ECE 455 Capstone Design in Electrical and Computer Engineering
Project Report

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

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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. The ASV works in tandem with an underwater autonomous vehicle (AUV), which has a 3-axis magnetometer on it that can sense the magnetic field generated by the ASV. This signal can help guide recovery teams to areas where aircraft debris might be buried or difficult to locate visually. We were challenged to build an ASV that could be built on a budget a budget of $500, uses accessible materials, fits in a suitcase, and 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:

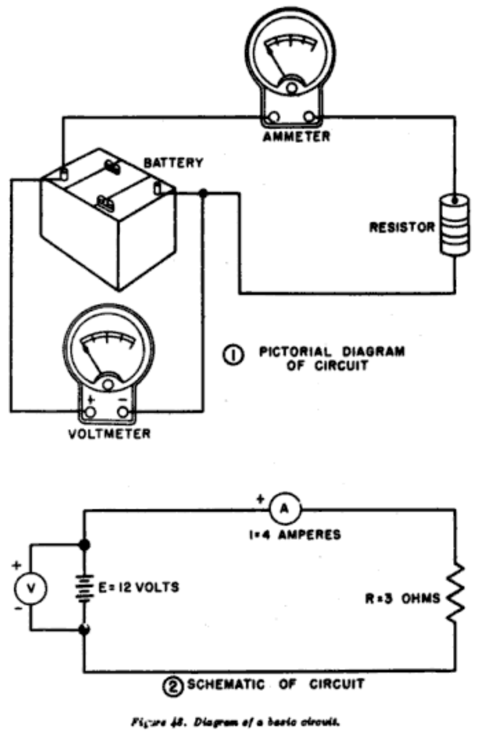

Figure 1: Caption

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

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 struts for rigidity and a polycarbonate sheet for mounting structural components. Polycarbonate was chosen for its strength and durability, but it is very flexible. The purpose of the MDF and EPS foam was to provide more of a rigid base, while the polycarbonate 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 buoyancy 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.

5.1 Motor Mounting and Flange Design

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.

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

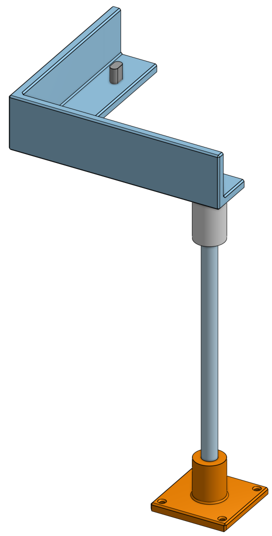

Figure 2: Solar Panel assembly view.

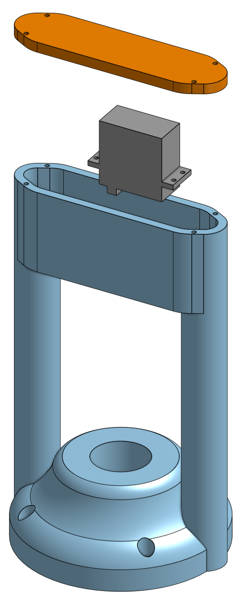

Figure 3: Flange Assembly View.

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 perimeters 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. Refer to the appendix for all isometric views of 3D printed parts.

6 Electrical

6.1 Power Distribution

The ASV is powered by two 12.8V 8Ah LiFePO4 batteries connected in parallel. A 100 W solar panel mounted above the electronics enclosure outputs power to an MPPT controller, which continuously 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. The MPPT controller outputs the current through Anderson Powerpole connectors, which are tied into the circuit via a 12p junction terminal block, which distributes power to the rest of the system. The use of Anderson connectors allows for easy connection and disconnection of the solar panel. The batteries are connected with F2 spade connectors, also allowing for easy connection and disconnection.

Power is distributed through two voltage regulators that step the 12.8V battery voltage down to 5V. One converter supplies the SpeedyBee F405 V4 flight controller and GPS, and the other is dedicated to the servo motor. All components are placed inside a waterproof enclosure without mounting hardware. Initially, the voltage regulator was a buck converter on a PCB, but was replaced with a voltage regulator on a protoboard. The buck converter was not able to handle the current draw of the Speedybee, which caused it to overheat and fail.

6.2 Flight Controller and GPS

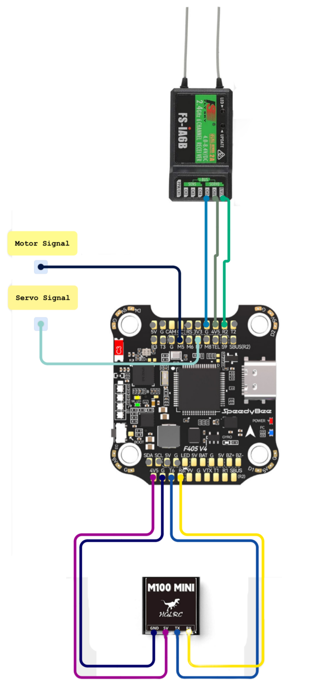

Figure 4: Schematic of the SpeedyBee F405 V4 flight controller and its connections.

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

Follow these steps to safely operate the Autonomous Surface Vehicle (ASV):

1. **Power On:**
    - Ensure the batteries are charged. The solar panel provides slow passive charging and should not be relied on for full charge.
    - Inside the electronics enclosure, connect the battery wires. Each lead is clearly labeled for polarity—connect positive to positive and negative to negative.
    - Verify that LEDs on the flight controller (SpeedyBee F405 V4) illuminate, indicating power to the system.
2. **System Initialization:**
    - Wait a few seconds for the flight controller to initialize.
    - Confirm GPS lock. The GPS module's LED (typically solid or blinking depending on model) indicates satellite connection.
3. **Manual Control (Optional):**
    - Turn on the FlySky transmitter. Ensure the receiver on the ASV is powered and paired.
    - When connected, you can use the transmitter to manually control throttle and rudder. This is useful for testing or override.
    - Manual control is not required for autonomous operation but is available at any time.
4. **Autonomous Mission Launch:**
    - Use iNav Configurator to upload or verify the waypoint mission.
    - Use iNav Configurator to verify basic telemetry such as GPS status, battery voltage, and input channel readings.
    - Confirm that all connections are secure and components are functioning.
    - Arm the vehicle using the transmitter or iNav interface. The motor should begin spinning, and the boat can now be manually operated or left to drift as designed.
5. **Magnetic Field Activation:**
    - The signal generator automatically powers on with the system and begins outputting a 40 Hz sine wave.
    - The output is amplified and fed to the coil. If needed, use a clamp meter to verify that current is flowing.
6. **Monitoring:**
    - Observe the ASV visually or via iNav telemetry if connected.

- Monitor GPS LED status and waypoint progress to confirm correct operation.

7. **Return to Home and Shutdown:**
   - Use the transmitter or iNav to switch to "Return to Home" mode. The ASV will autonomously return to its starting location.
   - Once the vehicle has returned and stopped moving, disarm it using iNav or the transmitter.
   - Disconnect the battery by separating the labeled leads.
   - Verify that all indicator LEDs are off and reseal the electronics enclosure to maintain waterproofing.

Before each deployment, double-check polarity labels, confirm dry connections, and verify GPS and flight controller status.

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

There is a considerable amount of work that can be done to improve the ASV, as this was a prototype. During our design phase, we were limited by time and budget constraints, but future teams can build on our work to create a more robust and effective systems, especially if they can learn from our mistakes. The following sections will discuss some of the most important areas for improvement, including physical design, electronics, software, and testing.

11.1 Physical Design

Several improvements to our prototype's mechanical structure should be considered for future ASV iterations:

- **Optimized Part Geometry for Weight & Strength:** Our 3D-printed components were designed under tight time constraints and saw only a few iterations. If budget allows, future teams should perform wear tests on the 3D printed parts to see where they fail, and then redesign to optimize for weight and strength. There were a few prints where it was clear that the part was acceptable, but could use an easy redesign to improve the functionality. For example, the flange was one piece, but if it was split into two pieces, it would be easier to print and assemble.

- **Bracket Offset & Mounting Security:** The solar panel (27.5" wide) extended beyond our only one of four bolts could engage, leading to instability. This could be solved by redesigning the bracket geometry or increasing the offset distance to ensure all fasteners seat properly. Additionally, the panel support rods currently rely on friction and panel weight to stay in their mounts. Introduce captive set-screws or spring-loaded clips in each bracket to mechanically lock the rods in place, preventing slippage under harsh conditions

- **Platform Material Stiffness:** Our polycarbonate sheet platform flexed under load. A stiffer base, such as treated wood, aluminum, or even a thicker sheet of polycarbonate, would reduce deflection, improve stability, and better support mounted components.

- **Waterproofing at Fastener Joints:** To preserve disassembly ease, we avoided epoxy and ran bolts through PVC fixtures, which allowed water ingress. Future designs should apply marine epoxy or silicone sealant at critical joints, or employ O-ring-sealed fastener assemblies, to balance rigidity, waterproofing, and maintainability. The mounting holes may have to be redesigned to accommodate this, as the current design doesn't allow for easy disassembly after the epoxy is applied.

11.2 Electronics

Several lessons from our prototype's wiring and power distribution should guide future iterations:

- **Modular Motor Connections:** Our motors were hard-wired via fully soldered leads, making removal and replacement cumbersome. Future designs should employ waterproof, keyed connectors inside the electrical box to allow rapid motor swap-outs for maintenance or upgrades without desoldering.

- **Reverse-Polarity Protection:** During our demo, the battery pack was accidentally connected backwards, risking damage to electronics and breaking our ESC. Future designs should incorporate reverse-polarity protection—using an ideal-diode IC or MOSFET-based blocker in the main power feed—to automatically guard against destructive reverse connections and prevent user error.

- **Overcurrent & Short-Circuit Safeguards:** We lacked fusing or electronic breakers on our high-current rails. Future designs should include appropriately rated fuses or resettable circuit breakers on each major branch (motor, batteries, electronics) to isolate faults and protect wiring and components.

- **Power Distribution Board (PDB):** Our prototype relied on wiring into a terminal junction bock, which increased bulk cabling and complicated troubleshooting. Future designs should use a custom PDB with integrated connectors, breakers, and status LEDs, with silk-screened labels marking each output (e.g. "Motor," "MPPT," "Servo"). A dedicated PCB, designed from the ground up, could consolidate off-the-shelf power components (amplifiers, signal generators, buck converters) into a single compact board, significantly reducing wiring complexity and system footprint.

11.3 Software

11.4 Testing

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.