Wetland Mapping with Multi-Spectral Cameras and Custom UAV

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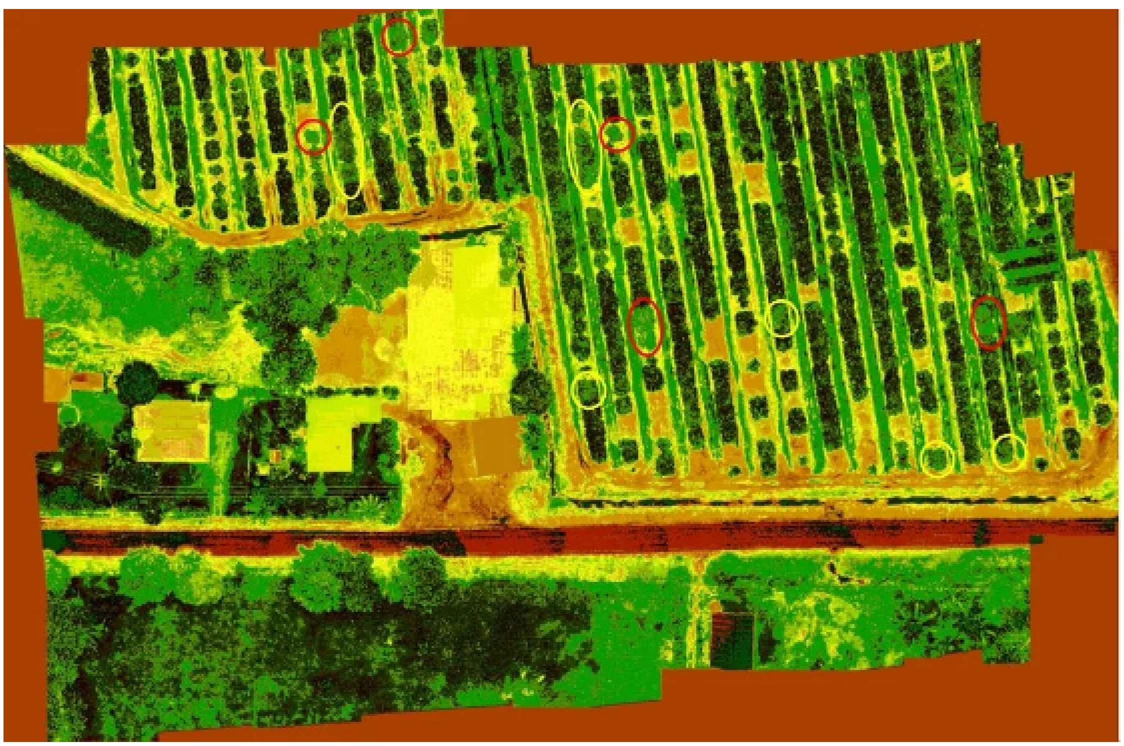
Abstract

Concord Academy is surrounded by wetlands, home to a wide diversity of flora and fauna. However, much of this biodiversity is unrecorded. Knowing the composition and health of the wetlands is crucial to pushing for better plans of action for the local government and conservation agencies. Our project aims to provide this data and engage the local community by educating them about the importance of wetland conservation and the role they can play in protecting these areas. Through workshops and interactive sessions, we plan to share the findings from our drone surveys and the implications for local biodiversity and ecosystem health. By involving community members in the project, we hope to foster a sense of stewardship and encourage actions that support wetland preservation.



[1]

[1] https://www.mdpi.com/2504-446X/7/8/536

Goals and Objectives

Our intent with this project is to use our custom-modified drone, Minmus 3000, image processing software, and multi-spectral cameras to capture and analyze wetlands in Concord and surrounding areas. The project from a technical perspective will consist of constructing the drone, testing various designs and features, and mapping wetland sites. The mapping will occur throughout the optimization phase and we plan to collect various timeframes for each site to cross-compare seasonal and annual changes to analyze the effects of climate change on the health of wetlands in terms of water quality, drying, and changes due to urban expansion.

We hope that through funding we can explore various designs and configurations to optimize the drone for further use, as well as provide as precise data as possible in a repeatable manner. The parts for the drones are not the only expense, however. The multispectral camera setup we are proposing for the drones requires 2 cameras, tracking hardware, and ground targets for calibration of the cameras. All of these will lead to a cleaner, more consistent image, which is crucial for our project goals. To get usable data and be able to cross-compare different sites and different mapping times, we will need consistent data.

The objectives of this project are to increase community engagement with wetlands awareness, collect data to provide a case for preservation efforts, and provide data to the CA community and beyond to further analyze and use for the benefit of the wetlands.

Being aware of these changes and proposing steps to prevent them is crucial for the ecosystems of Massachusetts. Wetlands are home to an incredibly diverse collection of flora and fauna, and the microbes found there are crucial to global water, sulfur, and nitrogen cycles.[2] However, they are also incredibly vulnerable to change, and the effects of climate change can be devastating to the delicate ecosystem. Wetlands also serve as sinks for greenhouse gas emissions, mitigating some of the effects of global warming. When these wetlands dry, or are changed, the gasses can be released back into the atmosphere. Wetlands also slow floodwaters, store snow and rain, clean

[2] (Department of Ecology, State of Washington and Yahnke)

polluted water, and contribute to groundwater[3]. This is just a small list of the importance of wetlands to mitigating climate change and supporting ecosystems, but it demonstrates that being aware of changes to them is incredibly important, and relatively unexplored. Our project serves to open up the doors to more awareness and scientific data collection.

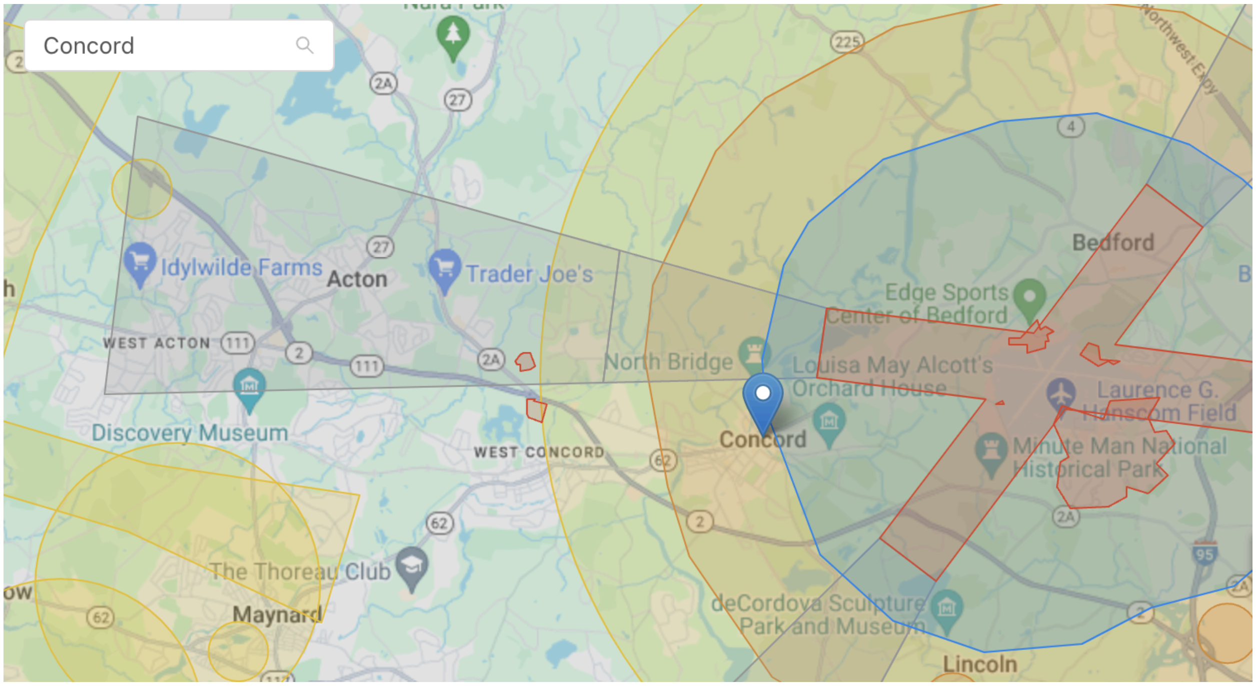
UAV Safety Considerations

According to DJI's latest FlySafe[4] map (Figure 1), which is in accordance with current Federal Aviation Administration (FAA) regulations, drones under 2.5 kg are allowed to be operated at a height below 120 meters in Concord, Massachusetts, provided that operators have received their FAA recreational pilot's licenses and are operating within line of sight.[5] The height restriction is lower in certain areas in line with Hanscom, at 45 m. Operating on-site and from the CA roof will allow line of sight easily. We have both obtained our recreational pilot's license and are thus permitted to operate in the town of Concord, Massachusetts. As we are using the data for non-commercial purposes, we do not need a license for photography either.

Not only are we operating by FAA regulations, but we have also added multiple fail safes to our drone design, discussed in the *Physical Design* and *Software Design* sections of this proposal, that guarantee the safe handling of our drone even under critical failures. Such fail-safes consider hardware/software redundancy, power loss

[3] (EPA)
[4] (DJI)
[5] (FAA)

scenarios, and the stall characteristics of our drone.



DJI FlySafe Map around Concord, MA[6]

Red and Blue regions designate no-fly zones while other regions are safe for our UAV

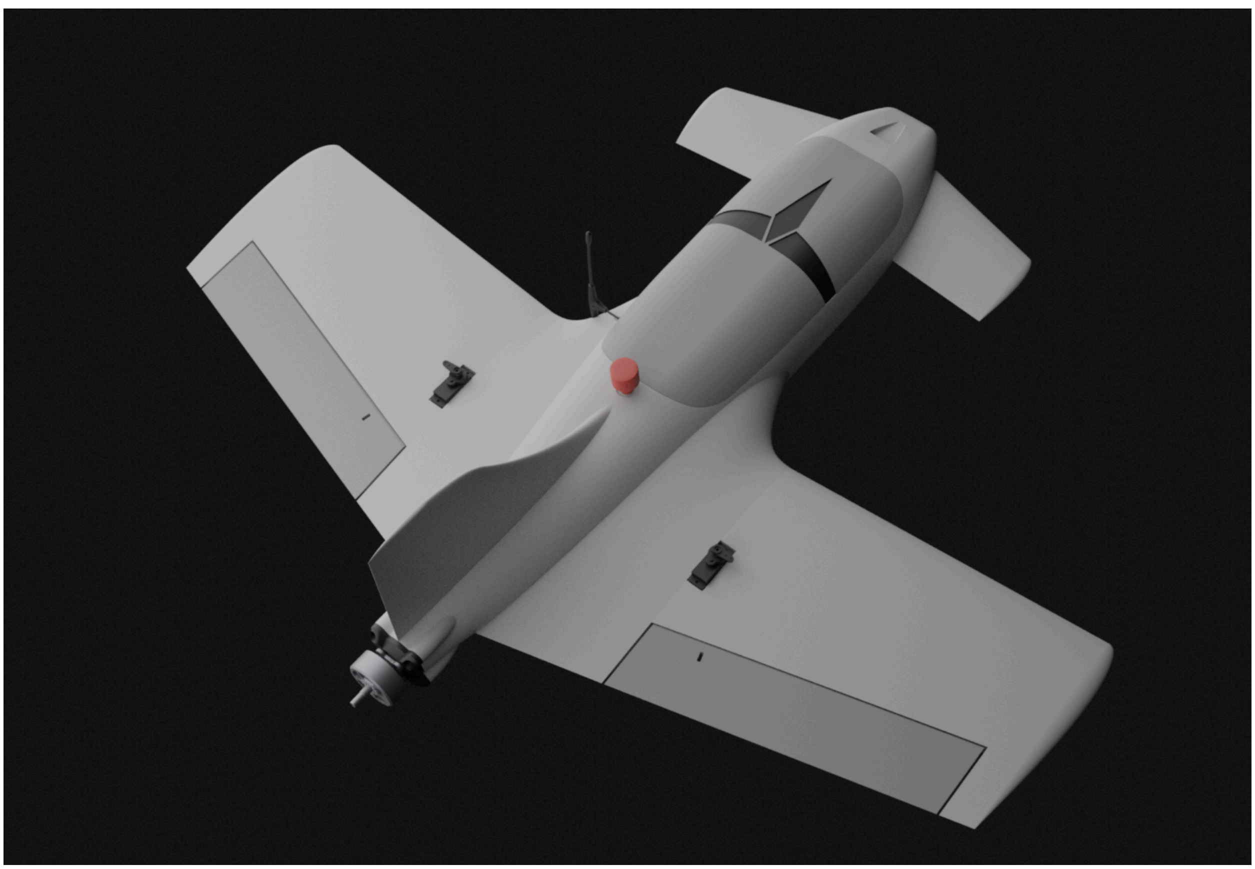
[6] https://fly-safe.dji.com/nfz/nfz-query

Challenges

The rationale for choosing a fixed-wing drone to complete the task is due to the speed and efficiency of fixed-wing configurations. Fixed-wing drones are also safer to operate due to the inherent stability of their design and their ability to hover after power out. However, there are drawbacks to using fixed-wing designs for a surveying drone.

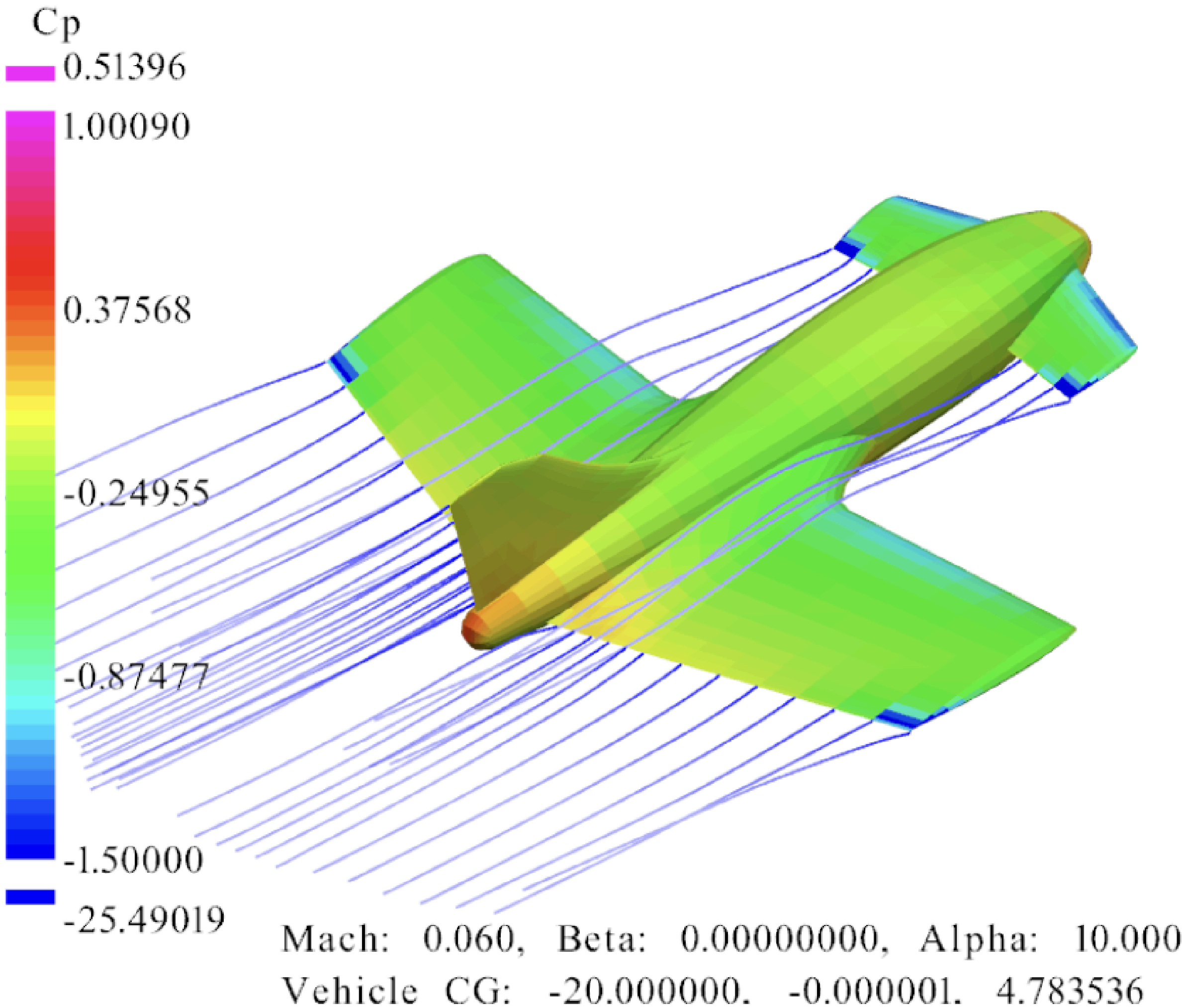
Take-Off and Landing Distance

First, fixed-wing drones need ample space during takeoff and landing due to their high cruising speeds. Thus, we wanted a drone that boasts great low-speed flight characteristics, required for short-range take-off and landings. We chose the Titan Hammerhead drone, a 3D-printed drone whose CAD files are sold by *Titandynamics* (Figure 2). The drone employs a front canard configuration as well as a forward-swept wing, design choices that give it great low-speed handling and high stall angles- desirable characteristics for STOL (Short Take-off and Landing).



Titan Hammerhead

Figure 2: The Titan Hammerhead Drone[7]



Titan Hammerhead showing good stall characteristics at high α[8]

Camera Blur

Then, motion blur effects on the multispectral images from the cameras become obvious at the low altitudes in which the drone operates, making it difficult to process the data. We can create significant overlap between areas we want to map by taking photos in short intervals. This will provide us with more precise data for a given point. The software we are using for post-processing and stitching, Pix4D, will be able to

[7] https://www.titandynamics.org/
[8] https://www.titandynamics.org/

handle a large number of photos, and the multispectral bands captured from our cameras for further refinement and processing.

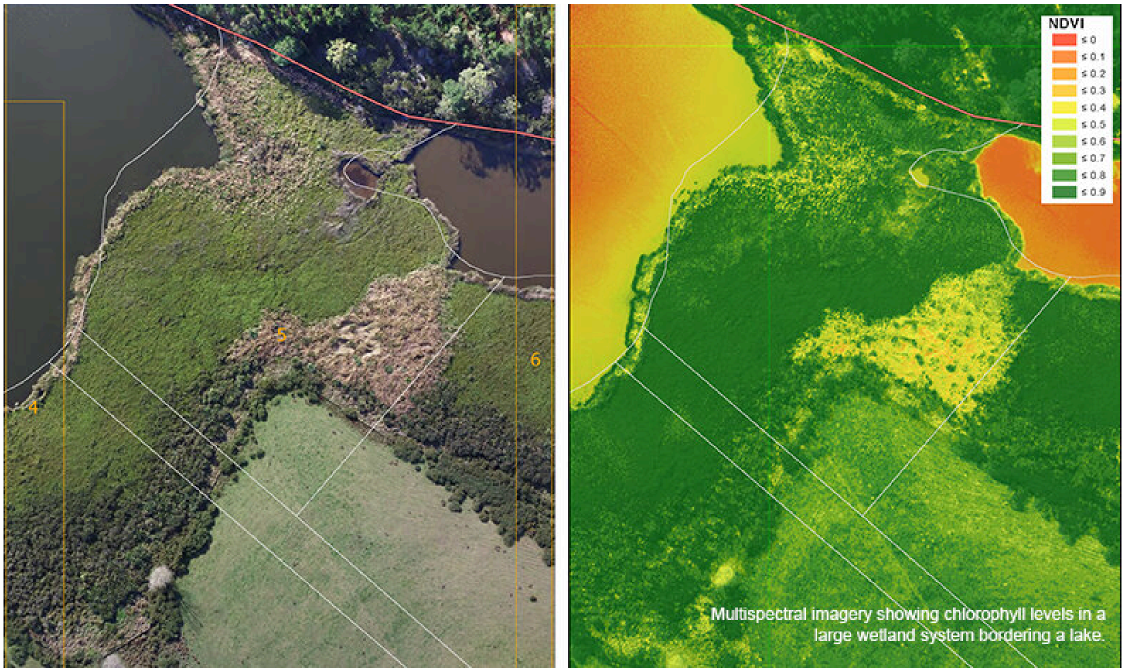
Evaluation Plan

One of the core goals of this project is to provide the CA community with data to use for their projects and analysis. Clubs at CA such as Big Data Club have already expressed interest in the project. This goal inherently required intense documentation and organization of data. We intend to keep track of all the data and keep it organized and stored in the cloud. We will write reports for our flight tests and site mapping associated with any data recorded.

As for how we intend to evaluate our success, we will do monthly check-ins on our goals, and how our progress stands up to the initial ideas. The nature of our project allows us to have flexible endpoints, and regardless of our ability to fully complete our goals, we will have data that can be used by future CA students, which in itself will be a success.

Presentation of Data

As mentioned in the evaluation plan, goals and objectives, and abstract, our intent is for this project to be very open. We will share our data via the cloud to the school when we record it. We will process the data in parallel with data collection and start to record our conclusions. We will likely not share processed data before publishing, as it wouldn't provide much insight until we've concluded. Hopefully, we will have collected enough data to write a research paper come winter-spring of 2025, which will be shared with the CA student body if published. The finer details of this will arise during the analysis phase of the project. There could be an all-school assembly if we can get a date and have enough interesting information to present.



Example of multispectral analysis of chlorophyll levels in a wetland[9]

Funding

Our funding section is broken down into our proposed UAV designs, camera equipment, software, and other parts. Many of the more expensive telemetry and FPV equipment can be reused among the builds to reduce costs. Reusable equipment will be highlighted in blue.

This section provides potential builds and the necessary camera equipment for our project. Since we intend to experiment with different designs and configurations, the amount of funding necessary for our project is not fixed.

The more funding we have, the more freedom we will have to optimize and collect precise data. We are thus seeking 3000-6000 dollars for our project. We arrived at this figure by stating that the multispectral equipment, which totals 1780, is crucial to the project's goals. We then include the cost of production for our Hammerhead drone, 650, and the minimum price of software, 210, and sum to 2640. To be able to iterate designs and have room for development, we assume another 400 for parts, bringing the total to roughly 3000 for a minimum project cost.

[9] (Brown and Watson)

Camera Equipment

Part	Qt	Price(USD)	Usage
DAQ-A Logger	1	400	Connects to cameras and provides geo-tagging as well as logging ambient light for calibration of images.
Calibration Target	1	500	The ground target is composed of 4 calibrated materials that provide data for specularity and reflectance values for the calibration of cameras in post-processing.
Survey 3 Rededge	1	400	Camera unit which captures redege wavelength light.
Survey 3 OCN	1	400	Camera unit which captures orange, cyan, and near-infrared wavelength light.
PWM HDMI Cable	1	24	Cable which connects to a computer to trigger camera captures on fixed intervals for automated data collection.
Raspberry Pi	1	62	Platform to trigger cameras and store image and GPS data.
Total		**1786**	

Hammerhead UAV

Part	Qt	Price(USD)	Usage
Cad files	1	29.99	Files for the 3D-printed parts of the drone
lwpla filament	1	27.99	Material used in the fuselage and wings 3d printed parts
tbs receiver	1	59.49	Receives telemetry data
tbs antenna	1	7.91	Antenna for the receiver
tbs transmitter	1	79	Transmits telemetry data
Servos	1	23.99	Motors that actuate control surfaces on the drone
Li-ion battery pack	1	36.4	batteries

t40 motor	1	40	motor
7x4 Prop	1	13.16	propeller
Carbon Fiber Spar(8x500)	1	20.88	Provide structural integrity to the wings and fuselage
Carbon Fiber Spar(2x300)	1	10.99	Provide structural integrity to the wings and fuselage
Control Horns	1	8.97	Attach servos to control surfaces
3M threaded inserts	1	8.99	Create threads in plastic parts
6x3 magnets	1	7.99	For removable parts
Polycarbonate filament	1	38.99	Stronger filament is used for parts that experience more stress
DJI Air Unit	1	229.99	FPV camera used for piloting the drone
Total		**644.73**	

2M large scale drone(VTOL potential)

Part	Qt	Price(USD)	Usage
Dragonlink telemetry transmitter/receiver		336	Transmits and receives telemetry data(set of parts)
Control horns		8.97	Attach servos to control surfaces
Servos		23.99	Motors that actuate control surfaces on the drone
Threaded Inserts		11.99	Create threads in plastic parts
DJI Air unit		229.99	FPV camera used for piloting the drone
Foldable Prop(specific TBD)		50	Propeller
Brushless Motor		45.99	Motor for prop
PLA Filament 3kg		59.99	Fuselage and wing 3d print material
Total		**766.92**	

Software/ect.

Item	Qt	Price(USD)	Usage
Pix4DMapper Educational License		210 - 420	Image processing software. Pricing is 105 per semester.

For product links and further information, refer to:

Autonomous Wetland Mapping Drone Hardware

Methods and Implementation

Project Timeline

Thanks to our diverse skills, we will be conducting the research in two parallel tracks: mapping and UAV setup. Quinn will be handling most of the mapping functionalities while Carey will work on vehicle testing and design.

Mapping Timeline:

Spring 2024:

April

- Purchasing of parts and allocation of funds
- Setting up repositories for data
- Becoming familiar with software

May

- Initial testing of multispectral cameras in a slower quadcopter configuration
  - Testing for pix4D feasibility and segmentation/Data processing methods
  - A more stable but less efficient platform allows reliable initial data collection

Summer 2024

June

- Initial Mapping of CA nearby wetlands outlined in National Wetlands Inventory
  - On-site testing of water quality and vegetation analysis
  - Cross-examination of multispectral data and on-site data
  - Likely to be done with the Hammerhead drone build
- Begin working with repository and data

July

- Research further testing sites
  - Western mass and New England

- Continue working on data analysis and processing

August

- Continue data collection and analysis
- Schedule data collection times
- Begin formulating conclusions on data

September

- Begin drafting paper

1. Initial testing of multispectral cameras in a slower quadcopter configuration
    a. Testing for pix4D feasibility and segmentation/Data processing methods
    b. A more stable but less efficient platform allows reliable initial data collection
2. Initial Mapping of CA nearby wetlands outlined in National Wetlands Inventory
    a. On-site testing of water quality and vegetation analysis
    b. Cross-examination of multispectral data and on-site data
    c. Likely to be done with the Hammerhead drone build
3. Set up a repository for storing findings/data
    a. Create some publicly available storage of our data and current findings
    b. Github, dropbox, local server, or some other method
4. Research further testing sites
    a. Find a larger wetland site to provide multiple mappings of
    b. Research ongoing preservation projects and contribute
5. Publish Findings
    a. Write a paper detailing our findings and results

Vehicle Design Timeline:

1. Print the Titan Dynamics drone and install all electronic components + solder connections
2. Perform PID tuning on the drone assembly in flight
    a. Raw data collection with onboard SD card
    b. Plant linearization in MATLAB
    c. PID Tuning in Simulink
3. Modify the drone with sensors

   a. Lidar ground distance sensor
   b. Multi-spectral camera kit
   c. Compass and GPS
4. Perform flight tests with new sensors
5. Repeat step 2 until an optimal state is reached

Feasibility Study

Both of us, Quinn and Carey, have extensive experience in the aspects of the projects we are going to be involved in- coding and setting up the plane. We are backed by teachers in the science and math departments (Max Hall, Brad Moriarty, Eric Henry, Chris Lobosier, James Booth, and Susan Flink) for our knowledge but also field work with UAVs and computer programs. We would deeply respect and appreciate the generous funding from the Seeds Committee. As such, we have taken steps to make sure that our project allocates the funding responsibly, and takes into consideration the room for development of our various UAV designs.

Firstly, we have chosen a well-established airframe as our drone, thus avoiding complications that might arise from designing and testing a plane from scratch. The drone is also 3D printed, meaning that it is easy to repair and modify. We coordinated with Max Hall, CA's maker space director and engineering teacher, to obtain speed 3D printers from Bambu Lab, ensuring that testing will be uninterrupted even after crashes. If the airframe we chose does not work out, Carey has spare flightworthy airframes from his club AER CA that we can use.

Then, the avionic system we chose for Minmus 3000 is the top-notch offering from Pixhawk, a company known for military-grade UAV flight controllers. These flight computers are crash-resilient and extremely precise once paired with external sensors such as GPS modules and barometers. Even when the avionic system fails or breaks, Carey has backup flight controllers he custom-made and manufactured for his other UAV projects. These flight controllers, running on modified open-source flight controller software, are easily adaptable to any fixed-wing airframe.

Lastly, the feasibility of creating image processing software is another area of concern we have considered and addressed. Quinn and Carey both have extensive knowledge of using MATLAB Simulink, a powerful tool for running analysis of camera software in the loop without actually testing the camera modules in real life and on a drone. This means Quinn can conduct a lot of his software work on the ground and in a simulated environment, greatly mitigating the time expense of developing custom software.

Independent Work

This project is undeniably quite ambitious and will require dedicated work from both of us. We intend to begin the project at the end of this spring, work over the summer, and into the fall and spring semesters of 24-25. We will keep in constant communication with our project advisor to remain accountable for our work.

Time Management: Quinn

My schedule this semester is reasonably dense, and I will be able to spend likely only a few hours a week beginning the project. Into the summer I am optimistic that I will be able to work on this project in conjunction with my summer internship which runs from June 1st to August 10th. The summer is when much of the development and fieldwork will be conducted on my part. I live near many of the potential sites, and 30 minutes away from Concord, so commuting will be a non-issue. Fall semester senior year should be marginally lighter extracurricular-wise, but of course, college applications will take up a large portion of my free time, so most work will be done on weekends and chunks of free time. After college applications, senior spring will be far more open and available to work.

Time Management: Carey

My portion of the project delves into areas that I am familiar with and have done projects in the past with. Therefore, I will be able to complete a working, flying **prototype** before the school year ends. However, I will continue to work on the project during the summer and communicate with Quinn to update the drone with any new software or firmware changes.

Relevant Experience and Qualifications

Quinn Williams

- Cohead of DEMONs(Dreamers Engineers Makers and Overt Nerds)
- Proficiency with Arduino language, Matlab language, and C-like languages (C++, C#, java)
- Expertise with Python, Blender 3D, Fusion 360 and Unreal Engine
- Current internship at data analysis firm
- Summer internship with surgical robotics at BWH and Harvard

Carey Cai

- Head of AER CA (Aerospace Engineering and Remote-Controlled Airplane Club) for 3 years
- Member of CA STEM Council
- Co-head of CA Peer Buddy system
- 1st Place Award for personal UAV project in Massachusetts State Science and Engineering Fair Region IV. Ranked Top 2 - 4 amongst roughly 150 projects. Judged by panelists from MIT CSAIL, the National Grid, and the US Air Force
- British Physics Olympiad (BPhO), Round 1 of British Physics Team selection, Top Gold
- Expertise with Wolfram Language, C++, Java, Arduino Language, Python, and MATLAB Script Language

Adult Sponsor

Our adult sponsor is Chris Labosier (chris_labosier@concordacademy.org), CA's Environmental Sustainability and Justice Coordinator as well as a biology teacher. We have met with Chris on multiple occasions to discuss and improve our project proposal. After receiving the approval, we will continue to work with Chris, who will both hold us accountable for our work and offer us feedback for improvement on the project.

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Titan Dynamics

https://www.titandynamics.org/