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

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***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 is capable of. 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.

Table I lists a the relative level of detail expected of the documents written at each stage of a project's life.

IV. Benefit to SPEX

By writing design documents and familiarizing undergraduate and graduate students from any discipline with this type of approach and execution, SPEX members will be better equipped convey their ideas to others in a methodical and organized manner. Ideally, an abundance of ideas and projects encapsulated in PDDs would outlive their respective authors and continue to sustain SPEX with valuable research

TABLE I
RELATIVE DETAIL EXPECTED AT EACH STAGE OF PROJECT DEVELOPMENT.

Document	Purpose	Contributors	Destination
Project Definition Document	To define the goals and requirements of a SPEX project.	2–3 people	SPEX Archive
Project Plans	Specific plans for when work is to be done (Gantt charts)	2–3 people	Project Repository
Design Reviews	To review designs before work is started.	6–8 people	Project Repository
Test Procedures	Specific instructions and data logs for tests.	3–4 people	Project Repository
User Manual	Instructions for future users of project deliverabels.	3–4 people	Project Repository
Posters & Presentations	Materials for sharing projects with the public.	5–6 people	Project Repository
Technical Report	Final technical summary of work done and results.	6 or more	SPEX Archive, Conferences & Journals

opportunities invariant of individual members' absences due to co-ops or graduations. Perhaps in the future, SPEX design documents may be used as baselines for grant applications and other funded research efforts.

A. *Mindset*

Firstly, it gets people in the right mindset for thinking about what is important and what needs to be considered before taking off on a project. Publishing a PDD imbues a sense of formality that hopefully makes its way into the level of seriousness and merit that is desirable for SPEX to pursue.

B. *Traceability*

Similarly, a PDD serves to provide the foundation for traceability in requirements and objectives to projects as they grow and change. This prevents blockers such as feature creep, rabbit holes, and spun tires, and hopefully prevents good projects from dying by getting too off track.

C. *Accessibility*

Having a "plug-and-play" template is the first step to learning how to one's own PDD. It removes a major barrier of starting from scratch, providing example content to which one could refer when creating their own. LaTeX may prove to be daunting for some people, but it is arguably better to encourage people to learn LaTeX than to rely on something like Microsoft Word.

V. IMPLEMENTATION

In the ideal case, every project begins with a design document. That design document gets sent around to SPEX members (and non-members) to draw support and build a team. Research and work takes place, documented along the way until an ending point is reached (e.g. project completion, end of the semester, team attrition, etc.).

At the end of the project (or end of semester, whichever comes first), the team writes a report of the project with what they did, if it was successful, and recommendations for future projects. A future SPEX member might pick up where the last paper left off, and the cycle repeats.

A. *Deliverables*

Physical or intellectual property may constitute a project's deliverables. Test articles, test stands, and other hardware, software, as well as posters, presentations or other reports are all valid deliverables. Not all deliverables may be known at the time of writing a PDD, but at least several key deliverables should be identified at the start of a project. This helps guide the final outcome and is a fundamental part of a project's life cycle.

B. *Milestones*

Deadlines and milestones provide clear goals from which timelines and schedules may be developed, and also set up a project for a series of "sanity checks" along the project's development cycle. Early on, these milestones include design reviews on system and subsystem levels. Later, milestones are usually important tests or experiments. Events such as ImagineRIT may also serve as milestones to mark a project's development progress or completion.

A notional timeline is shown in .

TABLE II
NOTIONAL TIMELINE OF PROJECT MILESTONES.

Phase	Task	Duration
1	Review existing designs and materials	2 weeks or less
2	Subsystem development	6 weeks
	Order PCB design and/or assembly	6 weeks
	Review changes and order materials	2 weeks or less
	Testing of individual subsystems	2 weeks
3	System assembly	1 week
4	System testing	2 weeks
5	Generate documentation and delivery to SPEX	1 week

VI. EXTERNALITIES

A. *Prerequisite Skills*

It is obvious that team members will learn certain skills as a project progresses, but there are always some tasks that require a minimum skill level to provide meaningful contributions to a project's development. These prerequisite skills are best identified by examining past projects and discussing the project with faculty or subject matter experts. It is strongly recommended to be conservative in skill estimation. Underestimate team member skill levels and overestimate the challenge. Many projects have failed because the team overestimated their own abilities or underestimated the difficulty of their project.

B. Funding Requirements

Like prerequisite skills, it is wise to overestimate the cost of components, materials and other resources that a project requires. For physical projects, costs may be estimated by benchmarking the costs of similar systems or determining a representative bill of materials and using the aggregate cost of its items.

C. Faculty Support

Support from university faculty is almost always essential to a project's success. Faculty provide not only guidance and subject matter expertise, but may also connect a team with resources and networking opportunities. SPEX projects do not require faculty support, but it is highly recommended to identify professors with an interest or expertise in a project as early as possible.

D. Long-Term Vision

As SPEX student members get more experience writing these papers, the group will build a library of meaningful work and be able to save it in an organized manner. Knowledge will be preserved and easily shared. Perhaps Project Design Document could eventually get published, in a journal or otherwise...

VII. Applications and Experiments

A. WUAP: where u at plants?

Vegetation density and NDVI. Mapping density with gps data.

B. WTFbiome: Wayfinding TransFormations and Biome identification

scene (biome) identification. morphological transformations to apply images to spatial coordinates.

C. SUP: Stereo groUnd mapping and Photometry

stereo 3d ground mapping and photometry.

D. PIP: Passive Instrument Payload

as an instrument: horizon detection. star tracking.

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