On-Board Image Processing and Computer Vision Techniques on Low-Cost Consumer Electronics for Vegetation Density Mapping and Other Experiments

Philip Linden*, Jeff Maggio†, T.J. Tarazevits‡
RIT Space Exploration, Rochester Institute of Technology
Rochester, N.Y.
Email: *pjl7651@rit.edu, †jxm9264.rit.edu, ‡tjt3085@rit.edu

***Abstract*—Advanced on-board image processing is a foundational component of a wide range of future space science and Earth observation missions. Extending these techniques to include computer vision opens the door to even more opportunities for science. It is critical to develop these techniques on low-cost, consumer hardware platforms so that the missions need not require expensive, specialized systems for every experiment. Demonstrating these systems are themselves opportunities for science as well.**

I. Introduction

Image processing has long been a critical element of Earth observation and space science. In recent years, the capabilities of inexpensive consumer electronics and computers have reached a point where advanced image processing can be performed on-board with lightweight, low-power computers. This has opened the door for low-cost, rapid development experiment payloads and platforms such as high altitude balloons, drones, and small satellites. Usually these platforms have limited communications bandwidth, so on-board processing may be used to significantly reduce the amount of data transferred back to ground without losing the information that the images contain.

Computer vision (CV) is defined as the automatic extraction, analysis and understanding of useful information from a single image or a sequence of images. CV is the realm between image processing and computer science where useful information is identified, extracted, and interpreted from images without human input. In addition to edge detection and other transforms applied to the pixel arrays directly, deeper and more abstract algorithms to interpret the contents of the images continue to mature in the field of machine learning. These algorithms are trained, or iteratively tuned with a large set of data, to classify objects or cluster multivariate data from an arbitrary set of inputs.

Naturally, any implementation of image processing or CV for space science must be tested in a flight setting. As this technology is developed, all tests are themselves opportunities for science. This Project Definition Document considers the logistics of this development in addition to discussing a number of experiments that may be conducted as tests or end-user applications of on-board image processing and computer vision with low-cost consumer electronics.

II. Primary Objective

The ideal result of developing robust image processing and computer vision techniques on flight electronics is a payload module for a high altitude balloon, small satellite or other flight system which is capable of reducing a video or image stream into a stream of processed useful information which can be relayed back to a ground station or efficiently saved to system memory.

While it is obvious that more powerful (and more expensive) electronics are capable of more advanced processing, the goal of this project is to push the limits of what entry-level hardware capabilities. In this way, software development takes the lead over hardware development. Since software can be reused between flights, loss of mission is not critical with low-cost flight electronics.

III. Secondary Objectives

Second to generalized platform development for an imaging and computer vision payload module is the science that payload would actually conduct. Every flight is a new opportunity to collect data, perform an experiment, or demonstrate new technology. Every module test will have a science goal in addition to any technology advancement goals. Specific experiment ideas are discussed in section VII.

IV. Benefit to SPEX

In addition to cultivating computer vision and image processing knowledge within SPEX, this approach favors clever and innovative solutions to squeeze every ounce out of inexpensive consumer hardware. By pushing the capabilities of these entry-level electronics, SPEX gains the most technological and science value possible. Computer-on-a-chip boards like Raspberry Pi are well-documented online and skills earned by SPEX members developing for this platform are easily applied to other projects that may also use this platform for computation.

A. Mindset

The mindset for development is to drive the hardware platform, software techniques, and science goals to the limit. Each experiment and every flight should aim to demonstrate a new technique and should have a strong science objective.

B. Traceability

GitHub shall be used for version control and issue tracking for software development. All library dependencies shall be documented.

C. Accessibility

The possibilities for scientific experiments with computer vision and image progessing are virtually limitless, and so are the opportunities for advancing knowledge within SPEX in imaging science. There are as many experiments accessible to beginners as there are available to experience imaging scientists.

In terms of software, computer vision and image processing requires a moderate familiarity in one of several computer languages, i.e. Python, and interfacing with hardware such as Raspberry Pi.

V. Implementation

This project will build off of work that's already been done by the RIT SPEX high-altitude balloon (HAB) team. First, simple data collection will be developed and flown along with basic image processing (see subsection VII-A). Once stable video processing is tested and a large dataset of images has been collected, more advanced computer vision techniques can be developed on the ground. These advanced methods may later be optimized for low-cost hardware and tested as a primary or secondary payload on future HAB flights. As this cycle of development repeats, more and more advanced image processing and comuter vision algorithms may require higher performance hardware. This is a natural progression, but the spirit of pushing to achieve the most out of the hardware available and keeping hardware costs low must be upheld.

A. Deliverables

Hardware deliverables may vary, but each experiment is expected to have a healthy repository of documentation for all systems. These documents will describe the usage and functionality of all software, hardware, and interfaces between the two such that experimental results are reproduceable by an independent investigator.

While thorough documentation is appreciated, it may be beneficial for the focus and vernacular to center on reproduceability and lessons learned. This way an experiment's supporting documentation will be more useful for future work that may expand upon or improve work that was done in the past.

VI. Externalities

A. Prerequisite Skills

This project is best suited for SPEX student members and alumni with at least some programming experience in Python or C++, and novice-level familiarity with using terminal commands. Some familiarity with image processing or imaging science is preferred, but is not required. There are plenty of online and university resources available for newbies to get up to speed on image processing, computer vision, machine learning, and programming with some effort.

B. Funding Requirements

Since the premise of this project is developing robust systems on low-cost consumer electronics, funding requirements are marginal compared to other hardware-centric projects and missions. For example, a Raspberry Pi 3, camera module, SD memory card, and barrty pack can be purchased for about $100, and the hardware may be reused in almost any other SPEX project.

Since machine learning and computer vision are at the forefront of technology at this time, "cool" experiments like these may lend themselves easily toward outreach and in turn building relationships with companies in the industry. There may be opportunities to receive in-kind donations such as software licenses (e.g. Matlab) or hardware (e.g. Raspberry Pi, Nvidia).

C. Faculty Support

Imaging and image processing experiments provide fertile ground for building a relationship between SPEX and the Carlson Center for Imaging Science, Center for Detectors, and Future Photon Initiative. Computer vision development poses an opportunity for SPEX to continue to network within the Golisano Center for Computing and Information Sciences. And, of course, all of the objectives of this project are directly applicable to space science and Earth observation, further building SPEX's mission of space exploration research.

D. Long-Term Vision

This project is intentionally broad. By keeping the focus on pushing the limits of hardware and doing science at every opportunity, it is easy to imagine an imaging payload on every HAB launch for the foreseeable future. Likewise, imaging experiments make for some of the simplest and most versatile small satellite payloads — perfect for a student-faculty research group striving to do space science like SPEX.

VII. Applications and Experiments

The following experiments are some initial ideas for experiments using on-board image processing and computer vision.

A. WUAP: where u at plants?

Raspberry Pi camera modules, one with and one without a near-infrared filter, are mounted to the ground-facing side of a HAB payload module. During flight, many color and near-IR images of the Earth are collected and may be used as training data for future computer vision algorithms. In flight, the visible-color frames are used to generate a binary mask from all "green" colors in each frame to identify areas of vegetation. Post-flight, the visible and near-IR images are aligned and used to find the Normalized Difference Vegetation Index (NDVI)[**?**] in each frame. The vegetation color masks are cross referenced with the NDVI results to create a vegetation density map.

A machine learning algorithm may be trained to estimate vegetation density from visible light images using the visible image frames as the training data and NDVI results as truth values. This way, the algorithm could be used as a computer vision method of estimating vegetation density without an infrared imager.

B. WTFbiome: Wayfinding TransFormations and Biome identification

Morphological transformations are applied to images of the Earth using 3D spatial instrument data collected in-flight on a HAB and aligned with open source map data. Using the transformed images as training data and the map data as truth, a machine learning algorithm is trained to identify biomes or urban areas from visible light aerial images.

C. SUP: Stereo groUnd mapping and Photometry

With two camera modules facing the same direction, stereo image data is transformed into 3D coordinates or distance measurements. Distance data is used to create 3D photometric models of the scene or used to estimate altitude.

Acknowledgements

The authors would like to thank all contributors to the Python open source community, especially the authors of the OpenCV and Numpy libraries, Adrian Rosebrock for his contributions at PyImageSearch.com, and all contributors to Stack Overflow.