ECE 455 Capstone Design in Electrical and Computer Engineering
Project Report

LOW-FREQUENCY ELECTROMAGNETIC EMITTING AUTONOMOUS BOAT FOR OFFSHORE PLANE RECKAGE RECOVERY

May 7, 2025

Grace Gao
Gavin McGowan
Miles Gansho
Esh K
Department of Electrical and Computer Engineering
College of Engineering
University of Wisconsin-Madison

1 Introduction

This project was developed to support the University of Wisconsin Missing in Action Recovery and Identification Project (UW MIA RIP), a program focused on locating and recovering U.S. service members who went missing during past wars. Many of these service members were lost when aircraft crashed in shallow coastal waters, especially in regions like Southeast Asia. Recovering their remains is difficult because traditional search methods are expensive and not always effective in those environments. Our team set out to design a low-cost, self-powered system that could help identify locations of underwater wreckage and assist with future recovery efforts.

The goal was to build an autonomous surface vehicle (ASV) that could generate a magnetic signal detectable by underwater equipment. This signal can help guide recovery teams to areas where aircraft debris might be buried or difficult to locate visually. We were challenged to stay within a budget of $500, use accessible materials, and build a system that could operate independently in the field.

To meet these goals, we constructed the boat using affordable components like PVC pipes for flotation, foam for stability, and a combination of wooden and polycarbonate boards for mounting electronics. A solar panel powers the system by charging two batteries, which then provide energy to the onboard electronics. These electronics include a flight controller for navigation, a Raspberry Pi for control, and a signal generator and amplifier to drive a coil that emits the magnetic field.

The boat is designed to follow GPS waypoints on its own, while also allowing manual control if needed. Electronics are enclosed in a waterproof box to keep them safe during outdoor testing. We used prebuilt circuit boards where possible to reduce development time and focus on integrating everything into a working prototype.

This report describes the design process, how the system works, and what we learned throughout the semester. We also discuss the challenges we faced and how future teams can continue building on this foundation to improve the technology and support the mission of recovering those who served.

2 Bill of Materials

Include a table with a list of all the materials. Include a description, quantity, cost/unit, total, and URL link for each item.

3 Circuit Schematics

In this section, provide detailed circuit schematics. Here is an example of how you insert a figure:

You can easily reference Fig. 1 (like that).

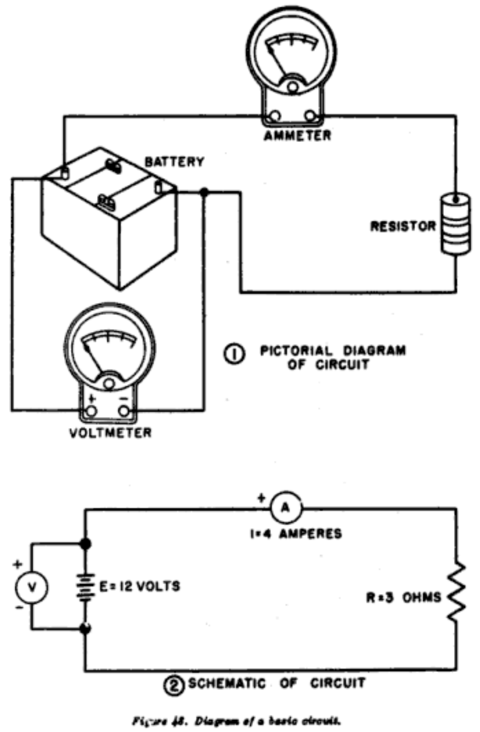

Figure 1: Caption

4 Simulation and Circuit Board Design

Include URL links to any circuit simulation or PCB design files. You can store them on a folder in OneDrive. **Please add me as an owner so I can access the files after your account closes.**

5 Physical Design

The ASV's frame is built from two 4" PVC pipes, each 30" long, mounted in parallel to provide flotation and structural support. A block of closed-cell EPS foam is secured beneath the pipes to improve buoyancy and overall water stability, as well as introducing some rigidity to the system. A closed cell foam was required for underwater use, as open cell foam would absorb water and lose its buoyancy. The foam was cut to fit the frame and held in place with 8 (1/4") bolts and nuts. A 24" wide platform is built on top of the PVC pipes, consisting of two (1/8") MDF wooden sheets for rigidity and a polycarbonate sheet for mounting structural components. Polycarbonate was chosen for its strength and durability, but it is very flexibe. The purpose of the MDF and EPS foam was to provide more of a rigid base, while the polycarbone sheet is used as a very strong mounting surface.

The density of saltwater is approximately 1.025 kg/liter, and we calculated the mass of the ASV to be approximately 14.4 kg. With a safety factor of 25%, our target buoyancy is 18 kg. To ensure the ASV would float, the bouyancy in kilograms is calculated by Buoyancy = Weight of water displaced $\times$ Volume of submerged object.

For a buoyancy calculation, the volume of the ASV is the volume of the EPS foam and the two PVC pipes together. The total volume of the two PVC pipes is 15.64 liters, and the volume of the EPS foam is 19.66 liters, for a combined volume of 35.3 liters. With a saltwater density of 1.025 kg/liter, the total buoyancy of the ASV is $1.025 \times 35.3 = 36.2$ kg.

A waterproof enclosure is mounted at the center of the platform to protect onboard systems. Above it, a 100 W solar panel is held in place by four pairs of custom 3D-printed brackets. The brackets attach to the four corners of the solar panel, and then are attached to the base of the boat via a 10" long (1/4") fiberglass composite rod, which is seated inside of the other piece of the bracket. These brackets were strong enough to hold the solar panel in place, but further iterations could add a set screw into each mount to ensure that the rods do not slip out of the brackets, as it is currently held in place by friction and the weight of the solar panel. These brackets allow for easy removal of the solar panel for ease of transportation. An assembly view of the solar panel mount can be seen below in Figure 2.

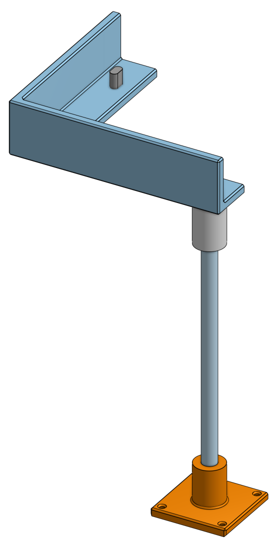

Figure 2: Solar Panel assembly view.

The motor is mounted at the stern using a custom 3D-printed flange. The flange is designed to fit a 1" PVC pipe which connects the motor to the servo, and keeps the PVC shaft vertical during operation. In Figure 3, the flange is shown with the servo inside of a recess to keep the servo protected from the elements. The servo's center of rotation is aligned with the center of the PVC pipe, allowing them to rotate together.

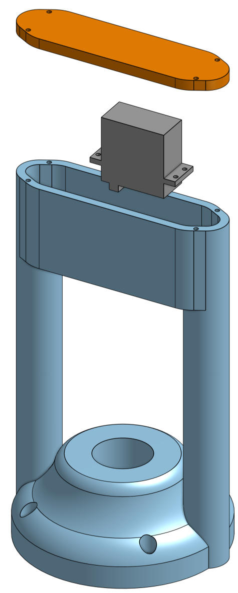

Figure 3: Flange Assembly View.

There are custom 3D printed brackets on either side of the PVC pipe to attach the motor to the PVC pipe on the bottom, and to attach the servo to the PVC pipe on the top. To keep the motor in place, two 3D printed bushing were designed to fit the PVC shaft, which keep the motor at a constant depth. The bushing rotate above the flange, but the coefficient of friction between the two is low enough to allow the motor to rotate freely. This design choice ensures that the motor remains securely in place during operation, even in rough water conditions. The choice of a friction based bushing and flange system was chosen over a bearing system to reduce cost and complexity, as well as to allow for easy replacement of parts if needed. The bushing is designed to be easily replaceable, allowing for quick maintenance and repairs.

Material choice for 3D printed parts was given careful consideration to ensure the ASV is lightweight, low cost, but also resistant to wear. The 3D printed flange is made from ASA, a material known for its excellent UV resistance and mechanical properties. All other parts were made from PETG, which is a strong and durable material that maintains its structure underwater, making it suitable for the ASV's environment. The use of these materials ensures that the ASV can withstand the rigors of outdoor use while remaining lightweight and cost-effective. Structural parts were printed using 5 perimters and 25% gyroid infill, which provided a good balance of strength and weight, while also keeping costs relatively low. The entire project used under 750g of PETG, and around 250g of ASA, which can be purchased for around $15. Further iterations could likely halve this number.

6 Electrical

The ASV is powered by two 12.8V 8Ah LiFePO4 batteries connected in parallel. A 100W solar panel mounted above the electronics enclosure outputs power to an MPPT controlller, which continuasly regulates the voltage and current to maximize the power output from the solar panel. The charge controller adjusts the variable DC that comes in from the solar panel to a constant voltage and current that is suitable for charging the batteries.

Power is distributed through three buck converters that step the 12.8V battery voltage down to 5V. One converter powers the Raspberry Pi, another supplies the SpeedyBee F405 V4 flight controller and GPS, and the third is dedicated to the servo motor. All components are placed inside a waterproof enclosure without mounting hardware.

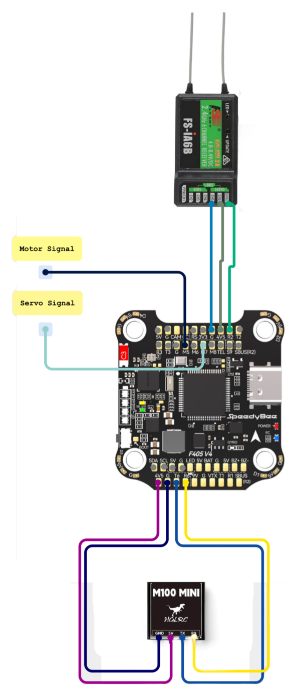

Figure 4: Schematic of the SpeedyBee F405 V4 flight controller and its connections.

The SpeedyBee F405 V4 flight controller runs iNav firmware and handles both GPS waypoint navigation and motor control. It outputs PWM signals to the brushed DC motor and rudder servo and receives location data from a GPS module. The GPS is soldered directly to UART6 on the flight controller: TX from the GPS is connected to RX6, and RX from the GPS is connected to TX6. A FlySky FS-iA6B receiver is soldered directly to the RX2 pad on the flight controller for SBUS communication, enabling manual RC override when needed.

To generate a magnetic field, a 40 Hz sine wave is created by a prebuilt signal generator and passed through a power amplifier. The amplified signal drives a large copper coil wrapped around the boat's structure, producing a low-frequency magnetic field detectable by submerged sensors.

The magnetic field B at the center of a circular coil is given by:

$$B = \frac{\mu_0 N I}{2R} \tag{1}$$

where:

- $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{T \cdot m/A}$ is the permeability of free space,
- N is the number of turns in the coil,
- I is the current through the coil,
- R is the radius of the coil.

This equation demonstrates that the magnetic field strength increases with more turns or higher current and decreases with a larger coil radius. The 40 Hz frequency was chosen to ensure good penetration through water with minimal signal loss, making it suitable for detection by submerged sensors.

All electrical connections are made using soldered wires. Power and signal lines are routed manually inside the enclosure. Signal and high-current paths are physically separated to minimize noise. Fuses are installed on the battery output lines to protect critical components from short circuits.

The electrical system is simple, modular, and designed for ease of repair and future upgrades. Components can be swapped or rewired without requiring full system disassembly.

7 Coding

In this section, please provide links to your code or directly pasted in the report. You can create subsections in LaTeX like this:

7.1 Ultrasonic Sensor Code

7.2 Motor Code

Please write a paragraph summarizing the operation of the code. You should cite any references or resources that you used to make the code. You can conveniently cite sources like this: [1] and [2]. LaTeX is really nice for writing out equations too:

$$V = \oint \overrightarrow{E} \cdot d\,\overrightarrow{l} \tag{2}$$

You can use this tool to help: https://webdemo.myscript.com/. Also this: https://mathpix.com/image-to-latex. You can also easily refer to equations like this: 2.

8 Operating Instructions

In this section, please provide detailed, step by step instructions on how to operate your project (what buttons you have to push, different display readings, etc).

9 Troubleshooting

If your device is not fully working, describe exactly what is not working and the steps you have taken to fix it. If you are still unsure of the problem, carefully describe your next steps you would take if you had time.

10 Testing and Experiments

Here you can talk about your experimental results and include plots of any relevant data. The plots should be of professional quality. Use Python, MATLAB, or OriginLab. Excel in the engineering world is not professional.

11 Future Work

In this section, please discuss future work that needs to be completed.

References

[1] M. Manteghi, "A navigation and positioning system for unmanned underwater vehicles based on a mechanical antenna," 2017, pp. 1997–1998.

[2] A. Sheinker, B. Ginzburg, N. Salomonski, L. Frumkis, and B. Z. Kaplan, “Localization in 3-d using beacons of low frequency magnetic field,” *IEEE Transactions on Instrumentation and Measurement*, vol. 62, pp. 3194–3201, 2013.