Hyperspectral Imaging UAV

Interim Project Report Rev 4.1

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University of California, Santa Cruz
Baskin School of Engineering

Senior Design Project 2014 - 2015

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Introduction

Abstract

The goal of our senior design project is to develop a low cost Unmanned Aerial Vehicle (UAV) capable of producing hyperspectral maps designated areas. Presently, hyperspectral cameras on the market are too heavy for mounting on small UAVs and can be expensive. The project aims to use an ultra-lightweight, cost efficient MEMS Fabry-Perot Interferometer (MEMS FPI) to replace the hyperspectral camera. The MEMS FPI can be used as a tunable filter to analyze a variety of light waves. By tuning the filter on the MEMS FPI we can capture a range of wavelengths that can replicate the results of a hyperspectral camera. The final product of the project will allow the UAV to map fields and collect humidity content, nutrient content, as well as other data, mainly, but not limited, to farmers.

Motivation

The growth of crops is essential for civilization and other species in the food chain. The demand for food continues to increase and so will the demand for crops, thus requiring more effective ways to grow produce. By developing a system that can monitor and inspect crop conditions autonomously, farmers can grow their products more efficiently.

Currently the simplest way farmers monitor their crops is by physical inspections, meaning the farmers physically go to their farm and check every plant. If the farmer has acres of land, physical inspection of the whole farm will be very time consuming and laboring for the farmer. With the use of an autonomous UAV with hyperspectral capabilities, a farmer can get information about his farm never before available with less physical strain and in considerably less time. Since the method is low cost the farmer will also be able to monitor the fields more frequently.

Approach

This project is intended to be done in two phases. The first phase is the prototype phase, where we experiment and test our equipment with a small quadcopter. This will reduce the expenses, in case of an accidental crash. Once we verify that the small autonomous quadcopter functions as desired, we advance to the next phase, which is transferring all the electronics from the small quadcopter to the big octocopter. The octocopter has several features that the small quadcopter doesn't have. Several of the more obvious features are a longer battery life, the ability to navigate through more harsh conditions, and the ability to carry larger payloads, up to 10 kg. In figure 1 below, you will find a block diagram of the small quadcopters basic components. The octocopter will essentially contain the same components, in a more organized fashion. Figure 2 shows a picture of the small quadcopter with all the components on it. Figure 3 illustrates the big octocopter that will be our final product.

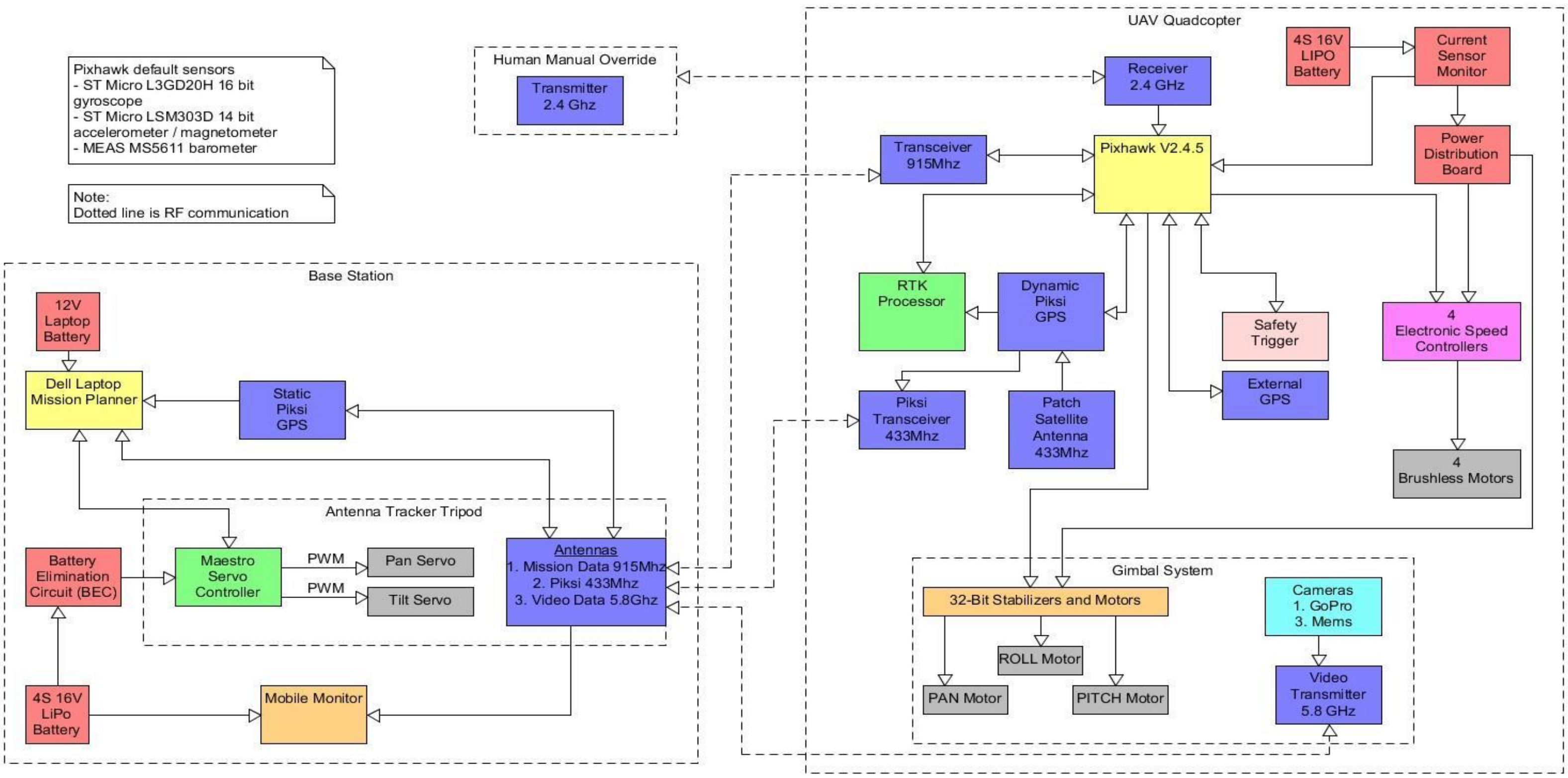


Figure 1: A high level block diagram of the UAV.

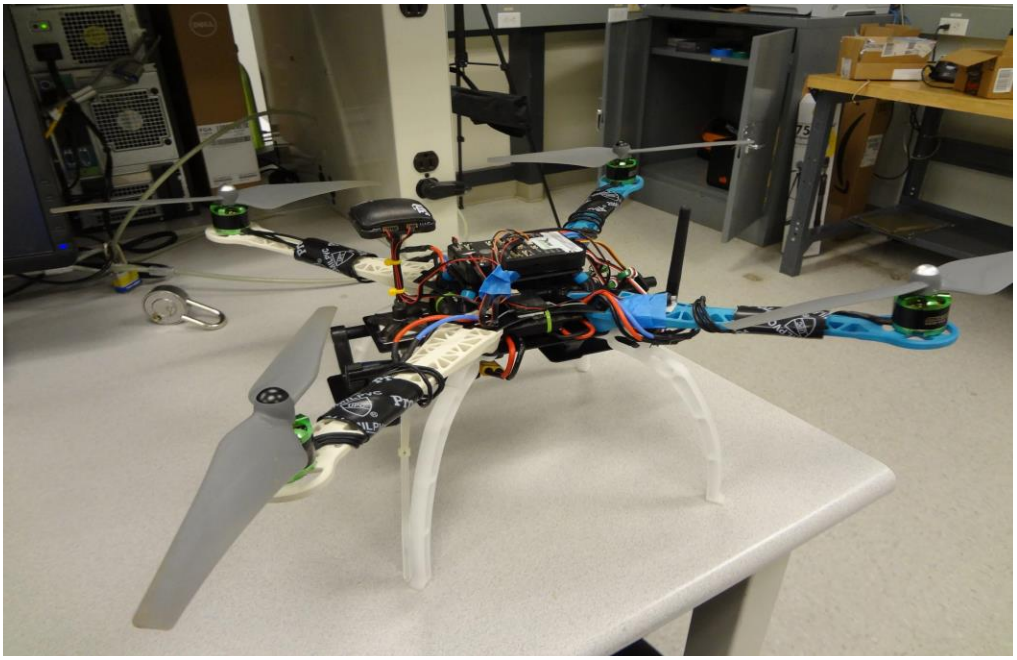


Figure 2: A picture of the quadcopter used for testing

Figure 3: A picture of the octocopter out in the field.

Methods

UAV Components:

Pixhawk Flight Controller

The Pixhawk Flight Controller is an advanced flight controller that is accompanied with open source code and the option to expand and add more functionality. It is a PX4 project and is supported by various GUI's. Mission planner, the GUI we decided would best fit our application, is used as an interface between the user and the flight controller. The Pixhawk uses Mavlinks as the communication protocol to send data packages between mission planner and the flight controller.

The PixHawk flight controller has about 14 Pulse Width Modulation (PWM) signal outputs that have the capability of controlling servo motors. Having numerous PWM signal outputs expands the possibilities that one can add to the UAV. Failsafe monitoring can be set up to protect the UAV from reaching low battery, communication lost, and other dangerous conditions. Along with numerous PWM signals, the Pixhawk also has designated ports for GPS modules. Currently we have a u-box external GPS connected and it can give us accuracy of about 5 meters. This GPS module will eventually be switched with the Piksi GPS, which has accuracy of about 3 cm. We also have a safety switch to ensure connectivity with the remote control. For telemetry purposes, the Pixhawk comes with a designated port to communicate messages between mission planner and the flight controller. Last but not least, the PixHawk also includes a power module port that allows battery life monitoring.

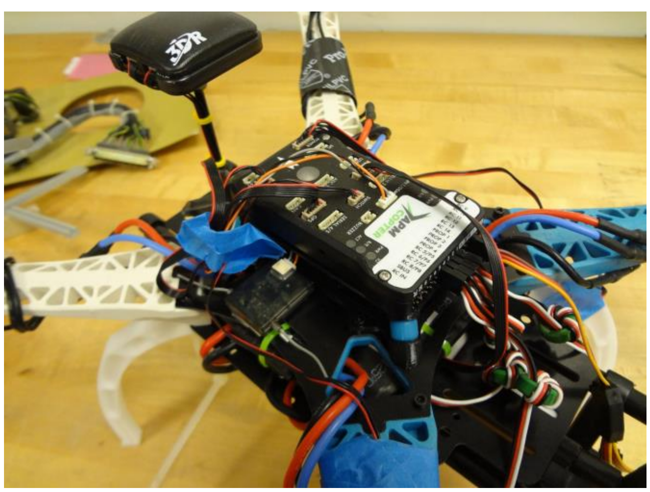


Figure4. The PixHawk controller mounted on the quadcopter

Electronic Speed Controllers (ESC's)

Electronic speed controllers are circuits take data from the flight controller and output signals that accurately spin the motors at the correct speed. For our UAV, we have an ESC for every motor. Before being able to use the ESC's one has to calibrate all ESC's at once so that the proportion between throttle and motor speeds are all in sync. If the calibration fails, the motors may not spin correctly or they may spin at different rates. The calibration of the ESC involves setting certain throttle threshold for certain speeds, i.e. half throttle will cause the UAV to lift off the ground.

Telemetry Radios

The UAV have multiple antennas and each operate at different frequencies. The first is a linearly polarized antenna that supports the communication between the drone and the base station laptop. This antenna operates at 915 MHz. The second is a circular polarized antenna for the video transmitter, low gain on UAV and high gain on GCS. This antenna operates at 5.8 GHz and allows us to have a real time video feed of what the GoPro camera is observing. The final antenna is a linearly polarized antenna, used for the Piski GPS, and it operates at the 433 MHz.

3DRobotics Global Positioning Systems (GPS)

The current GPS on our quadcopter is a 3DR uBlox GPS with a compass. The GPS accuracy of this unit ranges from 2.5 meters to 5 meters. The built-in compass of this unit has an accuracy of about +/- 5 degrees according to our testing with this device.

Imaging System

MEMS Fabry Perot Interferometer (FPI)

The novelty of this project is based on incorporating the MEMS Fabry Perot Interferometer (FPI) on the UAV. The MEMS FPI we plan to incorporate would behave as a tunable optical filter that would allow us to specify the wavelengths we intend to study. Being able to collect environmental data of agricultural fields will notify farmers which areas of the field they need to inspect. Typical studies of light outside the visible light range are possible with heavy, static and costly equipment. The MEMS FPI is similar in price to the low end hyperspectral cameras, but with time and an increase of demand, the device will become less expensive and more available for several of applications.

The MEMS FPI is composed of two highly reflective parallel mirrors which are spaced out at a certain distance, typically millimeters. The distance between the two mirrors can be adjusted by supplying the device with a different voltage which attracts the electrostatic plates, holding the mirrors, to each other. Figure 4, illustrates a cross section of the MEMS FPI and exemplifies the overall functionality of the device. The distance between the two mirrors, d, is what determines the band of waves let through the mirrors; all other wavelengths get either absorbed or trapped. Being able to adjust the distance between the two mirrors can tune the MEMS FPI to a desired band of waves and serve as a tunable filter. We intend to use the MEMS FPI as a tunable filter in front of an image sensor camera to collect light waves in both the visible light and the near infrared range.

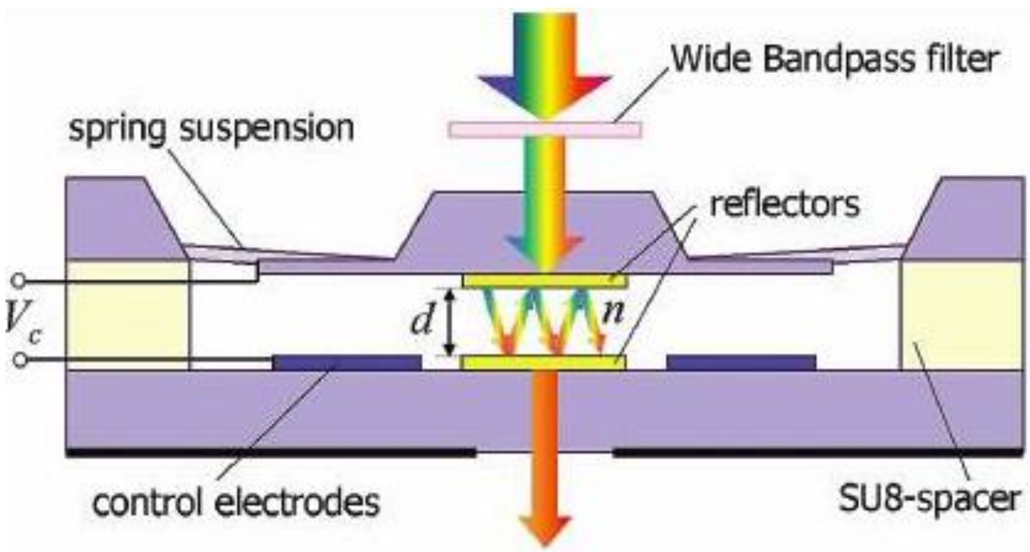


Figure 5: A cross-section of the MEMS FPI

We plan to use the Flea3, a monochrome camera as the image sensor used to collect the photons passing through the band pass filter. Figure 5 shows a high level block diagram of the system we intend to design. As you can see, we first have the light pass through a lens in order to focus the light. Next the focused light passes through the MEMS FPI, which filters out light we aren't interested in. Finally, we are able to collect the photons passing through the MEMS FPI. We will mount the entire system on the UAV and collect images during a survey.

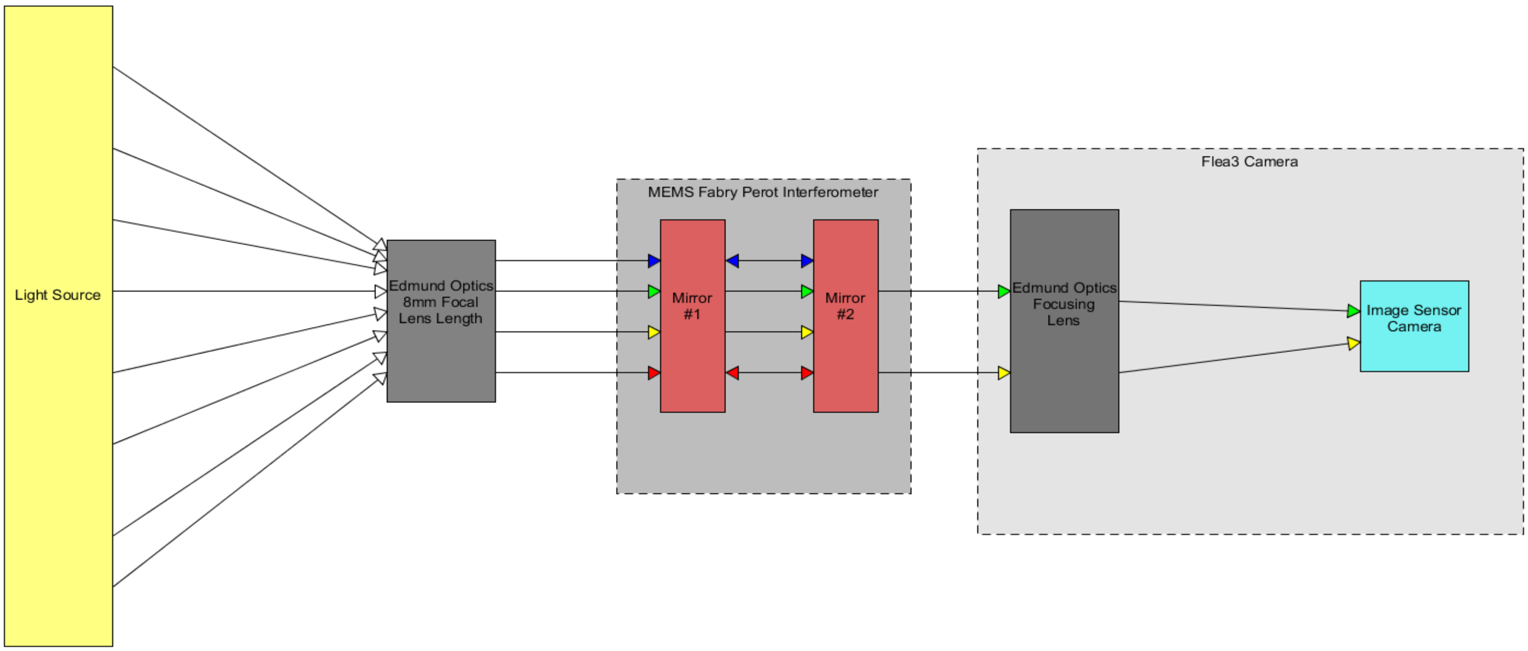


Figure 6: A high level block diagram of the optical system.

Hyperspectral Camera

Initially, we planned to compare the data we collected using the MEMS FPI system with an actual industrial hyperspectral camera. This would allow us to verify that the data collected from the MEMS FPI was applicable and useful for farmers. Initially, we had plans on purchasing the Pika II, but we decided to not do so after finding out that the lead time to receive the camera was 14 weeks. We continued to look for other cameras and came across the OCI hyperspectral camera from BaySpec. We were able to see a live demonstration of the camera's features but the price for the camera was out of our budget so we decided that we would compare the MEMS FPI data with a monochrome camera with band pass filters in front.

GoPro Hero4

An important component of our project is collecting image data with a camera that operates in the visible light range. To complete this task, we used a GoPro camera since it can process images at a high frame rate and be stable in. The GoPro camera is also very lightweight, small in size, and has the capability to geotag images. We have already started collecting images from raster scan survey missions that we have done. We are currently working on selecting an image stitching software that can correctly stitch our images together. Along with collecting images, the GoPro has external hardware that allowed us to transmit image data wirelessly to a monitor at our base station so that we can see what the GoPro is capturing.

Real Time Video Transmission

Our UAV is capable of producing of live feed of the data captured from the GoPro camera. The data is sent from an ImmersionRC video transmitter to a monitor at the base station. The operating frequency of the video transmitter is 5.8 GHz, which is the Industrial, scientific and medical (ISM) radio band. Our video transmitter is outputting 600 mW which is considered a low power communication system so we are transmitting and receiving signals legally.

Base Station

Mission Planner

Mission planner is the user interface that the team will be using to communicate and monitor the UAV. As previously stated, mission planner uses the Mavlinks protocol to send data and read data from the UAV. The interface allows for easy access to the parameters of the PixHawk, such as proportional-integral-derivative (PID) values, speed, acceleration, channels, flight mode and much more. Not only does it allow us to access such parameters, but we can also plan autonomous flights to survey an area. We can do very simple mission that only require a few waypoints, but the main application we seek and mission planner has available is survey mode. We sketch an area we want to cover and specification of our camera and we can create a mission that will cover the area. In our case, Mission planner was not capable of interfacing with the GoPro we used one of the available PWM pins to develop a mechanical trigger that triggers on command.

Mission Planner is an open source program, and within program there is a terminal. In this terminal we have the ability to add modifications to the PixHawk code as well as the Mission

Planner interface. We would use this feature to accommodate the precision flight using the Piksis.

UAV Live View Monitor

This monitor displays the view of the camera attached to the UAV in real time. The monitor has two antenna attached to it, an omnidirectional and directional antenna. One great advantage of this monitor over other monitors is that the monitor has a diversity receiver capable of selecting the stronger signal of the two antennas. The feed received from the monitor can serve to ensure that the camera is oriented in the correct position and is working correctly.

Piksi RTK (Real Time Kinematics) GPS

A RTK is a differential Global Navigation Satellite System (GNSS) that provides high positioning performance paired with a base station. The performance accuracies of using a RTK are around 3 cm, whereas the GPS built in phones are typically around 3 to 8 meters

The GNSS is an international collection of satellites allowed for GPS use around the world. The term 'differential' means there is a ground-based reference point (the base station) that broadcasts the difference between the stationary and roving positions indicated by the satellite systems. For a single GPS module to acquire an accurate position solution, it needs to track at least 4 satellites. Even after tracking 4 satellites the GPS will receive timing errors from the satellites caused by signals travelling through the atmosphere (ionospheric delay among other disturbances in the atmosphere) which can make the position solution less accurate. When there are two GPS modules that are tracking the same satellites, they will be receiving the same errors. By using differential GPS you can eliminate all common errors of the base station and the UAV, thus making the UAV position solution more accurate. Basically, the base station transmits corrected information to the UAV so that the UAV can correct its position.

Real Time Kinematic differential GPS calculates and broadcasts corrections from the base station to the UAV as the data from the satellites is received. Real Time Kinematics provides precision guidance to the UAV. Since the rover will be moving, the signal from the satellites may be blocked which can botch the data received. Reprocessing the data using Real Time Kinematics, we can ignore frequent discrepancies in our data. To be able to achieve precise autonomous flight with our drone, a RTK GPS is essential. Additionally the base station will be receiving a more stable signal from the satellites since it is not moving, whereas the UAV will be moving and receiving a less stable signal.

The SwiftNav Piksi RTK GPS is the specific product that we are currently trying to integrate into our project. The Piksi RTK has a built in Inertial Measurement Unit (IMU) that tries to predict where the Piksi will be when signal is lost, making for a more robust system. An IMU is a combination of accelerometers, gyroscopes, and magnetometers that can be used to determine the velocity, orientation, and direction of a craft.

Antenna Tracker

The base station will have an antenna tracker on a 75" tripod to maintain clear line of sight of the UAV. The reason for this device is to ensure we are always getting live feed from the cameras onboard the UAV. We have an omnidirectional antenna as well as a directional antenna. The omnidirectional antenna has an operating range of about half a kilometer. The UAV will be flying distances greater than half a kilometer so the directional antenna will be used to compensate for this. The operating range of the directional antenna is a little over a kilometer but it has to be pointing the direction of the UAV, thus there is a need for an antenna tracker.

The antenna tracker has two servo motors: a pan servo and a tilt servo. These two servos are driven with the Maestro servo driver and controlled by our GCS based on UAV GPS locations. The driver reads in commands from mission planner, and then sends the appropriate PWM signal to each servo motor.

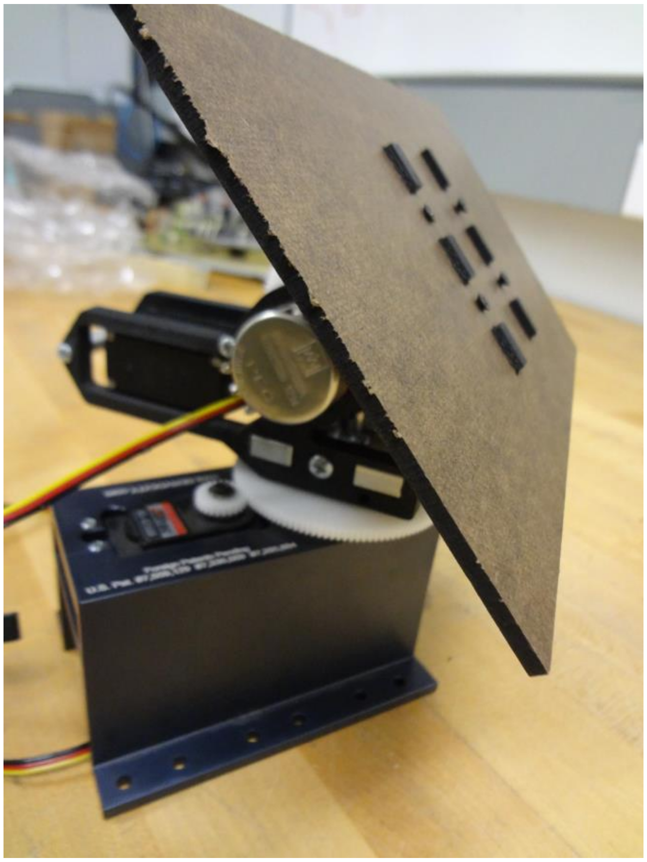


Figure 7: The antenna tracker with its current platform to hold the antennas.

Results

Autonomous flight

The UAV has completed several autonomous test flights. During the first test flight the UAVs compass encountered magnetic interference from the high currents running through the ESC's and motors. We determined that when the ESC consumed current they create an electromagnetic field that interferes with the compass readings. Using software, we were able to calibrate the compass by adjust the compass accordingly, to subdue the interference at each throttle point. Although there is still some interference at full throttle it is very minimal. After this problem was resolved the UAV was taken out to the field for another test flight. We started off with just a couple of simple missions that had no more than 5 waypoints. After observing the UAV was capable of completing the simple missions, we loaded a survey mission that consisted of over 30 waypoints and the UAV successfully completed the mission. We tested the UAV ability to complete a similar mission during strong winds and just as expected, the drone completed the mission, including auto landing and takeoff, without any issues.

Image Stitching

Combining multiple images containing overlapping elements to produce a single image is called image stitching. When mapping a geographic area using aerial images we need to use a specific type of image stitcher that can combine images taken at different positions in space with little distortion. This means we cannot use a panoramic image stitcher which is the most common type of image stitcher. A panoramic image stitcher combines images taken from a single position. The image stitching software we are using to do aerial mapping are Microsoft's Image Composite Editor and Autopano Giga 3.7 Lite.

Antenna tracker

As previously mentioned, the motivation for having an antenna tracker was to improve the range of both the UAV to Base station and the Video transmitter to monitor communication. In order to test the functionality of our antenna tracker, we had to go out to the field, where we had good GPS reception. We decided that the UCSC soccer field was a good location to test the antenna tracker, and we found that the antenna tracker can accurately follow the UAV. There are several parameters that we can vary to improve the performance of the antenna tracker, such as speed and acceleration. As of now, the parameters set for the antenna tracker are sufficient for the speed that the UAV is traveling.

Monochrome Camera Detector

We decided that it would be a good idea to verify that the Flea3 camera can collect data in the NIR range, before purchasing it. We were fortunate enough to have professor Kubby lend us a Flea2 camera (previous version of the flea3) that he has in his lab. We tested the Flea2 camera by placing a 950nm high pass filter in between the Flea 2 and an IR source. Just as predicted, the Flea2 was capable of collecting photons in the NIR range. Now we can proceed with placing the purchase of the Flea3 along with the proper lens for the Flea3.

Tasks Currently In Progress

Piksi RTK Integration with the PixHawk Flight Controller

The Piksi RTK still has issues working in ideal conditions (both Piksi units stationary). Most of the time the Piksis do not achieve a differential GPS fix, but when they do the RTK fix is spotty, meaning the differential GPS becomes regular GPS. This break in differential GPS may be due to the communication link between the two Piksis. Because the Piksi RTK is designed and manufactured by a start-up company it still has noticeable flaws and bugs that need to be ironed out by the developers to make a more robust product. SwiftNav often releases new firmware to fix and improve their previous firmware problems, which disrupts the consistency of our collected data especially when the new firmware causes more problems. Although the Piksis have inherent obstacles to overcome the concept of using a low cost differential GPS for our project is a task we will continue to pursue.

Our next test is to use an individual Piksi which can be used as a regular GPS unit and test whether we can obtain a better GPS solution compared to the 3DR GPS unit. After testing one Piksi unit with the PixHawk, we will test the Piksi GPS in dual setup with the 3DR GPS. We need to have dual setup because the 3DR GPS has a built-in compass and the Piksi does not.

Problems Unresolved

Purchasing MEMS FPI through UCSC

We decided that we would be purchasing the MEMS FPI from Rikola, a company from Finland. The reason why we decided on their product is because the MEMS FPI they manufacture is intended to be used for UAVs. The other MEMS FPI manufacturers we found had MEMS FPI that was designed to work in static and close range analysis. After placing the order, we found that Rikola needs to be added to the UCSC payee system before the order can be processed. This step in our order is out of our control but we have continually been pressuring the purchase specialist to process the order sooner.

Limited Flight Time

As of right now, the small quadcopter can fly for about 10 minutes on a full battery. With this battery life, the quadcopter is only capable of completing only about 2 flight plans, both of about 150 x 150 meters across. This becomes an issue since some areas, we hope to survey, will be larger than the areas we have previously surveyed. We know that if we reduce the weight of the UAV and purchase higher quality and more efficient motors we will improve the battery life. Purchasing new, more efficient motors is an option, but we intend to not pursue it. The reason for that is because we don't want to spend more money from our budget if it's not entirely necessary. Presently, we have a 4s battery powering up our UAV, and if we can swap the battery with a 3s battery, we would reduce the overall weight of the UAV. These are two solutions to consider and will be taken into account next quarter as the complexity and length of the flights increase.

Current Status of Project

The project is currently ahead of what he had previously envisioned. We had an end of the quarter goal be to have the UAV able to complete a survey autonomously with a GoPro taking images. The images we have collected thus far are imperfect due to glare and a low sampling rate. We also have the antenna tracker now successfully following the UAV, we now need to make a platform for the antennas to be placed on. We have ordered the MEMS FPI and are currently developing an imaging system for the device. As far as the Piksi is concerned, we have been able to obtain accurate data consecutively out on the field and plan to begin to integrate the Piksi with the UAV.

Conclusion

Thus far, we have been able to complete the majority of the challenges we set for the team at the start of the quarter. With that said, we have also encountered several other obstacles along the way. One of the biggest obstacles we encountered is the purchase of the MEMS FPI. We just found out that Rikola has been added to the UCSC billing system, now more paperwork is to be done. We hope to have this issue resolved soon, so that we can have the device shipped to us. We have had close contact with the Rikola representative and he agreed to ship the item to us as soon as he receives the payment. Once we receive the item, we can start working with the optics for the MEMS FPI. The team has discussed possible image sensors with Professor Kubby and we plan to have one ordered before the end of finals week. Professor Kubby has given our group access to his lab, where numerous optical systems are setup. We can use the systems as references and ask his graduate students for help, if needed.

As far as electronics for the UAV, we plan to transfer the electronics from the quadcopter to the octocopter and conduct performance tests on the octocopter to verify the electronics are properly functioning. We are currently asking to obtain access to the UCSC soccer field since it would serve as a better controlled environment, compared to our current location. We hope to do the transfer of the electronics by midterm of this upcoming quarter but our timeline is heavily dependent on the MEMS FPI order. If we can have the MEMS FPI, by the end of this month, then we will still be on schedule.

Appendices

Appendix A: Small UAV – Project Survey (Taken from Enes Mentese's Report to NASA)

SMALL UAV – PROJECT SURVEY

NASA Class I aircraft only

Part 1. General

Name of project: Low-cost hyperspectral imaging for UAV's
PI and contact: Joel Kubby, jkubby@soe.ucsc.edu, (831) 459-1073
PI Institution: University of California Santa Cruz
NASA Contact: Robert Dahlgren
Agreement (SAA, RSAA, Co-Op, IAA, etc.): Aligned Research Program of the UARC
Type of Project

- ☒ Project uses NASA UARC funds.
- ☐ External project: NASA is service provider for externally owned and flown aircraft.
- ☐ Non-commercial or model aircraft, static testing, unpowered glide testing.

Mission Location: UC Santa Cruz campus and NASA Crows Landing Airport
Mission Summary: This project is to develop and test a low-cost, light-weight, low-power spectral imaging system for UAV's (drones) that can be used to inspect crop conditions (over/under watering, nutrients, readiness of crops for harvesting, crop stress due to pests) for 'precision agriculture.' It can also be of use for studies of algal blooms in the ocean. The project will involve remote sensing, sensor technology development and applications, and UAV-utilization and control. The goal will be to substitute low-cost MEMS technology (MEMS Fabry-Perot Interferometer (FPI) and navigation) for high-cost spectral imaging cameras. By flying a hyperspectral camera based on the use of a MEMS-FPI filter, the cost and weight of hyperspectral imaging can become more affordable for farmers.

Part 2. Platform

Please respond to each item. This form will assist the Airborne Science Team at ARC in preparation for your AFSRB and FRRB. If an item does not apply or is yet to be determined, indicate so with “Not Applicable” (N/A) or “To Be Determined” (TBD).

Platform	Value and units	Notes	Documentation
UAV Manufacturer	DJI innovations	☐ Fixed-wing	Attach 2-sided copy of certification
UAV Model	Spreading Wings S1000+	☒ Rotorcraft	
Tail Number	N/A		Required per XXX
Wingspan	1.4 meter diameter		
Length	1.4 meter diameter		
Weight, empty	4.5 kilograms		
Weight, with payload	11.5 kilograms	☐ Estimated	
Weight, max. GTW	N/A	≤ 55 lbs (24.95 kg)	Per NPR 7900.3C
Maximum airspeed	70kph (37.8 kt)	≤ 70 kt (101.9 lm/hr)	Per NPR 7900.3C
Max. endurance	23.5 minutes		
Max. range	1 km		
Battery Mfgr/Model	RMRC 6S Lipo, Lumenier 6S Lipo		Refer to DOT regs.
Battery Capacity	12,400 mAh, 21,000 mAh		
Battery Chemistry	Lithium Polymer		Attach MSDS
Other chemicals	N/A	e.g. LN_2, Fuel, cal. gas	Attach MSDS
Ground Station Mfgr/	Dell, Mission Planner		
Autopilot Mfgr/Model	DJI Wookong-M, 3D Robotics Pixhawk		
Radio Rx Mfgr/Model	Spektrum AR9020, 3D Robotics Telemetry radio, Lumenier Diversity video Rx		
Radio Tx Mfgr/Model	Spektrum DX9, 3D Robotics Telemetry radio, Immersion RC Video Tx		
Radio Tx Power	600mW		FCC license > X mW
Radio Range	1km		
Frequency, uplink	2.4GHz, 915MHz, 433MHz, 5.8GHz		De-conflict per XXX

Frequency, downlink	2.4GHz, 915MHz, 433MHz, 5.8GHz		De-conflict per XXX
Safety Mux Mfgr/Mod	N/A		

☒ R/C, visual line-of-sight (VLOS).

☒ R/C, First-person view (FPV).

☒ Autopilot (A/P).

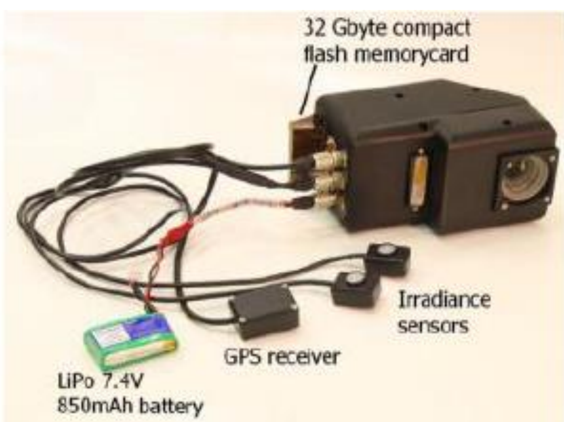
☐ Unpiloted (balloon, etc).

Part 3. Payload

Please describe the sensor ideally including a photo of the entire instrument. Describe how the instrument will be integrated into the platform and specific needs (e.g. nadir viewing, LN2, etc). Describe in detail anything that modifies the aerodynamics of the platform (e.g. use of pre-existing ports for sampling, external pod-mounting, penetrations in the fuselage, etc).

Payload	Value	Notes
Manufacturer	Rikola, Point Grey	Fabry-Perot interferometer, CCD camera
Model Number	N/A	
Description	Wavelength range: 400-1000nm Aperture diameter: 14mm	
Length (fore-to-aft)	8 cm	
Width (left-to right)	3 cm	
Height	3 cm	
Weight	0.7 kg	
CG	TBD	
Voltage requirements	15 V	From EIP
Power requirements	< 4 W	From EIP
Cooling requirements	None	
Sampling requirements	0.8 Sec scan per waypoint	
Data recorder/downlink	5.8Ghz	

Payload Details: Payload is composed of a CCD camera, a Fabry-Perot filter, a control unit, 5.8Ghz transmitter, 3 axis brushless motor gimbal system with control, and a payload battery and power harness.



Part 4. Mission

Please describe in detail where the mission will occur and other information to help estimate costs associated with mission support. Please provide kml files or images of the proposed flight path to and from the sampling area, along with an accurate estimate of total distance that will be flown. If a lawnmower pattern is used upon arrival to the sampling area, please show it, and include this distance in the estimated total distance.

Mission	Value	Notes
Location, general	UCSC campus	Santa Cruz, CA
Location, deployment	Loc. 1 long/lat 36.987689, -122.051510 Loc. 2 long/lat 36.983238, -122.056006	Altitude less than 120m (400ft) Loc. 1 UCSC East Field Meadow (Cowell) Loc. 2 UCSC Farm Coordinates indicate test area center point
Location, sampling area	Loc. 1 area 228,908 m^3 Loc. 2 area 88,750 m^3	Altitude less than 120m (400ft) Loc. 1 UCSC East Field Meadow (Cowell) Loc. 2 UCSC Farm
Proposed date(s)	All year	During fair weather
Proposed time	Daylight hours	Must be daylight hours per XXX
Max altitude, AGL	120 m (400ft)	
Estimated total distance	<1 km	
Estimated total time	<30 minutes	Limited by battery capacity

Mission Details: Flights over the UC Santa Cruz East Field Meadow near the east remote parking lot to test GPS waypoint navigation. Flights over the UC Santa Cruz farm to test precision agriculture goals (i.e. soil moisture content, crop health conditions.

☐ Domestic class G airspace current regulations (typically < 1,200 ft [365.7m] AGL.[1]

☐ Domestic class G airspace, proposed regulations (< 500 ft [152.4m] AGL.[1]

☐ Domestic restricted airspace. Details: Click here to enter text.

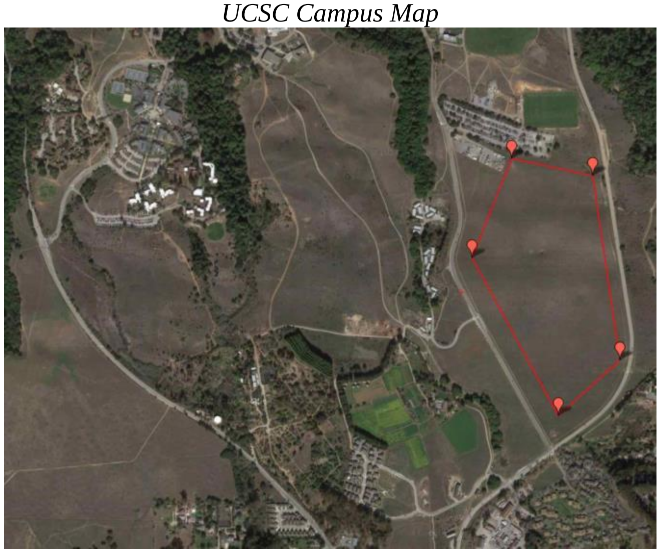
☐ International airspace. Details: Click here to enter text.

☒ Other airspace. Details: University of California campus and NASA Crows Landing Airport

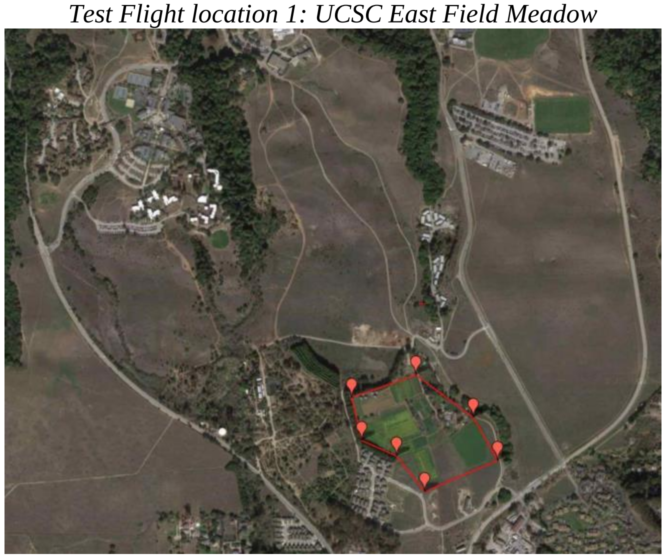
☐ Non-FAA permits needed (e.g. National Park Service)

[1] No Class C veil, > 5 mi [8.05 km] from any airport.

UCSC Campus Map



Test Flight location 1: UCSC East Field Meadow



Test Flight location 2: UCSC farm

Part 5. Crew

Please provide the names of the project personnel, including unpaid collaborators and student interns.

Personnel	Name	Documentation
Mission Manager	Joel Kubby (PI)	
Pilot in Command (PIC)	Enes Mentes (Xiaodong Tao backup)	
Range Safety Operator (RSO)	Robert Dahlgren (Enes Mentes and Xiaodong Tao backups)	
Ground Station Operator (GSO)	Xiaodong Tao (Enes Mentes backup)	
UCSC Student working on the project for Senior Design	Edgar Valdez, Eric Paredes, Matthew Silva	

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