Autonomous Sailboat for Penguin Tracking

<u>ECE4011 Senior Design Project</u>

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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 track new-born penguins' path from the warm island back to their south habitats including Antarctica. During the tracking process, the boat will monitor the ocean conditions using different sensors, for example, monitoring temperature and carbon concentration. Furthermore, devices including cameras and recorders will be installed in the boat in order to record behaviors of the penguins. The boat is autonomous and has a self-energy harvest system, so no human control and external power supply is needed. These two features guarantee the sailboat to self-navigate on the ocean without external help and supply from the shore. The sailboat is also designed to overcome the extreme conditions of the ocean. For instance, most part will be waterproof and function at a considerate cold temperature. The budget of this project is approximately about 980 dollars. With this low-cost autonomous sailboat, the team anticipate the outcome to find the exact location of the penguin's habitats and to collect and analyze the data of the ocean conditions along the penguin's immigrating path.

Autonomous Sailboat for Penguin Tracking

1. Introduction

The Georgia Tech ECE Senior Design Penguin Tracking Autonomous Sailboat Team is requesting 980 dollars to develop the autonomous sailboat to track the penguins and analyze their habitats.

1.1 Objective

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 and wind energy with a rechargeable battery to store and provide energy for the boat. A Global Positioning System (GPS) tracker will be placed on the penguin. The sailboat utilizes the GPS and the long range wireless communication for navigation. It will also be equipped with various sensors to detect the ocean conditions along the tracking path. The autonomous boat will also be able to take pictures and record the target penguin. Additionally, if time permits, the team would also prefer to track the nearby penguins by analyzing the sound they make using Digital Signal Process (DSP) techniques.

1.2 Motivation

Traditionally, scientists utilize GPS and sail drone to track ocean animals such as whales and penguins. However, sail drone tracking cost a large amount of money and the big tag might affect the penguin's daily life [1]. The research utilizing the GPS tracking tag 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 would not affect penguin's daily life and it is fast and flexible enough to follow the penguin for a long period of time without running out of harvested energy. From the perspective of cost, the unmanned self-powered sailboat will cost 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 hybrid energy supply system and open-source electronic prototyping platforms to gather and transmit data. It utilizes the GPS and the long range wireless communication 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 and protection of the penguins. Replacing normal sensors for research such as thermometers and anemometers with GPS tracking and cameras, scientists and environmentalists are able to utilize this product to track and analyze the conditions of the penguin's habitats. At the beginning stage of the design, the team will investigate an appropriate sailboat kit. Starting from a drone ship, more sensors and modules will be implemented to the sailboat.

The main building blocks of the project are the energy harvesting system, navigation system and algorithm, and the penguin tracking system.

2. Project Description and Goals

The team plans to design and prototype the following parts of the sailboat:

1. An energy harvest system to harvest energy from the environment including wind and solar energy, and use a rechargeable battery to store the rest of the unused energy.
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 and communication system to navigate the sailboat by tracking the penguin.

The goals of the final product are listed above:

1. Help scientists find the habitat of the penguins near Antarctica and gather data for the habitat environmental conditions.
2. Test the contamination level of the habitat area and along the route.

The target price of the product is $3500, and the team's target users are environmentalists and scientists.

3. Technical Specifications

3.1 Quantitative Specifications

Table 1. Quantitative Specifications

Sustainability	
Uninterrupted Operation at 20 °F	
Hardware	
Data Collection & Navigation Unit	
Operating Voltage	5V
Clock Speed	96MHz
Memory	32KB RAM, 512 KB FLASH
Dimension	Maximum: 55.25mm x 26.35mm
Processing Unit	
Clock Speed	900MHz
Power	5V @ 700 mA
RAM	1GB
Dimension	Maximum: 54mm x 26mm x 20mm
GPS	
Horizontal Position Accuracy	2.5m
Power	3.3V
Update Rate	max 5Hz
Dimension	25.5mm x 31mm
Wireless Module	
Date Rate	~150kb/s

Usable Range	~10km
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

4. Design Approach and Details

4.1 Design Approach

As shown in Figure 1, there are three main parts of the overall system. Sailboat platform, its peripherals, 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 sensors, cameras, and other devices which closely related to the project mission. Base station is the equipment that enables us to get real-time data feedback and operate the sailboat and task devices on board.

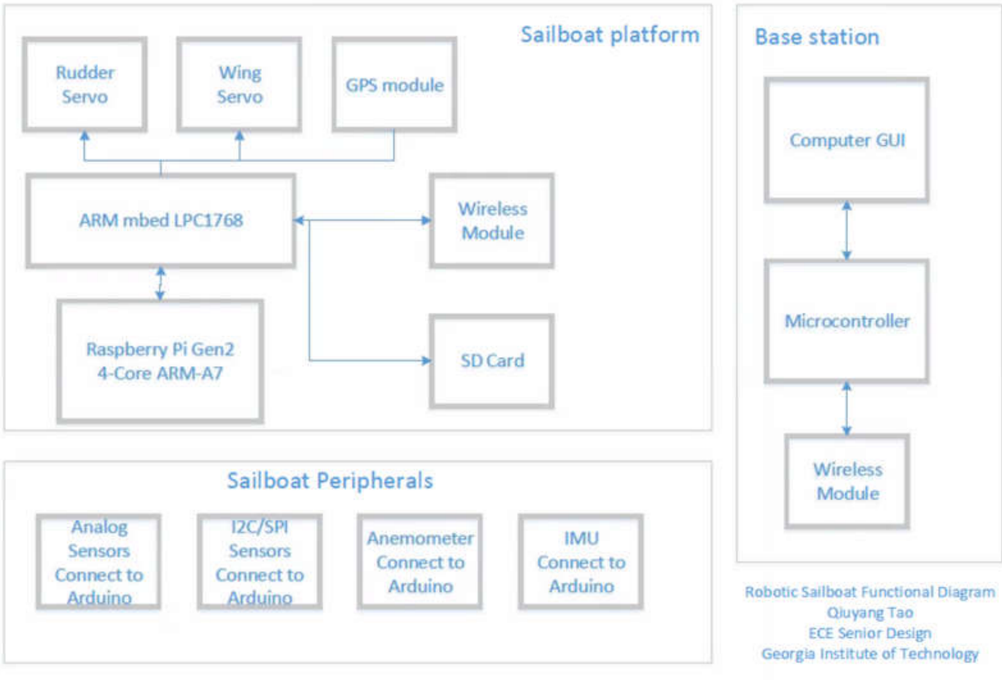

Figure 1. Functional diagram of the overall system.

4.1.1 Sailboat Platform

The platform performs navigation, data communication and signal processing for the sensors.

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 Figure 2, the sailboat harvests energy from multiple sources, and each source have 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, one part of the incoming energy is feeding the onboard devices and the remaining is stored in the battery [4]. When there is no enough energy harvested, the system will pump power from the battery for the onboard electronic devices. Also, coulomb counter [5] will track the battery status and provide accurate estimation for battery remaining capacity.

There are three outputs of the system. Two of them is regulated, low ripple power supply for onboard electronics and sensors. The other one is a high-current output which is specifically for servos and other actuators.

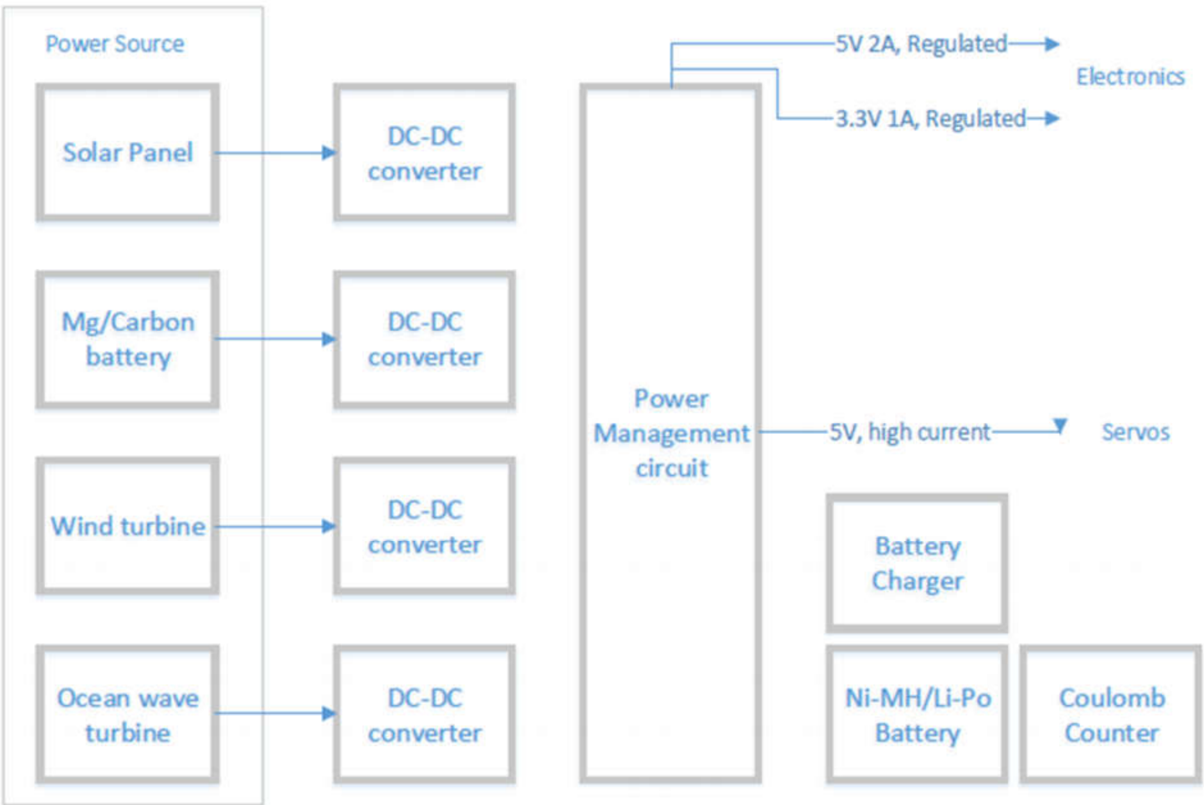

Figure 2. Functional diagram of the power management system.

4.1.1.2 Navigation system

To navigate to a certain location, the sailboat needs to know the coordinate of the current location and the destination. The destination is given to the navigation system but the current location needs to be acquired from the GPS module. To get higher accuracy but still acceptable cost, we chose the U-blox M8 series GPS module, which is compatible with GPS/QZSS, GLONASS and BeiDou. Thanks to this brilliant GPS receiver, we can get horizontal position accuracy of 2.5m CEP (Circular Error Probable) and 10Hz update rate [6].

Since the energy is very limited, we decided to use ARM mbed (LPC-1768) to handle the navigation. GPS data will be sent to mbed [7] via serial bus [8]. Mbed will calculate the route and send 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 very far away from base station. Satellite is ideal for this kind of tasks but the cost is above our budget. Alternately, just to test our system, we plan to use high power wireless modules. The modules support transparent transmission [10], so we can easily change the module we use according to detailed tasks.

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 gets data from a sensor, the electronic switch will connected the mbed to the SD card and data will be immediately stored into the SD card. After a certain number of data is collected, mbed will switch the SD card to Raspberry Pi and turn on its power. Raspberry Pi will automatically process the collected data according to pre-set algorithms. If we want to do some complex tasks such as take a photo, Raspberry Pi will be waked up. Overall, the low-power mbed [7] handles all the “daily” tasks and the high performance quad-core Raspberry Pi will be waked up only there is a heavy task.

4.1.2 Sailboat Peripherals

To complete our mission, multiple sensors are essential. We chose mbed(LPC1768) in order to provider almost all commonly used buses and ports for the sensors [7]. Also, our power supply provides both 5V and 3.3V regulated voltage which is widely used among sensors. Also, the mbed has 26 digital I/O pins [7], this makes the sailboat extensible and upgradable for future tasks. In addition to the digital signals, there are 6 analog channels [7]. This feature makes it much easier to add on analog sensors. For example, if we want to record voice using a microphone, the sound signal can be sampled by the analog channels.

4.1.3 Base Station

We need to monitor the status of the sailboat and send command to it. A computer based base station is the best solution. The wireless module is connected to the USB port of a PC via a serial-to-USB adapter.

On the PC, a Linux based ROS (Robot Operating System) will be used to receive, visualize data and send command to sailboat [12]. A GUI (Graphical User Interface) will be designed to make user interact more efficient.

4.2 Codes and Standards

1). **I2C, Inter-Integrated Circuit.** A simple bidirectional 2-wire [13] peripheral bus in order to connect a wide range of devices. I2C supports multiple devices connected to our microcontroller in different speed rates. Bidirectional data transfer rate can be achieve up to 100kbps in standard mode, 400kbps in fast mode and 3.4Mbps in ultra-fast mode [14]. Most of our on-board sensors are connected using I2C bus.

2). **SPI, Serial Peripheral Interface.** Synchronous serial interface which uses separate clock, data lines and a select line to make higher speed rate [15]. We use SPI bus to connect to relatively higher speed sensors and SD card in our project [16].

3). **UART, Universal Asynchronous Receiver/Transmitter.** A key component of serial communication subsystem in our project. UART is commonly used innon-networked, point-to-point communication between devices [17]. There are two terminals, TX and RX, which in charge of sending and receiving data. In our project, the UART is mainly used in communicate with the wireless module [18].

4). **IEEE 802.15.4. Basis of Zigbee.** A suite of high-level communication protocol which has capability to form multiple network topologies [19]. Since the application of our mission need more than one sailboats and multiple base stations, the support for multiple network topologies as point-to-point, point-to-multipoint and mesh networks is essential. Also, the low duty cycle of data transmission is very energy efficient [19]. There are multiple transceivers and modules that works at ISM band, so we can use it for free [20].

5). **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 [21]. In our sailboat project, we want the vehicle be capable to take several pictures and on-shelf USB camera is a good choice [22].

6). **TTL, Transistor–Transistor Logic.** A standard logic level used in many applications such as computers, industrial controls and instruments [23]. Logic 0 is defined between 0V to 0.8V and logic 1 has range from 2.2V to 5V (Vcc) [24]. This standard will be used in our digital circuit design. Unfortunately, some sensors only support 3.3V logic level, so bidirectional logic level converters will used to make our system more compatible[25].

7). **SD, Secure Digital.** High capacity, nonvolatile memory card we will use to store sensor data and system logs. All SD card families use 3.3V initially, but SDHC and SDXC uses 1.8V. The SD cards have a default speed of 25MHz and the host device can also switch it to a higher transfer speed [26]. In our project, two SD card will be used. One of them is for storing 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 will cruise on ocean for a long period and all energy to power the electronics is harvested from the environment. The limited and unstable energy source requires the on-board devices consume as less power as possible.

2). Limited Budget. Satellite communication is ideal for the mission of the sailboat which need to travel a long distance on ocean. Unfortunately, a single satellite transceiver costs higher than our whole project budget. Also, due to the limited budget, we can only use commercial grade electronics, which cannot survive in extreme temperature conditions [27].

3). Accuracy of Sensors. Although we are using the best available option among the category, but the accuracy of the GPS module we choose is only 2.5m CEP [6].

Also, gyroscopes drift with time and its full-scale range is limited. Additional effort will be needed to compensate the imperfection of the inertia measurement unit.

4). Limitation of Actuators. On shelf servos have limited precision, speed and torque. Also, they consume a lot of energy. The servo we chose has torque of 42kg-cm and speed of 0.18s/60deg [9]. So these limitations need to be considered while we are designing the feedback control system.

5). Extreme Cases. The environment conditions varies a lot while the sailboat cruising a long distance. Extreme temperature at arctic and equator area greatly challenges the on-board electronics [27].

6). Limited Size. The electronics need 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. Also, the limited size of the sailboat limits the area of the solar panels.

4.3.2 Alternatives

1). Navigation system

To get high solution for our navigation system, the first candidate come to our mind is differential GPS [29]. With a stationary receiver station at known location, the inaccuracy can be gauged and compensated. Thanks to this ideal, the differential GPS have accuracy of 10cm, which is much better than conventional GPS. But the cost is above our budget and additional system will be needed to receive the correction 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 [30]. It is much more powerful than mbed but power consumption is not acceptable.

2). Communication system

In order to be connected to our base station far away on the ocean, satellite communication is ideal for the sailboat system. The satellite transceiver is very expensive so we decided to use other communication methods.

3). Sensor data processing system

We have two alternate solution to process sensor data. One of them is BeagleBoard Black [28]. The benefit of using this product is its fast booting capability. The small computer can boot in 10 seconds, which is faster than the solution we are using. But the reason we didn't choose is its performance is much weaker than Raspberry Pi 2. We need to process the data as fast as possible and the high-performance, quad-core Raspberry Pi meets the goal.

The other alternate is Intel NUC. A series of small size computers equipped with up to 3.1GHz Core i7 processor [31]. The performance is very outstanding among its category but power consumption is but acceptable.

4.3.3 Tradeoffs

1). Computational Performance vs. Power Consumption.

Mbed is equipped with 96MHz 32-bit processor and it consumes very small amount of energy. In contrast, Raspberry Pi equipped with 1GHz quad-core ARM Cortex-A7 processor but it is more energy hungry [9]. To get a balance, we designed a methodology which just turn on the high-performance computer only the task is very heavy. Also, the SD card is shared between the two devices with a switch.

2). **Rechargeable battery vs. Super capacitor.**

Super capacitor provides almost unlimited charge/discharge cycles while most rechargeable batteries are less than 1000. Also, the charge/discharge speed is much faster than chemical batteries. But the drawback is, like all capacitors, the voltage drops a lot during discharging. Another disadvantage is that the supercapacitors can store much less energy than rechargeable batteries. In contrast, rechargeable batteries can provide stable output voltage, and has much lower self-discharge than super capacitors [32]. If we need extreme long life cycle, super capacitors is the best choice and rechargeable batteries works better if high energy density and stable discharge voltage is required [33].

3). **System performance vs. Cost.**

Ideally, differential GPS, precision IMU, professional servo and satellite transceiver can provide optimized performance and full functionality. But considering our budget is limited and this is an early prototype, we chose to use less-expensive components. Because of this, upgradable characteristics is a major concern in our design. For instance, the wireless module we chose support transparent transmission and we can easily replace it by a better one without changing any other part of the whole system [10].

5. Schedule, Tasks, and Milestones

The Robotic Sailboat team will design and implement an Unmanned Surface Vehicle (USV) which is aimed to monitor habitat condition of penguins. Appendix A contains the list of all essential millstones, people who lead the tasks, and their difficulty levels and significance level. Several tasks will be 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 are specified with their timelines, and duration. The development timeline starts from Fall 2015.

6. Project Demonstration

The robotic sailboat is designed to operate over the ocean surface. The formal demonstration will be conducted in the following process:

1. Observer will plan a route of a mission for the sailboat

2. Solar energy supply will be used individually to test whether the prototype achieves the minimum energy conservation specification.
3. While the hybrid energy supply system is implemented, data sampling and processing will be tested and assured functional.
4. Long range wireless communication and real time data sampling will be tested by comparing it with the local data storage.
5. The sailboat will then be tested in a small pool. Trackers will be placed at the edge of the pool to imitate the existence of penguins. The sailboat should be able to sense and track down those trackers and report their location to the observer.
6. With all modules built-in, the sailboat will be operated over a lake in Savannah to assure the prototype satisfies the design specifications like operation duration and data sampling accuracy.
7. A stand-alone penguin voice recognition algorithm will be developed and tested in Matlab. It aims to track untracked penguin flocks.

The sailboat is tested under an optimistic situation. It will be operated under the situation that there is enough wind for it to propel but not too much to overturn. The specifications will be 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.

- **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

Penguin Sailboat is a product that can be used for tracking and detecting the route of new-born penguins from warm islands back to South Antarctic as well as the water conditions along the route. The target market for this boat is college and company research teams or individuals who would like to explore more about 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 do not have to trace the penguins all the way along. The expected basic feature of the product is to be equipped with a receiver for transmitting the data from the tracker. Meanwhile, various sensors for detecting the condition of the seawater such as the pH and content of CO2 will also be available for satisfying seawater biological investigation. For further potential functions, a system that recognizes the penguins through the sound could be developed, which allows users free from figuring out the places of the penguins.

7.2 Similar Products

Currently no sailboat product provides the functions of the detecting and tracking penguins as well as monitoring the environment conditions, but there are some autonomous boats similar to our expected 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 [34].

Table 2. Wave Glider SV3 Specifications

Product Name	Wave Glider SV3
Functions	Mission control; Status Monitoring; Autonomous Navigation
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; Wi-Fi
Navigation	GPS: 12 channel WAAS; Accuracy: 3m radius

7.3 Cost Analysis

1). Prototype Cost of Development

Table 3 summarizes the cost of development for the Penguin Sailboat. It is assumed that the development will require 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 $48964.794. A breakdown of the hardware cost can be found in the Appendix II.

Table 3. Total Development Cost Analysis Breakdown

Project Component	Labor Hours	Labor Cost	Equipment Cost	Total Component Costs
Hardware Assembly	**10**	**300**	**661.27**	**961.27**
SBC Design	**40**	**1200**		**1200**
SBC Configuration	**60**	**1800**		**1800**
Peripherals	**20**	**600**		**600**
Base Station Configuration	**30**	**900**		**900**
Power Management	**50**	**1500**	**320.00**	**1820**
Sound Detector Design	**60**	**1800**		**1800**
Demonstration Preparations	**40**	**1200**		**1200**
Weekly Meetings	**30**	**900**		**900**
Lectures	**60**	**1800**		**1800**
TOTAL LABOR	**400**	**12000**		
PART COST			**981.27**	

Fringe Benifits				**3600**
Overhead				**19513.524**
PROJECT TOTAL				**36094.794**

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 $3500.00 per unit. The hardware cost is $981.26. 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. Production Run Cost Breakdown

Production Run Components	Component Cost
Development Cost	**36094.794**
Hardware Cost	**147190.5**
Labor Cost	**15000**
Fringe Benefits	**4500**
Overhead	**194400**
TOTAL	**397185.294**

The total expected production cost is $397185.294, yielding a total profit of $127814.706 for a sales price of $3500. Therefore, the profit per unit is $852.1.

8. Summary

Currently, the team has submitted a request for the order of SBC and its peripherals, and still waiting for the successful delivery. For the power management, the team is now seeking better power management circuit chips and buck-boost converter designs available for use. Some of team members staying in Atlanta will begin the work for penguin detection part to determine its eligibility during summer. The remaining parts will be done in Fall after all of the components arrive.

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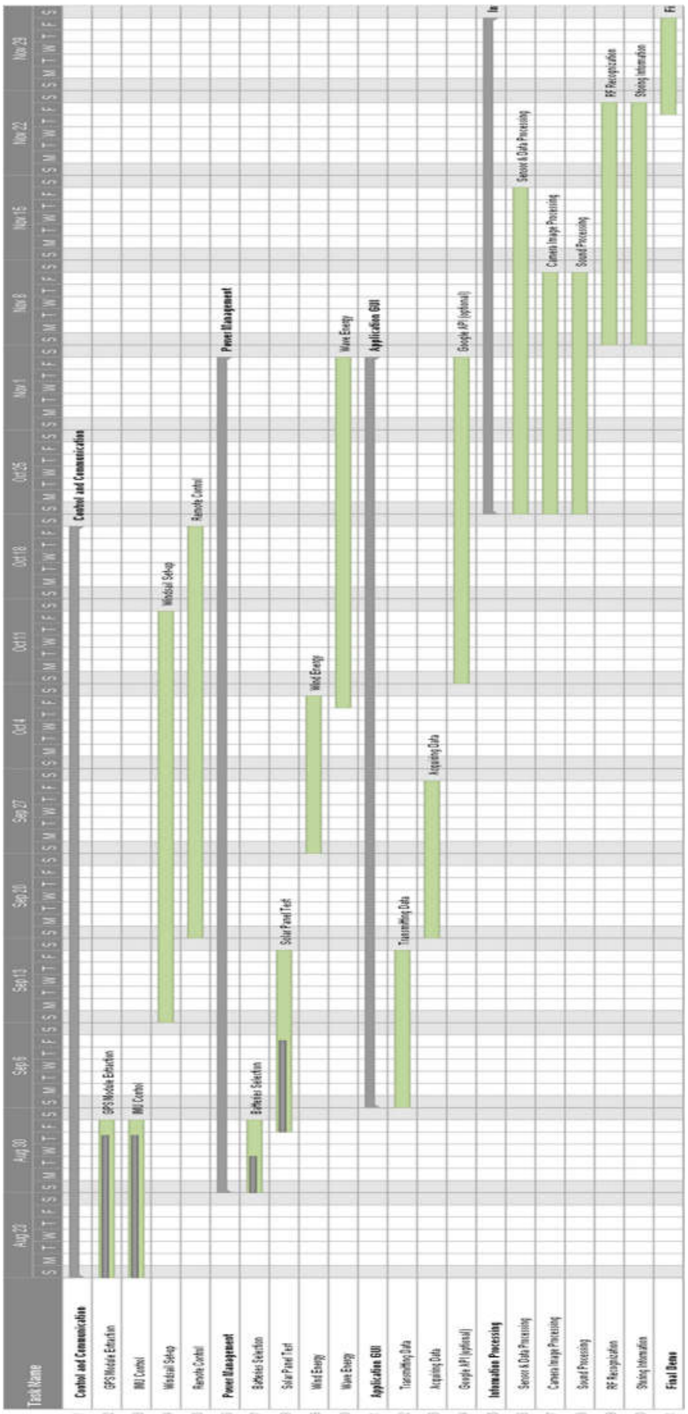
Appendix A

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
Power Management	CC, XJ, YP	High	High
Solar Power	QY	Low	High
Wind Power	ED	Medium	Medium
Sea Water Battery	ED	Low	Medium
Wave Glider	All	High	Low
Data	All	Medium	High
Data Sampling (Sensors)	QY, CC	Medium	High
Data Processing and Storage	ED, XJ, YP	Medium	High
Data Transmission and Receiving (Wireless Communication)	ED, YP	High	High
Tracking System	All	Medium	High
Navigation System	All	Medium	Medium
Penguin Voice Recognition	ED, CC, XJ	High	Medium
Improvements	All	Medium	Low

Appendix B



Task Name
Aug 23
Aug 30
Sep 6
Sep 13
Sep 20
Sep 27
Oct 4
Oct 11
Oct 18
Oct 25
Nov 1
Nov 8
Nov 15
Nov 22
Nov 29
Control and Communication
GPS Module Extraction
IMU Control
Windsail Set-up
Remote Control
Power Management
Batteries Selection
Solar Panel Test
Wind Energy
Wave Energy
Application GUI
Transmitting Data
Acquiring Data
Google API (optional)
Information Processing
Sensor & Data Processing
Camera Image Processing
Sound Processing
RF Recognization
Storing Information
Final Demo

Appendix C

Product	Quantity	Unit Price ($)	Total Price ($)
IMU Chipset	1	35	35
Micro SD card (8GB, OS)	1	12.99	12.99
Micro Sc card (16GB, high speed)	1	20.98	20.98
Keyboard/Mouse (Logitech MK270)	1	20.99	20.99
Camerasi	1	25	25
Enclosures	1	7.35	7.35
PSUs	1	9.88	9.88
Mbed LPC-1768	1	49	49
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	25.28	25.28
Wireless Module	1	100	100
Solar Panel	4	18	72
Buck-boost converter	1	7	7
Surface-mount components	1		0
Rechargeable batteries	1	50	50
charger			0
Power management PCB	3	60	180
Miscellaneous	1	320	320