Autonomous Sailboat

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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. It can also be a very dangerous activity with a high possibility of accidents due to the user mishandling the sailboat. Thus we propose the idea of an autonomous sailboat that would be capable of sailing without any input from a user.

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. Operating an autonomous sailboat would not require significant training unlike a normal sailboat and would thus allow people to use sailboats without having to either go through a lengthy training process. There is also 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. Lastly 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 move to given destination from a starting point without help from user
- Boat should be able to switch between RF and autonomous
- Boat should be able to plot a course using data collected from the GPS and sensors

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 three servos used to control the two sails and rudder of the boat. 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. 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

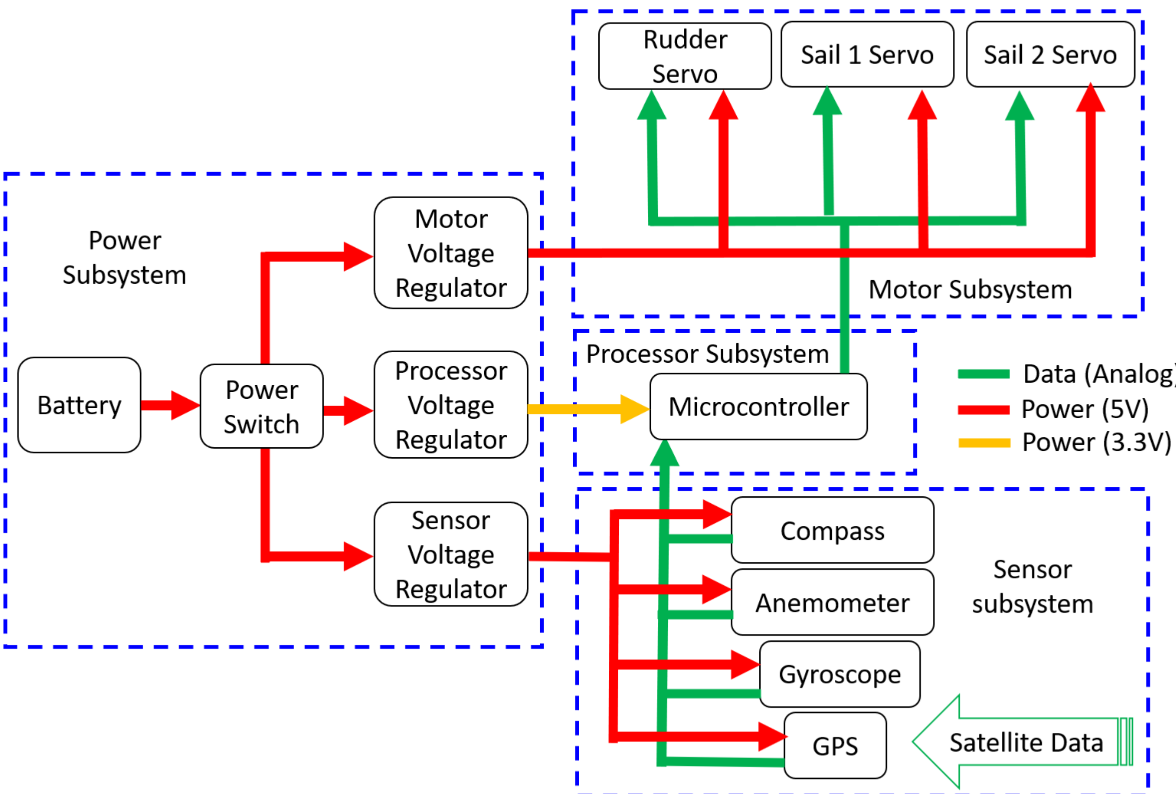

Figure 1: Block Diagram

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.

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

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

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 5 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 5 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

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

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 less than 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.

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 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.

3. Ethics & Safety

3.1 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.

3.2 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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3.3 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.

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.