A Procedure for the Rapid Processing and Georeferencing of Hyperspectral Imagery for Real-Time use by an Autonomous Aerial Vehicle

John Waczak

2023-09-29

Abstract

Recent developments in hyperspectral imaging technology have led to dramatic reductions in both size and weight of imaging platforms. Due to these improvements, it is now possible to incorporate the technology as the payload of highly mobile autonomous aerial vehicles such as drones. However, the massive volume of hyperperspectral datacubes poses significant computational challenges to their adoption in real-time applications. In this paper, we demonstrate a procedure for the rapid georeferencing of pushbroom imagery and demonstrate its application for real-time remote sensing… Results indicate that a typical image can be processed in ~10 seconds while it takes x seconds to capture.

Introduction

For decades, *multi-spectral imagers* have seen wide spread adoption in the remote sensing community as a means to take advantage of the wealth of information contained in the reflectance spectra of materials. In addition to the three color filters of traditional cameras, *multi-spectral* imagers, like those deployed on MODIS, Sentinel 2, and other satellite missions, capture many additional features by utilizing wavelength bands ranging from the near-UV, through the visible spectrum, and into the Infrared. With this additional information, multi-spectral remote sensing platforms are able to aid in a variety of domains from tracking land change, characterizing deforestation, monitoring erosion, evaluating crop health, and many others (add references here).

(**add a figure showing the different wavelength bands of publically available satellites**)

These uses are justified by the reflectance features of materials across the electromagnetic spectrum; water has vibrational modes in the IR, pigments have absorption peaks in the visible, etc...(discuss the particular features present in different regions of the reflectance spectrum). Many currently used spectral indices like the *normalized difference vegatation index* (NDVI) take advantage of these spectral regions by comparing ratios of pigment sensitive passbands to the constant signals infrared to infer the abundance of chlorophyll, and consequently, the health of plants, to identify forest canopy, etc..(**add citations and expand**)

However, despite the plethora of successful applications of multi-spectral imaging, more can be accomplished with the additional information provided by fully resolved spectra. For example, in the laboratory, spectrophotometry allows the direct determination of the concentrations of chemicals constituents in solution (**add more detail and references**) by deconvolution of a sample spetrum against libraries carefully collected of reference spectra: individual chemicals be uniquely identified by the characterstic location and shape of their absorption features. We should mention something about algal blooms– harmful species display shifted reflectance peaks that can be used to identify toxic species. This information is effectively filtered away by the broad passbands of existing (find the spectra used in that book that show the different species of algae). To that end, *hyperspectral imagers* (HSI), which sample hundreds of wavelength binds at each pixel, have become the natural next step for remote sensing platforms with many planned to deployed in the coming years (**add references about soon-to-be-deployed HSI satellites**).

At the terrestrial level, drones (commonly, quadcoptrs, octocopters, and other similar multi-rotor craft) equipped with cameras are able to utlize techniques of photogrametry together with continuously sampled imagery to produce high quality digital elevation maps, high quality mosaics, 3-dimensional reconstructions, etc... These capabilities provide significant aid for structural analysis, smart agriculture, etc... Today, kilogram-scale HSI can be comfortably mounted to the payload of film-scale drones such as the AltaX and advancements in spectral sensing such as (**reference Ethan Minot's recent paper**) suggest that sizes of HSI will continue to shrink further expanding their application in this domain.

The increased spectral resolution of HSI systems poses unique challenges to their adoption for real time applications primarily stemming from the considerable size of generated data files. Current data collection workflows see researchers first perform the aerial survey (data collection) and then transfer data to ground based computers for post processing. This workflow is well established in the remote sensing community where, as an example, compressed raw imagery from Sentinel-2 are transferred to the ground and then subsequently post processed into their final L1C (top of atmosphere) and L2A (bottom of atmosphere) data products ((**add citation here**)). Drone based applications often operate in a similar manner: images or video are collected by a survey and then post-processed and analyzed with software such as Open Drone Map to produce the desired data products (tile mosaics, 3d reconstructions, etc.) (**add citation**). For an HSI platform to function in real time, three key computational tasks are critical: 1. **FileIO**: captured imagery need to be quickly read by the on-board processing computer 2. **Post-processing**: Raw imagery need to be rapidly converted to the chosen data product (typically, Reflectance), and importantly, must be georeferenced so that each image pixel can be located on the ground. 3. **Ground Transfer**: Sufficient wireless communication must be avaiable to transmit the final

The first can be readily accomplished by means of light weight, high volume solid state drives. To address the second, we need both sufficient compute and optimized processing software. Finally, ground transfer of final post-processed data products can be accomplished in a variety of ways. As we rarely need the full hyper-spectral datacube right away, once can generate the desired data products on board (NDVI for example) and transfer only the relevant information to a ground station

We should now make the argument about the need for improved methods for processing of HSI due the their dramatically larger size, i.e. the standard workflow of collecting imagery and then post processing (re: Open Drone Map) is a fantastic and well tested solution but prevents the use in time-critical applications. We can also reference the continued improvements to single-board computers such as the raspberry pi 4b (8 Gb of Ram), Jetson family (GPU equipped), and intel nuc (powerful work horses with miniscule form factors). To make real-time possible we need two things: 1. Conversion from raw data (digital counts) to physical units like Reflectance 2. Georeferencing of captured imagery so features can be quickly geolocated

We can always re-process the imagery later for an in-depth reanalysis, but for time-critical applications, we need all of the processing to happen on board the drone.

Add a paragraph about georeferencing in particular: - Georectification = georeference + orthorectification - outline other papers that have discussed georectification techniques: - ground control points (not reasonable for dangerous or water-based environments) - IMU / GPS - different type of sensors: square, pushbroom, whiskbroom

Discuss configurations of imagers and the development of georeferencing strategies, e.g. starting with the Muller paper and going to today. Mention potential for the incorporation of digital elevation maps together enabled by GPUs and video game engines (**reference that one paper that suggests using Unity or something similar for the projective geometry optimized for Cuda on NVIDIA GPUs**).

In our previous work, we demonstrated a prototype autonomous robot team employing a drone based hyper-spectral imager which can learn the mapping from reflectance spectra to concentrations of variety of chemicals-of-concern by utilizing the information contained in the reflectance spectra captured with a HSI together with a (Lary et al. 2021). In this paper, we present a procedure based on the method of (Muller et al. 2002) for the rapid processing and georeferencing of imagery captured by a pushbroom HSI mounted on an autonomous. Associated code can be freely accessed and downloaded in (**add reference to our repository**)

(**This point can be saved for the supervised learning paper**) what we really want (usually) isn't the full spectra at each pixel

IMU - inertial measurement unit

Materials and Methods

An HSI Equipped Autonomous Aerial Vehicle

Results

Discusion

Conclusion

Lary, David J, David Schaefer, John Waczak, Adam Aker, Aaron Barbosa, Lakitha OH Wijeratne, Shawhin Talebi, et al. 2021. "Autonomous Learning of New Environments with a Robotic Team Employing Hyper-Spectral Remote Sensing, Comprehensive in-Situ Sensing and Machine Learning." *Sensors* 21 (6): 2240.

Muller, R, Manfred Lehner, Rainer Muller, Peter Reinartz, Manfred Schroeder, and Beate Vollmer. 2002. "A Program for Direct Georeferencing of Airborne and Spaceborne Line Scanner Images." *International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences* 34 (1): 148–53.