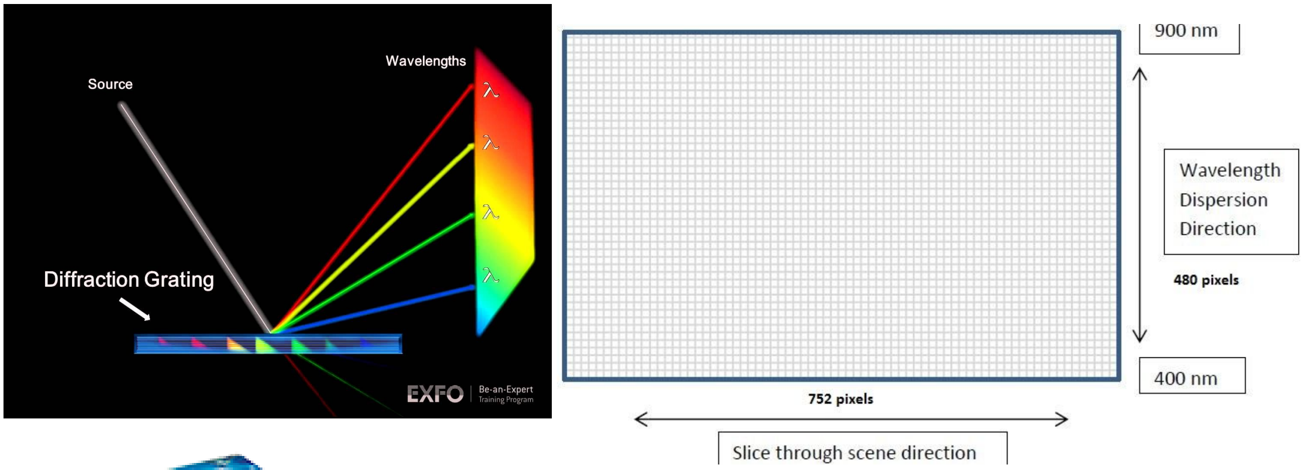
CubeSats, with their low cost and fast development cycles, represent an attractive medium for collecting multispectral data on coastal ecosystems. While multispectral imaging is possible from a UAV or aircraft platform, CubeSats can be a cheaper alternative when attempting to sample the same large-scale area over a longer period of time. By combining the payload derived vegetation indices with data from an NSF-funded Georgia Coastal Ecosystems Long Term Research (GCE-LTER) site on Sapelo Island, Georgia, the SPOC team will increase the precision of earlier methods used for GPP estimation, which yielded discrepant results (O'Connell et al. in Press). In addition, data obtained through this sensor will be used to map coastal and estuarine water quality using empirical models already developed by the SSRL group (D. R. Mishra et al. 2015). These models will be used to derive the Inherent Optical Properties (IOPs) of several Optically Active Constituents (OACs) including Canopy Chlorophyll-a (chl-a) (proxy for phytoplankton), phycocyanin (PC) (proxy for cyanobacteria), Colored Dissolved Organic Material (CDOM), and Total Suspended Sediment (TSS) (S. Mishra and Mishra 2012). The University of Georgia has an internationally respected team of remote sensing and Earth scientists, coastal ecologists, and modelers in the Center for Geospatial Research who address issues of multispectral and hyperspectral airborne and spaceborne remote sensing of vegetation health, primary productivity, ocean productivity, sediment, and organic matter (Madden et al. 2015; D. Mishra and Ghosh 2015). The development of this payload capability will enhance ongoing NASA, NSF, and National Oceanic and Atmospheric Administration (NOAA) funded research to assess and monitor near-shore water quality and carbon sequestration potential of coastal salt marshes using moderate resolution multi-spectral imagery from Landsat and Moderate Resolution Imaging Spectrometer (MODIS).

To meet the research goals laid out in this section, a 3U CubeSat with an adjustable multispectral imager is being developed by UGA SSRL. This imager is designed by Cloudland Instruments but constructed and integrated by UGA would and meets the mission success criteria for this mission. The 3U CubeSat will contain all relevant flight systems, including Attitude Determination and Control System (ADCS), 2.4 GHz radio band used for data transmission (S-band) and radio bands used for commands/telemetry (UHF/Sband) communications, a Microcontroller Unit (MCU), and power and thermal dispersion. The CubeSat will have an orbit passing over the mission target and will then downlink data when not collecting data. We have partnered with NASA Ames Research Center (ARC) for certain aspects of testing of the satellite, while other aspects of testing will occur at the University of Georgia.

Payload

Background and Basic Physics/Terminology

The payload structure for SPOC has been designed by Cloudland Instruments, and the SSRL SPOC team will build the optical structure. The payload is based off a previous Cloudland Instruments design, the HawkEye Sensor, on board the SeaHawk mission from the University of North Carolina-Wilmington. The HawkEye sensor is a multispectral sensor with 8 bands and a finderscope for locating targets. SPOC's payload will use the HawkEye finderscope sensor (a CMOS sensor designed for video applications) as its main sensor.



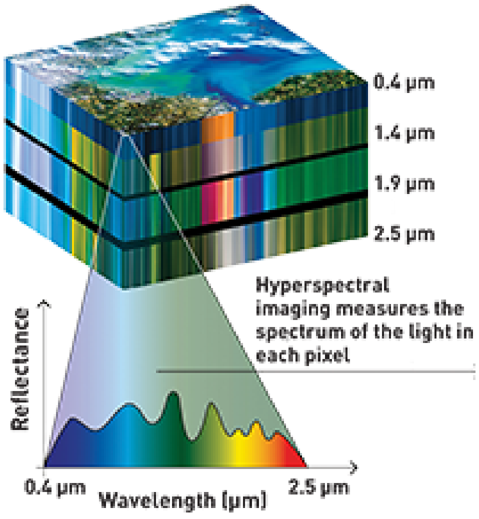


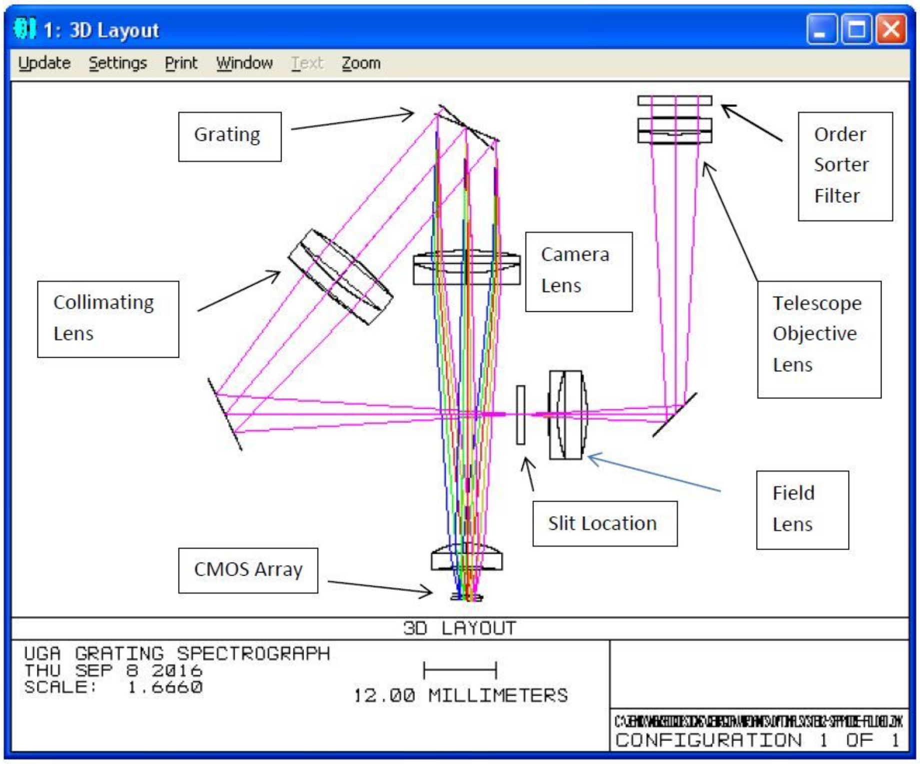
Figure 1. Top left, Example of a diffraction grating; top right, layout of the CMOS array; bottom left, example of the resulting dataset, called a data cube.

The SPOC payload will utilize a diffraction grating to acquire a continuous spectrum of light instead of specific spectral bands (Figure 1, top left). The payload will image a horizontal strip on the ground (752 pixels in length and 1 pixel wide) and diffract the incoming radiation from this strip across the entire vertical portion of the sensor up to 55 times a second. This equates to a single image consisting of 135 km x 180 m strip across the ground; however, the light from that horizontal stip is also being spread across all wavelengths between 400 - 900 nm (480 pixels) in the vertical portion of the array (Figure 1, top right). So each image SPOC acquires will cover 135 km x 180 m spatially but also 433 - 866 nm spectrally. Therefore to acquire a square image on the ground the payload needs to acquire ~750 separate images; this type of dataset is called a data cube (Figure 1, bottom left).

Payload Specifics

The design of the payload is laid out with incoming radiation entering the optical structure through a long-pass filter, thus eliminating the majority of wavelengths below 420 nm. This design is shown in Figure 2. Next, a telescope-style lens system will focus the light onto a linear slit before it interacts with the diffraction grating spectrometer. After passing through the linear slit, the light is collimated by a collimating achromatic lens, to ensure all the light interacting with the spectral grating is parallel. The spectral grating consists of a 150 line-per-mm grating blazed for 500 nm. The final lens, the camera lens, re-images the spectrally dispersed image of the entrance slit onto the CMOS array. Overall, the spectrometer breaks down into two sections: the fore-optics, which focuses the light onto a slit, and the spectrometer, which uses the light that passes through the slit and disperses it across the 752 x 480 pixel

CMOS array (Figure 1, top right).



UGA GRATING SPECTROGRAPH
THU SEP 8 2016
SCALE: 1.6660
12.00 MILLIMETERS
CONFIGURATION 1 OF 1

Figure 2: Optical design of UGA/Cloudland Instrument Multispectral Imager

The 752 pixel-wide slice is moved across the scene in a “pushbroom” scanner manner, with the image being built up slice by slice. The wavelengths for the slice are dispersed across the height of the array, 480 pixels, with a resolution of about 1.042 nm per row. For each slice the entire array has to be read out creating a 752 x 480 pixel image for each ground based slice.

This CMOS array is designed for low cost video applications and runs at a maximum speed of 55.55 frames a second. The longest exposure that can be supported at this readout rate is about 17.5 milliseconds. From a CubeSat orbit of 400 km or below, with a ground velocity of 7223 meters per second, this is about 180 meters of motion during a 17.5 ms exposure.

The design plan created by Cloudland would currently generate up to 3000 frames of 10 bit data, for a total data volume of 1.35 gigabytes per scene. This is far too great to be returned to earth over a CubeSat (S-band) downlink in one pass. Different options are being explored to create smaller more manageable data sets, including increased compression, binning processes, and acquiring only 50-100 frames over some targets.

In addition to the primary payload, we will also utilize the ucam-III as a true finderscope to aid in the primary mission objectives. In addition to its primary purpose to help spatially correct spoceye data, it will also allow arbitrary images to be acquired with a GSD of approximately 1km. Since the ucam-III is also a 10-bit 640x480 array, the data generated is significantly less than SPOCeye meaning that SPOC will be able to acquire images for educational purposes.

Payload Onboard Processing

Within the payload system, the data is currently set to be aggregated in the onboard processor by summing 4 rows together to produce 4.16 nm wide spectral data.This significantly reduces file sizes needed for data downlink while still preserving the spectral properties of the dataset.
Beyond the initial binning of spectra to 4.16nm the software on the payload allows for further binning at the discretion of the ground operator. The payload is set to store up to 16 bands onto the onboard computer, but these 16 bands are adjustable in both bandwidth and band center. Besides having a few default configurations already loaded onto the system, new configurations can be uploaded to the satellite instructing it to store different band variations for different scenes making it a truly adjustable system.

Data Budgets

However, other options for further data manipulation are being explored which involve using SPOC's OBC and ground-based commands. Options that are being explored to reduce data downlink loads include:

1) Summing bands even further through spectral binning. For example, bin bands 4 more times resulting in spectral bands that are ~16.6 nm wide;
2) Choosing only specific spectral bands for downlinking (this can be decided later). By understanding how data is stored selecting only specific lines of the file for data downlink, e.g., selecting only lines in the file that correspond to the spectral range of 400 - 500 nm (important for ocean color);
3) Attempting to downlink very small spatial areas.

Since the data is being stored external to the payload, simple file manipulation using the master file app can be achieved using pre-programmed ground-based commands. All of the resulting datasets will allow for spectral analysis comparisons with some of NASA's legacy satellites (MODIS, Landsat, etc.).

Initial Tests

Initial tests of signal to noise on the sensor have already been provided by Cloudland Instruments in Table 1. The table shows single 20 nm bandwidth pixels and their associated SNR.

Wavelength (nm)	Bandwidth (nm)	SNR per pixel
443	20	181
490	20	185
510	20	171

555	20	157
670	20	139
750	20	83
865	20	63

Table 1: SNR ratio of the multispectral CMOS sensor.

Structural Requirements

There is no special cooling requirement for the payload; the only mechanical requirement is for an unobstructed ±15° off-nadir view below the spacecraft.

References

Crain, Caitlin M., Benjamin S. Halpern, Mike W. Beck, and Carrie V. Kappel. 2009. “Understanding and Managing Human Threats to the Coastal Marine Environment.” Annals of the New York Academy of Sciences 1162 (April): 39–62. doi:10.1111/j.1749-6632.2009.04496.x.

Dahl, Thomas E. 2011. Status and Trends of Wetlands in the Conterminous United States 2004 to 2009. US Department of the Interior, US Fish and Wildlife Service, Fisheries and Habitat Conservation.

Madden, Marguerite, T. Jordan, Sergio Bernardes, David Cotten, N. O’Hare, and A. Pasqua. 2015. “Unmanned Aerial Systems and Structure from Motion Revolutionize Wetlands Mapping.” In Remote Sensing of Wetlands: Applications and Advances, edited by Ralph W. Tiner, Megan W. Lang, and Victor V. Klemas. CRC Press.

Mandl, Daniel, Gary Crum, Vuong Ly, Matthew Handy, Karl F. Huemmrich, Lawrence Ong, Ben Holt, and Rishabh Maharaja. 2016. “Hyperspectral Cubesat Constellation for Natural Hazard Response.” In . 6-11 Aug. 2016, United States. http://ntrs.nasa.gov/search.jsp?R=20160009139.

Mishra, Deepak, and Shuvankar Ghosh. 2015. “Using Moderate Resolution Satellite Sensors for Monitoring the Biophysical Parameters and Phenology of Tidal Wetlands.” In Remote Sensing of Wetlands: Applications and Advances, edited by Ralph W. Tiner, Megan W. Lang, and Victor V. Klemas, 283–314. Boca Raton FL, USA: CRC Press.

Mishra, Sachidananda, and Deepak R. Mishra. 2012. “Normalized Difference Chlorophyll Index: A Novel Model for Remote Estimation of Chlorophyll-a Concentration in Turbid Productive Waters.” ResearchGate 117 (February): 394–406. doi:10.1016/j.rse.2011.10.016.

NASA 2014 Strategic Plan 2014. NASA. http://www.nasa.gov/sites/default/files/files/FY2014_NASA_SP_508c.pdf.

O'Connell, Jessica, Deepak Mishra, David Cotten, Li Wang, and Merryl Alber. in Press. "The Tidal Marsh Inundation Index (TMII): An Inundation Filter to Flag Flooded Pixels and Improve MODIS Tidal Marsh Vegetation Time-Series Analysis." Remote Sensing of Environment.

Pendleton, L., and Jaime Rooke. 2006. "Understanding the Potential Economic Impact of SCUBA Diving and Snorkeling: California." Working Paper, University of California Los Angeles. http://dfg.ca.gov/mlpa/pdfs/binder3diii.pdf.

Selva, Daniel, and David Krejci. 2012. "A Survey and Assessment of the Capabilities of Cubesats for Earth Observation." Acta Astronautica 74 (May): 50–68. doi:10.1016/j.actaastro.2011.12.014.