Compliance

The product complies with FCC standard CFR Title 47, Chapter 1, Part 95 governing the use of Personal Radio Service. The remote-control system included in this design falls under Subpart C specifically, and meets all requirements, including operation frequency, output power, and transmission information type.

The product also complies with FCC standard CFR Title 47, Chapter 1, Parts 15 and 18 governing the use of Industrial, Scientific and Medical Equipment. The onboard data transmission system is included in this category of devices. This system meets all requirements, including operation frequency, output power, and radiated power.

Power Requirements

The product requires a 14.8 V power source that can provide a continuous 22 A current. Ideally, two batteries would be used to provide equal weight distribution on the boat and extended runtime. Batteries with XT60 plugs will allow for easy connections to the power bus. The capacity of the batteries will determine the total runtime. In order to use the battery monitoring system, the batteries will need to consist of 4 cells in series, with a balance plug.

Interfacing

In order to work with this product, the user will need a computer with a USB port. This will allow the user to connect to the Arduino board that is part of the receiver. This device will display the transmitted GPS data and battery voltages.

To modify the autonomous navigation software, the user will need the Raspberry Pi OS.
Follow the instructions in the Software/Raspberry Pi/readme.md to install the Raspberry Pi OS.
Connect the Raspberry Pi to a monitor and connect a keyboard and mouse to the Raspberry Pi.
Boot up the Raspberry Pi and open up a new terminal window.
Follow the instructions here and set up the Pi to communicate through its serial port:
https://projects.raspberrypi.org/en/projects/raspberry-pi-using/9

Performance

Conducting several experiments demonstrated the capabilities of the boat. Running tests for the battery life yielded the results below. The cells were averaged for each battery.

Trial	Average Cell Voltage Start (1,2)	Average Cell Voltage End (1,2)
1	4.19,4.19	N/A
2	4.18,4.18	3.81,3.81
3	4.21,4.21	3.89,3.89

The time it took to deplete the batteries was measured and used to determine the battery life of the system, which was approximately 3 hours.

There are two options for operating the GPS system: with the base station active or without the base station. Conducting tests to determine the accuracy of the GPS data yielded the following results. The experiment that was conducted without the base station demonstrated that the GPS on its own has a precision of a few centimeters and an accuracy of around 1.5 meters. The experiments that used the base station had a higher precision but a lower accuracy of more than 2 meters. This can be improved by entering in the actual location of the base station into the base station receiver. These results are below.

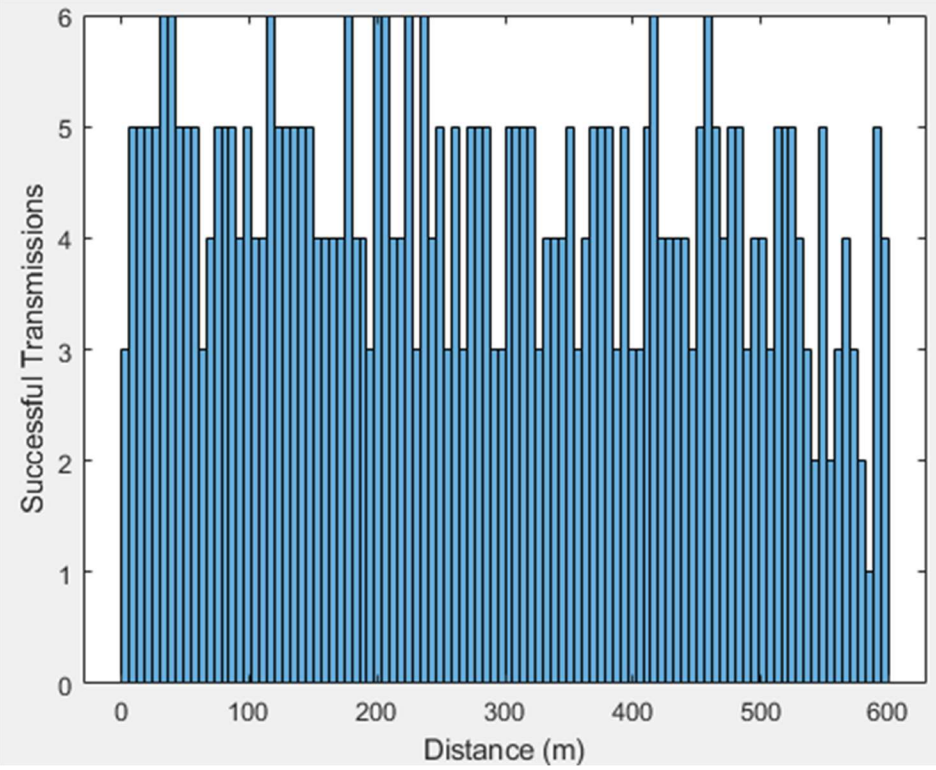
Time	Latitude	Longitude	Distance Traveled	Distance Error
1	35.15380617	-84.934224		0.133968694
2	35.15380633	-84.934224	0.018532489	0.116705191
3	35.1538065	-84.934224	0.018532488	0.099897442
4	35.15380667	-84.93422417	0.023938386	0.076667046
5	35.15380683	-84.93422417	0.018532488	0.060091975
6	35.15380683	-84.93422417	0	0.060091975
7	35.153807	-84.93422433	0.023938387	0.036638523
8	35.15380717	-84.93422433	0.018532488	0.021199134
9	35.15380717	-84.9342245	0.015152338	0.01482599
10	35.15380733	-84.93422483	0.035522192	0.030530496
11	35.15380733	-84.934225	0.015152335	0.045607867

To determine the speed of the boat, a program was used to calculate the speed based on the distance between each consecutive GPS points and the time it took to travel that distance. As shown below, the maximum speed of the boat is approximately 6 m/s.

Calculated Speed		**GPS**	
m/s	**ft/s**	**ft/s**	**knots**
0.853650238	2.80068889	2.72243753	1.613
1.291084294	4.235839549	5.05161533	2.993
1.687061359	5.534976498	5.91408624	3.504
1.762406881	5.782173016	5.81281764	3.444
1.750675217	5.743683317	5.6541635	3.35
1.749804652	5.740827136	5.68623189	3.369
1.791932696	5.879042461	5.84826165	3.465
1.803692507	5.917624504	5.83138355	3.455

1.743540368	5.720275027	5.43643601	3.221
1.50336582	4.932301033	4.66510684	2.764
1.422289608	4.666303045	4.48113555	2.655
1.229897744	4.035096336	3.75875287	2.227
1.120623063	3.676583714	3.54946443	2.103
1.001201636	3.284781255	3.24397082	1.922
0.785945962	2.578562071	3.11063383	1.843
0.918383873	3.013069519	3.05999953	1.813

An experiment was also conducted to determine the maximum range at which data could be transmitted from the boat to the technician onshore. The following plot shows the number of successful transmissions over the distance traveled from the land radio module. Each bin in the histogram represents 6 meters. The final measured distance was about 596 meters. (Note: This histogram is not able to capture the time spent at each distance. For example, more time was spent at the end point, and this allowed for more transmissions to be received than might be expected.)



The autonomous control algorithm was initially implemented using a case-based algorithm that would adjust the movement of the boat when certain conditions were met. This algorithm was improved by replacing the case-based approach with an algorithm that implemented a

feedback loop. The algorithm considers the error in the lateral distance from the desired path and the error of the trajectory angle to adjust the boat's movement. Basic preliminary testing in a lab setting with the boat immobilized showed that this improved algorithm was attempting to make the anticipated corrections to the boat's position toward the first programmed GPS location (a left turn toward the West).