ENG 102: Sink or Swim

From Theory to Practice

Homework 3

Dang Hung Duong[1], Dinh Viet Hoang[2], Le Nhat Minh[3]

[1]220218, [2]220019, [3]220196

November 12, 2024

1 Boat Design and Engineering Decisions

1.1 Design Overview

We designed a miniature boat with the primary goals of stable control, navigation, and speed. The boat's main body is a rectangular box, measuring 6 cm in height, 8.9 cm in width, and 15.6 cm in length. These dimensions balance stability and compactness, ensuring a low center of gravity essential for smooth navigation.

To enhance the boat's hydrodynamics, we added a 3D-printed pointy head resembling half a cone (figure 1). The head extends 7 cm from the base to the tip and stands 4 cm high. This streamlined design minimizes water resistance, allowing the boat to cut through water more efficiently, maintain steady speed, and reduce turbulence. We positioned the two propellers as close together as possible to avoid collisions (figure 4). This arrangement improves maneuverability and provides balanced thrust distribution, crucial for precise control. By reducing the distance between the propellers, we minimize differential torque, ensuring the boat stays on course and responds effectively to navigational adjustments.

Although adding a shaped hull to the bottom could improve hydrodynamic performance, we opted for a flat bottom (figure 2) to keep the weight of 3D-printed components manageable. The flat bottom offers a stable platform, particularly in calm waters, simplifying construction while still supporting balanced control.

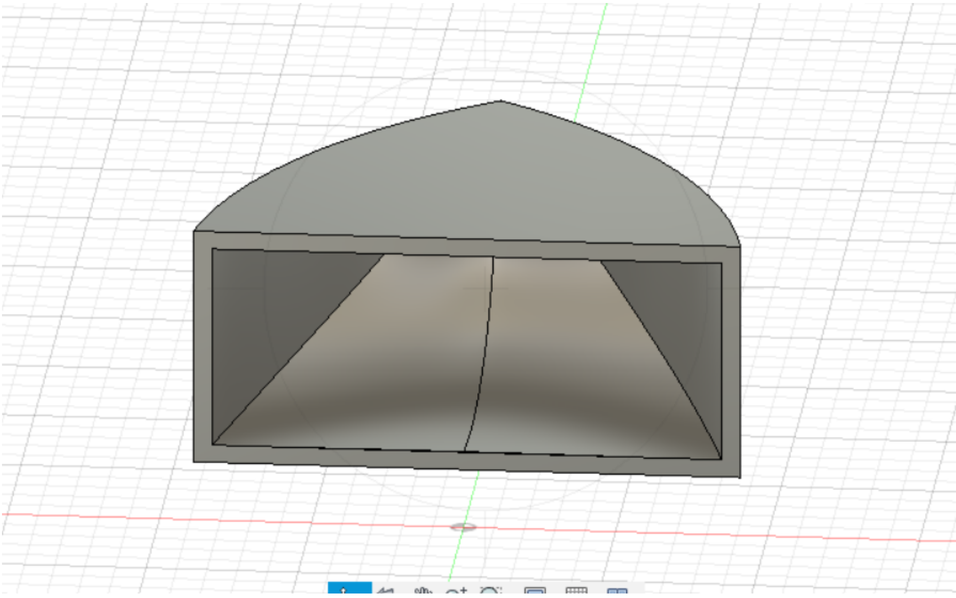

Figure 1: 3d-printed Head

The boat's final weight of 501.5 grams allows it to sit well in the water without becoming too heavy to maneuver efficiently. This balanced weight ensures that the boat maintains stability and responds appropriately to control inputs—crucial for achieving both stable navigation and speed.

Overall, our design choices—from dimensions and shape to propeller placement and weight—work together to create a boat that navigates smoothly and maintains stability. This careful planning reflects an understanding of boat design principles and their impact on performance, resulting in a functional and efficient miniature boat.

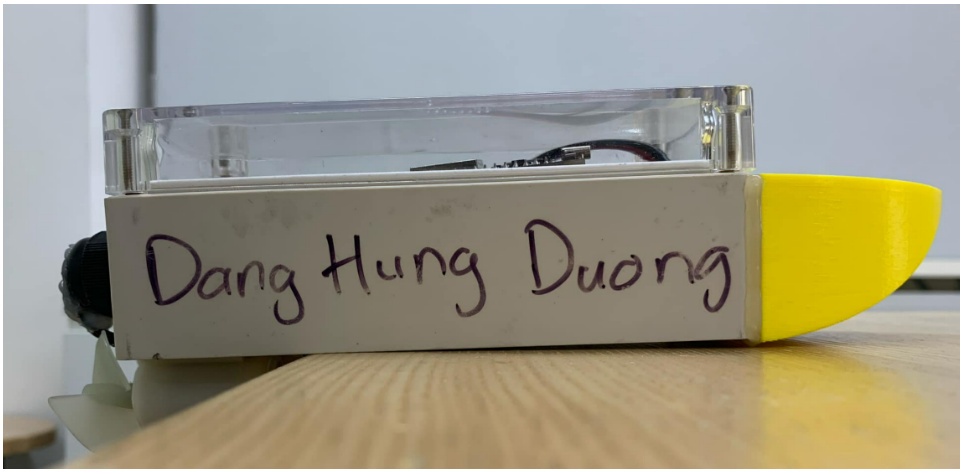

Figure 2: Boat's Side View

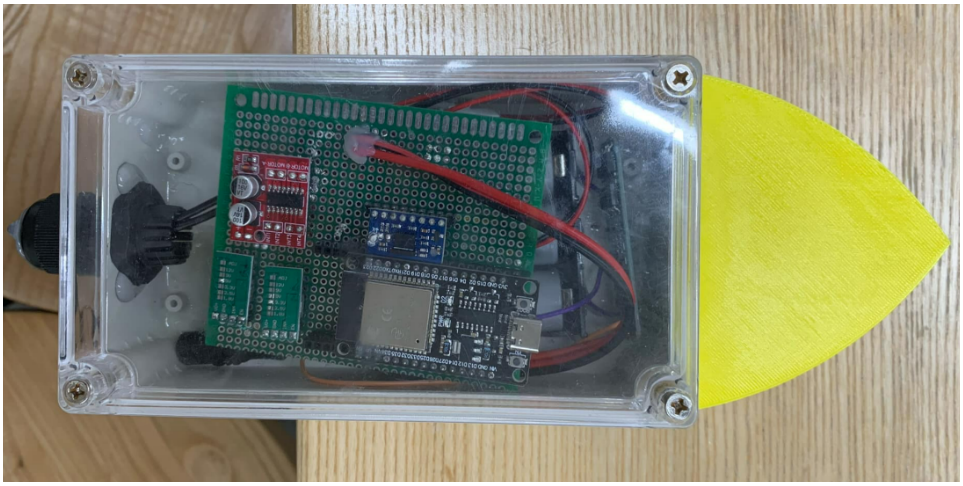

Figure 3: Boat's Top View

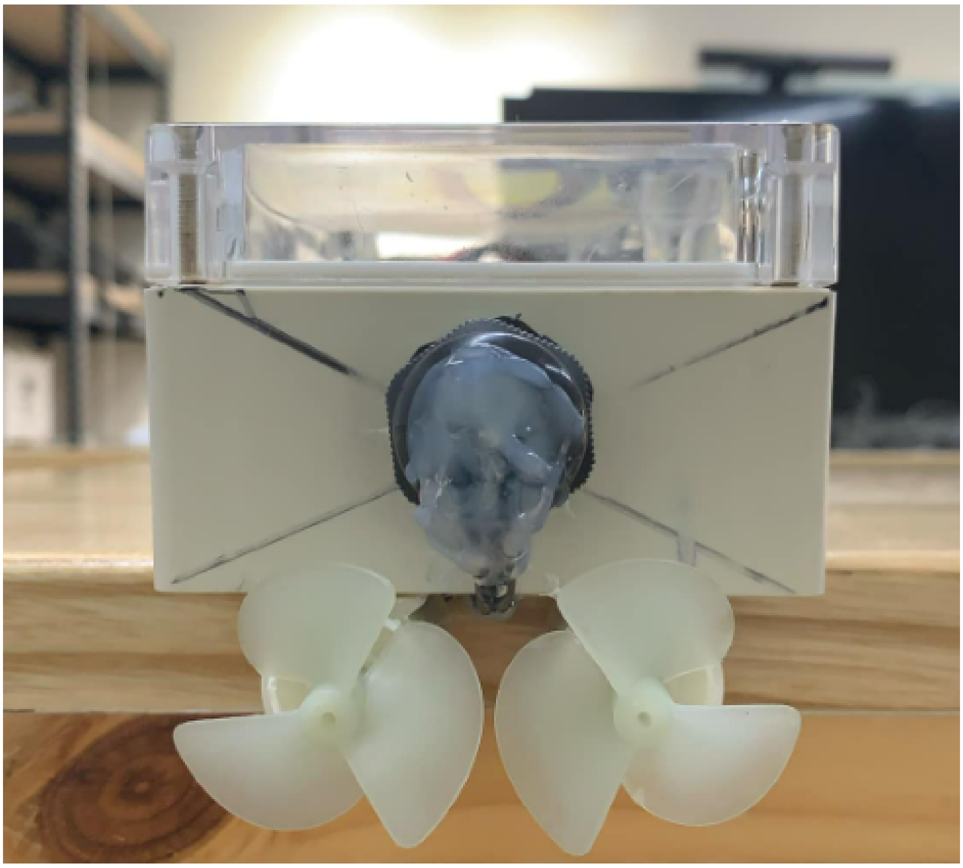

Figure 4: Boat's Back View

1.2 Control System

1.2.1 Both Motors Forward

When turning on the button “Both motors on” command, the boat moves forward. Each motor runs in the same direction, which makes the boat run straight forward. The code of both motors is HIGH (figure 5).

boat_control_base.ino

```
void handle_bothMotorsOn() {
  moveMotor1(1);
  moveMotor2(1);
  server.send(200, "text/plain", "Both Motors are ON");
}

void moveMotor1(int direction) {
  digitalWrite(M1_Left, HIGH);
  digitalWrite(M1_Right, LOW);
}

void moveMotor2(int direction) {
  digitalWrite(M2_Left, HIGH);
  digitalWrite(M2_Right, LOW);
}
```

Figure 5: Codes for Both Motors Forward

1.2.2 Turning Mechanism

- Right turn: The boat turn will turn right when only the left motor moves forward and the motor on the right stops making the boat turn right. Only the motor on the left is set to HIGH.
- Left Turn: Only the motor on the right moves forward, creating the leftward movement. Only the right motor is set to HIGH.

```
void moveMotor1(int direction) {
  digitalWrite(M1_Left, HIGH);
  digitalWrite(M1_Right, LOW);
}
```

```
void moveMotor2(int direction) {
  digitalWrite(M2_Left, HIGH);
  digitalWrite(M2_Right, LOW);
}
```

Figure 6: Turning Mechanism Codes

1.2.3 Stopping Mechanism

Pressing the “stop” command will lead both motors to stop, stopping the boat; both pins are set to LOW (figure 7).

```
void stopMotor1() {
  digitalWrite(M1_Left, LOW);
  digitalWrite(M1_Right, LOW);
}

void stopMotor2() {
  digitalWrite(M2_Left, LOW);
  digitalWrite(M2_Right, LOW);
}
```

Figure 7: Stopping Mechanism Codes

1.3 Circuit Diagram

The components needed for the boat's circuit (figure 8) are:

- ESP-WROOM-32: A powerful microcontroller with Wi-Fi and Bluetooth capabilities. It is the brain of the system, processing sensor data and controlling motors to maintain stability and achieve navigation goals.
- 2 DC Motors: These provide the boat's movement.
- Dual Channel H-Bridge (MX1508): Controls the direction and speed of the DC motors. By adjusting voltage, it makes motors move forward, backward, or stop.
- 2 DC Voltage Step Down Modules: A 5V module powers the MX1508, while a 3.3V module powers the ESP-WROOM-32 and BNO055 sensor. These ensure components operate within their required voltage range.
- BNO055: An absolute orientation sensor providing data (tilt, rotation, heading) to the ESP-WROOM-32. This data is essential for stable navigation, allowing the system to adjust motor speeds and directions to maintain balance and follow the desired path.

- Power Supply with 3 Batteries and 3S Protection Board (12.6V 20A): Provides energy to all components. The protection board ensures safe battery charging and discharging, preventing overcharging, over-discharging, and excessive current draw.

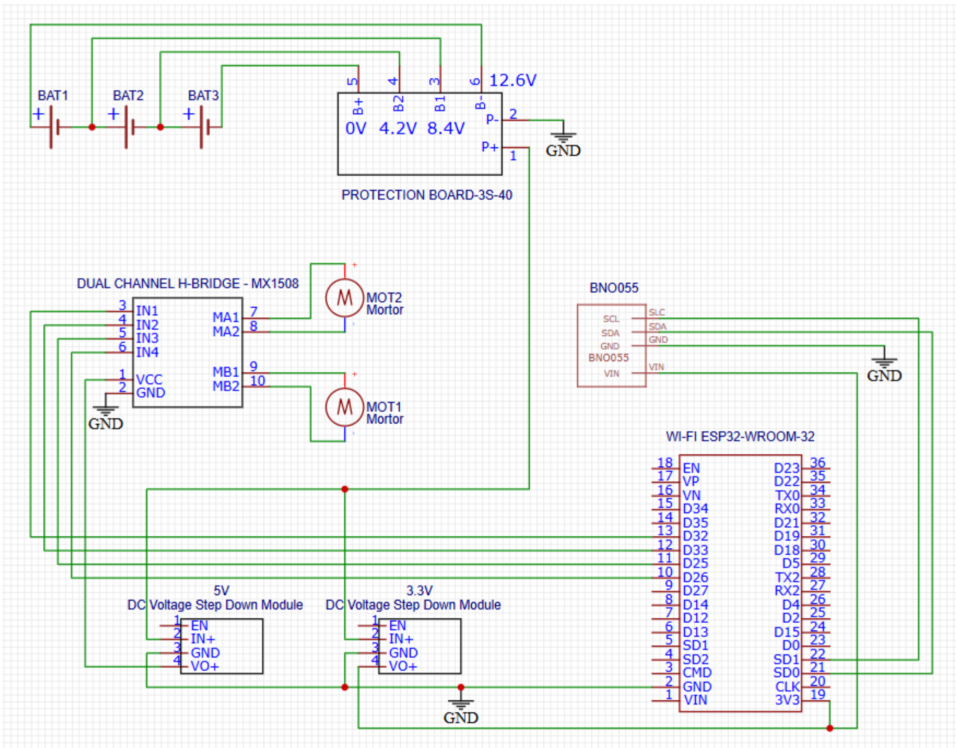

Figure 8: Boat Schematic

Each circuit section plays a vital role in navigation and movement control. The ESP-WROOM-32 processes sensor data and controls motors via the H-Bridge. Voltage step-down modules ensure correct power distribution. The BNO055 sensor provides essential orientation data, while the power supply keeps everything running smoothly.

2 Model Prediction and Real-World Testing - Physics and Control Aspect

2.1 Predictions and Modeling

We have,

$$F_{drag} = \frac{1}{2} \times \rho_{fluid} \times k \times A \times v^2$$

$$v = v_0 + a_0 \times \Delta t$$

$$F_{net} = F_{thrust} - F_{drag}$$

$$a = \frac{F_{net}}{mass}$$

where:

- k is the drag coefficient
- A is the cross-sectional area
- v is the velocity
- a is the acceleration

Time (s)	Acceleration	Velocity (m/s)	Distance (m)	Drag force (N)
0	0,7185628743	0	0	0
0,2	0,6760195411	0,1437125749	0	0,0213142099
0,4	0,5583157176	0,2789164831	0,02874251497	0,08028382547
0,6	0,4043231079	0,3905796266	0,08452581158	0,1574341229
0,8	0,2607345532	0,4714442482	0,1626417369	0,2293719889
1	0,1538514411	0,5235911588	0,2569305865	0,282920428
1,2	0,08552745392	0,554361447	0,3616488183	0,3171507456
1,4	0,0458585953	0,5714669378	0,4725211077	0,3370248438
1,6	0,02409227577	0,5806386569	0,5868144953	0,3479297698
1,8	0,01251826153	0,585457112	0,7029422266	0,353728351
2	0,006466682801	0,5879607643	0,820033649	0,3567601919
2,2	0,003330442991	0,5892541009	0,9376258019	0,3583314481
2,4	0,001712541882	0,5899201895	1,055476622	0,3591420165
2,6	0,000879891891	0,5902626979	1,17346066	0,3595591742
2,8	0,000451894273	0,5904386762	1,2915132	0,359773601
3	0,000232033963	0,5905290551	1,409600935	0,359883751

Figure 9: Simulation Data

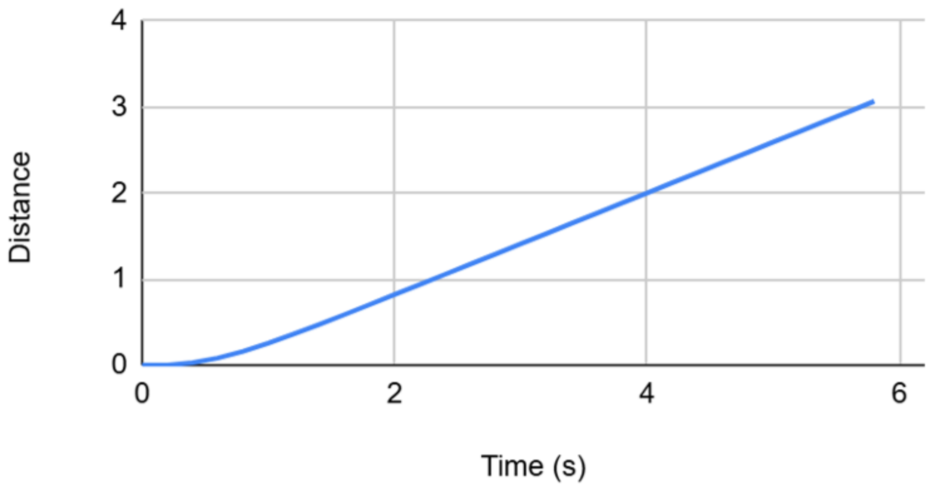

Figure 10: Time vs Distance on Simulation

2.2 Testing and Comparison

Distance	Predicted Time (s)	Actual Time (s)	Differences
1	2.4	2.8	0.4
2	4	4.5	0.5
3	5.8	6.5	0.7

Figure 11: Predictions vs Reality

After testing the mini boat in the real world, there are a few differences compared to our initial predictions (figure 11). Some possible reasons for these discrepancies are:

- Water Resistance (Drag): The design aims to reduce water resistance with a pointy head and flat bottom. However, real-world conditions can introduce more drag than expected. Turbulence, waves, and water surface quality significantly affect the boat's speed and stability.
- Motor Efficiency: DC motor efficiency varies in real-life conditions. Power supply consistency, motor load, and wear can lead to performance differences. Underpowered motors or increased drive system friction may result in less thrust than expected.
- Battery Performance: Battery charge levels affect performance. Low charge can lead to slower speeds, less responsive control, or frequent disconnections.

- Weight Distribution: Even slight imbalances in component placement can impact stability and maneuverability, potentially leading to less stable navigation.
- Hull Shape: While the flat bottom provides simplicity and stability in calm waters, it may struggle in rougher conditions. The lack of a contoured hull can result in more resistance and instability in choppy waters.