

CSE 145/237D

# E4E Mangrove Monitoring - GPS and Canopy Height

June 14, 2019

## Final Report

### Abstract

Mangroves are an important part of our environment as they contribute to sequestering carbon from the atmosphere, sheltering the coast from destructive waves, and providing habitats for delicate ecosystems. To aid in the conservation of mangrove forests, precise location and biomass measurements provide valuable information directly related to the estimated economic and environmental impact of the forest. Thus, our projects focused on providing low-cost and accurate methods of acquiring canopy heights estimations and mangrove geolocation.

### Introduction

The two devices in our project, the Real-time kinematic (RTK) GPS Device and the Canopy Height Sensor Pod, were developed to solve two issues in our mangrove field expeditions workflow. The methods to receive both of these measurements were very primitive and resulted in inaccurate measurements. Building these two devices enable us and our collaborators to gain accurate measurements of mangrove geolocation and mangrove canopy height to reduce error in measurements such as mangrove biomass estimations.

#### RTK GPS Device

In order to take measurements of each mangrove site, scientists need to track where they have been and their current location. Geolocation provides important information about which sites have been surveyed and how far the researchers still have to go. Currently, we are using a portable, handheld Garmin GPS to document coordinates that is easy to carry into the field and water proof. However, this GPS has an error range of about 10 meters which is further exacerbated by working under dense vegetation (Support.garmin.com). Since the measured areas are only about 4 m<sup>2</sup>, this range yields large deviations from the true result.

Previous studies that monitor and map mangrove forests do not keep precise GPS points of their surveyed sites, with an error range of up to 15 meters (Simard et al, 2012, Jachowski et al, 2013). By collecting accurate geolocation data, we can reasonably track all the surveyed plots that have been conducted in the forest to verify our drone collected data.

We proposed using an RTK GPS in the mangroves to obtain measurements down to centimeter level precision. This device is extremely accurate, but it is also susceptible to water and mud (Errors and (RTK), 2019), and is too cumbersome to use in the mangrove ecosystem. Consumer grade outdoor GPS devices can withstand the difficulties of the mangroves, but these devices lack the ability to give an accurate geolocation of mangroves under the thick canopy. Standard survey grade RTK systems Our system stores the device in a water-proof pelican case, protecting the RTK and provides researchers a relatively low-cost, robust method of obtaining real time location.

## Canopy Height Sensor Pod

Canopy height measurements of mangrove forests can be used to estimate the biomass of the forest - a variable with direct impact on the economic and environmental impact of the forest. Despite the importance of biomass measurements, existing methods are prohibitively expensive, unacceptably inaccurate, or unwieldy to use.

One important variable for the biomass calculation is the height of the canopy. To cross-validate the data calculated using the Digital Elevation Model. The current method of measuring canopy height involves the stack of PVC pipes to get an approximation through the summation of PVC pipe length. We would then come up with two approaches to measuring canopy height: top-down and bottom up.

Current methods of estimating canopy height used by other facilities involve using an airborne drone equipped with Light Detection and Ranging (LiDAR) (Simard et al., 2006), (Lee and Fatoyinbo, 2015), (Fatoyinbo and Simard, 2012). However, each study reports root mean squared errors ranging from around 1 meter (Lee and Fatoyinbo, 2015) to 3.55 meters (Fatoyinbo and Simard, 2012). Although our current PVC approach is too unwieldy to continue and fails to scale to canopy heights larger than around 10 meters, it results in a much more accurate measurement, within 1 meter. Additionally, drones powerful enough to deploy large LiDAR systems tend to be too expensive to use on a large scale, and may require up to three operators - the pilot (flies the drone), the data manager (handles the payload and records data), and the visual observer (watches for potential safety issues and assists pilot with general operations). Quality LiDAR drone systems may cost upwards of \$50,000, potentially reaching as much as \$250,000.

Our work involves proposing a low-cost, low-power, and accurate method to measure canopy heights. We present a sensor pod deployable by telescopic pole to improve upon our existing methods and allow for better scalability.

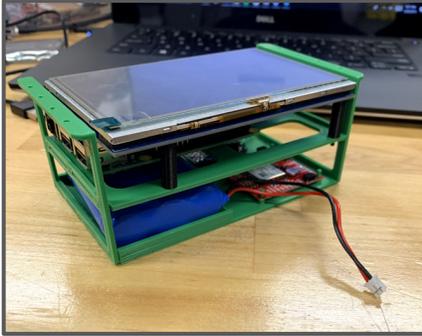
## Technical Material - RTK GPS Device

### RTK GPS Device System Overview

The RTK GPS Device is a system that can withstand the conditions that exist within the mangrove ecosystem. Typical devices, such as the handheld Garmin GPS, are portable and easy to bring in these environments. However, they yield an error range up to 15 meters and significantly skews our data as the surveyed quadrats are only 4 m<sup>2</sup>. Our customized RTK GPS system combines the accuracy of an RTK device and encloses it in a water-proof case that can be brought into the mangroves, improving the precision of our coordinates while keeping the entire system robust.

## RTK GPS Device Architecture

We used an RTK-2 module to continuously obtain GPS coordinates in real time and powered it by an 6600 mAh battery. These components were stored within a laser cut front plate, using buttons to control the system and a Raspberry Pi with a screen to view. The entire system is enclosed within a weatherproof Apache case for protection against mud and water.

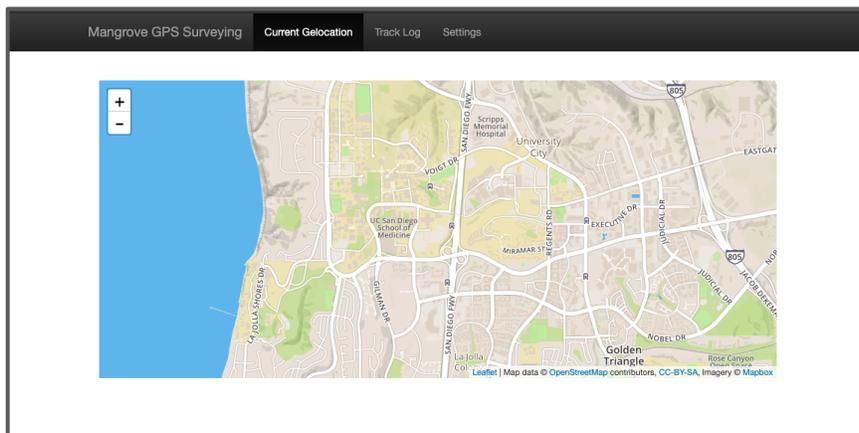


*Internal view*



*Assembled System*

We also designed an interface that can be accessed through mobile phones to provide an easy way of tracking current location and marking previously surveyed locations. This component is written in Python, using flask and Leaflet to put the GUI on a webpage with detailed maps. Future work will involve putting the maps offline so they can be used anywhere and including more options for tracking.



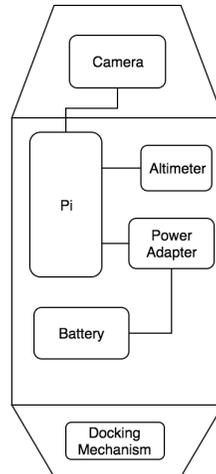
## Technical Material - Canopy Height Sensor Pod

### Sensor Pod System Overview

Our system involves deploying a sensor pod via telescopic pole to the top of the mangrove canopy. The sensor pod acts as a wireless access point, allowing any browser-equipped devices to connect to it. While the operator elevates the pod, a real-time video feed displays the pod's progress. Once the canopy has been reached, the operator may capture altitude measurements and store them to disk for later processing.

# Sensor Pod Architecture

Below we present a breakdown of the various components of our sensor pod's architecture.



Canopy Height Sensor Pod: System Architecture

At the center of our architecture, we use a Raspberry Pi Zero W as the controller of the whole system. The Pi provides a relatively low-powered microcontroller capable of interfacing with each of the various sensors. Additionally, the Pi Zero W comes equipped with built-in WiFi capabilities, allowing us to configure the Pi to act as an access point to connect to with external browser-equipped devices.

We use a Lithium Ion Polymer Battery, providing 3.7V at 500mAh, to power our system. Since the Pi expects an input voltage of 5V, we use the PowerBoost 1000 Charger - Rechargeable 5V Lipo USB Boost as a power adapter to step the input voltage up to 5V. This power adapter also allows us to plug in to a charging cable to recharge the battery between uses or during use.

Our altitude measurements are taken by the MPL3115A2 - I2C Barometric Pressure/Altitude/Temperature Sensor. This sensor communicates with the Pi over an I2C interface, and can provide within 0.3 meter accuracy.

We use the Smraza Raspberry Pi Camera Module, a fish-eye camera to provide a real-time video feed from the point of view of the sensor pod.

Finally, we are still in active development of the external structure and docking mechanism. We have prototyped with a wire mesh frame and water bottle, and produced the first iteration of a 3D printed housing with a built-in tapered docking mechanism. Future work will entail 3D printing a more refined structure that better accounts for airflow and protection of the various components before the system is deployed in the field for actual use.

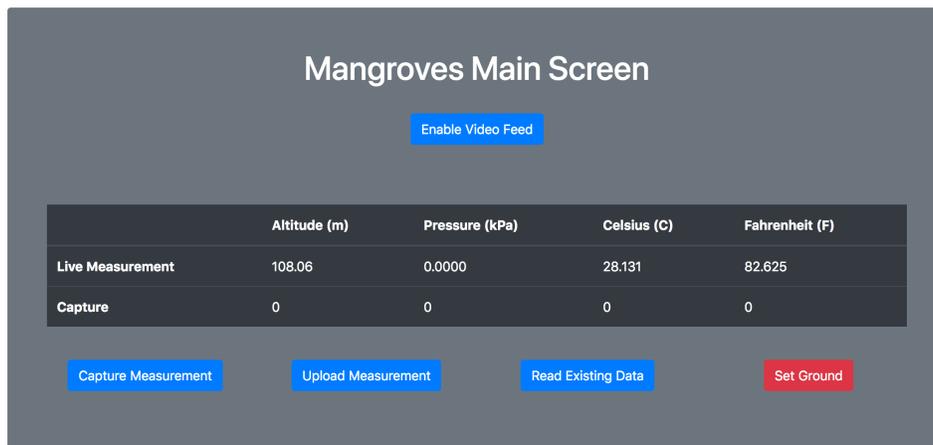
## Sensor Pod Software Components

We used python to run most of our programs. The web server is hosted using Flask API. The camera stream and altimeter readings are obtained on the RaspberryPi and returned as data to be

displayed on the web server. We used Bootstrap library for the front-end of the web server. Data is requested using AJAX and obtained through url "POST".

There are several core feature that our websites. These include camera stream, live data measurements, and data uploading. We calibrated our camera to stream with a frame rate of 12 and resolution of 320x240. We avoided increasing the resolution and frame rate because we noticed a delay in the video stream.

We originally had pressure included in our live measurement display, but decided to modify our data calculation. We discovered that constantly re-configuring the sensor to obtain both altitude and pressure increased in time interval between reading from the altimeter. We also used SQLAlchemy to set up a SQLite database to store and retrieve our measurement data.



Pi-hosted Webpage

## Milestones

### GPS Tracking Milestones

#### Week 2:

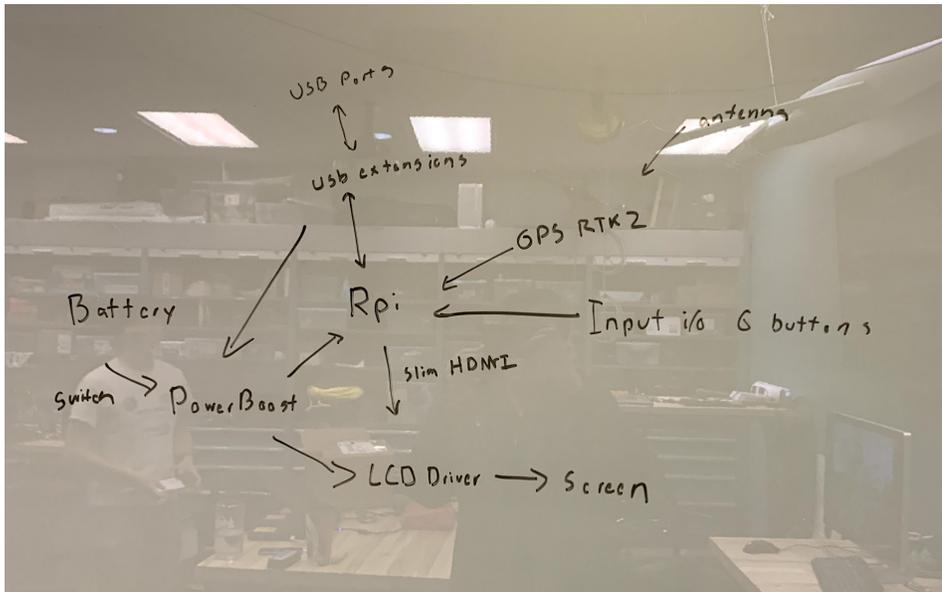
- Brainstorm and propose feasible methodologies. The ideas are proposed to the team as a whole and discussed.
- Each team member does independent research evaluating the pros and cons of their approach. Team members keep track of notes outlining potential problems or benefits.

#### Week 3:

- Commit to single methodology as a group.
- Each team member continues doing research into the different proposed methodologies to determine which are feasible. Team members continue to compile notes of any important considerations discovered.
- A group consensus is arrived at to determine the single approach to take. The demonstration of completion from this milestone is this document.

#### Week 3/4:

- Plan out architectural components with description of entire system. As a group, break apart the design into the various components and determine the requirements of each piece.
- Create a diagram showing how the system fits together.



#### Week 4/5:

- Begin software design and implementation for non-hardware related components. Completion of this milestone entails showing any code developed to team as well as any diagrams outlining software design.
- Obtain required materials for hardware implementation.

#### Week 5/6:

- Implement the required software to interface with hardware components.

Using PyUblox module:

<https://github.com/tridge/pyUblox>

#### Week 7:

- Assemble all hardware and software components into the system.
- Run system tests to ensure that the system functions as expected in a lab setting. Outcome of tests and any resulting action items will be recorded
- Run integration tests to ensure hardware and software are communicating properly. Outcome of tests and any resulting action items will be recorded.

#### Week 8:

- Run field tests. Take the system out and ensure that it works. Outcome of tests and any resulting action items will be recorded.
  - Eucalyptus Grove, Canyon behind Warren....

### **Week 9:**

- Draft and edit the final project report
  - Document findings and issues run into along the way
- Prepare for final presentation video

### **Week 10:**

- Finish the final presentation and final report
  - Have system ready to be worked on for future iterations

## **Canopy Height Milestones**

### **Week 2:**

- Brainstorm and propose feasible methodologies. The ideas are proposed to the team as a whole and discussed.
- Each team member does independent research evaluating the pros and cons of their approach. Team members keep track of notes outlining potential problems or benefits.

### **Results:**

We created presentations of top-down and bottom-up methodologies and discussed tradeoffs. We looked at existing methodologies of canopy height measurements which uses

### **Week 3:**

- Commit to single methodology as a group.
- Each team member continues doing research into the different proposed methodologies to determine which are feasible. Team members continue to compile notes of any important considerations discovered.
- A group consensus is arrived at to determine the single approach to take. The demonstration of completion from this milestone is this document (originally meant the Project Specification document, provided below).

### **Results:**

We decided to go with the bottom-up approach due to the many inconveniences and risks of deploying a drone. The bottom-up approach is more stable and lower cost due. The measurements obtained while flying a drone may be highly inaccurate for low canopy-height measurements and is more costly than installing sensors on a pole.

### **Week 3/4:**

- Plan out architectural components with description of entire system. As a group, break apart the design into the various components and determine the requirements of each piece.
- Create a diagram showing how the system fits together.

### **Results:**

With the E4E mangrove team, we drew out the system diagram and discussed the hardware components that we'll need. We tested pole by attaching objects at the maximum height. From our tests, we were able to limit the total weight of the devices to 100 grams. We also calculated the amount of power that the devices will require and the capacity of our battery.

### **Week 4/5:**

- Begin software design and implementation for non-hardware related components. Completion of this milestone entails showing any code developed to team as well as any diagrams outlining software design.
- Obtain required materials for hardware implementation.

Results:

We set up the github for the software to be used on our RaspberryPi. We soldered hardware components together and tested hardware functionalities on a breadboard.

#### **Week 5/6:**

- Implement the required software to interface with hardware components.
- Run integration tests to ensure hardware and software are communicating properly. Outcome of tests and any resulting action items will be recorded.

Results:

We set up a web server using python Flask for the backend and Bootstrap for the front end. We improved our frontend-backend communication using ajax and implemented additional

#### **Week 7:**

- Assemble all hardware and software components into the system.
- Run system tests to ensure that the system functions as expected in a lab setting. Outcome of tests and any resulting action items will be recorded.

Results:

We were able to test most of the hardware and noted the variation in measurements of the altimeter. We have not tested the accuracy of the altimeter in the field test

#### **Week 8:**

- Run field tests. Take the system out and ensure that it works. Outcome of tests and any resulting action items will be recorded.
  - Eucalyptus Grove, Canyon behind Warren....

Results:

We were unable to run field tests immediately because there were variables we did not account for (metal mesh that allowed airflow interfered with the circuits).

#### **Week 9:**

- Complete final project report
- Prepare for final presentation video

Results:

We are preparing for field tests and will be ready to document how to use the sensor pod device.

#### **Week 10: (As time permits, useful but not high priority)**

- Finalize document outlining the system and the intended usage. Provide information detailed enough to replicate the system and train a new user to utilize the system effectively.

Results:

We have produced the document outlining our system, providing information for how to replicate our system. We ran field tests showing promise for deployment, but wish to create a more rugged and protective housing before deployment in the field to ensure more accurate measurements and better protection of the components.

## Conclusion

Mangroves are incredibly important to our ecosystem. Although they protect our shores from harsh ocean conditions and pull carbon from the atmosphere, mangrove forests are at huge risk of destruction from our ever-expanding industrialization. To better help preserve mangrove forests, we have explored two different areas of interest: producing precise GPS measurements and accurately estimating canopy heights. Together, these two pieces of information can be combined to better educate legislators about the value of mangrove forests, ultimately leading to better protections for these at-risk environments.

While previous methods of calculating location are portable and waterproof, they lack the precision we require for locating relatively small plots of land and tend to be relatively expensive. This quarter, we have designed a durable and waterproof system using real-time kinematics capable of producing location data accurate to within centimeter-level precision. These measurements can then be used to verify drone-collected data and to help researchers on the ground keep track of their location as they survey various points of interest.

Our future work includes integrating the RTK and processing into the system, making geolocation tracking extremely accurate. We have gone through multiple iterations of designing the device to be robust enough while still maintaining its precision. In addition, our webpage still requires the addition of more options for tracking and adjustable settings for the users. It also still requires integration and processing of the RTK data to use in finding current location without internet, so these components will be designed before taking the system into the field.

Existing methods of calculating canopy height fall short in terms of unwieldiness, cost, and maintainability. Our previous PVC approach, while low-cost, is too inaccurate, and requires the movement of many pieces of equipment through dense forests. Other approaches in the literature involving drone-mounted sensors are simply too expensive to scale up, and often require infeasible numbers of operators. By designing and implementing a sensor pod deployable by telescopic pole, we have provided a low-cost, low-power, and reasonably accurate method for producing canopy height estimations.

In the near future, we plan to design a robust casing for the sensor pod. This would require multiple prototypes to figure out the ideal shape and components to make it waterproof and resistant to random weather changes. Part of this process involves considering the tradeoffs of water resistance and the amount of ventilation allowed in our casing. The website could be improved to include more features, but currently the focus should be on figuring out a robust design that could withstand the irregularities caused by nature. In addition, we currently use a bottom-up approach to deliver the sensor pod to the top of the canopy. There are still alternative methods that should be explored to find a more efficient way to deliver the sensor pod to the top of the canopy, whether it'd be by drone delivery, a more efficient pole, or an unorthodox method unimagined by anyone.

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