Autonomous Sailboat for Penguin Tracking

ECE4012 Senior Design Project

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Executive Summary

Penguins are one of the species with a high extinction risk due to the global warming and environmental contamination. Currently, scientists have not finalized the exact locations of the penguins' habitats around the icy area due to the extreme environmental conditions, especially two kinds of penguins, Adélie penguin and Emperor penguin, whose habitats are in the Antarctica area. Searching the penguin's habitats in the far south part of the Earth could help biologists and environmentalists to research and protect this precious species. The main mission of the penguin tracking autonomous sailboat is to detect new-born penguins and track their movement around the habitats in the Antarctic. Devices including Infrared cameras and Go-Pro were installed on the boat to detect the habitats and record behaviors of the penguins. In addition, a GUI with data from IMU and GPS was designed for users adding the wavepoints, and then adjusting the direction directly with the in case of abrupt change of the tracks of the penguins. The boat has a self-energy harvest system, so no external power supply is needed. These features guarantee the sailboat to self-navigate on the ocean without external help and supply from the shore. The sailboat was also designed to overcome the extreme conditions of the ocean. For instance, most parts are waterproof and can function at a considerate cold temperature. The cost of the boat is 1240 dollars. The sailboat can find the exact location of the penguins' habitats and track their migration routes, and therefore it could help scientists collect and analyze the data for penguins research.

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1. Introduction

The Georgia Tech ECE Senior Design Penguin Tracking Autonomous Sailboat Team have requested 1240 dollars to develop the autonomous sailboat to locate the penguins and analyze their behaviors.

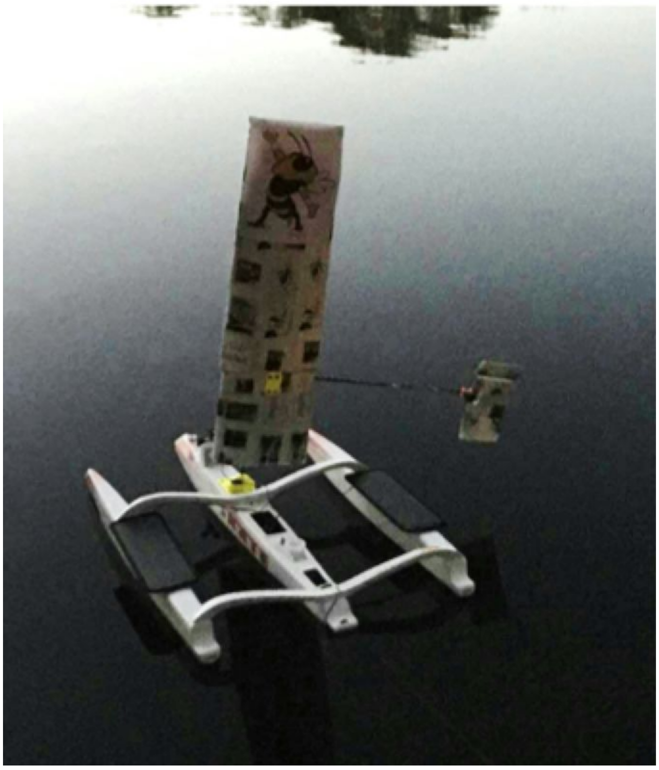

Figure 1. The autonomous sailboat prototype for penguin detecting and tracking.

1.1 Objdective

The overall goal of the project is to design an autonomous sailboat that is able to navigate unmanned for a long period of time with a self-energy harvest system. The self-energy harvest system is based on solar energy with NiMH rechargeable batteries to store and provide energy for the boat. The Global Positioning System (GPS) tracker and Inertial Measurement Unit (IMU) module are placed on the boat for controling the movement. The Infrared (IR) camera and Go-Pro camera are placed to detect the location of the habitats and record the behaviors of the penguins. The wireless module provides the communication between the boat and the users, and users can use the GUI with Google API to add the waypoints and change the direction of the servos directly in case of abrupt change of the penguins.

1.2 Motivation

Traditionally, scientists utilized GPS and sail drone to track ocean animals such as whales and penguins. However, sail drone tracking costs a large amount of money and the large noise might affect the penguin's daily life [1]. The research utilizing the GPS tracking is aimed at investigating penguin's routes for finding food [2]. Tracking the penguin utilizing an autonomous sailboat is a brand new method. The sailboat is quiet, so it would not affect penguin's daily life and is fast and flexible enough to follow the penguins for a long period of time without running out of harvested energy. Besides, the GUI provides users with a more comprehensive approach to add the wavepoints, and thus adjust the positions of the boat by changing the direction of the servos. For the perspective of cost, the unmanned self-powered sailboat costs much less than the current products.

1.3 Background

The Robotic Sailboat System is one kind of unmanned surface vehicles (USV) which is designed to provide an effective ocean sampling capability. Current commercial products are too expensive and cannot achieve the best engineering tradeoffs because energy management prevents such USV from maintaining high speed and long operation duration simultaneously. Our design combines a solar energy supply system and open-source electronic prototyping platforms to gather and transmit data. It utilizes the GPS and the short-range wireless communication (which could be substituted with advanced modules with larger range) for navigation.

Current commercial products aim to be implemented in the research area, and therefore sold at a very high price. By lowering the prices, our device can be accepted by general research teams and hobbyists who are interested in exploring the habits of penguins. Replacing normal sensors for research such as thermometers and anemometers with GPS tracking module and cameras, scientists and environmentalists are able to utilize this product to locate penguins quickly and analyze their habitats.

The main building blocks of the project are the energy harvesting system, navigation system, computer-end user interface, wireless communication and the penguin tracking system including video and image transmission.

2. Project Description and Goals

The team designed and prototyped the following parts of the sailboat:

1. An energy harvest system to harvest energy from the solar, including the solar panel, NiMH rechargeable batteries that stores the energy and DC-DC buck converter that decreases input voltage to desired battery input voltage. Other types of energy supply such as wind energy and wave energy were not implemented due to light weight of the boat and limited budget. They could be added in the similar way as solar power supply for the future work.
2. An autonomous sailboat platform. This platform is a reliable, intelligent and fully autonomous surface vehicle which is able to carry the system to a certain destination. The whole platform includes peripherals and a base station.
3. A navigation system composed of GPS, IMU and the servos based on mbed. The mbed-based IMU and GPS provide the specific direction and location of the boat, and servos are controlled to change the movement of the boat.
4. A GUI that displays the updated information from GPS, IMU and servos and waypoints of the sailboat. It could help the users to add the waypoints on the Google Maps API, and then directly control the servos changing directions according to the location of penguins.
5. A tracking and recognition system based on Raspberry-Pi II. The IR camera and Go-Pro camera based on Raspberry-Pi offer video streamline that lets users detect and observe the penguins habitats.

The goals of the final product are listed below:

1. Help scientists find the habitats of the penguins near Antarctica and gather data for the habitat environmental conditions.
2. Record the path of longer migration of the penguins with cameras and GUI.

3. Trace the penguins continuously without external power supply.
4. Promote the waterproof characteristics under severe ocean conditions.

The target price of the product is $6000 with all of the components inclusive, and the target users are environmentalists and scientists.

3. Technical Specifications & Verification

3.1 Quantitative Specifications

Table 1. Quantitative Specifications

	Measured Characteristics	Expected Characteristics
Sustainability		
Uninterrupted Operation Temperature	0 °F	-4 °F
Hardware		
Data Collection & Navigation Unit		
Operating Voltage	5 V	5 V
Clock Speed	96 MHz	96 MHz
Memory	32KB RAM, 512 KB FLASH	
Dimension	Maximum: 55.25mm x 26.35mm	
Processing Unit		
Clock Speed	900MHz	900 MHz
Power	5V @ 700 mA	5V @ 700 mA
RAM	1GB	
Dimension	Maximum: 54mm x 26mm x 20mm	

GPS	Cheap Module	Advanced module desired
Horizontal Position Accuracy	2.5m	10cm
Power	3.3V	
Update Rate	max 5Hz	
Dimension	25.5mm x 31mm	
Wireless Module	Cheap Module	Advanced module desired
Date Rate	~150kb/s	~ 1Mb/s
Usable Range	~25m	~ 50km
Frequency	900MHz	
Power	3.3V @ 210mA	

3.2 Qualitative Specifications

- Ability to keep sailing with harvested energy.
- Well-maintained communication channel.
- High reliability under extreme condition.
- Timely power switch between data collection and processing.
- Intuitive base station GUI system.

Figure 2. Sailboat Prototype displayed at Capstone Design Expo Fall 2015.

4. Design Approach and Details

4.1 Design Approach

As shown in Fig. 3, there are 4 main parts of the overall system. Sailboat platform, its peripherals, machanical stucture and base station. Sailboat platform is a reliable, intelligent and fully autonomous surface vehicle which is able to carry the system to a certain destination. The peripherals are the cameras and wireless module which provide tracking eligibility. Mechanical structure contains the sailboat kit, wing sail and tail, which supports the fundamental ability for sailing in the ocean. Base station is composed of a computer-end GUI and wireless module based on microcontrollers, which enables the users to acquire real-time data feedback and adjust the sailboat manually in case of sudden change of the route of the penguin.

4.1.1 Sailboat Platform

The platform performs navigation, data communication and storage for the information. A PCB is designed for integrate all of the components.

4.1.1.1 Power system

First of all, a stable and high performance power management module is key to the whole platform. As shown in Fig. 4, the sailboat harvests energy from the solar, and it has its own DC-to-DC converter to ensure the performance and reliability of the system [3]. The power management circuit is powered by the regulated voltage from DC-to-DC converter, partial incoming energy feeds the onboard devices, and the remaining is stored in the NiMH rechargeable batteries [4]. When there is no enough energy harvested, the system will pump power from the batteries for the onboard electronic devices. Due to the limited budget and

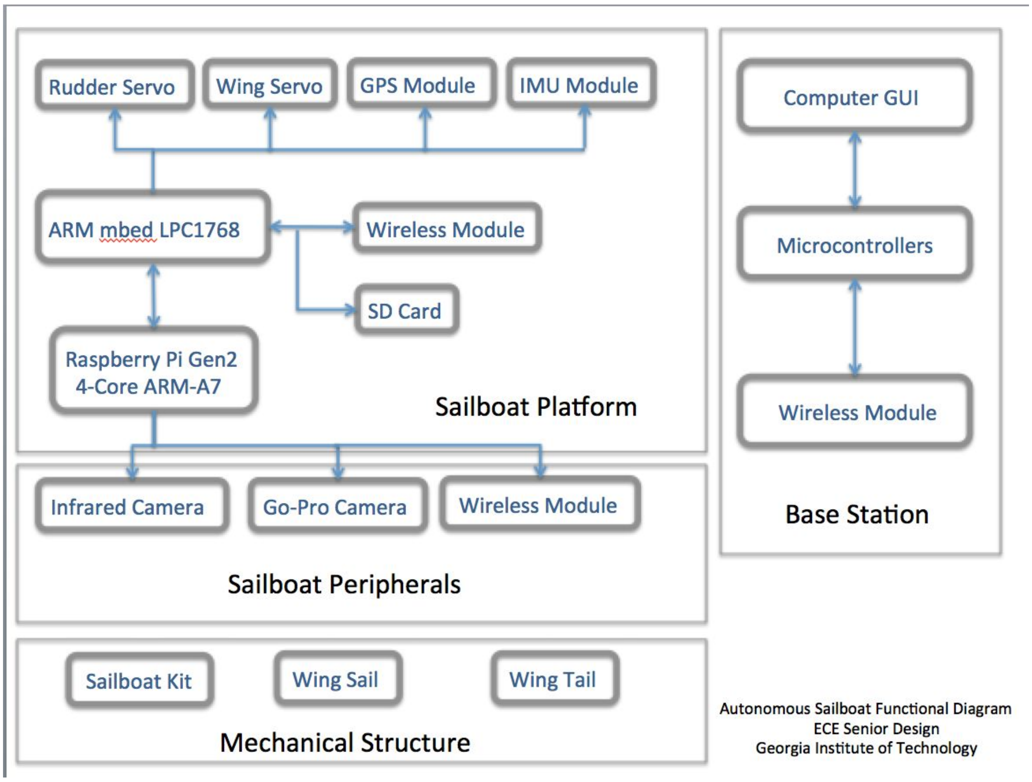

Figure 3. Functional diagram of the overall system.

light weight of the boat, the wind turbine installation becomes a future task. As for the improvement for the system, coulomb counter [5] had better be added to track the battery status and provide accurate estimation for battery remaining capacity. This will enhance the accuracy of the eligible potential duration of the sailboat.

There are three outputs of the system. Two of them are regulated, low-ripple power supply for onboard electronics and sensors. The 3.3 V regulated output is produced from 5.5 V output by voltage level translator. The other one is a high-current supply which is specifically for servos.

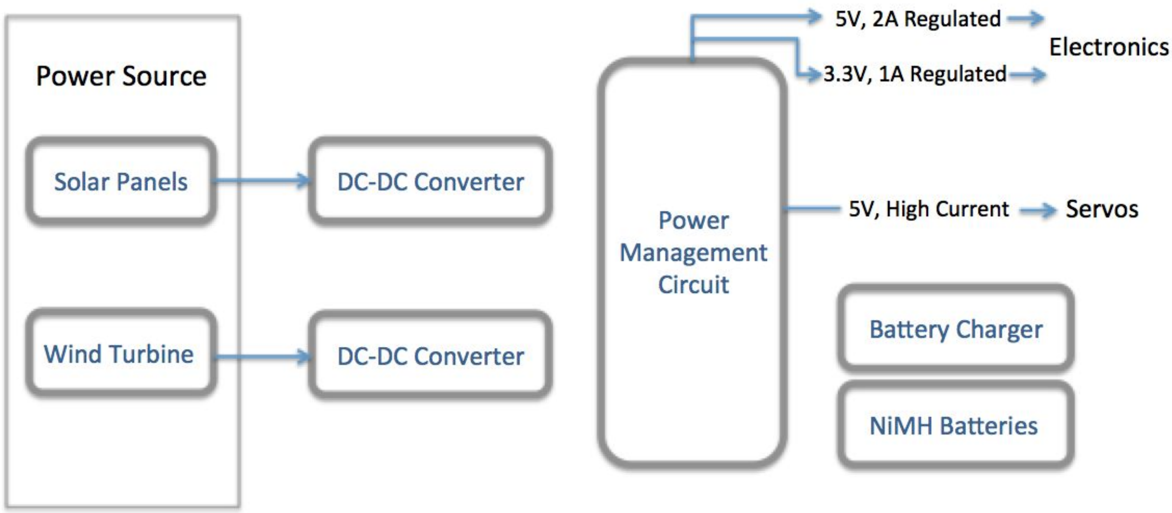

Figure 4. Potential functional diagram of the power management system.

Figure 5. Solar panels on the sailboat.

4.1.1.2 Navigation system

To navigate to a certain location, the sailboat needs to know the coordinates of the current location and the destination. The destination is given to the navigation system, but the current location has to be acquired from the GPS module. To acquire higher accuracy but acceptable price modules, the U-blox M8 series GPS module, which is compatible with GPS/QZSS, GLONASS and BeiDou, has been chosen. From this brilliant GPS receiver, horizontal position accuracy of 2.5m CEP (Circular Error Probable) and 10Hz update rate can be achieved [6]. The Nano-Ahrs 9-degree IMU was used to provide gyroscope, accelerometer and magnetometer data.

Since the energy is very limited, the ARM mbed (LPC-1768) is used to handle the navigation. GPS data is sent to mbed [7] via serial bus (SPI) [8]. Mbed calculates the route and sends commands to the servos [9].

4.1.1.3 Communication system

The mission of the sailboat is to travel a long distance on the ocean and get data back far away from base station. Satellite is ideal, but the cost is above the budget. Alternatively, the high power wireless modules have been chosen for basic short-distance test, so this prototype is the proof of concept for the communication part. Besides, the modules support transparent transmission [10], so they can be easily changed for more advanced distance requirements.

4.1.1.4 Sensor data collection and processing system

The data collection task is handled by mbed, which consumes much less power than Raspberry Pi [7, 11]. Once mbed receives data from sensors, the electronic switch connects the mbed to the SD card, and the data can be immediately stored into the SD card. After certain number of data is collected, mbed switches the SD card to Raspberry Pi and turns on its power. Raspberry Pi can automatically process the collected data according to pre-set algorithms. Overall, the low-power mbed [7] handles basic tasks, and the high performance quad-core Raspberry Pi works only for heavy tasks.

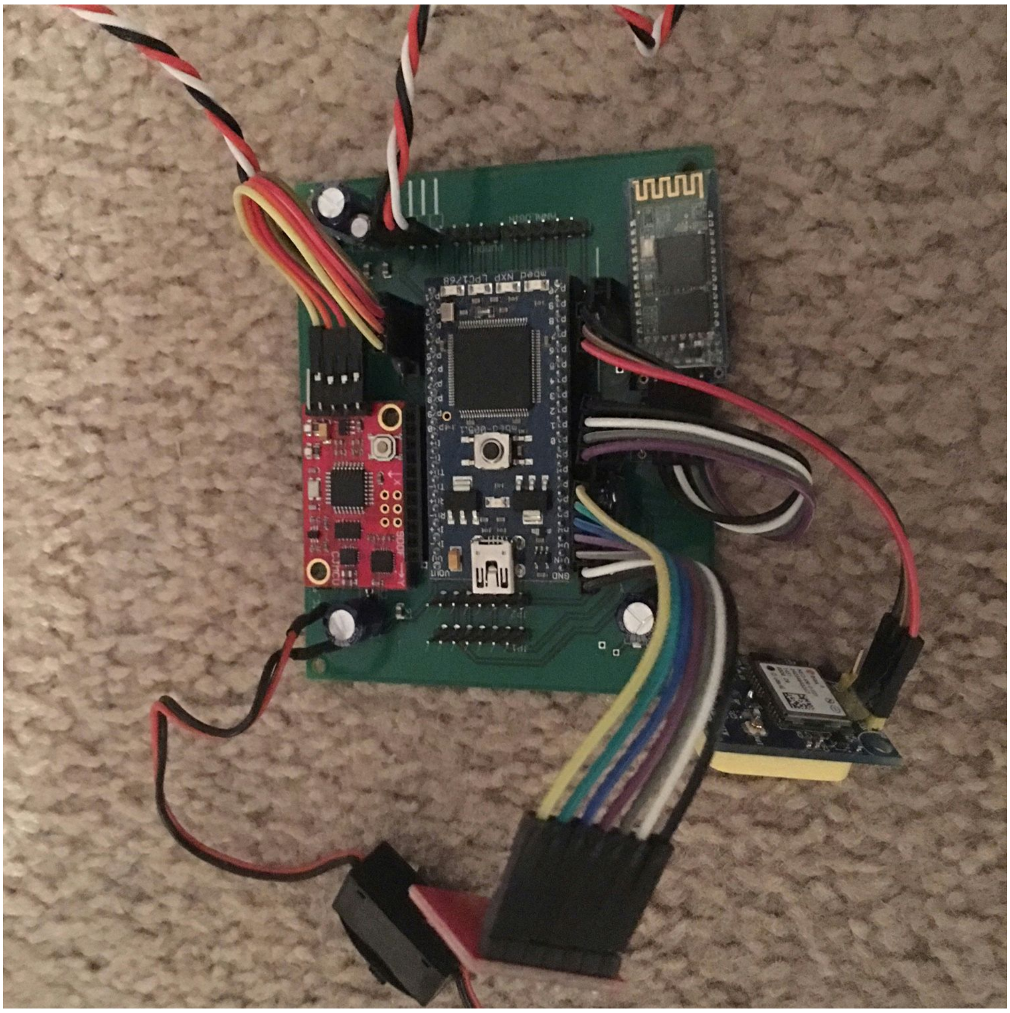

Figure 6. Printed Circuit Board (PCB) designed for the Sailboat Platform.

4.1.2 Sailboat Peripherals

There are cameras and wireless modules to add functions for detecting and observing penguins' behaviors. For the cameras, the IR camera was equipped for detecting the higher temperature of the penguins within cold surroundings, and a waterproof Go-Pro camera that could be installed beneath the water records the penguins behaviors under the sea. Users can observe the penguins from the computer by the data trasmitted from the wireless module. The LPC1768 mbed provides commonly used buses and ports such as SPI, I2C, USB, CAN and Ethernet for the sensors [7]. The power supply provides both 5V and 3.3V regulated voltages which are widely used among sensors. There are also 26 I/O pins [7], which makes the sailboat extensible and upgradable for future tasks.

Figure 7. Raspberry Pi system including cameras and WIFI adaptor.

4.1.3 Mechanical structures

The mechanical structure of this prototype is based on an sailboat kit and some parts were modified to fulfill the mission. There are many differences between a conventional sailboat and a vehicle using wingsail. As an analogue to airplane, wingsail uses a tailplane to control the “angle of attack” of the wing and produce “lift” to drive the boat. Part of the airfoil of a model glider was used as the wing of our boat and a carbon fiber rod was used to connect the wing on the deck. It is hard to find parts on shelf to turn the sailboat kit into a wingsail, so daily materials such as foam board as well as 3D printed parts were used to achieve the goal.

4.1.4 Base Station

The status of the sailboat needs to be monitored and users had better send commands to the boat. Therfore, the computer based base station was designed for this desire. The wireless module was connected to the USB port of a PC via a serial-to-USB adpater, and a Linux based ROS (Robot Operating System) was used to receive, visualize data and transmit the command to the sailboat [12]. The GUI (Graphical User Interface) was designed for better interaction between users and the boat. It applies the Google Maps API, where users could add the waypoints directly on the map. Besides, uers could also change the angles of the servos by typing the values desired.

4.1.4.1 GUI

The GUI interface for the boat has 2 parts: the web application part and the python container part. The web part provides users with the options to set waypoints and view the current status of the boat (GPS location, different IMU parameters, etc). The users are allowed to set 5 waypoints at maximum. They can add, delete, or modify any waypoint. To make the user experience better, Google Map API was applied. To add waypoints, users can either directly type in latitude and longitude, or just click on the Google Map interface and the corresponding location information will be pre-entered for them. All waypoints can be shown on the google map. In addition, the boat's position will also be constantly updated on the map. When this update happens, the previous positions will not be deleted, so that the users can view the complete path the boat has been through so far. The web application was written using HTML, CSS, Javascript, and JQuery. The Google Map is implemented using Javascript.

To use the wireless module, the GUI needs to transfer data over serial port. It is very hard to do serial communication using a normal web browser, so a container was added to make up this deficiency. After testing, python was found to perform the best for doing serial communication for this project, so the container was written using a python GUI framework called PyQt. PyQt has a web interpreter so that the website no longer has to be opened by a browser. It also offers an approach to enable Javascript and Python to pass data between each other. After putting the web into the container, information can flow between mbed and GUI successfully. Fig. 8 displays the GUI interface.

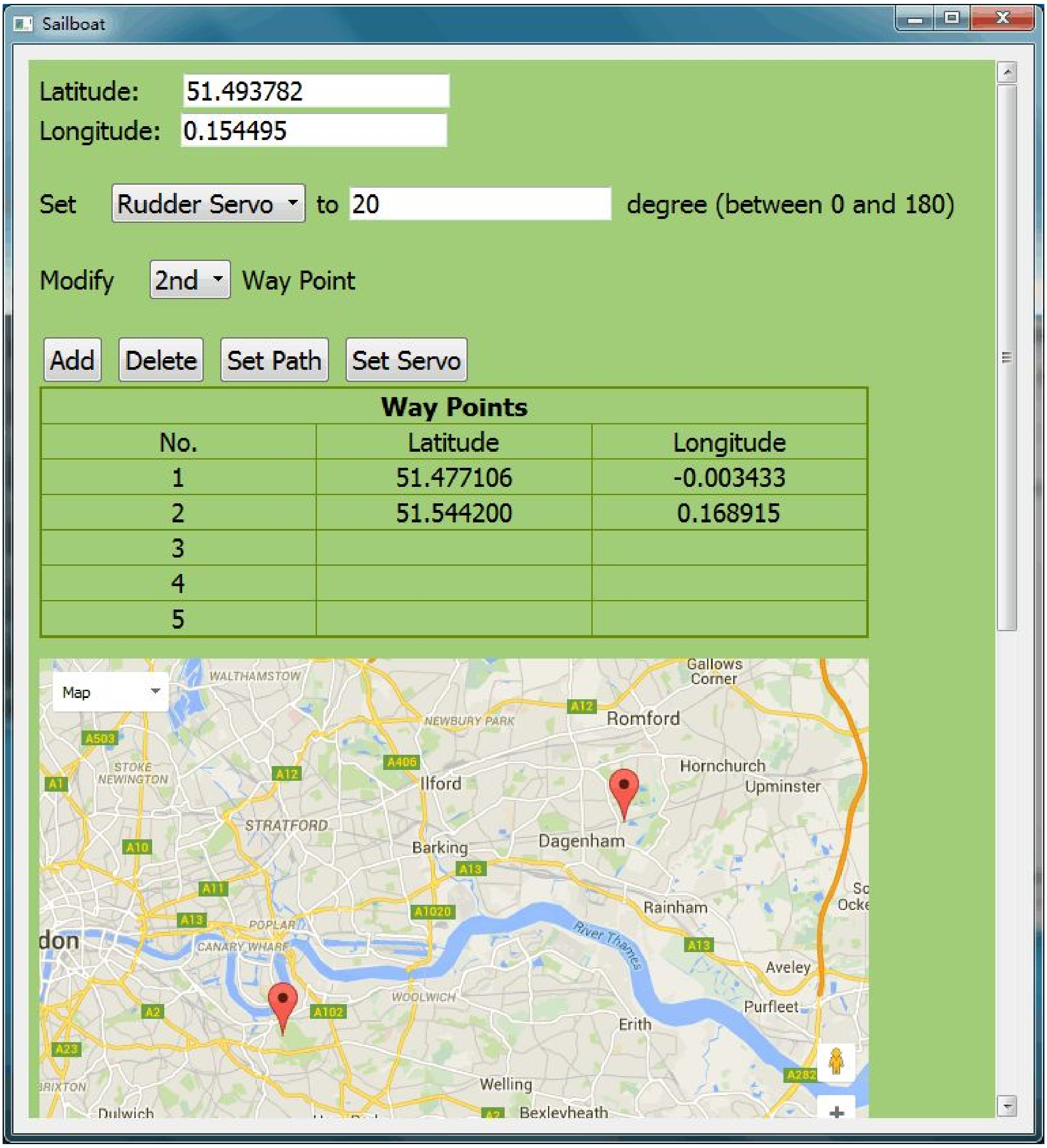

Figure 8. Computer-end GUI with Google API for the Sailboat system.

4.2 Codes and Standards

1. **SPI, Serial Peripheral Interface.** Synchronous serial interface that uses separate clock, data lines and a select line to achieve higher speed rate [13]. The SD card is connected to the SPI bus in the project [14].
2. **UART, Universal Asynchronous Receiver/Transmitter.** A key component of serial communication subsystem in the project. UART is commonly used innon-networked, point-to-point communication between devices [15]. There are two terminals, TX and RX, which in charge of sending and receiving data. The UART is mainly used in communicate with the wireless module [16].
3. **IEEE 802.15.4. Basis of Zigbee.** A suite of high-level communication protocol which has capability to form multiple network topologies [17]. Since the application of our mission needs multiple base stations, the support for multiple network topologies as point-to-point, point-to-multipoint and mesh networks is essential. Besides, the low duty cycle of data transmission is very energy efficient [17]. There are multiple transceivers and modules that works at ISM band, so they can be used for free [18].
4. **USB, Universal Serial Bus.** High speed bus designed to standardize the connection of computer peripherals. Usually, I2C and SPI bus cannot support high-definition camera and other devices that requires a high connection speed [19]. In this project, the boat is expected to take pictures, and the on-shelf USB camera is a good choice for this function [20].
5. **TTL, Transistor–Transistor Logic.** A standard logic level used in many applications such as computers, industrial controls and instruments [21]. Logic 0 is defined between 0V to 0.8V and logic 1 has range from 2.2V to 5V (Vcc) [22]. This

standard is used in the digital circuit design. Unfortunately, some sensors only support 3.3V logic level, so bidirectional logic level converters have been used to make the system more compatible [23].

6. **SD, Secure Digital.** High capacity, nonvolatile memory card used to store sensor data and system logs. All SD card families use 3.3V initially, but SDHC and SDXC use 1.8V instead. The SD cards have a default speed of 25MHz and the host device can also switch it to a higher transfer speed [24]. In this project, two SD cards are used. One of them is to store data and the other one works as boot disk for Raspberry Pi.

4.3 Constraints, Alternatives, and Tradeoffs

4.3.1 Constraints

1. **Energy Efficient.** The sailboat cruises on ocean for a long period of time and all energy to power the electronics is harvested from the environment. The limited and unstable energy source in the Antactic requires the on-board devices consume as less power as possible.
2. **Limited Budget.** Satellite communication is ideal for the mission of the sailboat that needs to travel a long distance on ocean. Unfortunately, a single satellite transceiver costs higher than whole project budget. Also, due to the limited budget, only the commercial grade electronics could be chosen, which cannot survive in extreme temperature conditions [25].
3. **Accuracy of Sensors.** Although the best one among available categories is opted, the accuracy of the GPS module chosen in this project is only 2.5m CEP [6]. In addition,

gyroscopes drift with time and its full-scale range is limited. Additional tests and adjustments were performed to compensate the imperfection of the inertia measurement unit.

4. **Limitation of Actuators.** On-shelf servos have limited precision, speed and torque. They also consume large amount of energy. The servos chosen for the project have torque of 42kg-cm and speed of 0.18s/60deg [9]. Therefore, these limits the accuracy of the feedback control system.
5. **Extreme Cases.** The environment conditions varies intensively for long distance and unstable weather in Antactic area. Extreme temperature at arctic and equator area greatly challenges the on-board electronics [25].
6. **Limited Size.** The electronics have to be sealed in a water-proof enclosure. The limited size of the housing requires the on-board devices to be as small as possible. The PCB was designed to suit the boat hole dimensions, but for more devices, they had to be placed outside the board which might effect the waterproof eligibility. In addition, the limited size of the sailboat limits the area of the solar panels.

4.3.2 Alternatives

4.3.2.1 Navigation system

To obtain high resolution for navigation system, the first candidate is the differential GPS [26]. With a stationary receiver station at known location, the inaccuracy can be gauged and compensated. This ideal, differential GPS has accuracy of 10cm, which is much better than conventional GPS. But the cost is above the budget and additional systems are needed to receive the corrected data.

Instead of using mbed, the alternate way is to use BeagleBoard Black. An open-source single-board computer powered by 1GHz single core ARM Cortex-A8 processor and 512MB DDR3 memory [27]. It is much more powerful than mbed but power consumption is not acceptable.

4.3.2.2 Communication system

In order to connect to base station far away on the ocean, satellite communication is ideal for the sailboat system. The satellite transceiver is far beyond the budget so the inexpensive wireless modules were chosen.

4.3.2.3 Sensor data processing system

There are two alternate solutions to process sensor data. One of them is BeagleBoard Black [28]. The benefit is its fast booting capability. The small computer can boot in 10 seconds, which is faster than the resolution used. However, its processing rate is much slower than Raspberry Pi II. The quad-core Raspberry Pi has data rate high enough for the project.

The other one is Intel NUC, a series of small size computers equipped with up to 3.1GHz Core i7 processor [29]. The performance is very outstanding, but power consumption is higher than requirement and its weight is beyond the design requirement.

4.3.3 Tradeoffs

4.3.3.1 Computational Performance vs. Power Consumption.

Mbed is equipped with 96MHz 32-bit processor and it consumes little amount of energy. In contrast, Raspberry Pi equipped with 1GHz quad-core ARM Cortex-A7 processor requires more energy hungry [9]. To obtain a tradeoff balance, the Raspberry Pi II was turned on only for heavy tasks. The SD card is shared between two devices with a switch.

4.3.3.2 Rechargeable battery vs. Super capacitor.

Super capacitor provides almost unlimited charge/discharge cycles while most rechargeable batteries are less than 1000 cycles. Besides, the charge/discharge speed is much faster than that of chemical batteries. However, the drawback is, like all capacitors, the voltage drops a lot during discharging. The supercapacitors can not store much more energy than rechargeable batteries as well. On the contrary, rechargeable batteries can provide stable output voltage, and have much lower self-discharge rate than super capacitors [30]. In the case of high energy density and stable discharge voltage, rechargeable batteries work better for this project [33].

4.3.3.3 System performance vs. Cost.

Ideally, differential GPS, precision IMU, professional servos and satellite transceiver can provide optimized performance and full functionality. Due to the limited budget, less-expensive components were opted for the prototype. Thus, upgradable characteristics were the major concern through the project design cycle. For instance, the wireless module chosen supports transparent transmission, and it can be easily replaced by a better one without changing any other parts of the whole system [10].

5. Schedule, Tasks, and Milestones

The Robotic Sailboat team designed and implemented an Unmanned Surface Vehicle (USV) which is aimed to detect and record penguins' behavior. Appendix A contains the list of all essential millstones, people who led the tasks, the difficulty levels and significance levels. Several tasks were implemented and tested in parallel in order to boost up the development process. Appendix B contains the Gantt chart that illustrates the project schedule. All major tasks were specified with their timelines and duration. The development timeline started from August 2015 to December 2015.

6. Final Project Demonstration

The robotic sailboat was designed to operate over the ocean surface. The formal demonstration was conducted in 2 parts. Before the boat was tested in water, communication between GUI and the boat was be tested first.

Things to be tested for GUI included:

1. Users could add, delete, and modify any waypoints
2. Users could use Google Map interface
3. Boat infomarion could be correctly shown in GUI

4. Boat's GPS location could be correctly shown in the Google Map interface
5. When user sent rudder or wing control information, the corresponding part should move correctly

Things to be tested for the energy system included:

1. Solar panels were able to charge the rechargeable batteries.
2. A proof of concept but calculated how many solar panels were needed for the sailboat to operate in the ocean.

Things to be tested for the boat in water included:

1. Observer planned a route of a mission for the sailboat
2. Solar energy supply were used individually to test whether the prototype achieved the minimum energy conservation specification.
3. While the hybrid energy supply system was implemented, data sampling and processing were tested and assured functional.
4. Long range wireless communication and real time data sampling were tested by comparing it with the local data storage.
5. The sailboat were then be tested in a small pool. Trackers were be placed at the edge of the pool to imitate the existence of penguins. The sailboat were able to sense and track down those trackers and report their location to the observer.
6. With all modules built-in, the sailboat were operated over a lake in Piedmont Park to assure the prototype satisfies the design specifications like operation duration and data sampling accuracy.

The sailboat was tested under an optimistic situation. It was operated under the situation that there is enough wind for it to propel but not too much to overturn. The specifications are demonstrated as follows:

- **Operation Duration**: the length of time that the sailboat with different energy supply systems can run. The minimum required energy supply system is solar energy. More energy supply systems like wind power, wave potential energy, and sea water battery can also be implemented to extend the operation duration for the future work.
- **Real Time Data Sampling Accuracy**: Data sensing is relatively easy to achieve. Data stored in memory are treated as references against real time data obtained from wireless communication.
- **Tracking Accuracy**: The sailboat serves as a mobile data transceiving base station so that the observer is able to track penguins without being within the sensing range of trackers placed on penguins. The location data will be transmitted to base station to compare with real life simulations.
- **Routing Accuracy**: In order to provide possible real time visual data, it is desirable to route close to within a few meters. It is possible to measure this specification with length measurement tool or even naked eyes.
- **Voice Recognition Accuracy**: Pure penguin voice records will be mixed with a loud wind voice and white noise to simulate the condition of recoding voice on the sea surface. The voice recognition accuracy will be evaluated based on the outcomes and the degree of noise.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

7.1.1 Marketing

The sailboat is a product that can be used for detecting and tracking penguins around their habitats. The target market for this boat is college and company research teams or individuals who would like to explore the habits of penguins. Currently, the boat is targeted for Georgia Tech Research Institute (GTRI) for seawater biological research. In the future, it will be used for larger groups of scientists. Due to the autonomous tracking system, the users can remotely observe the behaviors of the penguins and control the tracks of the sailboat as well. For further potential functions, a system that recognizes the penguins through the sound and the faster movement system could be developed, which allows users to gain more statistics about penguins.

7.2.2 Similar Products

Currently no sailboat product provides the functions of the detecting and tracking penguins, but there are some autonomous boats similar to the design. Wave Glider SV3 is a latest autonomous boat that can permanently complete tasks with the propulsion from the wave energy. It is the first hybrid wave and solar propelled unmanned ocean robot. The features include real-time onboard processing of large data and an adaptable operating system designed for intelligent autonomy to enable coordinated fleet operations. Table 2 shows some characteristics of Wave Glider SV3 [32].

Table 2. Wave Glider SV3 Specifications

Product Name	**Wave Glider SV3**
Functions	Mission control; Status Monitoring; Autonomous Navagation
Size	Float: 120in x 32in x 9in; Sub: 84in x 56in x 8.3in
Energy Sources	Wave; Solar
Weight	330 lb
Communication	Satellite: Iridium 9602; Cellular; WiFi
Navigation	GPS: 12 channel WAAS; Accurace: 3m radius

7.2 Cost Analysis

7.2.1 Prototype Cost of Development

Table 3 summarizes the cost of development for the Sailboat. It is assumed that the development requires a qualified engineer earning $30 per hour. Applying fringe benefit as 30% of total labor and overhead as 120% of all of the material and labor, the total development cost for the PengBot is $19792.794. A breakdown of the hardware cost can be found in the Appendix C.

Table 3. Sailboat Development Cost

Project Component	Labor Hours	Labor Cost	Equipment Cost	Total Component Costs
Hardware Assembly	10	300	661.27	961.27
SBC Design	10	300		300
SBC Configuration	30	900		900
Peripherals	20	600		600
Base Station Configuration	20	600		600
Power Management	40	1200	320.00	1520
Demonstration Preparations	10	300		300
Weekly Meetings	30	900		900
Lectures	40	1200		1200
TOTAL LABOR	210	6300		
TOTAL PART COST			981.27	
Fringe Benifits				1890
Overhead				10621.524
PROJECT TOTAL				19792.794

7.2.2 Production Run Cost

Since this sailboat is mainly for research use, the team assumes the production run will consist of 150 units made over 5-year period at a price of $6000.00 per unit. The hardware cost is $1238.09. A group of technicians will be employed at $20 per hour to assemble the hardware and perform the test. The team estimates that one labor takes 5 hours to complete the production. The Table 4 shows the production run cost breakdown.

Table 4. Sailboat Production Run Cost

Production Run Components	Component Cost
Development Cost	19792.794
Hardware Cost	185713.5
Labor Cost	15000
Fringe Benefits	4500
Overhead	240856.2
TOTAL	465862.494

The total expected production cost is $465862.494, yielding a total profit of $434137.506 for a sales price of $6000. Therefore, the profit per unit is $2894.25.

8. Conclusion

The Sailboat designed for the senior design project can be used for detecting the penguins and tracking them near their habitats. The sailboat is autonomous and can supply itself with the power management system that harvests energy from the solar panels for a long time. Users can use PC-end GUI to add waypoints and directly change the directions of the servos from information provided by the IMU and GPS on the boat. They can detect the penguins using IR camera and track them near their habitats with Go-Pro. For most of the parts in the prototype, they can be directly substituted with advanced part. For example, the current wireless module can only work within short distance, but it can be substituted with a more advanced one with higher range. Currently, an IR camera is applied for detecting temperature difference to figure out the existence of the creatures, but it will not accurately detect penguins among other animals. Therefore, other kinds of recognition system such as sound recognition can be added for future work. For better movement under severe ocean conditions, larger boat, more servos and more solid sails need to be implemented. As for the power sources, due to the limited budget and light weight of the boat, only solar power is applied. Thereofore, for the future work after changing a larger sailboat, the wind turbine and seawater battery can be implenmented for more supply sources for longer sailing duration.

9. References

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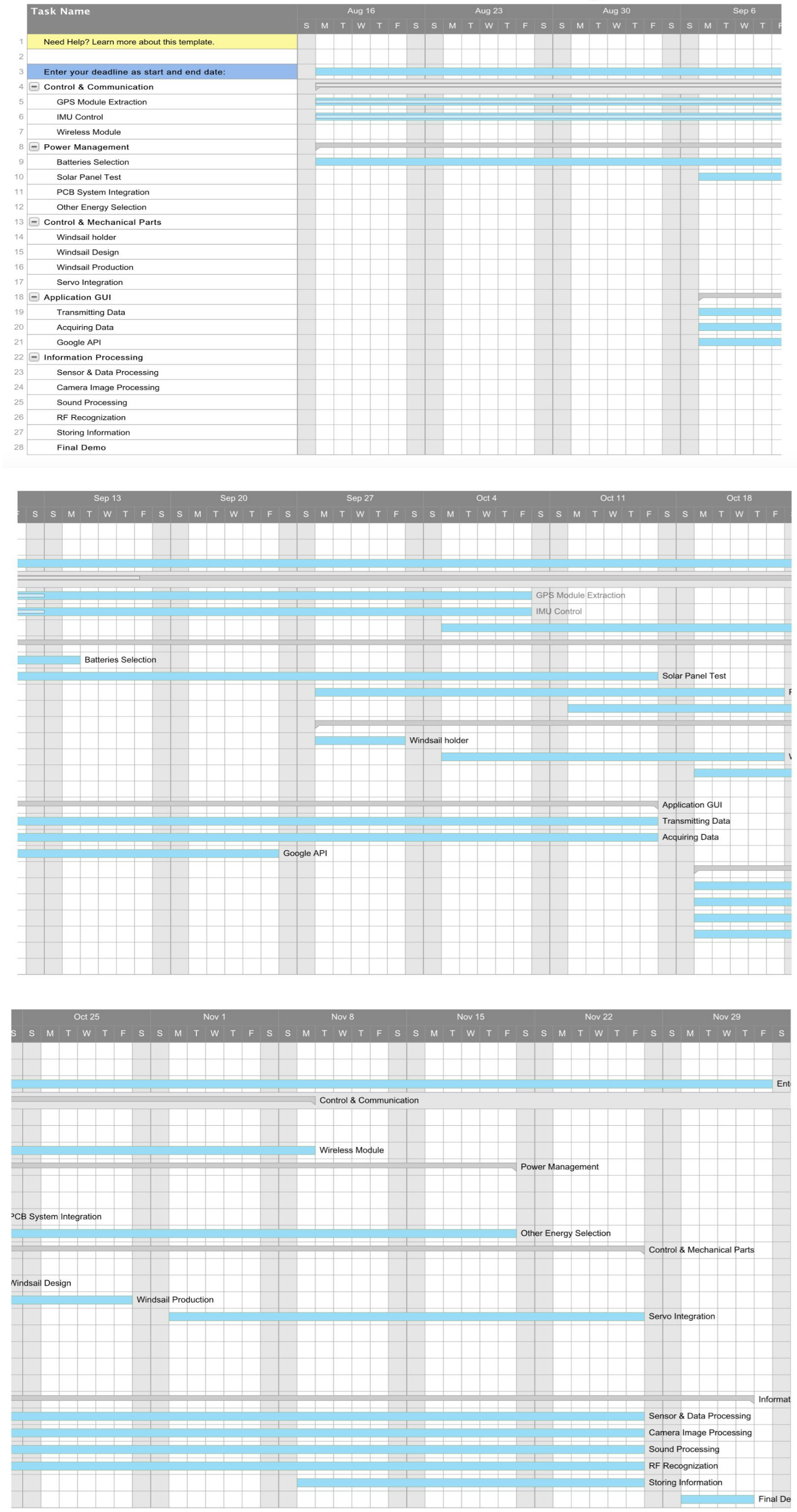
Appendix A - Task Distribution

Task Name	Task Lead	Risk Level	Significance Level
Preparing, Presentations and Documentation	All	Low	High
Technical Review Paper	All	Low	High
Project Summary	All	Low	High
Project Proposal	All	Low	High
Parts Ordering	QY	Medium	High
Weekly Log Presentation	All	Low	Medium
Final Project Presentation	All	Low	High
Final Project Demonstration	All	Low	High
Final Project Report	All	Low	High
Self-Sustained Sailboat	All	Medium	High
Sailboat Kits Assembling	All	Low	High
Power Management	CC, XJ	High	High
PCB System Integration	XJ	Medium	High
Data	All	Medium	High
Cameras Selection and Placement	QY, CC	Medium	High
Data Processing and Storage	QY, ED	Medium	High
Data Transmission and Receiving (Wireless Communication)	QY, CC	High	High
Application GUI	YP, ED	Medium	High
Navigation System	All	Medium	Medium
Improvements	All	Medium	Low

Appendix B - Gantt Chart



Appendix C - Breakdown of Hardware Cost

Product	Quantity	Unit Price ($)	Total Price ($)
Raspberry Pi Gen2 Model B	1	35	35
Micro SD card (8GB, OS)	1	12.99	12.99
Micro SD card (16GB, high speed)	1	20.98	20.98
Keyboard/Mouse (Logitech MK270)	1	20.99	20.99
IR Camera	1	259.95	259.95
Go Pro Hero 4	1	399.99	399.99
Enclosure for Raspberry Pi	1	7.35	7.35
PSU for Raspberry Pi	1	9.88	9.88
Water-proof servo for rudder	1	46.62	46.62
Water-proof servo for wing	1	19.63	19.63
Ublox M8N GPS module	1	24.51	24.51
Ublox NEO-6M GPS module	1	14.89	14.89
CJMCU-99 Nano-Ahrs 9-axis IMU	1	21.41	21.41
Wireless Module	1	30	30
Solar Panel	2	18	36
Buck-boost converter	2	8.96	17.92
Eneloop AA Ni-MH Batteries	2	19.99	39.98
Power management PCB	1	70	70
Miscellaneous	1	150	150
TOTAL			**1238.09**

END