Autonomous Sailboat

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Date: 2/15/2021

ECE 445

1. Introduction

1.1 Background

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 Objective

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 [2], [3]. 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

- Boat must be able to sail to given destination 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

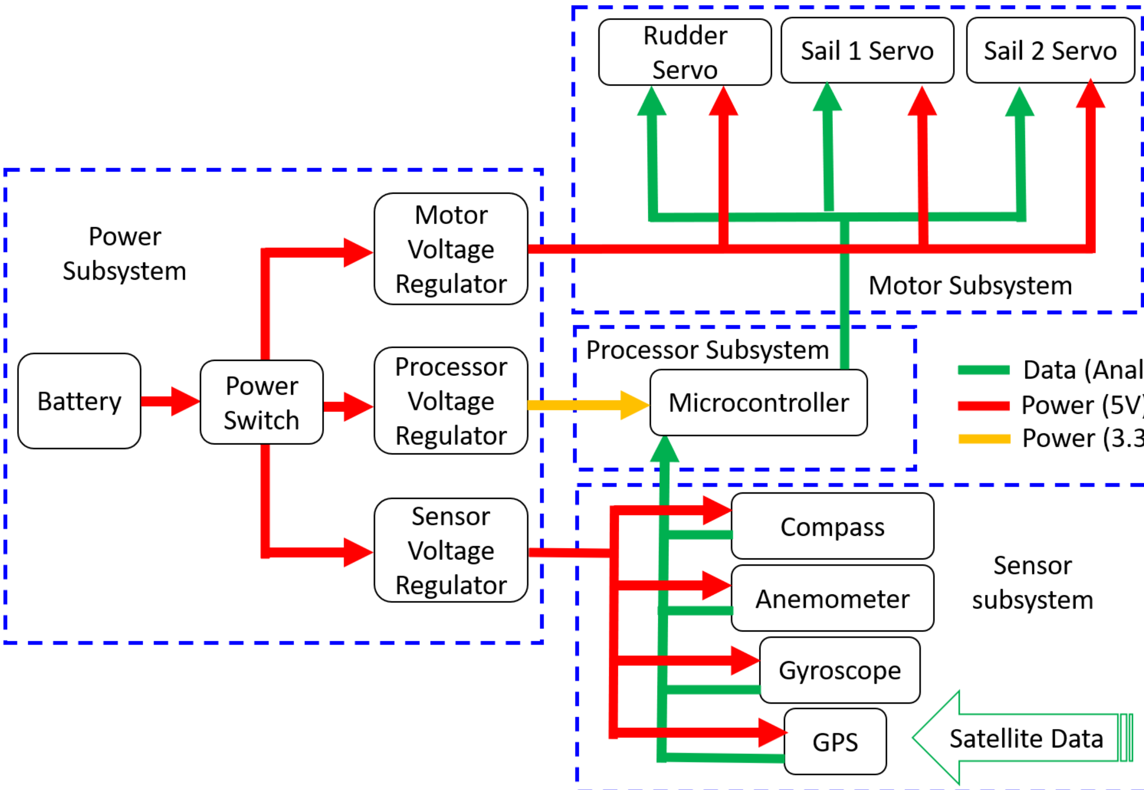

Figure 1: Block Diagram

2.2 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.

Requirement 1: Must include a light that will flash on when there is a power failure to inform the user of loss of power

2.2.1 Battery Pack

The sailboat is powered by a battery pack of 4 AA batteries and is used to distribute power to all of the other subsystems.

Requirement 1: Power subsystem must be able to output at least 5 watts of power

Requirements	Verifications
Battery Pack/AA Batteries: 1) Supply +6V ± 2%	AA Batteries: 1) A multimeter should be used to check whether the voltage is equal to the specific values. 2) Plug the black probe into COM and the red probe into +. Set the multimeter to 'V' in the DC range. 3) Connect the black probe to a battery's ground or '-' and the red probe to power or '+'. Squeeze the probes with a little pressure to ensure the probes are connected to the battery. 4) The display should output around 1.5V. 5) Do step 1) to 4) for all 4 AA batteries.
Voltage Regulator: 1) Voltage must be regulated to 3.3V ± 2% as required for the microcontroller	Voltage Regulator: 1) Use the multimeter to connect the positive and negative side of the voltage regulator. 2) The display should output around 3.3V

2.2.2 Voltage Regulators

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.

Requirement 1: Voltage regulators must be able to produce 3.3V output for the microcontroller.

2.3 Boat Location/Direction Sensor Subsystem

Requirements	Verifications
GPS: 1) GPS must reliably receive the boat's position on the water within 2 meters	GPS: 1) Connect GPS device to microcontroller 2) Connect microcontroller to computer in order to view the location information outputted by the GPS 3) Record the location information outputted by the GPS 4) Compare the location outputted by the GPS with the actual location of the device to check if it is within 2 meters

Compass: 1) Compass must reliably calculate the boat's heading relative to true north within 1-3 degrees	Compass: 1) Connect compass device to microcontroller 2) Connect microcontroller to computer in order to view the direction information outputted by the compass 3) Move the compass in several directions while recording the direction information outputted by the compass at each of those points 4) Compare the recorded directions outputted by the compass with the actual directions at those points and check if it is within 2 degrees
Anemometer: 1) Anemometer must reliably calculate the boat's heading relative to true north within 1-3 degrees 2) Must be able to give accurate readings in strong winds with speed over 11km/h	Anemometer: 1) Connect anemometer device to microcontroller 2) Connect microcontroller to computer in order to view the direction information outputted by the anemometer 3) Use fan and blow wind at 11km/h at the anemometer 4) Record the wind direction information outputted by the anemometer at each point the fan direction is changed 5) Compare the wind directions outputted by the anemometer with the actual wind directions at those points and check if it is within 1-3 degrees

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.

2.3.1 GPS

The boat will be equipped with a GPS to determine its position on the water, so it can plot and adjust its route on the water.

Requirement: The GPS must reliably receive the boat's position on the water within 2 meters.

2.3.2 Compass

The boat will use a compass to show direction relative to the geographic cardinal locations to tell where the boat is facing.

Requirement: The compass must reliably calculate the boat’s heading relative to true north within 1-3 degrees

2.3.3 Anemometer

An anemometer will provide the microcontroller with wind speed and direction for determining the direction of the sails.

Requirement 1: Must be able to give accurate readings in strong winds with speed over 11km/h.

2.3.4 Gyroscope

The gyroscope will be utilized to determine the angle of the boat relative to the water to help prevent capsizing.

Requirement 1: Gyroscope must be accurate enough to be able to determine the angle of the sails relative to the water within 5 degrees

2.4 Boat Processor Subsystem

Requirements	**Verifications**
Microcontroller: 1) Microcontroller should be able to receive data from the GPS, compass, anemometer and gyroscope. 2) Processor must be able to calculate boat position, boat heading, wind speed, and wind direction with relative errors within 1-5% in magnitude. 3) 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: 1) Connect GPS device to microcontroller 2) Connect microcontroller to computer in order to view the location outputted by the GPS 3) Change the location of GPS. If the output changes, the microcontroller receives data from the GPS. 4) 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. 5) Do step 1) to 4) for compass, anemometer and gyroscope. Change the conditions of each component that it measures (i.e. boat

	direction for compass, wind speed for anemometer and wind direction for gyroscope). 6) Connect the servos to the microcontroller 7) Record the correct information collected from the sensors and use them as input. 8) Release the boat and check whether the boat reaches the target and comes back.

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.

2.4.1 Microcontroller

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.

Requirement 1: Processor must be able to tell which way to move the boat and what instructions to give the servos based on information from sensors.

Requirement 2: Processor must be able to calculate boat position, boat heading, wind speed, and wind direction with relative errors within 1-5% in magnitude.

2.5 Boat Steering/Servo Subsystem

The Boat Steering Subsystem contains the servos for steering the boat. It receives instructions from the processor subsystem.

Requirements	Verifications
Servos: 1) 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 2) Servos must be able to turn to precise angles needed to perform sailing maneuvers within 1-5 degrees.	Servos: 1) Switch boat over to user control mode 2) Use fan and blow wind at 11km/h at the sails of the boat 3) Move sails against wind in order to test whether the sails are servos are strong enough to move against the wind 4) Measure the angle of the dails relative to

3) Must be able to generate 2lbs of force necessary to strong enough to turn the sails in strong wind	the angle inputted into the controller and see if it is within 1-5 degrees

2.5.1 Servos

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.

Requirement 1: Servos must be able to turn to precise angles needed to perform sailing maneuvers within 1-5 degrees.

Requirement 2: Must be able to generate 2lbs of force necessary to strong enough to turn the sails in strong wind

2.6 Risk Analysis

The greatest risk in implementing this project will likely 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. The anemometer will be especially difficult to implement because in order to collect useful information it needs to be very precise in order to detect slight changes in the wind while also avoiding interference from the environment such as water splashes and debris.

The anemometer should not need to detect wind that will not blow on the sails of the boat so the anemometer will need to be placed near the sails. The best way to accomplish this is to place the anemometer on top of the mast. We will also need to tune the sensor to avoid interference from the environment by adjusting the sensitivity of the anemometer.

Properly tuning the anemometer will be critical for allowing the boat to effectively navigate. Knowing the direction of the wind is critical for successfully navigating the boat to its destination without user interference. If the sensor fails then the microcontroller will not know which direction to turn the sails and it will become impossible to move the boat. There would also be a big risk of the boat getting damaged or even capsizing due to the anemometer being inaccurate and steering the boat incorrectly.

2.7 Tolerance Analysis

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		$
Haoyu Wang	$30		$
Megan Shapland	$30		$
Total			$

Table X. Labor Costs

3.1.2 Part Cost

Description	Quantity	Manufacturer	Vendor	Cost / unit	Total Cost
ATmega?					
Total					

Table (X+1). Component Costs

3.1.3 Grand Total

Section	Total
Labor	$
Parts	$
Grand Total	$

Table (X+2). Grand Total Cost (Labor + Part)

3.2 Schedule

Week	Task	Responsibility
2/15/2021	Project Proposal due (Thur)	All
2/22/2021	Eagle Assignment (Thur)	All
3/1/2021	Design Document Check (Mon & Tue) and Design Document due (Thur)	All
	Study datasheets of sensors and microcontroller available and choose hardware required for the project	All
3/8/2021	Design Document Review (Mon & Tue)	All
	Purchase hardware & all parts	
	Test sensors using Arduino board	
3/15/2021	Teamwork Evaluation I (Wed) and Simulation Assignment & Soldering Assignment due (Fri)	All
	Test servos and use Arduino board to control the boat	
	Test sensors’ accuracy and place sensors on the boat to collect data with errors below expectation	
3/22/2021	Collect data for boat’s reaction for certain circumstances in order to reach the destination	
	Design PCB	
3/29/2021	Write program to develop the function and weights of boat’s reaction	
	Test PCB	
	Working on Individual Process Reports	All
4/5/2021	Individual Process Reports due (Mon)	All
	Test the function for boat’s reaction on the boat and fix bugs	
4/12/2021	Assembling all parts on the boat	
	Modify the remote control to switch between people and self navigating if able	

4/19/2021	Mock Demo	
	Mock Demo preparation	
	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	Final paper due (Wed)	All
	Lab checkout and finalize final paper	
	Finalize presentation	

Table (X+3). 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 it 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" [1]. 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] Ieee.org, "IEEE Code of Ethics", 2021. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 17-Feb-2021]

[2] 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.

[3]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.

[4] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html, Centers for Disease Control and Prevention, March 01, 2021