Autonomous Sailboat

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ECE 445

1. Introduction

1.1 Objective

There is a large barrier to entry in learning how to operate a sailboat. Using a sailboat is very complex and people often have to spend many weeks or even months just learning the basics. This prevents many people from enjoying this activity simply because they may not have the time to learn. On the other hand the capabilities of autonomous machines have advanced rapidly in recent years. It is now possible to have machines do things that would have required a person many hours of training just a few years before. Thus we propose the idea of an autonomous sailboat that would be capable of sailing without any input from a user.

One of the major benefits to operating an autonomous sailboat is that it would not require significant training unlike a normal sailboat. Sailing a boat by hand is frequently very difficult. In order for a user to sail the boat to a desired destination, they must be able to determine the destination of the boat relative to the destination, judge the direction of the wind then calculate the optimal position of the sails/rudder in order to move the boat in the direction of the destination. A user also needs to perform many complex maneuvers such as tacking,whereby the user moves back and forth at 45 degree angles into the wind order to move upwind, and jibing, whereby the sailboat heading turns its stern through the wind in order to sail downwind, Thus a long training process is necessary for anyone who would like to use a sailboat. An autonomous sailboat would allow people to use sailboats without having to either go through a lengthy training process. Due to all of the complex maneuvers a person has to do, using a sailboat can also be a very dangerous activity with a high possibility of accidents due to the user mishandling the sailboat. With an autonomous sailboat there is a greatly reduced possibility of accidents that are caused by user error as the sailboat will not rely on a human in order to operate. The most difficult part of operating a sailboat however is navigation. It can be very easy for a user to become lost when operating a sailboat as there are frequently very few landmarks when out at sea which can be very dangerous for the user if they do not know how to navigate back to shore. With an autonomous sailboat there would be no danger of a sailboat getting lost while navigating to its destination as the boat would be able to determine its own location relative to its objective.

1.2 Background

The idea of an autonomous sailboat that would be able to navigate to and from a location without the need of a pilot has been proposed in the past but presents many significant obstacles [1], [2]. The sailboat must be able to identify its current location as well as ascertain which direction the boat is facing, The sailboat would also need to determine the direction of the wind while also manipulating the sails and the rudder so that it can steer itself in any direction. Most importantly it must be capable of plotting a path to a given destination from any starting point.

In order for the boat to accomplish these missions while still being marketable the components used will need to be inexpensive so as not to increase the cost of the autonomous sailboat relative to other sailboats on the market. The various sensors used to gather information on the boat's environment must not be too bulky so as to avoid taking up space on the boat. Lastly we hope to make the system relatively simple to install even on boats that were initially designed to be non-autonomous allowing non-autonomous boats to be able to be converted into autonomous boats very easily

1.3. High Level Requirements

Be more specific add

- Boat must be able to sail to within 5 meters of a given destination that is 100 meters from a starting point without help from user
- Boat should be able to switch between user and autonomous control
- Boat should be able to plot a course to its destination using data collected from the sensors and its GPS location relative to its destination

2. Design

The autonomous boat will require four subsystems in order to function. The Sensor Subsystem that will use sensors in order to collect data from the boat's environment so that it will be able to navigate. It will consist of a GPS, a gyroscope and an anemometer. The Motor Subsystem will control the sails and rudder of the boat in order to move the boat in the desired direction. It will consist of two servos used to control the two sails and rudder of the boat.The User Input Subsystem will send a signal to the sailboat indicating that the user would like to switch from autonomous to user control mode or vice versa. In user control mode the subsystem will send commands from the user to the boat to sail the boat in a direction the user wants. It will consist of a controller that the user will input commands into. The Microcontroller Subsystem will consist of a microcontroller that will process information from the Sensor Subsystem and determine what instructions to send to the Motor Subsystem in or to reach the desired destination. It will also process signals from the User Input Subsystem to switch between user and autonomous control and determine how to move the boat based on user input in user control mode. Finally there is the Power Subsystem which will provide power to all of the components of the other subsystems. It will consist of a power supply and three voltage regulators, one for each the three other subsystems.

2.1 Block Diagram

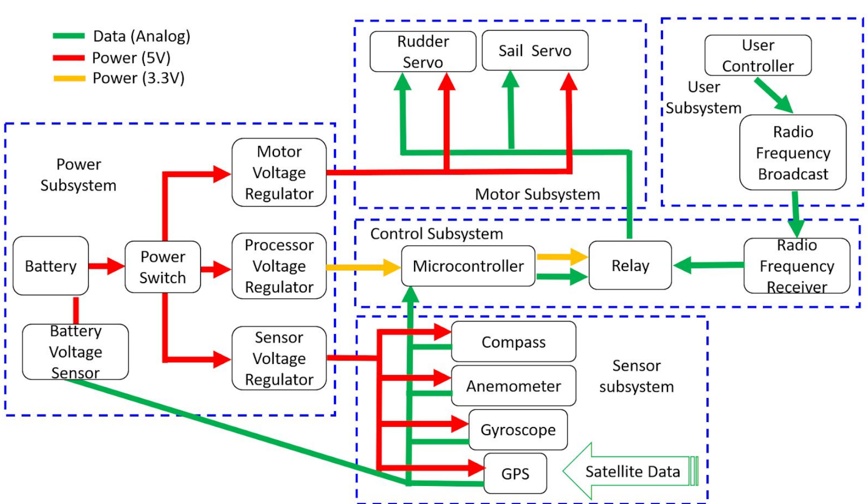

Figure 1: Block Diagram

2.2 Circuit Schematics

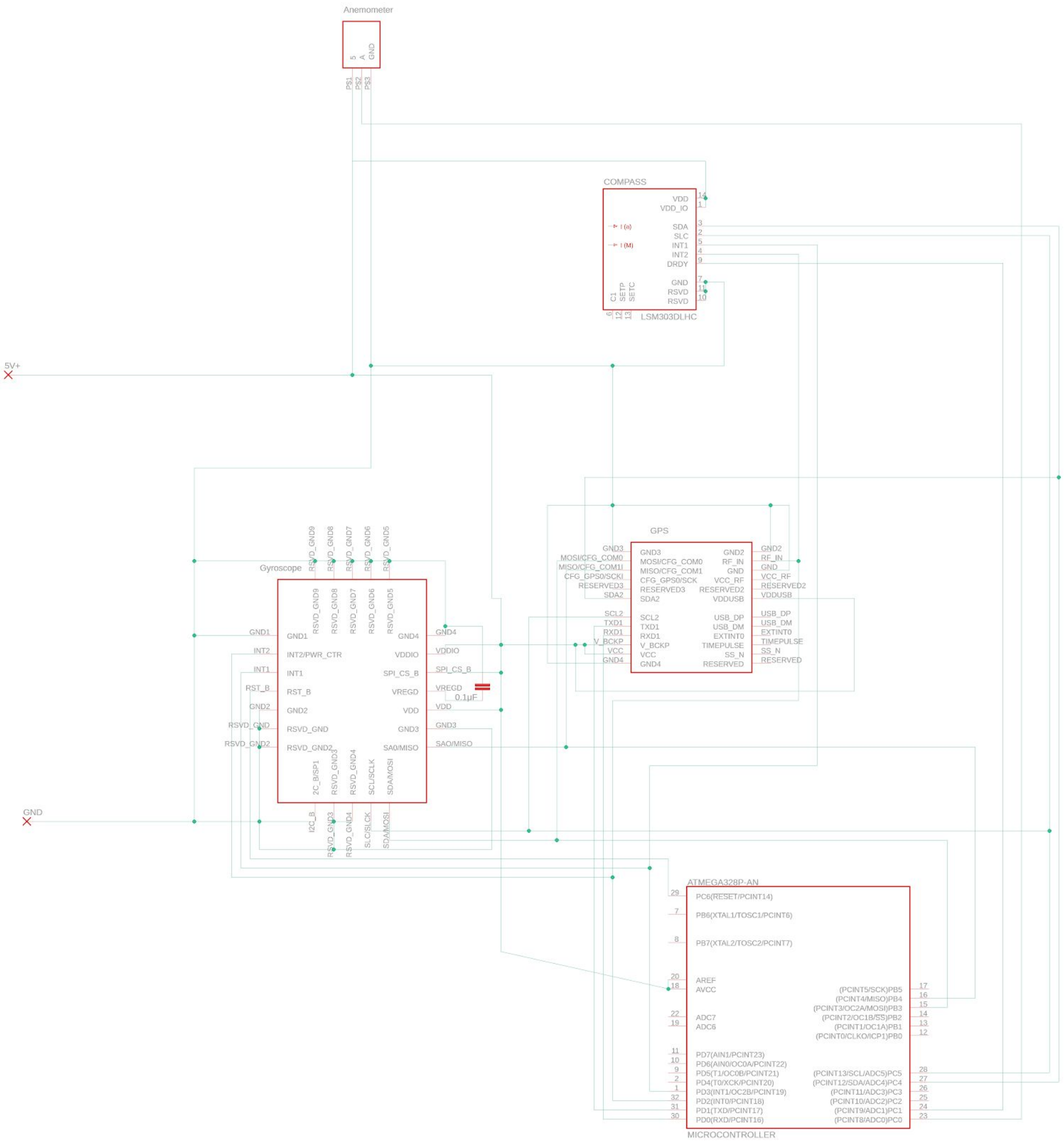

Figure 2: Circuit Schematic

2.2 Flowchart for sailing software

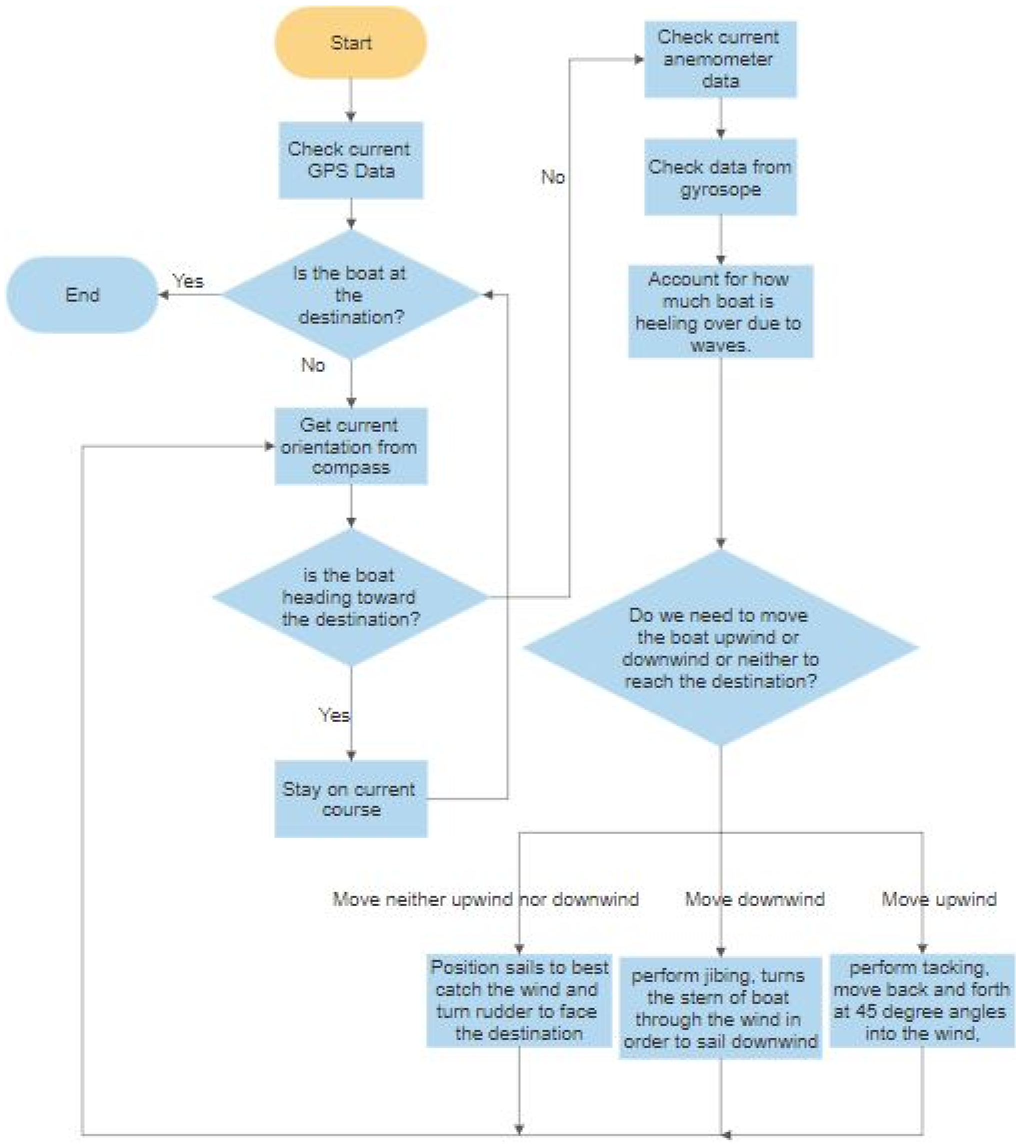

Figure 3: Flowchart of sailing software

2.3 Boat Power Source Subsystem

The boat power source subsystem is required to power up all other subsystems by providing other subsystems with appropriate voltage inputs. The battery voltage will be regulated to other voltages for other subsystems to operate. The sailboat is powered by a battery pack of 4 AA batteries and is used to distribute power to all of the other subsystems. Voltage regulator circuit is used to regulate the voltage and generate various voltage outputs to power subsystems which require voltages different from the battery voltage. We also include a low voltage LED that will flash on when there is a power failure to inform the user of loss of power.

Requirements	Verifications
Battery Pack/AA Batteries: a) Supply +6V ± 2%	AA Batteries: a) 1) Use a multimeter to check whether the voltage of each one of 4 AA batteries is around 1.5V. 2) Use a multimeter to check whether the whole battery pack can supply voltage 6V ± 2%.
Voltage Regulator: a) Voltage must be regulated to 3.3V ± 2% as required for the microcontroller	Voltage Regulator: a) 1) Use the multimeter to connect the positive and negative side of the voltage regulator. 2) The display should output around 3.3V
Low Voltage LED: a) Must be able to light up when the battery is at or around 20% of power to notify the user of low power	Low Voltage LED: a) 1) Use the power sauce to supply a voltage of 6V and the LED should not light up 2) Use the power sauce to supply a voltage of around 5V, the LED should light up

2.4 Boat Location/Direction Sensor Subsystem

The sensor subsystem is responsible for collecting all the data about the boat's position and heading as well as the wind's speed and direction. The data is then given to the processor for interpretation. Similar systems have been used in the past to make an autonomous paddle boat, using two paddles to propel the boat and guided by compass and GPS [2]. We also care about wind speed and direction since we will be using a sail to propel the boat instead of paddles. An anemometer will provide the microcontroller with wind speed and direction for determining the direction of the sails. The gyroscope will be utilized to determine the angle of the boat relative to the water to help prevent capsizing.

Requirements	Verifications
GPS: a) GPS must reliably receive the boat's position on the water within 2 meters	GPS: a) 1) Connect GPS device to microcontroller and computer to view the location information 2) Move the GPS to five locations where we already know the exact coordinates 3) Compare the location information outputted by the GPS with the actual

Compass: a) Compass must reliably calculate the boat's heading relative to true north within 1-3 degrees	location that we already measured to check if it is within 2 meters Compass: a) 1) Connect compass device to microcontroller and computer to view the direction information 2) Point the compass in four directions (North, South, East, West) 3) Compare the recorded directions outputted by the compass with the actual directions and check if it is within 2 degrees
Anemometer: a) Anemometer must reliably calculate the boat's heading relative to true north within 1-3 degrees b) Must be able to give accurate readings in strong winds with speed over 11km/h	Anemometer: a) 1) Connect anemometer device to microcontroller and computer in order to view the direction information 2) Use fan and blow wind at the anemometer from four directions (North, South, East, West) 3) Compare the wind directions outputted by the anemometer with the direction the fan is pointed at and check if it is within 1-3 degrees b) 1) Use fan and blow wind at 11km/h at the anemometer 2) Compare the wind directions outputted by the anemometer with the direction the fan is pointed at and check if it is within 1-3 degrees
Gyroscope: a) Gyroscope must be accurate enough to be able to determine the angle of the sails relative to the water within 0.1 degrees	Gyroscope: a) 1) Connect gyroscope device to microcontroller and computer in order to view the direction information outputted by the anemometer 2) Tilt gyroscope over by 10, 15, 20, -10, -15, -20 degrees relative to 90 degrees 3) Compare the degrees of angle outputted by the gyroscope with the actual degree of tilt and check if it is less than 0.01 percent the actual degree of the tilt

2.5 Boat Processor Subsystem

The Processor accepts data from the Sensor subsystem, and calculates the angles the sails and rudders need to be at to sail to the destination. It then sends instructions to the Steering Subsystem. The sail boat will use an Arduino board which holds the software that interprets sensor data and determines how the boat should navigate. The microcontroller should be able to receive data from the sensor subsystem, interpret data, and send messages to the boat steering subsystem.

Requirements	Verifications
Microcontroller: a) Microcontroller should be able to receive data from the GPS, compass, anemometer and gyroscope. b) Processor must be able to calculate boat position, boat heading, wind speed, and wind direction with relative errors within 1-5% in magnitude. c) Processor must be able to tell which way to move the boat and what instructions to give the servos based on information from sensors.	Microcontroller: a) 1) Use GPS device to view the location 2) Change the location of GPS. If the output changes, the microcontroller receives data from the GPS. 3) Do step 1-2 for compass, anemometer and gyroscope. Change the conditions of each component that it measures (i.e. boat direction for compass, wind direction for anemometer and angle of tilt for gyroscope) b) 1) Compare the recorded location outputted by GPS with the actual location of the boat and check if the relative error is within 1-5% in magnitude. 2) Do step 1 for compass, anemometer and gyroscope. Check for the data each component measures (i.e. boat direction for compass, wind direction for anemometer and angle of tilt for gyroscope). c) 1) Connect the servos to the microcontroller 2) Record the correct information collected from the sensors and use them as input 3) Release the boat and check whether the boat reaches the target and comes back.

2.6 Boat Steering/Servo Subsystem

The Boat Steering Subsystem contains the servos for steering the boat. It receives instructions from the processor subsystem. The servos are used to adjust the angle of the sails and the rudder in order to steer the boat in the intended direction of travel. Using servos enables us to be precise in our angles of the sail and rudder without a tachometer. For the sails, the servos are connected to a winch that moves the mast.

Requirements	Verifications
Servos: a) Servos must be able to adjust the angle of the sails and the rudder in order to steer the boat in the intended direction of travel b) Servos must be able to turn to precise angles needed to perform sailing maneuvers within 1-5 degrees. c) Must be able to generate 2lbs of force necessary to strong enough to turn the sails in strong wind	Servos: a) 1) Move sails against wind of 5km/h in order to test whether servos are able to adjust the angle of sails 2) Repeat steps 1 from four directions (North, South, East, West) b) 1) Measure the angle of the dails relative to the angle inputted into the controller and see if it is within 1-5 degrees 2) Repeat steps 1 from four directions (North, South, East, West) c) 1) Use fan to change wind speed to 11km/h 2) Move sails against wind in order to test whether servos are able to adjust the angle of sails 3) Repeat steps 2 from four directions (North, South, East, West)

2.7 Tolerance Analysis

A major risk in implementing this project will be the anemometer of the Sensor Subsystem. The Sensor Subsystem will be required to interact with not only other subsystems but the environment of the boat as well. Thus, unlike the other subsystems, we cannot control what the inputs will be and it will be very difficult to take into account all of the possible inputs from the environment.

For example on very windy days the height of waves in a lake can be as high as 5 meters [3]. These waves could potentially throw off the accuracy of the sensors by causing the boat to heel over by as much as 20 degrees.

We use the following formula to calculate the percent accuracy of the sensor now that the boat has been tilted over where Θ represents the angle of the mast of the boat relative to the water that the sensor is calibrated to measure and b represents the degree to which the boat heels over.

$$y=\sin(\Theta+b) \qquad \text{Eq. 1}$$

Assuming that the angle of the boat relative to the water that the sensor is calculated to measure from is 90 degrees and the boat heels over 20 degrees then we see that the extra tilt of the boat can cause the sensors to be inaccurate by as much as 6 degrees. A 6 degree inaccuracy is beyond our tolerance of 1-3 degrees and would seriously impede the ability of the boat to sail. If the sensor were to give such an inaccurate reading then the microcontroller will not know which direction to turn the sails in order to take advantage of the wind and could potentially lead to the boat sailing in circles.

To address this issue we will add a gyroscope in order to estimate the degree to which the boat is heeled over. The gyroscope is capable of calculating the heel of the boat to about 0.1% the actual heel of the boat. With the gyroscope added we will recalculate using the following formula with the same variables as the first formula

$$y=\sin(\Theta-(b*1\pm0.1)+b) \qquad \text{Eq. 2}$$

Assuming that the angle of the boat relative to the water that the sensor is calculated to measure from is still 90 degrees and the boat still heels over 20 degrees then we can see that adding the gyroscope reduces the inaccuracy of the measurement to 0.07% which is within our tolerance.

2.8. COVID-19 Contingency Planning

In order to avoid potential COVID-19 infections when testing and operating our autonomous boat design all group members will wear gloves and masks at all times. If the group is working indoors or outdoors we will maintain social distancing by being six feet apart from one another and make sure to ensure good ventilation. After completing all assignments we will clean and disinfect all surfaces and wash our hands thoroughly. We will also make sure that every member of the group is regularly tested for COVID-19 and if any member tests positive they will quarantine for two weeks [4].

3. Cost and Schedule

3.1 Cost analysis

3.1.1 Labor Cost

Name	**Hourly Rate**	**Hours**	**Total**
Franklin Liu	$30	80	$2400
Haoyu Wang	$30	80	$2400
Megan Shapland	$30	80	$2400
Total			$7200

Table 1. Labor Costs

3.1.2 Part Cost

Description	**Quantity**	**Vendor**	**Cost / unit**	**Total Cost**

ATmega328P	1	Digi-key	$2.51	$2.51
NEO-6 u-blox 6 GPS Modules	1	ebay	$9.37	$9.37
MA3 Absolute Encoder	1	AndyMark	$56	$56
Gyroscope (FXAS21002CQR1)	1	Digi-key	$5.8	$5.8
PCBs	5	PCBWay	$1	$5
LSM303DLHC Module	1	Amazon	$6.19	$6.19
Total				$84.87

Table 2. Component Costs

3.1.3 Grand Total

Section	Total
Labor	$7200
Parts	$84.87
Grand Total	$7284.87

Table 3. Grand Total Cost (Labor + Part)

3.2 Schedule

Week	Franklin Liu	Haoyu Wang	Megan Shapland
2/15/2021	Project Proposal	Project Proposal	Project Proposal
2/22/2021	Eagle Assignment	Design Document	Eagle Assignment
3/1/2021	Revise Design Document and research for PCBs	Revise Design Document and research for neural network	Study datasheets of sensors and microcontroller available and choose hardware required for the project
3/8/2021	Design Document review	Design Document review	Test sensors using Arduino

	and purchase hardware & all parts	and purchase hardware & all parts	board
3/15/2021	Test sensors' accuracy and place sensors on the boat to collect data with errors below expectation	Develop functions of how the boat will move by changing the angle of mast	Test servos and use an Arduino board to control the boat
3/22/2021	Design PCB	Collect data for boat's reaction for certain circumstances in order to reach the destination	Collect data for boat's reaction for certain circumstances in order to reach the destination
3/29/2021	Write program to develop the function and weights of boat's reaction	Write program to develop the function and weights of boat's reaction	Test PCB
4/5/2021	Test the function for boat's reaction on the boat and fix bugs	Test the function for boat's reaction on the boat and fix bugs	Test the function for boat's reaction on the boat and fix bugs
4/12/2021	Fix bugs of programs and optimize the program	Modify the remote control to switch between people and self navigating if able	Assembling all parts on the boat
4/19/2021	Prepare for Mock Demo	Prepare for Mock Demo	Fix remaining issues and test the boat as a whole
4/26/2021	Prepare for demonstration	Prepare for presentation	Write final paper
5/3/2021	Finalize presentation and write final paper	Finalize presentation and write final paper	Lab checkout and finalize final paper

Table 4. Project Schedule and Task Allocation

4. Ethics & Safety

4.1 Boat Safety

One concern regarding the boat is the possibility of overloading the weight of the boat due to how many additional components we will have to add. An overloaded boat will have a large possibility of overturning, so as a safety measure we will carefully measure the weight of all components and make sure that the boat weight is less than the overload weight.

Furthermore, we want to avoid the components being damaged due to water exposure as this could cause a breakdown and leave the user stranded with no ability to steer the boat if something falls into the water unexpectedly. Thus every component we use should be waterproof to prevent these kinds of accidents.

Another concern is that there could be a great deal of damage to the boat if there is a collision.

4.2 Data Privacy

By using the GPS, we are connecting the user’s boat to the Internet. This will broadcast the user’s location and it is important to protect people’s data privacy by not giving way the GPS data and not violating private property, which meets the standards of #9 of the IEEE Code of Ethics, “to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses” [5]. To avoid compromising the user’s data we will make the user’s data private and not allow anyone else to utilize it.

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4.3 Electrical Hazards

There are several potential electrical hazards with our project. The battery could explode and damage other parts of the boat or even injure the user if the circuits are improperly wired. To avoid this we will make sure that we do not short batteries by adding some resistances in the circuit and carefully test our circuits before implementing them within the final system.

Additionally, batteries which are used up may pollute the environment if not disposed properly. We will prevent potential damage to the environment by making sure that every battery that is used up during experiments should be collected and disposed properly and providing any users with careful instructions on how to properly dispose of the batteries.

5. References

[1] D. S. dos Santos, C. L. Nascimento and W. C. Cunha, "Autonomous navigation of a small boat using IMU/GPS/digital compass integration," 2013 IEEE International Systems Conference (SysCon), Orlando, FL, USA, 2013, pp. 468-474, doi: 10.1109/SysCon.2013.6549924.

[2]Roland Stelzer, Tobias Pröll, “Autonomous sailboat navigation for short course racing,”Robotics and Autonomous Systems, Volume 56, Issue 7,2008,Pages 604-614,ISSN 0921-8890, https://doi.org/10.1016/j.robot.2007.10.004.

[3] N. O. A. A. US Department of Commerce, “GLCFS,” *Home: NOAA Great Lakes Environmental Research Laboratory - Ann Arbor, MI, USA*. [Online]. Available: https://www.glerl.noaa.gov/res/glcfs/glcfs.php?lake=m&ext=wv&type=F&hr=60. [Accessed: 01-Mar-2021].

[4] “How to Protect Yourself & Others,” Centers for Disease Control and Prevention. [Online]. Available: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html. [Accessed: 01-Mar-2021].

[5] Ieee.org, "IEEE Code of Ethics", 2021. [Online]. Available:
http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 17-Feb-2021]