

Unmanned Aerial Vehicle Imaging System Creation for Water Quality Analysis

by
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Abstract

The proposed project involves purchasing a multispectral six-camera system with spectral bands ideal for water quality analysis, mounting it onto a UAS, producing a calibration protocol, and using the system to generate in-water constituent maps in near-real time. This imaging system can also be adapted for other remote sensing applications and will be a valuable addition to the Digital Imaging and Remote Sensing (DIRS) laboratory at the Chester F. Carlson Center For Imaging Science.

Background Theory

The U.S. Environmental Protection Agency (EPA) protects human health and the environment through the development and enforcement of regulations and environmental laws. It studies and measures the state of environmental features and provides this information to the public for education, awareness, and support of fish and wildlife. Under the Clean Water Act, lists of impaired waters must be developed to identify waters that are too polluted to meet the water quality standards set by their states[1]. The Rochester Embayment, primarily consisting of the region near where the Genesee River flows into the Lake Ontario Central Basin, is on the EPA's impaired water list. Traditional remote sensing platforms have been used to monitor its water quality, but each has its serious limitations.

Temporal, spectral, and spatial aspects of image collection are difficult tradeoffs. The NASA Jet Propulsion Lab Airborne Visible InfraRed Imaging Spectrometer (AVIRIS) instrument gathers hyperspectral image data on a Twin Otter aircraft using 224 contiguous spectral bands spanning the 400 to 2500nm wavelength range [2]. In 1999, AVIRIS was used to image the Rochester Embayment area with impressive spectral resolution. Unfortunately, as an airborne platform used to only collect this data once, it is not practical for long term monitoring. Conversely, the NASA Landsat 8 satellite is a spaceborne platform launched in 2013 that images the entire Earth every 16 days. This makes Landsat 8 attractive for monitoring ecological change regularly over time. However, its multispectral band combination is not ideal for water quality analysis. The presence of atmosphere and clouds during collection is an issue because it influences the measured signal and calculated water parameters, leading to possible misinterpretations or misleading conclusions. Only two cloud-free scenes have been obtained of the Rochester Embayment since Landsat 8 achieved orbit. In addition, the spatial resolution of a system orbiting at such a high altitude is limited to 30m pixels. This low resolution limits the ability to assess finer constituent fluctuation within a body of water, which may be important for some applications.

A newer, alternative type of system which can overcome these limitations is on the horizon. Unmanned Aerial Systems (UASs) are aircraft systems that are flown remotely through pilot control or autonomously through the use of computers. The Northeast UAS Airspace Integration Research (NUAIR) Alliance operates and oversees UAS test ranges with the ultimate goal of safely integrating UASs into commercial airspace. RIT is one of their partners and has been designated as one of the primary UAS research and development academic institutions in New York to further advancements with this technology [3].

Considering models that are reasonably priced, capable of carrying 3+ pounds, and feature onboard GPS for geo-referencing purposes, this technology has advanced to a point where it is attractive for endeavors within the scientific community. This work proposes to create a UAS-based imaging system for remote sensing applications. More specifically, a 6-band multispectral camera will be used to image bodies of water such as those within the Rochester Embayment area to monitor their constituent levels. The UAS's low flight altitude reduces the issues introduced by imaging through large amounts of atmosphere from space, and the ability to select a custom combination and range of filters for each of the 6 cameras will allow the system to have an ideal spectral sensitivity for water quality analysis. Data collection will no longer be limited by an orbit, pilot availability, or the presence of clouds.

Research / Design Objectives

This project will focus on the generation of a UAS-based imaging system to ultimately measure in-water constituent levels in near-real time. By combining off-the-shelf UAS and camera technologies, the main bulk of the project involves developing algorithms to stitch together captured imagery, implement algorithms to perform water quality parameter identification based on spectral signals, and present constituent maps as the end product. These maps will illustrate where various constituents such as chlorophyll and suspended sediments are dominant within a scene. The accuracy of these maps will be compared to those generated using Landsat data as well as ground truth collected from the body of water being imaged. This project will incorporate all steps of the imaging chain and involve a variety of staff and students within and outside of the Chester F. Carlson Center For Imaging Science.

Plan of Study / Experimentation

I plan to gain experience with the following major components of imaging system design, development, and testing:

- Writing grant proposal for funding
- Modeling to determine spectral bands most pertinent to water quality analysis
- Acquisition and integration of hardware components
- Learning to operate UAS & program flight collection paths
- Ground truth data collection
- ELM Calibration to account for atmospheric effects
- Collaboration with other academic institutions for measurements
- Stitching together collected imagery
- Programming algorithms to extract water quality information from imagery
- Producing RGB and in-water constituent map for scene

To understand the radiometric response of the multispectral camera system, an in-situ Empirical Line Method (ELM)-based calibration procedure will be performed. Panels with a series of known reflectances will be placed in the scene. CIS already has some calibration panels, but there is potential to also incorporate calibration panel creation into the scope of this project. During the time of collection, ground-based reflectance measurements will be made of the panels. The sensor gain and bias can then be determined through a linear regression between the measured panel reflectance and corresponding image digital count values. This calibration procedure helps to account for signal contributions from the atmosphere and instrument drift.

Efforts at RIT to support the monitoring of the Rochester Embayment are ongoing. Under a grant by the USGS to support the Landsat Science team, students and staff are already taking in-situ measurements of key bodies of water in the Embayment, so no complicated lab procedures will need to be learned on behalf of the research team regarding the collection of ground truth.

At the completion of this project, equipment will join the Digital Imaging and Remote Sensing laboratory collection of instruments to be used for future remote sensing applications.

The team is aware of and respects current restrictions in place regarding the use of UASs outside of designated flight zones.

Detailed Budget

Another faculty member at RIT will purchase the UAS. The main cost of this project is the multispectral camera system – a Tetracam 6-camera Micro-MCA (Multiple Camera Array) Snap chosen for multiple reasons (the global shutter minimizes motion blur artifacts and other distortions, and the down-facing cameras are already synchronized and registered with one another for accurate temporal and spatial registration between images [4]).

The Tetracam 6-camera Micro MCA costs ~\$15,000.

I applied for a CIS Micro Grant for \$5,000, Aaron Gerace and Carl Salvaggio each agreed to match the \$5,000 with available funds, and there is also interest from additional faculty and staff within the DIRS group that may lead to more funding to help bring the cost down for the primary contributors.

The calibration target materials will cost ~50 for wood and paint.

Timeline

Summer 2015

- June-July
 - Modeling to choose spectral bands of camera filters
 - Hardware acquisition and integration*
 - Initial experimentation with UAS flight control software*

* to be completed by faculty, staff, and/or interns at RIT while I am away for a summer internship

- August
 - Preliminary calibration
 - Initial test flight and image collection through remote piloting
 - Ground truth collection

Fall 2015

- Develop code to stitch images and create mosaic
- Advanced characterization and calibration (geometric, radiometric) of system
- Apply existing in-water parameter retrieval algorithms to estimate water quality parameters
- Program UAS collection path

Spring 2016

- Refine algorithms
- Improve performance for near real-time constituent map creation
- Fly system over Long Pond, part of the Rochester Embayment
- Compare results to Landsat
- Write report summarizing results of the project, issues related to using drone technology to conduct remote sensing studies, and future work that can be done to improve and expand the system's capabilities

Resources

[1] "Impaired Waters and Total Maximum Daily Loads." *Water Laws and Regulations: Clean Water Act*. United States Environmental Protection Agency, 12 Mar. 2015. Web. 05 May 2015. <<http://water.epa.gov/>>.

[2] "AVIRIS Overview." *AVIRIS - Airborne Visible / Infrared Imaging Spectrometer - General Overview*. NASA Jet Propulsion Laboratory, 22 Apr. 2015. Web. 05 May 2015. <<http://aviris.jpl.nasa.gov/>>.

[3] "Northeast UAS Airspace Integration Research Alliance (NUAIR)." *NUAIR Alliance*. NUAIR Alliance, 2015. Web. 05 May 2015. <<http://nuairalliance.org/>>.

[4] "Tetracam Micro-MCA." *Tetracam's Micro-Miniature Multiple Camera Array System*. Tetracam, Inc, 2011. Web. 05 May 2015. <<http://www.tetracam.com/>>.