Team ECE-410

ENGR Final Capstone Report:

Remote Aerial Mapping Spectrometer (RAMS)

4 May 2017

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Contents

I. Executive Summary

Our project locates harmful algal blooms (HABs) by mapping the material composition of surfaces from an Unmanned Aerial System (UAS). HABs significantly harm an ecosystem, pose a toxic threat to humans, and cause millions of dollars of economic damage. Local scientists need spectroscopic data to detect these events because wavelength characteristics give the best indication of HAB presence. Current methods of spectral analysis are costly. Our project develops an inexpensive tool that precisely analyzes the natural world for environmental researchers. Our system employs laser surveying and field spectroscopy as remote sensing techniques to produce a three-dimensional graphic which describes localized spectral signatures.

II. Project Description

Environmental scientists desire spectral monitoring of plant life in high resolution in order to monitor for HABs and quantitatively analyze the health of a region. When large amounts of spectral measurements are collected, an additional need is the clear positioning of the measurement [1]. Localized spectroscopy provides a dimensionality to surface compositions to help visualize the big data. Our system is designed to make ecosystem monitoring more useful and accessible. We employ a single spectrometer to be financially considerate. More research projects will be able to use our tool as it is considerably less expensive than two-dimensional hyperspectral cameras. Additionally, our system's laser ranging technique precisely locates the sample for analysis. This has not been previously achieved and will lead to many new implementations of spectroscopic analysis.

UAS provides a mobile platform for remote sensing that can collect an area's spectral information at previously unfeasible resolutions. Their domain branches the gap between individual researchers' data gathering (which is slow and costly to analyze large areas) and aerial/satellite hyperspectral imagery (which has low spatial resolution). Remote sensors are developing reduced size, weight, and power (SWaP) requirements. Additionally, inexpensive UAS are expanding their capabilities. These advancements will grow the market for UAS spectroscopy. There is an opportunity now to create a new kind of UAS spectroscopy system: our novel technique accurately locates its spectral measurements via calculations using angular orientation and laser rangefinding.

Spectral datas not only locate HABs, but also benefit crop management which demands plan-specific monitoring and biodiversity research where ecological health is closely monitored [2]. Our solution is different from existing techniques of spectral imagery as it localizes the spatial position of each measurement. We combine laser surveying with spectral analysis to create a virtual structure of material characteristics. Current hyperspectral imagers are expensive and bulky so that they must be mounted on NASA aircraft and satellites to survey large areas of land at low spatial resolution. Our project is used close to the ground level, where material compositions are mapped at the individual plant level.

We want to best help researchers who watch over the health of the environment, in particular those monitoring harmful algal blooms. But gathering a spectral data map at one location could be useful to any number of scientists and agriculturalists. The data that our sensor package produces are filtered with compositional constraints, revealing different growth structures. Various studies of surface compositions could thus use the same data map. If a researcher is hunting for a particular spectral characteristic, our map could reveal that material's locations. Likewise, the researcher could use pick interesting samples from within the data to find similar surfaces. The user could pilot the UAS or the flight pattern may be performed autonomously; the sensor package doesn't need coordination with the aerial platform.

The system gathers data in the immediate vicinity of the UAS. Its laser rangefinder and long-focus lens spectroscope limits data gathering to objects at most 40 meters. The UAS may move around, but it is not necessary for gathering information because the system swivels a gimbal which holds the spectroscope and laser rangefinder. This scanning technique saves the UAS power by avoiding back-and-forth search flights. The system weighs less than one kilogram and will have the battery capacity of at least 90 minutes for an extended flight. It is small enough to be mounted beneath a UAS and will not interfere with the airframe.

III. Project Plan

Our project plan is to first tackle the sample localization problem, developing our usage of the rangefinder and Inertial Measurement Unit (IMU) which provide sample distance and angular orientation. The gimbal controller is commanded by the main microcontroller to aim in a particular direction. The gimbal employs the IMU to stabilize the laser rangefinder and collimating lens at a desired angle. With this information, the system is able to construct a point cloud of surfaces. The gimbal controller appropriately powers three brushless motors to correctly adjust the yaw, pitch, and roll of the sensors. The laser rangefinder sends a NIR light pulse and times the reflection for distance computation. This wavelength is not collected by our chosen spectrometer and thus will not interfere.

The spectrometer was able to integrate within the system after receiving additional funding by the Sternheimer Grant on November 23rd. It uses a long-focus lens coupled by a custom-made fiber optic cable with a minimal divergence angle, providing high resolution. This approach achieves precise spatial localization of spectra. A technique of pinpoint spectral measurement coordinates strongly with the laser rangefinder; together they create a point-in-space or voxel of wavelength characteristic. The spectrometer's collimating lens is aligned with the laser rangefinder so they sample the same spot. The spectrometer uses an API called SeaBreeze that has been successfully used with our microcontroller. We will develop a program to link the positional data and spectra in an easily parsed manner. On the following page is is a breakdown of the components' weights and costs.

IV. Budget

	WEIGHT (g)	PRICE	
Gimbal			
DYS BLG3SN 3 Axis Gimbal Kit	328	$64.30	ebay
3x Etec PM3505 Brushless Motors w/ encoders	135	$136.50	EtecPower
Tiny Pro Alexmos BaseCam Gimbal Controller	68	$104.48	aliexpress
	531	**$305.28**	
Spectrometer			
Ocean Optics STS-VIS	60	$1500	Ocean Optics

84-UV-25 Collimating Lens	15	$628	Ocean Optics
	75	**$2128**	
Laser Rangefinder			
Garmin LiDAR-Lite v3	**22**	**$149.99**	SparkFun
Microcontroller			
Raspberry Pi 3 Model B+	42	$35.70	amazon
Adafruit Ultimate GPS	9	$33.93	amazon
SanDisk 32GB Ultra Class 10 SDHC amazon	n/a	$11.79	
	51	**$81.42**	
Battery			
4x Rechargeable LG HE4 18650 2500mAh 20A 3.7v	188	$25.88	amazon
NITECORE i4 lithium ion charger	n/a	$25.75	amazon
	188	**$51.63**	
TOTAL			
	867g	$2716.32	
Needed beyond initial Capstone fund:		$1966.32	

V. Timetable

Following is a detailed time table used to make sure a successful outcome was obtained, outlined is Fall and Spring Semesters.

Task Name	Start	End	Duration (days)
FALL SEMESTER (2016)	9/9/2016	12/10/2016	92
Project Research/Learning	9/9/2016	9/17/2016	8
Brain Storm / Gather Ideas	9/12/2016	9/19/2016	7
Sponsor Details	9/12/2016	9/15/2016	3
Problem Defined	9/16/2016	9/23/2016	7
Figure Requirements /Best Approach/Research	9/23/2016	10/23/2016	30
>>>> Article/ Patent Research	9/24/2016	9/25/2016	1
>>>> Advisor Meeting	9/25/2016	9/26/2016	1
>>>> Review Information Gathered	9/26/2016	9/30/2016	4
>>>> Define Approach	9/30/2016	10/2/2016	2
>>>> Advisor Meeting	10/2/2016	10/3/2016	1
>>>> Gather what parts needed & COST	10/3/2016	10/7/2016	4
>>>> Document What has been gathered	10/7/2016	10/9/2016	2
>>>> Advisor Meeting /grant Check (Col Day)	10/9/2016	10/10/2016	1
>>>> Document/ Finalize/Sterhnheimer Award	10/10/2016	10/14/2016	4
>>>> Current Assets Review	10/14/2016	10/16/2016	2
>>>> Advisor Meeting	10/16/2016	10/17/2016	1
>>>> Document parts/ Order Parts	10/17/2016	10/20/2016	3
READING DAYS	10/20/2016	10/22/2016	2
See where we stand	10/22/2016	10/23/2016	1
Advisor Meeting/ Where we stand	10/23/2016	10/24/2016	1
Revew What we have	10/24/2016	10/30/2016	6
>>>> Sketch / layout	10/24/2016	10/26/2016	2
>>>> Model	10/26/2016	10/30/2016	4
HALLOWEEN	10/30/2016	10/31/2016	1
Design review/ what parts used/Build Prototype	10/31/2016	11/13/2016	13
>>>> Evaluate Feasability with model	10/31/2016	11/4/2016	4
>>>> Start implementing Prototype	11/4/2016	11/6/2016	2
>>>> Advisor meeting	11/6/2016	11/7/2016	1
Documentation Update	11/7/2016	11/13/2016	6
>>>> Parts Documentation / Assemble	11/11/2016	11/13/2016	2
Implentation	11/13/2016	11/23/2016	10
>>>> Advisor Meeting	11/13/2016	11/14/2016	1
>>>> Assemble/ Test/ Debug	11/14/2016	11/18/2016	4
>>>> Document/ Test	11/18/2016	11/20/2016	2
>>>> Advisor Meeting	11/20/2016	11/21/2016	1
>>>> Document / Test/ Debug	11/21/2016	11/22/2016	1
FALL BREAK	11/22/2016	11/27/2016	5
Pototype Testing / Debuging/ Proof of working	11/27/2016	12/10/2016	13
FINAL EXAMS	12/10/2016	12/21/2016	11
UNIVERSITY CLOSED (Winter Break)	12/23/2016	1/16/2017	24

SPRING (2017) SEMESTER	1/17/2017	5/2/2017	105
Regroup,Figure out where we left off/Headed	1/17/2017	1/23/2017	6
Continue working on localizing system	1/23/2017	1/30/2017	7
Order Spectrometer using Sternhimer award	1/30/2017	2/1/2017	2
Figure 3D Print mounting	2/1/2017	2/5/2017	4
Documentation Update	2/5/2017	2/11/2017	6
Implement Spectrometer	2/11/2017	2/18/2017	7
Data storage & Data transfer	2/18/2017	2/27/2017	9
Develop data output GUI	2/27/2017	3/3/2017	4
>>>>Gather power supply requirements	2/27/2017	3/3/2017	4
Spring Break	3/5/2017	3/12/2017	7
Gimbal Controller tuning & command program	3/12/2017	3/18/2017	6
Design Board for expo	3/18/2017	3/20/2017	2
Real time clock integration	3/20/2017	3/25/2017	5
Print Board	3/25/2017	3/27/2017	2
Synched data transfer from microcontroller	3/29/2017	4/1/2017	3
Remote data gathering initialization on for PI	4/1/2017	4/4/2017	3
Wire management & PCB integration	4/4/2017	4/6/2017	2
Mount entire system on to gimabal	4/6/2017	4/8/2017	2
Run system independently	4/8/2017	4/14/2017	6
Prepare simulation for expo	4/14/2017	4/17/2017	3
Documentation	4/17/2017	4/21/2017	4
Final Day of senior design seminar	4/21/2017	4/22/2017	1
Documentation	4/22/2017	4/24/2017	2
Should have board and expo Scenario/Simulation Finished	4/24/2017	4/25/2017	1
Go over Pitch for expo	4/25/2017	4/27/2017	2
Expo Setup: 2-5pm	4/27/2017	4/28/2017	1
Public Session for expo	4/28/2017	4/29/2017	1
Last days of classes, CELEBRATE!!!	4/30/2017	5/2/2017	2

VI. Expected Outcomes

We believe that this project will positively impact the world. Our technique of remote sensing will provide researchers an inexpensive and mobile tool for material analysis. The fate of our stressed environment lays in engineers' hands: we can and must help earth science. Our technology will allow researchers to autonomously gather real time spectral data at the local level. This system can be a tool to detect harmful algal blooms. We can prevent toxic exposure and help researchers determine the causes of these harmful events. The following page presents a visualization of our product in its completion, as well as a functional diagram describing the responsibilities of each component.

VII. Parts Visualization:

Our Remote Aerial Mapping Spectrometer (RAMS) produces a three-dimensional graphic of spectral signature positions via a combination of field spectroscopy and laser surveying. The system samples spectra at precise locations through a long-focus lens; it also takes a laser distance measurement to the surface. The sensors scan the area by rotating on a three-axis gimbal which tracks yaw, pitch, and roll. The host microcontroller computes three-dimensional positioning with a calculation of angular orientation and ranging. The now localized spectra are transmitted to researchers in real time, producing a map of harmful algal blooms and other nearby plant characteristics. [3]

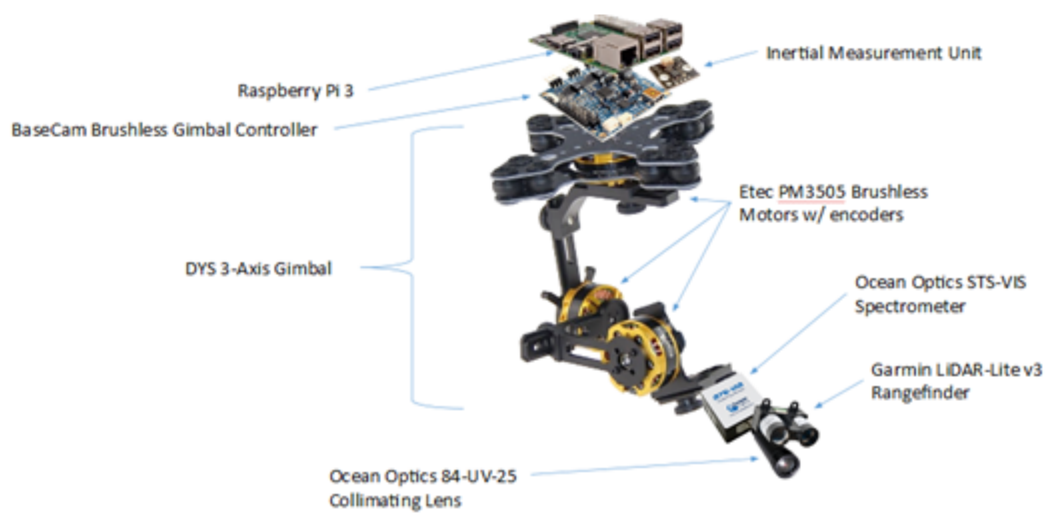


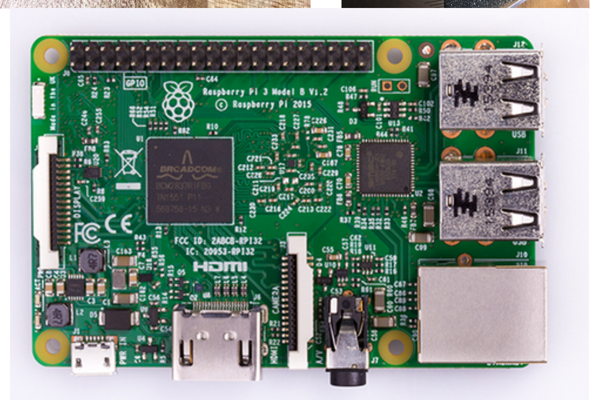
Fig: Initial concept design: layout of system parts

Spectrometer

Collimating lens

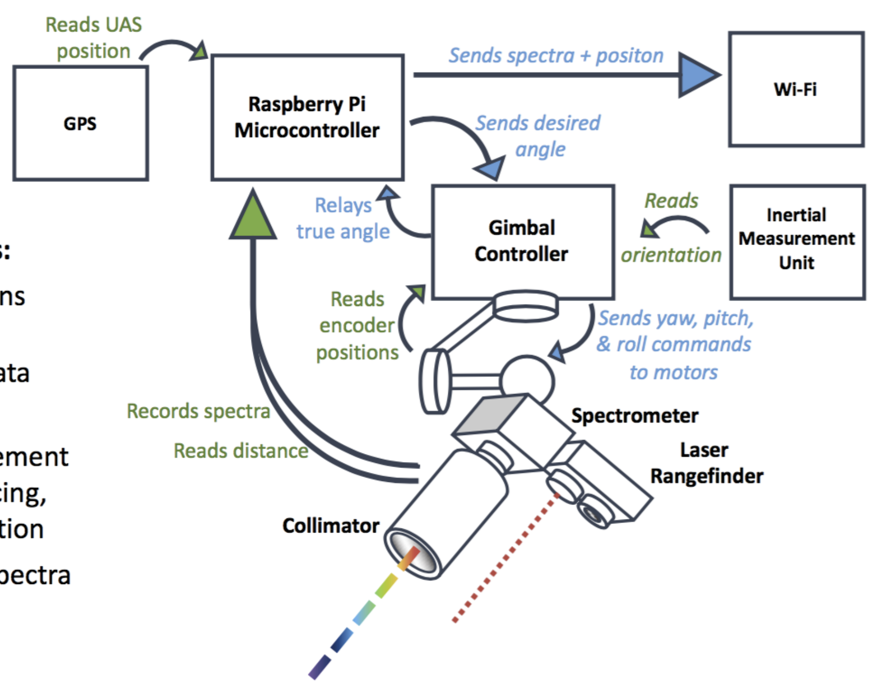
Custom fiber optic cable

LIDAR-lite V3 Laser Rangefinder



Raspberry PI 3 Microcontroller

Functional Diagram



Microcontroller Tasks:

- Algorithmically scans surroundings
- Records spectral data from STS-VIS
- Calculates measurement position via distancing, orientation, & position
- Outputs localized spectra to ground station

VIII. Engineering Design Specifications

a. Customer Requirements

1. *Human factors considerations*

Our design will be easily mounted beneath the UAV and will not pose a hazard to users by unexpectedly rotating while still on the ground. Nor will our system be so heavy to be considerably dangerous should the UAV unexpectedly decent. The spectral data that our system sends back to the base will have an encapsulated position metadata field. This will greatly aid researchers' quantitative analysis of the environment.

2. *Metrics for customer satisfaction*

The RAMS system provides a local spectral mapping with previously unavailable resolutions for a price considerably lower than existing techniques. Consumers will undoubtedly be satisfied. To gauge how pleased they are, we ensured that our positional data is within reasonable tolerances to reality. Additionally, we have calibrated our spectrometer in the lab against an accurate benchmark unit to ensure that it performs as the customer would expect.

3. *Single use (consumable device) or reusable*

The RAMS system is highly reusable, so long as the UAV doesn't crash and the batteries are recharged.

4. *Sterile or non-sterile product*

With remote sensing, RAMS doesn't contact harmful algal blooms and so will remain safe to touch. However, RAMS won't have to be kept too clean: it's a field tool.

b. Functional Requirements (What should the product do?)

The RAMS system can deliver to researchers data points that encapsulate three spatial coordinates and one array of spectral intensity. This greatly aids environmental analysis as it makes the spectral data points visually localizable.

c. Performance Metrics (How well should it do "it"?)

Our RAMS system achieves high spatial resolution as the laser ranging module can take samples at up to 500 Hz

d. Engineering Characteristics (units, ranges, limits with tolerance ranges, etc)

1. *Size, dimensions, weight (should be constant with medical application norms)*

RAMS weigh less than one kilogram. Its dimensions alter while it rotates, but the entire system is enclosed by a box that is 20 centimeters per side.

2. *Mechanical properties*

There are three brushless motors that freely rotate. We prevent full rotation to ensure that the wires don't become tangled.

3. *Material properties*

   1. Important material surface characteristics and properties

      Our gimbal is made of carbon fiber and cast aluminum so that it is lightweight. We 3D printed a custom bracket to hold the spectrometer in parallel with the laser rangefinder and well as printing a custom case to hold our host microcontroller and gimbal controller.

   2. Biocompatibility issues

      The gimbal has a mode which prevents it from scanning while the operator is managing the Unmanned Aerial System on the ground. This will prevent finger pinches within the gimbal.

   3. Electrical, non-electrical requirements

      Our project is battery powered, and the capacity requirements will be determined after construction of the full system. This is because energy usage depends on our motor's energy requirements (gimbal motors use more power for heavier payloads but our package will be very light)

   4. Any other characteristics specific to this project

      RAMS wirelessly sends data back to ground researchers while also storing the localized spectral information on board. It will comply with the necessary FCC regulations on data broadcast, which is especially critical for usage on flying vehicles.

e. Constraints

1. *Does this product have to function with specific other products? i.e. If computer program is part of design, what is spec on required hardware, etc.*

The system is intended for attachment to the underside of a UAV. There are two primary criteria for successful implementation. The host vehicle must have an available payload of at least one kilogram. It must also have space available on its underside for the unit. Examples of systems not applicable for

RAMS use are small, less powerful UAVS, and those which have cameras or other components attached underneath.

2. *Does solution have to utilize specific materials or manufacturing processes?*

In order to properly mount the motors to the gimbal, two small alterations were necessary. If the product is to be replicated, the team will consider manufacturing a customized gimbal frame to avoid this. The most labor intensive aspect of design is interfacing and calibrating the positioning and spectral analysis systems. Once completed, this portion can be smoothly replicated to successive products, and will require occasional software updating.

3. Target manufacturing cost (materials and assembly)

Materials: $2,644.30 is the rate for a one-off, we would find custom high volume components for commercial construction.

Assembly: With technical build guide, the RAMS system could be constructed without a high degree in engineering.

f. Production Methods

1. Appropriate manufacturing methods based on scale of components and design requirements

Our system should be hand manufactured because of the intricacy and precision necessary in assembly.

2. Sterilization or cleaning methods based on materials used (if applicable)

Our system does not need sterilization or cleaning methods; it will not come in contact with harmful algal blooms or any other contaminants. We highly do not recommend this device to be used on rainy, windy, or any high storm weather.

3. Quality Requirements with Allowable Tolerance levels

Tons of major testing will be done before releasing our product and will also ensure a tolerance level under 5% for spatial measurements and spectral analysis as compared to an calibrated lab spectrometer.

4. Packaging and Storage Requirements

Due to the relative fragility of the lightweight carbon fiber and aluminum components , and the precise level of sensor calibration, it will be necessary to store in a shock absorbing, well protected environment

5. Brief cost analysis

The majority of our parts fall within our standard Capstone budget of $750. Those components used for spectroscopy, however, bring the overall cost to an estimated $3,000. This was made possible after receiving the Mark A. Sternheimer Award grant of $1,800 and also an additional Capstone award of $500.

IX. Prior Art

Our team utilized the VCU Innovation Gateway, whose mission is to facilitate the commercialization of inventors. An important aspect of developing intellectual property is to thoroughly research what may already exist. This is a tedious process, but may avoid conflict, loss of time, and wasted investment down the line of development. In one instance, a patent (No. 9,488,630 B2) had been filed after we had defined our own design. This is a brutal reality of product innovation, it is important to never assume that you are the only party interested in solving a particular problem. Below are two patents that relate to our design. The first uses a camera and gimbal mounted to a balloon to monitor crops; the second is a relatively old patent (2002) concerning hyperspectral imagery paired with a gimbal device. [4] [5]

(12) **United States Patent**
Coram et al.

(10) **Patent No.: US 9,488,630 B2**
(45) **Date of Patent: Nov. 8, 2016**

(54) **INTEGRATED REMOTE AERIAL SENSING SYSTEM**

(71) Applicant: **DOW AGROSCIENCES LLC**, Indianapolis, IN (US)

(72) Inventors: **Tristan Coram**, Zionsville, IN (US); **Yang Yang**, Zionsville, IN (US); **Terry R. Wright**, Carmel, IN (US); **Pradeep Setlur**, Carmel, IN (US); **Fikru Haile**, Carmel, IN (US)

(73) Assignee: **Dow AgroSciences LLC**, Indianapolis, IN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 145 days.

(21) Appl. No.: **14/535,118**

(22) Filed: **Nov. 6, 2014**

(65) **Prior Publication Data**

US 2015/0134152 A1 May 14, 2015

Related U.S. Application Data

(60) Provisional application No. 61/901,940, filed on Nov. 8, 2013.

(51) **Int. Cl.**
B64B 1/50 (2006.01)
B64B 1/44 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01N 33/0098*** (2013.01); ***B64B 1/44*** (2013.01); ***B64B 1/50*** (2013.01); ***B64B 1/66*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B64B 1/44; B64B 1/50; B64B 1/66; B64F 1/12; B64F 1/14; B64D 47/08; B64C 39/022; B64C 2201/148; F03D 5/00; G01N 33/0098
USPC 701/3; 244/33
See application file for complete search history.

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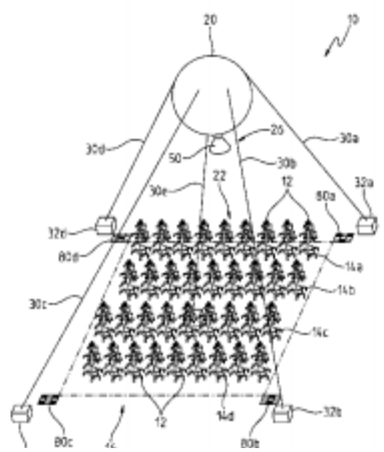
Primary Examiner — Khoi Tran
Assistant Examiner — Robert Nguyen
(74) *Attorney, Agent, or Firm* — Eric J. Kraus; Faegre Baker Daniels LLP

(57) **ABSTRACT**

A system for high temporal and high spatial resolution monitoring of a field of plants is disclosed. Illustratively, the system includes a plurality of ground based reference objects, a balloon adapted to be positioned above the field of plants, and a balloon positioning system coupled to the balloon and configured to position the balloon relative to the field of plants. An imaging system is supported by the balloon and includes a locations system, at least one camera, and at least one gimbal configured to orient the at least one camera. The imaging system captures at least one image of the field of plants including the plurality of ground based reference objects in the at least one image.

27 Claims, 7 Drawing Sheets



(12) **United States Patent**
Barnes

(10) **Patent No.: US 6,422,508 B1**
(45) **Date of Patent: Jul. 23, 2002**

(54) **SYSTEM FOR ROBOTIC CONTROL OF IMAGING DATA HAVING A STEERABLE GIMBAL MOUNTED SPECTRAL SENSOR AND METHODS**

(75) Inventor: **Donald Michael Barnes**, Indialantic, FL (US)

(73) Assignee: **Galileo Group, Inc.**, Melbourne, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/543,465**

(22) Filed: **Apr. 5, 2000**

(51) **Int. Cl.**[7] **F41G 7/00**; F42B 15/01
(52) **U.S. Cl.** **244/3.16**; 244/3.15; 342/52; 342/53; 342/54; 342/55; 342/58; 342/62; 342/63; 342/64; 342/65; 342/66; 342/192
(58) **Field of Search** 342/61–66, 89, 342/90, 175, 195, 52–56, 189–197; 244/3.15–3.19

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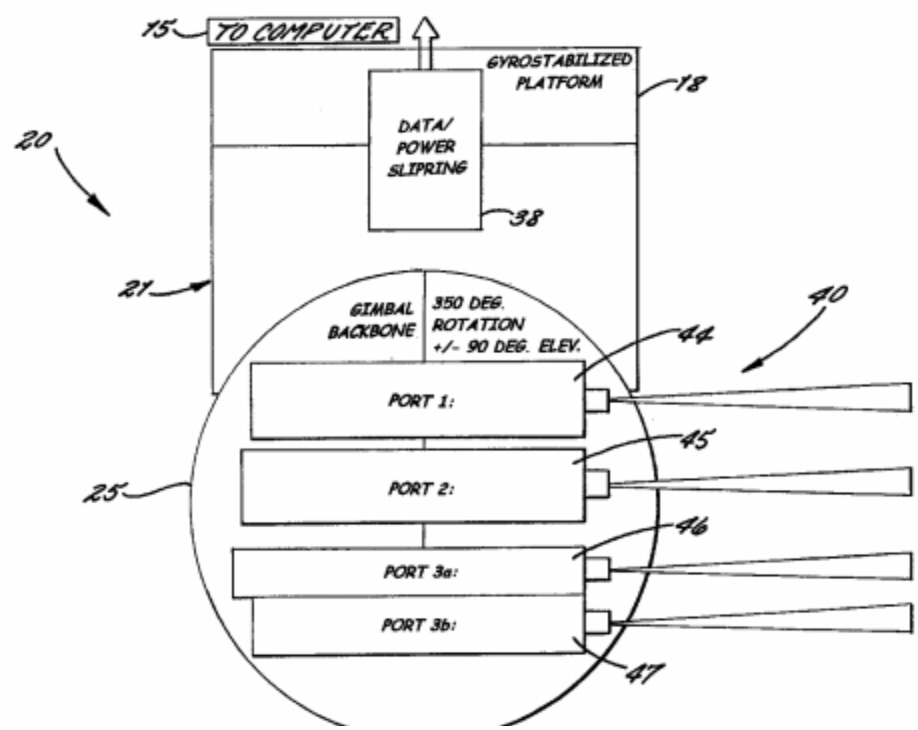
Primary Examiner—Bernarr E. Gregory
(74) *Attorney, Agent, or Firm*—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

A robotically controlled steerable gimbal mounted virtual broadband hyperspectral sensor system and methods provide a highly mobile, rapidly responsive and innovative system of locating targets and exploiting hyperspectral and ultraspectral imaging and non-imaging signature information in real-time from an aircraft or ground vehicles from overhead or standoff perspective in order to discriminate and identify unique spectral characteristics of the target. The system preferably has one or more mechanically integrated hyperspectral sensors installed on a gimbal backbone and co-boresighted with a similarly optional mounted color video camera and optional LASER within an aerodynamically stable pod shell constructed for three-dimensional stabilization and pointing of the sensor on a direct overhead or off-nadir basis.

34 Claims, 11 Drawing Sheets



X. Impacts

Environmental:

The initial interest of this project was to investigate new methods regarding the detection of Harmful Algal Blooms (HABS) in the Chesapeake Bay region. The affected area increases each year and is characterized by oxygen-depleted water, which results in reduced or no ecological growth. We are providing environmental researchers and other scientists with more accurate data. This improves their ability to deter the incidence and prevalence of HABs in the future.

As the project developed, our team began to realize that the RAMS would prove useful in many other areas of environmental research. These include, but are not limited to precision farming, measuring erosion over time, and monitoring invasive species.

Societal:

The Information Age was brought about by advancements in computing - the storage and processing of mass quantities of data. We can only predict the next game changing technology that advance our society. Many believe it will be the application of photonics on these digital technologies. We see this today in optical fiber communication, however there is much more to be determined.

The RAMS system is a product of the digital and optical realms. There is powerful area of research is not understood by modern researchers. As we develop new technologies in these realms, our society new, innovative technologies

Our project is more than an individual solution; it is a platform for other innovations that improve the world around us.

Regulatory:

Another area of rapid development is within autonomous flight. Increased accessibility to unmanned aerial vehicles (UAVs) has cause an enormous upswing in the density of private aircraft in the Country's airspace. Current legislation has not caught up with this surge in drone usage; and unsurprisingly, changes in legal ramifications cause instability regarding what is and is not allowed [6]. As our society grows into new rulings, the process of data collection and management may vary widely. As our project continues to develop, it will be important to monitor these changes and adjust our system accordingly.

Safety:

HABs are detrimental to the health of the animals and humans who contact them. For this reason is it important not only to detect them, but to do so with minimal exposure to the researcher. This product is focused on human safety by providing useful, high resolution data without putting the researcher into harm's way.

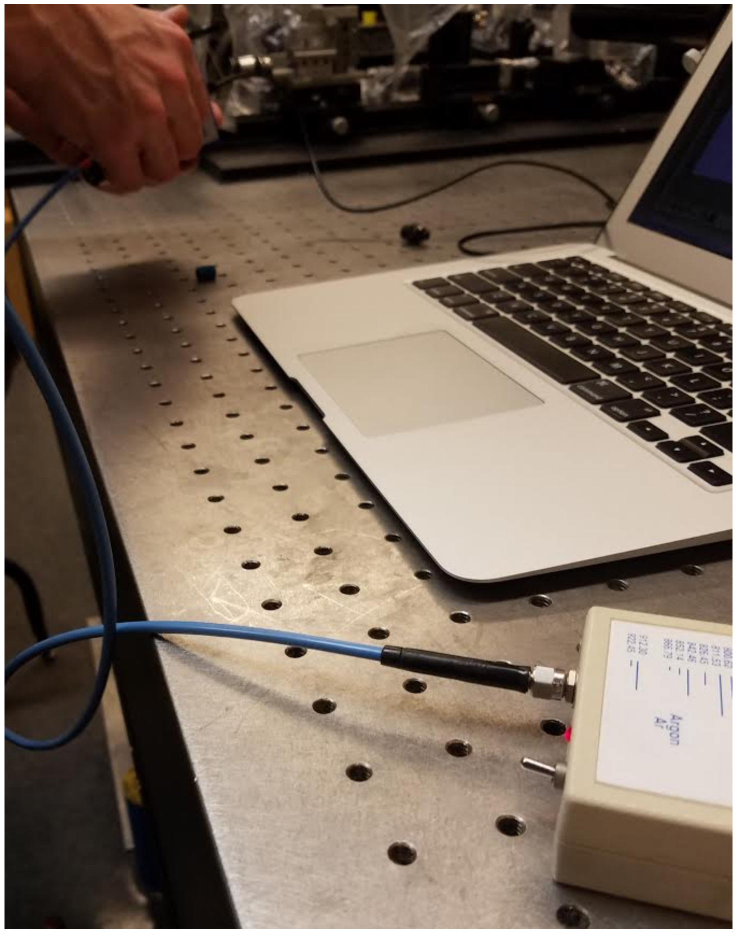
Financial:

Through project initiation, definition, development, and implementation, we have presented our goals to a variety of audiences, each of whom provided constructive feedback from a new perspective. This process was critical to refining the scope of our project to the needs of the eventual client.

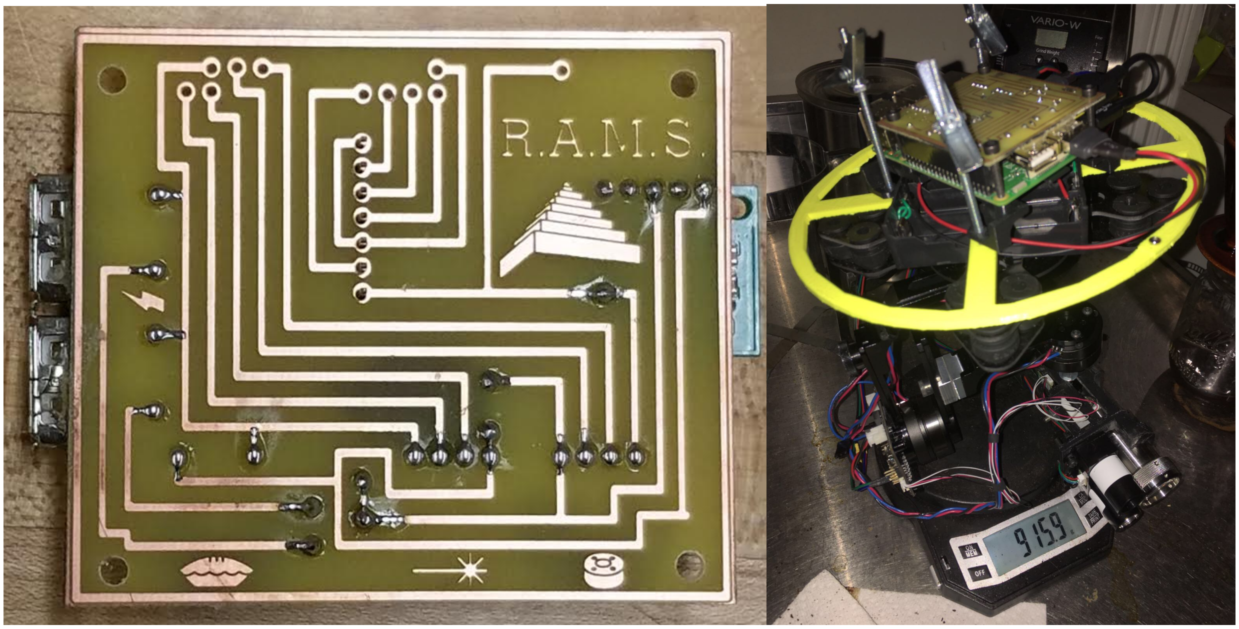
Across all audiences, precision farming was perhaps the most popular application the RAMS system. Although we do not intend to restrict the project to this, we realize the importance of providing the client with their immediate need. Our product will be useful to both small scale and commercial farmers by accurately monitoring the health of their crop. Spectral characteristics of a particular region of a cornfield, or even an individual plant, can be compared to that of a healthy yield. This is turn will show the client areas that are being under- or overnourished. Proper utilization of this data will improve the health of the vegetation and increase the overall yield, while eliminating wasted fertilizer and water. Based on our client interaction, our team sees this as the most immediate financial gain attributed to the RAMS system.

XI. Proof of concept prototype and testing protocol

RAMS consists of many components that are not typically integrated together. For this reason it was important not only to test these parts individually, but to observe their function within the system.

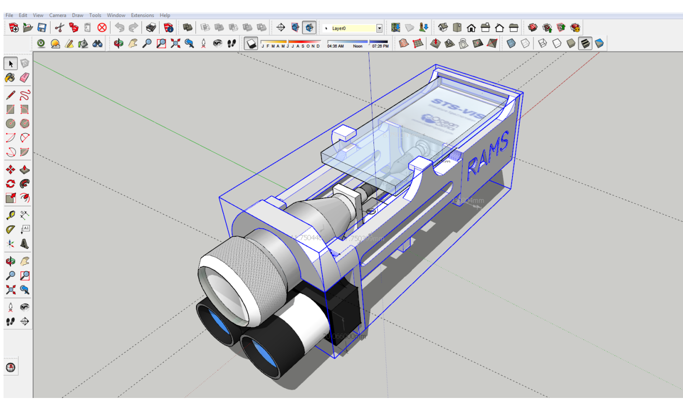


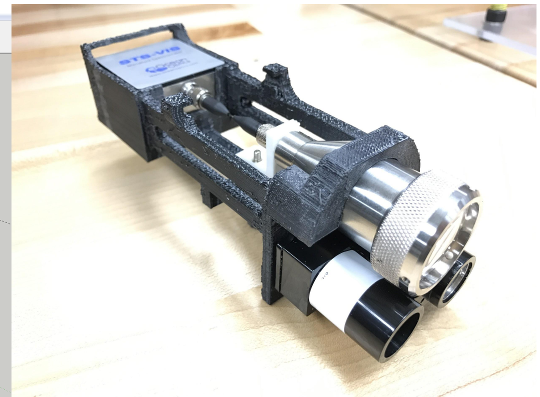
The STS-VIS spectrometer (held, top of picture) was tested using a Helium-Neon calibration lamp (lower right corner) courtesy of the VCU Photonics and Optics Laboratory. This lamp emits light with very precise spectral peaks, which can be recorded by a spectrometer was coupled directly. Data was recorded and then compared to the known spectral peaks of the laser. The STS-VIS is a relatively low-cost device but proved to collect data with high precision.



(Left) A primary design goal was to maintain low space, weight and power (SWaP). To achieve this our team developed and etched a daughter circuit board to stack above the Raspberry Pi Microcontroller. This design provides space between these two components for a real time clock, voltage regulator, and reactive components needed for the Lidar Lite system. Additionally we employed a basic auctioneering circuit so that our system can switch between two different power sources without experiencing a disruption in power delivery. This is helpful in case the system undergoes a long flight and returns with low battery power. Auxilly power can be supplied from other batteries or via an AC/DC converter to avoid shutting of the microcontroller.

(Right) The final weight of the prototype, neglecting the batteries. These are intended to be included in the overall weight. The typical weight of an 18650 rechargeable lithium ion batteries is 45 [g]. RAMS uses four of these batteries putting the estimated total weight at 1.0959 [kg]. This is less than 10 percent above our goal overall weight and is sufficient for many unmanned aerial vehicles. As with most prototypes, there is room for improvement in many areas, and we hope that future teams will be able to reduce this overall weight.

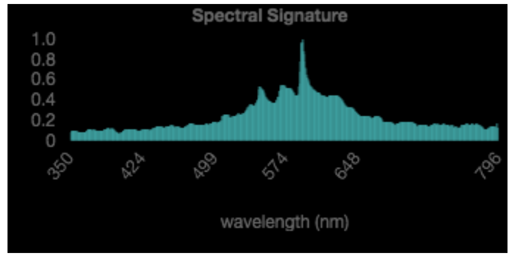


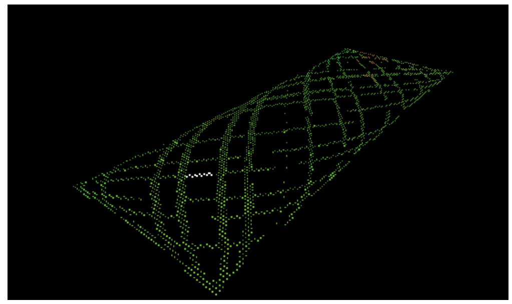


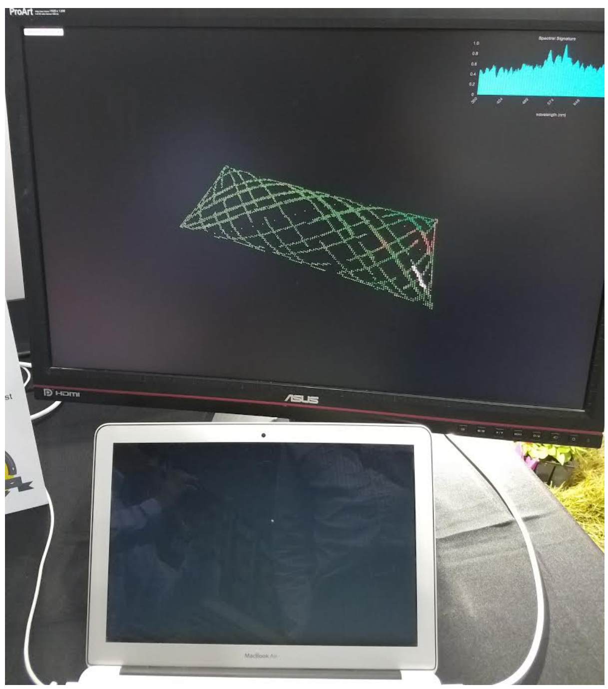
(Left) Final model of the housing for the RAMS sensor payload. The model features lightweight design, yet is sturdy enough to hold its components together while the system is mobile. These criteria ensure the sensors are pointing in precisely the same direction, which otherwise would provide inconsistent pairing of localization and spectral data. Additionally, this structure provides support for the optical fiber, which couples the spectrometer and the collimating lens. The integrity of the fiber is critical to providing high resolution spectral output. The device would otherwise fail to operate at any distance above ground level.

(Right) Integration of the sensor payload. Our model was 3D printed using the VCU Makerspace for Electrical and Computer Engineering

The RAMS datapath is comprised of many layers and stages. The output of each sensor needed to be processed on RAMS. As each sampled data at different rates, a multithreaded program infrastructure was developed in the C language. Nine main C files and 16 headers were necessary to combine the dozens of libraries and APIs that RAMS employed, amounting to 3787 lines of code written across 29 files. The codebase of RAMS is stored on Github [7]. Individual threads push onto atomic generic data queues the raw distance, orientation, and spectra recorded. Then a consumer thread pops these values sequentially to properly associate them over time. The data was written to a MySQL database for later retrieval or multiple-access live feed of the scan.







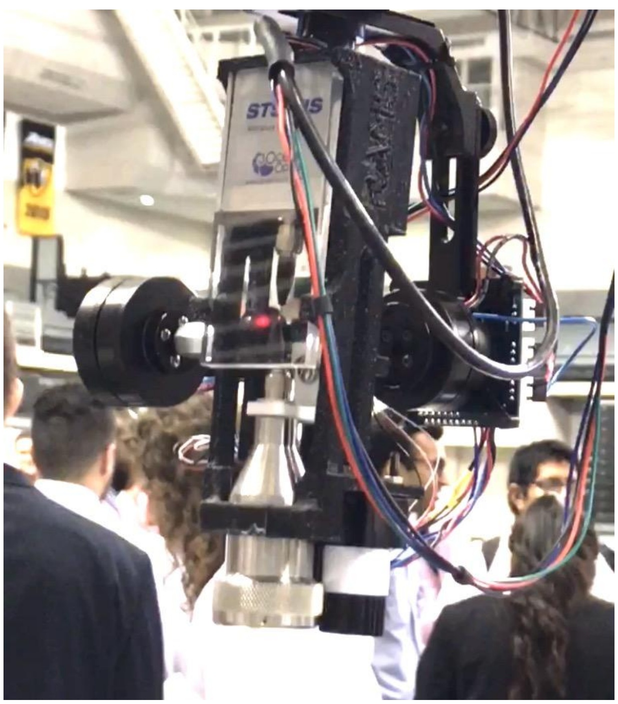
(Left) The ground station visualization environment.
(Top Right) A sample spectral signature. (Bottom Right) The spatial point cloud.

The RAMS device works as a wireless access point, allowing researchers to connect their computers directly to the system to access data. Onboard RAMS is a MySQL relational database that contains gathered session scans and the three dimensional voxels and spectra taken during the scan. The ground station fetches data from the RAMS with a preprocessor that manipulates the spectral signatures to filter and normalize them. The data is then cloned on the ground station with additional fields for voxel colors sampled from the intensity of red, green, and blue light in the spectral signature.

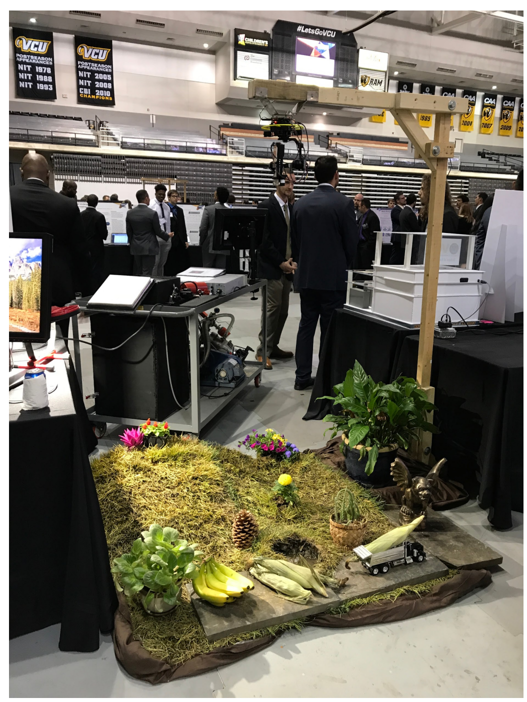
The visualizer presents the point cloud in Javascript with controls to change perspective and zoom. Hovering the mouse over groupings of voxels taken during a spectral measurement presents the spectral signature on the top right of the monitor. This allows researchers to find out the spectral composition at given locations.

XII. Results

The outcome of RAMS development was successful considering the numerous engineering challenges. One unfortunate loss to the system was that the onboard laser rangefinder suffered an electrical fault during initial transportation to the expo and was unable to be recovered. The system outputted a flat rendering of the observed spectra and was unable to present the 3D point cloud that was expected.



Close up of RAMS system



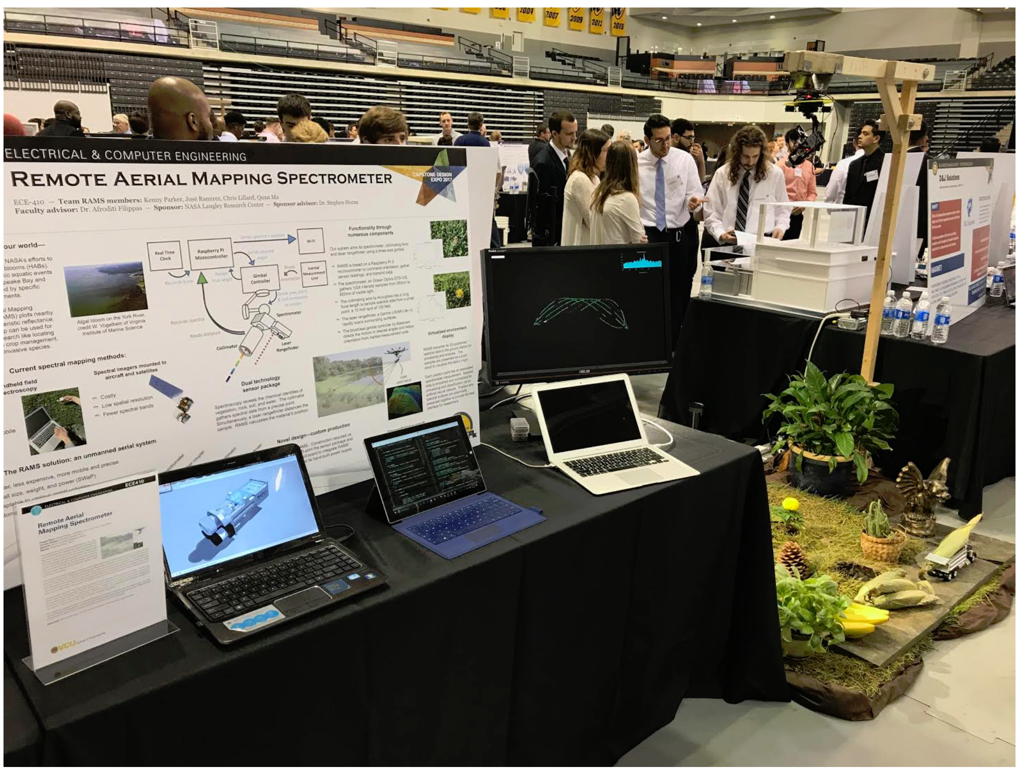
Scene RAMS is scanning

XIII. VCU Capstone Design Expo

The Senior Design experience culminates at the end of the Spring Semester, where each team has the opportunity to demonstrate their product to sponsors, faculty, students, and the general public.

It is critical for each team member to possess a thorough understanding of the scope of the project and the details of it's design. Students will speak to audiences of various backgrounds, ranging from intrigued children to professionals with decades of experience in the given field. The team must be prepared to discuss the project based on the technical knowledge and interest of the guest.

Our team had a wonderful experience at the design expo. Although our sponsor was not able to attend, we were greeted by other industry representatives from the same department. Our display drew interest from many industries, and we were prepared to field questions regarding everything from to monitoring characteristics to tobacco fields.



XIV. Conclusion and Future progression

Our team was successful in creating a working prototype of the Remote Aerial Mapping Spectrometer. This required multi-stage rapid prototyping, customization and machining of mechanical components, creation of software platforms and algorithms, and developing a way to merge and analyze data types completely unrelated to one another. Along the way, there were consistent pitfalls and obstacles requiring scope adjustment or redefinition. The true value of the senior design experience is learning to recognize these problems and overcome them without sacrificing credibility or losing sight of the goal at hand. Despite these issues, we were able to deliver a product that met the critical goals set out at the initialization of the project.

There are many aspects of our system that could be improved. Some of these are existing components that may need further attention, some are concepts that were deemed "above and beyond" the minimum criteria. A key aspect of our idea is UAV implementation. This is an area that we were not able to test, however VCU has shown interest in UAV design and testing. There is potential that our project could eventually be run in conjunction with the UAV lab. Our hope is that another team will be interested in continuing our work next semester. As described throughout the report, we believe that this technology will be useful in many areas of research. This opens the door to teams who are interested in system architecture, optics, environmentalism, and many other concentrations

XV. References

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[4] US Patent No. 9488630 B2

[5] US Patent No. 6422508

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[7] Github for the Remote Aerial Mapping Spectrometer https://github.com/KennyParker/RAMS