ECE 445

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Project

Design Document

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1 Introduction

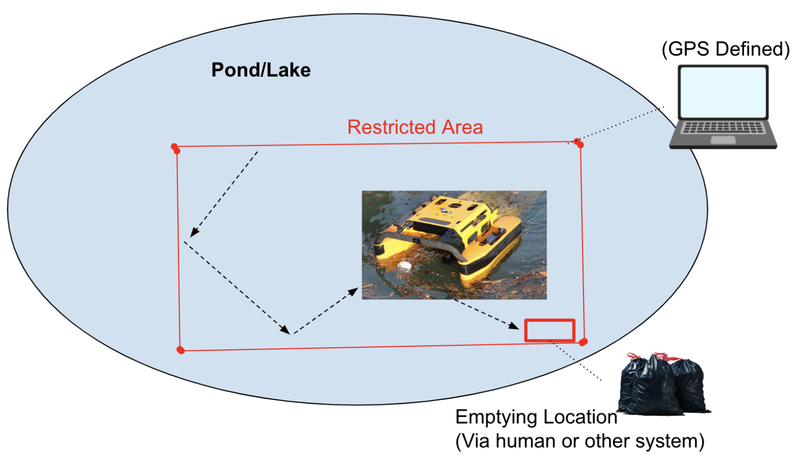
1.1 Problem:

Water pollution from man-made debris, poor waste management, and invasive species threatens aquatic ecosystems and public health. Traditional cleanup methods, such as manual removal or large-scale collection efforts, are often inefficient and labor-intensive. They fail to address the persistent presence of small trash, which can have harmful effects on aquatic habitats. To us, this highlights the need for an automated solution. As environmental concerns continue to grow, there is a pressing need for innovative solutions to protect marine ecosystems.

1.2 Solution:

We propose a robotic system that autonomously skims water surfaces to collect small floating debris within a predefined area. The lightweight robot will float and roam a body of water to collect material in a skimming net for disposal or analysis. It will use GPS and sensors for efficient coverage and steering, allowing for it to return to a set of coordinates for emptying. Additionally, the system will include water quality sensors, specifically a turbidity sensor, to monitor pollution levels. The turbidity sensor will be connected to LED lights to provide real time feedback on water clarity: a green light for normal conditions and an orange light for high pollution levels. Our system can be tested in a nearby lake or pool on a small scale to evaluate both its collection capabilities and its ability to provide water quality data.

1.3 Visual Aid:

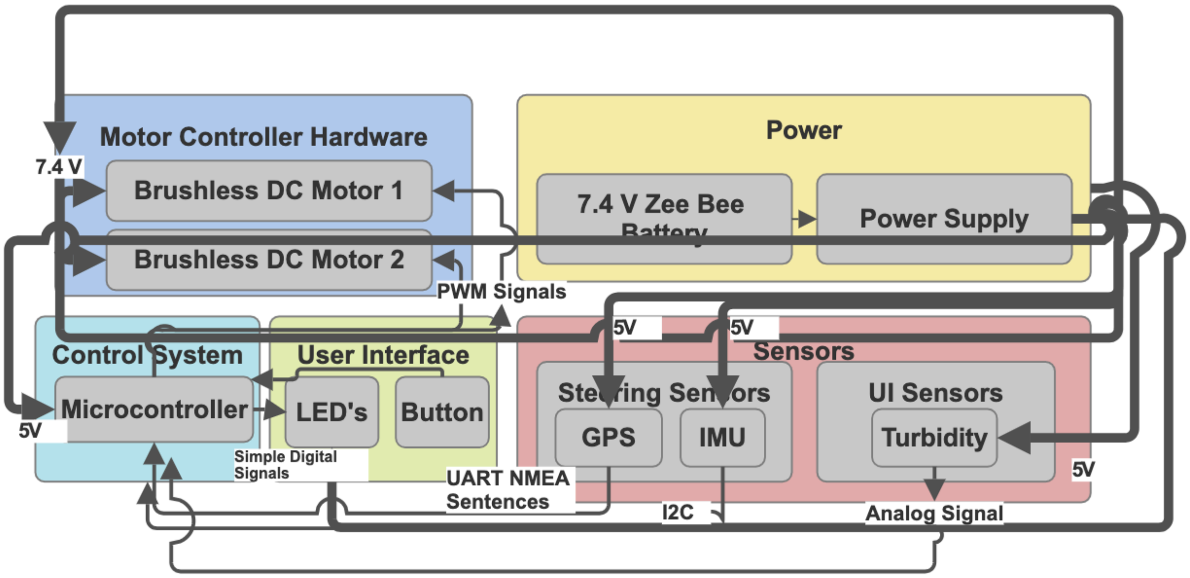


1.4 High-Level Requirements List:

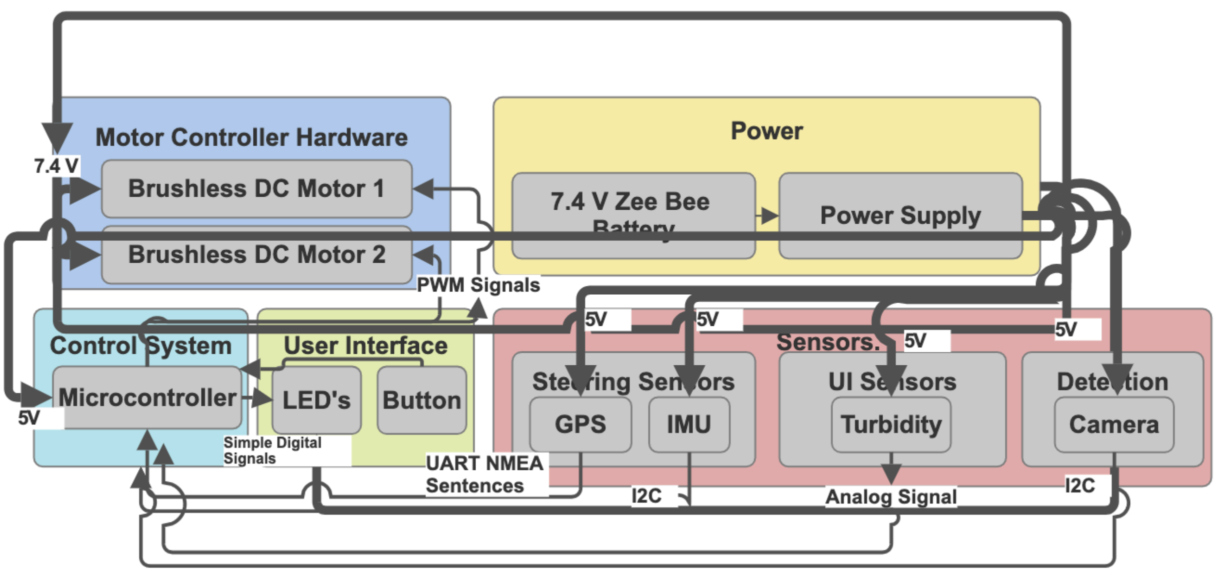
1. Autonomous Navigation
   The robot must be able to autonomously navigate a predefined water source without crossing boundaries that we will set. It should detect these boundaries using GPS and IMU data with an accuracy of 10 feet to show proper coverage of the water surface.
2. Debris Collection and Return:
   The robot must detect and collect floating debris using its skimming net. Every 10 minutes, it should be able to hold and transport at least 250 grams of debris and return to a predefined coordinate with the same accuracy of 12 feet.
3. Water Quality Feedback:
   The system must monitor water clarity using a turbidity sensor. Real Time feedback will be provided by LED lights, where green indicates acceptable water quality (the turbidity is below 50 NTU) and orange signals unacceptable water quality (the turbidity is at or above 50 NTU).
4. Reach goal: If we have time, we can add pollutant object detection to steer towards floating debris captured via a camera in real time. This would require incorporating an OpenCV Convolutional network into our pre-existing control algorithm. Being able to identify and steer the chassis towards floating trash within 5 feet of the front of the robot would be a stretch goal.

2 Design

2.1 Block Diagram:



Block Diagram



Block Diagram (with reach goal add-ons)

2.2 Physical Design:

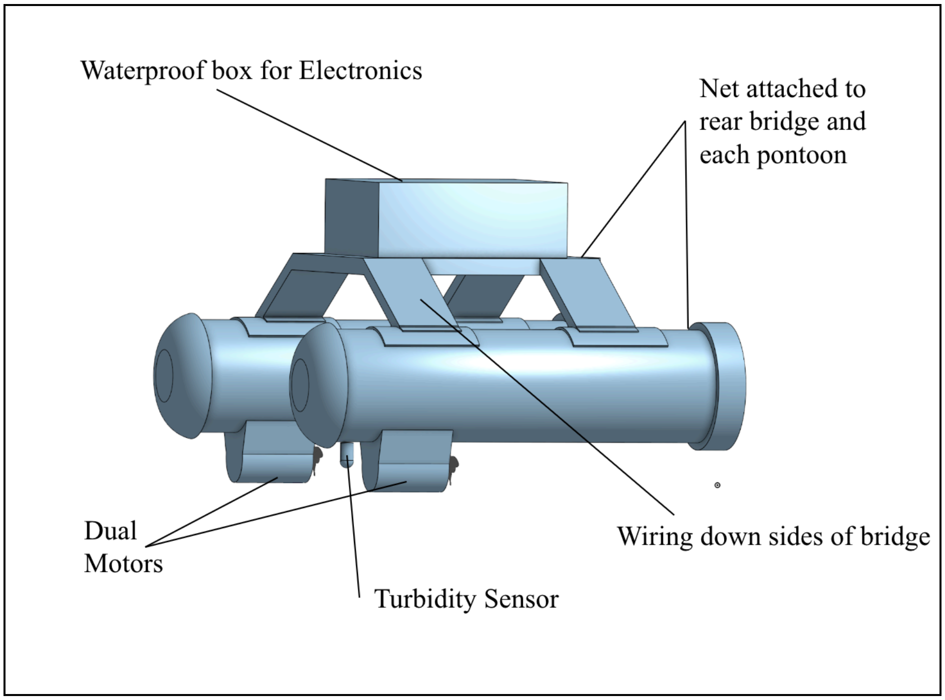


Figure 1: *3D model of chassis*

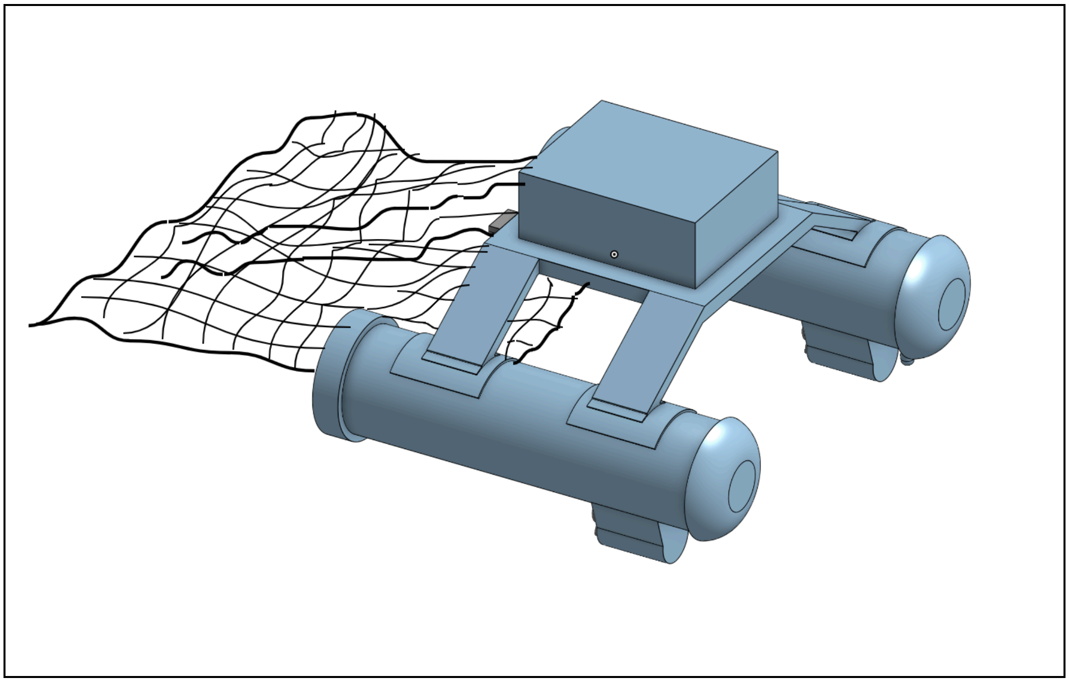


Figure 2: *3D model of chassis with net*

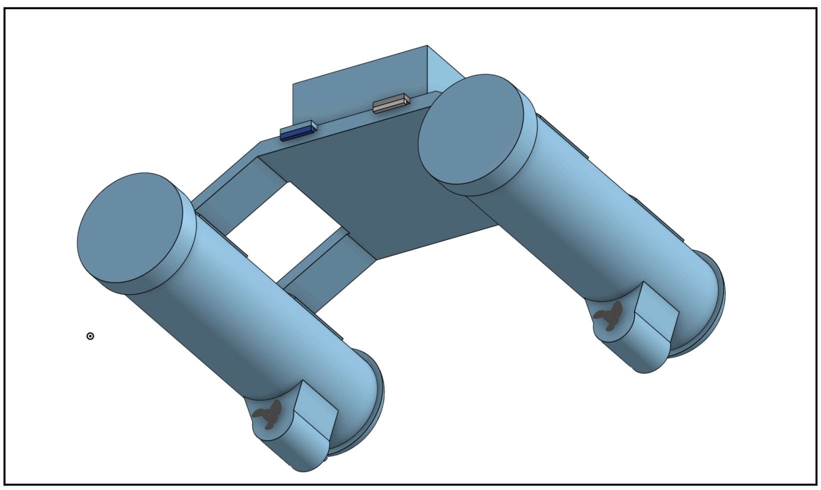


Figure 3: *3D model of chassis, bottom view*

2.3 Subsystem Overview/Requirements:

2.3.1 Subsystem 1: Motor Control Hardware

The motor hardware consists of dual brushless DC motors with rotor attachments for water. We have selected the LICHIFIT RC Jet Boat Underwater Motor Thruster 7.4V 16800RPM CW,

which should have sufficient torque for our slow-moving purpose. This will be attached to our power system and regulated by our microcontroller through PCB connections.
Requirements:

- Motor control hardware must be able to propel chassis with loaded net at at least ~1mph
- Motors must be able to work within water surface without short circuiting

Requirements	Verification
• Motor control hardware must be able to propel the chassis with loaded net at at least ~1mph	• Mount dual motors on built chassis and propel at full power in pool and observe movement with time • Or, mount dual motors on test floating bed with 3.5 lb weight to simulate inertia
• Motors must be able to work within water surface without short circuiting	• Partially submerge the motors in water to ensure they run • Try again with the motors fully submerged and ensure that they don’t short circuit

2.3.2 Subsystem 2: Autonomous Steering

The actual steering will be done using the motor differential between the 2 motors. This will also be attached to the power system and microcontroller. A random walk with boundary correction control algorithm will be implemented much like how an autonomous vacuum cleaner operates. It will be roaming the expanse of its body of water, adjusting the angle to avoid the gps-defined boundaries of the body of water. This will have to use a GPS Module Receiver, Navigation Satellite Positioning NEO-6M, and a Sparkfun 9-Dof IMU to determine when the front of the robot is nearing these edges. Additionally, after 10 minutes, the robot will return to a specified set of coordinates using its GPS and IMU information in order to dispose of the contents of the net.

Requirements	Verification
• The robot must be able to accurately track its location with an error range of 1 feet	• Perform a location test by checking the longitude and latitude of the robot via the microprocessor vs on a phone • Perform the same test but while the robot is moving to ensure the accuracy
• Must be able to control the left and right motors	• Place marks on the motor fins and record them in slow motion to ensure a difference in speed

independently to create a differential when turning is required	in the 2 motors ● Place the robot is a controlled environment with still water to prevent the tide from interfering from the test ● Test the robot by performing a 90° turn from a still position ● Test the robot by performing a 90° turn while moving ● Test the robot by performing a 180° turn and returning to the initial position as a stress test ● Repeat with no weights attached up to 250 grams of weight in 50 gram increments as a comparison to its weight when full of waste collected.
● The robot must be able to stay within the boundary with an error rate of ± 12 feet	● Move the robot from inside the defined boundary to outside boundary manually ● Check when exactly the robot determines itself to be outside the boundary ● Ensure the distance from the boundary is less than 12 feet

2.3.3 Subsystem 3: Power Systems

The 7.4 V 1500 mAh Zeee battery should be sufficient to run all the sensors, motors, and LED's. The power system must regulate the variable battery output voltage to 5 Volts for the microcontroller, LED and sensor uses. The components will be housed in a waterproof case to protect the electronics from any water damage.

Requirements:

- Power system must be able to supply 1500mAh to the rest of the system continuously at 7.4 V +/- 0.1V

Requirements	Verification
● The battery power system powers the motors at the command of the autonomous steering subsystem. The commands may be to set duty cycle, set current, or set RPM.	● Ensure the system is at an idle state such that the motors are not spinning. Then, send a command to motors from the board microcontroller to either set a nonzero duty cycle, current, or RPM, then confirm both motors begin spinning.

• Must be able to regulate battery voltage to power components throughout the discharge cycle of the battery and cut out power when voltage drops too low.	• Connect voltage supply and regulator, ensure voltage supply is 7.4 Volts using a multimeter at motor inputs, and 5 volts elsewhere. Ensure output voltage drops to 0V when the input voltage drops to somewhere between 7.2 and 7 volts.

2.3.4 Subsystem 4: Chassis and Storage

The main chassis will be made mostly of 3D printed parts and lightweight materials like PVC pipes and styrofoam. We will use a standard plastic debris net which has an entrance mounted at the end opening of the floating device, with the rest of the net trailing behind.

Requirements	Verification
• Must stay afloat for at least 5 minutes with the max load of 250 grams while moving	• Place robot in a controlled environment with minimal waves to test if the robot will stay afloat • Retest with 250 grams of added weight • Retest without the waiting but with the robot constantly moving • Retest with the added weight • Retest all of the above in a place with waves

2.3.5 Subsystem 5: Turbidity Monitoring Subsystem

The turbidity monitoring subsystem is responsible for measuring water clarity using a DFRobot SEN0189 turbidity sensor, connected to a microcontroller that processes the sensor's analog output and controls ultra-bright orange and green LEDs for visual feedback. The sensor measures the turbidity by analyzing the scattering of infrared light caused by particles in the water. The microcontroller maps the sensor's output to a corresponding NTU (Nephelometric Turbidity Unit) value. When the water's turbidity value is below 50 NTU, the ultra-bright green LED will then display a green light to indicate normal water conditions. When the turbidity sensor exceeds the 50 NTU value, the ultra-bright orange LED will switch to orange to indicate elevated levels of water pollution. The system operates on a continuous feedback loop, updating the turbidity readings every 5 seconds to ensure real-time data and response. This subsystem is essential for environmental monitoring and immediate feedback during water cleanup operations.

To ensure visibility in outdoor conditions, ultra-bright LEDs will be used. These LEDs, which are rated at 1.85cd for the green LED and 2.75cd for the orange LED, provide better visibility under direct sunlight. This allows the user to easily see the feedback in both daylight and low-light conditions. The turbidity sensor operates on 5V DC with a rated current of 30mA. It is tested for reliable readings from 0 NTU (clear water) up to 100 NTU, focused on practical environmental conditions.

Requirements	Verification
• The turbidity sensor must detect water clarity with an accuracy of ±10 NTU, updating every 5 seconds.	• Ensure the microcontroller is correctly programmed to interpret the sensor's analog output as an NTU value.\ • Use the formula NTU = 1.873 + (0.518 X Total Suspended Solids in mg/L) to establish the relationship between flour mixture in water and NTU. • Test with water samples of varying NTU values (e.g., 45, 50, 55 NTU) and verify accurate readings within the ±10 NTU threshold. Use diluted water as a base (NTU = 0). • Verify the sensor's readings at multiple points across the 0 to 100 NTU scale to ensure accuracy is consistent. • Use a stopwatch to confirm that the system updates the turbidity readings every 5 seconds.
• The ultra-bright LEDs must be visible during the day and switch to green when turbidity < 50 NTU and orange when turbidity ≥ 50 NTU.	• Connect the ultra-bright orange and green LEDs to the microcontroller and verify correct operation through simulated NTU levels. • Submerge the turbidity sensor in water samples with < 50 NTU and verify that the green LED is illuminated. • Submerge the turbidity sensor in water samples with ≥ 50 NTU and verify that the orange LED is illuminated. • Measure the response time of the LED when changing between green and orange as the turbidity crosses the 50 NTU threshold, making sure the change happens within 5 seconds.
• The subsystem must function continuously for at least 5	• Perform a 5 minute continuous operation test in a controlled water environment.

minutes without the latency exceeding 5 seconds.	• Introduce turbidity changes during the test and verify that the system adjusts the ultra-bright LEDs illuminated color based on the detected turbidity levels, with no delays beyond 5 seconds. • Monitor the microcontroller's real-time data processing and verify the LED response matches the readings of the turbidity sensor. Verify the system functions without interruptions or noticeable latency.

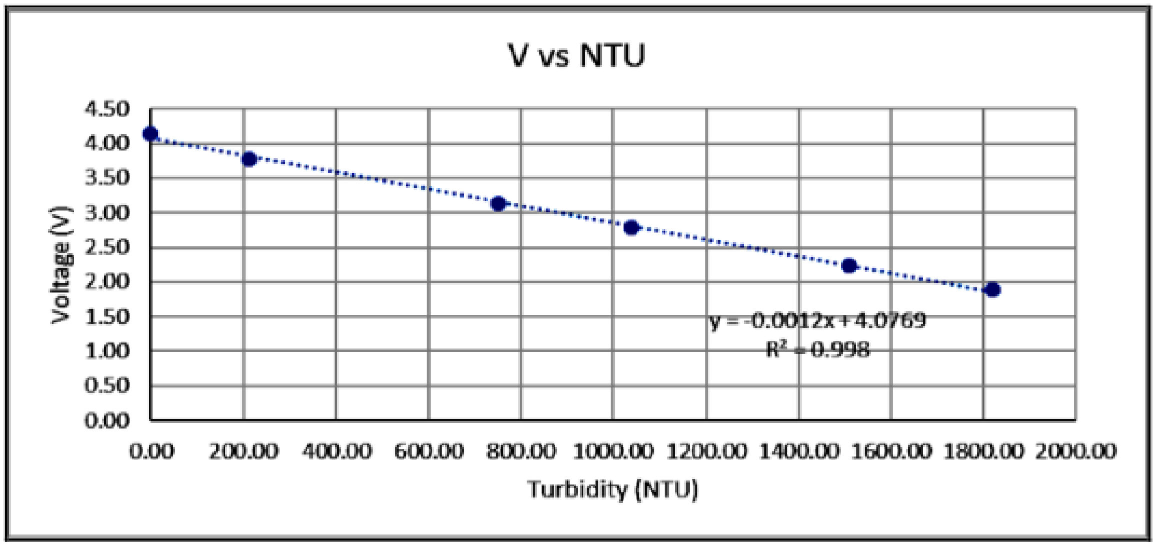


Figure 4: *Graph of Voltage value vs. Turbidity [8]*

2.4 Software Design

2.4.1 Turbidity Monitoring Subsystem Software Design

The turbidity monitoring subsystem measures water clarity by using the analog output from the turbidity sensor. As water turbidity increases, the sensor's voltage output decreases. The microcontroller reads this analog signal, converts it into a voltage, and then calculates the NTU (Nephelometric Turbidity Unit) value. The system processes this NTU data and updates the LEDs to indicate whether the turbidity level is above or below the set threshold.

The system processes the sensor data every 5 seconds and updates the LEDs based on the calculated NTU values. The goal is to provide real-time feedback on the turbidity of the water, with visual feedback from the LEDs indicating whether the turbidity is above or below the threshold.

2.4.2 Turbidity Monitoring and LED Control Process Outline

The software reads the analog output of the turbidity sensor, converts the sensor's voltage to NTU, and compares it to a threshold of 50 NTU. Based on this comparison, the system activates the appropriate LED to indicate water clarity:

1. Read the analog output from the turbidity sensor.
2. Convert the sensor's analog value to voltage using:
   a. Voltage = (Analog Value x (5.0/1024))
3. Convert the voltage to NTU (Nephelometric Turbidity Unit) value using the equation from Hakimi and Jamil [8]:
   a. Turbidity = ((4.0769 - V)/0.0012)
4. Compare the NTU value to the threshold of 50 NTU.
5. Compare the NTU value to the threshold of 50 NTU.
   a. If NTU < 50: Illuminate Green LED.
   b. If NTU ≥ 50: Illuminate Orange LED.
6. Update the LEDs based on the NTU comparison.
7. Wait for 5 seconds: The system will loop every 5 seconds to guarantee real-time response.
8. Repeat.

2.4.3 Autonomous Steering Subsystem Software Design

The Autonomous steering Subsystem is designed to ensure the robot stays within the declared boundaries and roams around the declared area randomly much like a roomba, it must also return to a determined location to dump all the trash after 10 minutes and must do all of these tasks autonomously. We will be using a random walk approach with boundary correction, meaning the system will be continuing in a straight line most of the time to optimize trash trapping, and only initiate a turn when the system deems it is near a boundary, at which point it will make a fixed angle turn, then repeat. Each time the robot successfully returns to base, it will enter an idle state where the motors will deactivate. Once the robot's net is emptied, returned to the water and the pushbutton pressed, the robot will once again begin its cleaning procedure.

A major part of this subsystem is the designation of the boundary of the robot as it is the most vital in ensuring the robot does not get beached or run into obstacles. This will be done on a external device and will be transferred to the device before its deployment

2.4.4 Autonomous Steering Software Flowchart

Below is a high-level flowchart for the Autonomous steering control system:

- Start: The robot is in an idle state, waiting for the system to be activated via button press to start its mission.
    - If Start signal received: transition to *Straight-line Navigation*
- Straight-line Navigation: Robot moves forward in a random direction within the boundary.
    - Heading Angle is 0 degrees; L/R motors same speed
    - Localize own location using GPS; Compare to nearest point of boundary
    - If GPS boundary distance < 12 feet: Transition to *Boundary Detected*
    - If timer > 10 minutes: Transition to *Return to Base*
- Boundary Detected: The robot detects that it is near or crossing the boundary.
    - Generate a random return angle (angle between the aimed heading and the opposite of current heading) between 30° and 180°, in the left or right direction chosen randomly, to make a course correction; Adjust L/R differential accordingly to slowly (within 12 seconds) make the course correction
    - After turning period, If GPS boundary distance < 12 feet: Transition to *Boundary Detected*
    - After turning period, If timer > 10 minutes: Transition to *Return to Base*

- Stuck Detected (Desirable for field testing): The robot recognizes that it is making repeated boundary corrections or is oscillating between boundaries, indicating it might be stuck in a small area.
    - If the robot has made four consecutive corrections within a short time period (55 seconds), turn off the L/R motors, return to *Start* state.

- Return to Base: The timer has reached the 10-minute limit, and the robot must return to the base location.
    - Calculate the straight-line path to the base using the robot's current GPS position and the known base coordinates; Adjust L/R accordingly to slowly (within 12 seconds) make the course correction
    - Heading Angle is 0 degrees; L/R motors same speed
    - If GPS boundary distance < 12 feet: Transition to *Boundary Detected*
    - Once the robot reaches the base, transition to *Start.*

2.5 Tolerance Analysis:

The main physical component with possible tolerance faults that could hinder movement and control are the two motors. For motor tolerance analysis, we first estimated the thrust produced by the Dual LICHIFIT Underwater Propellers. With a maximum efficiency power output of 78 W and a torque of 0.041 N·m, the joint motors operate at approximately 2891 RPM under load. Using a simplified thrust calculation, assuming a low-speed advance velocity of 1

m/s, the motor can generate an estimated thrust of 78 N. Given that our design should weigh a maximum of 3.5 lbs, we can provide a basic estimate of the drag force we need to overcome, using a simplified drag equation: $F_d = (1/2)C_d\rho A v^2$
This comes out to about 15 N. Therefore, the combined pushing power of the motors are capable of providing significantly more thrust than is required to propel the boat. Therefore, we conclude that the motors will sufficiently meet the propulsion needs of our system.

For the steering timing tolerance analysis, we first calculated the boat's moment of inertia, approximating it as 0.0554 kg·m², based on a mass of 3.5 lbs, estimated dimensions of 1.5 feet by 1.5 feet and the formula for rectangular body moment of inertia : $I = (1/12)M(L^2 + W^2)$ With the two motors in opposite directions providing a maximum torque of 0.082 N·m, we calculated the resulting angular acceleration to be approximately 1.48 rad/s² using $\alpha = \tau/I$. We now use the angular displacement formula: $\theta = (1/2)\alpha t^2$ to find the time for an arbitrary angular displacement. To achieve a 30-degree turn, it would take only about 0.814 seconds from the motors actuating. This quick response demonstrates that the system has more than sufficient torque to effectively turn the boat by 30 degrees while in motion, ensuring adequate steering control.

2.6 Cost and Schedule

2.6.1 Cost analysis:

Description	Manufacturer	Quantity	Extended Price	Link
GRAVITY: ANALOG TURBIDITY SENSOR SEN0189	DFRobot	1	$9.90	Link
ULTRA BRIGHT GREEN LED 1.85CD 572NMC 2.1V 85MW	MULTICOMP PRO (BOUGHT VIA ECE SUPPLY CENTER)	1	$0.41	Link
ULTRA BRIGHT ORANGE LED 2.75CD, 625NM, 2.1V	MULTICOMP PRO (BOUGHT VIA ECE SUPPLY CENTER)	1	$3.29	Link
LICHIFIT RC Jet Boat Underwater Motor Thruster	LICHIFIT	1	$23.99	Link

7.4V 16800RPM CW CCW 3-Blades Propeller				
MakerFocus GT-U7 GPS Module Satellite Navigation Positioning GPS Receiver	MakerFocus	1	$12.99	Link
7.4 V 1500 mAh battery	Zeee	1	$24.29	Link
SparkFun 9DoF IMU Breakout-ICM-20948 Low power I2C & SPI enabled 9 axis motion tracking	SparkFun	1	$18.50	Link
Arduino Uno Rev3	Arduino	1	$27.60	Link

2.6.2 Schedule:

Week	Task	Person
1: 10/7	Order Parts/Make BOM	Zach
	Begin prototyping PCB	Dylan
	Research control algorithm specifics	Malay
	Communicate with Machine shop to specify requirements for chassis build	Dylan
2: 10/14	Pass PCB Audit and Order Board	Dylan
	Start Pseudo-coding control algorithm mock-up	Zach

	Look into options for GPS mapping of an area	Malay
3: 10/21	Connecting drive motors to microcontroller using breadboard and getting movement	Malay
	Connecting GPS/IMU to microcontroller using breadboard and getting data represented	Malay
	Start developing and testing control algorithm to guide system within GPS boundaries	Dylan
	Start developing and testing control algorithm to guide system to predefined GPS deposit point and then back	Dylan
	Connect turbidity to microcontroller using breadboard and getting data represented; Level represented on LED	Zach
4: 10/28	Working with battery/any extra components to control power supply for the entire system; battery life testing	Zach
	PCB conversion of all breadboard prototypes	Dylan
	Pass PCB Audit and Order Board (Second Round)	Malay
	Scout out Possible Testing locations (Ponds/lakes/Pools) in person	Zach
5: 11/4	Integrate with floating chassis and net structure	All members
	Start Field tests and refine control algorithm	All members
6: 11/11	Continue field tests and test demo-requirements under different conditions	All members
	Aesthetic-based corrections	All members

7: 11/18	Mock Demo Week	All members
8: 11/25	Fall Break	
9: 12/2	Final Demo	All members
10: 12/9	Final Presentation	All members

3 Discussion of Ethics and Safety

The development of our Water-Skimming Robot involves several important ethical considerations and safety measures to guarantee it is both effective and responsible in its environmental impact. We want to address ecological concerns while following safety standards during development, testing, and any future operation.

From an ethical perspective, our goal is to create a robot that actively contributes to the reduction of pollution in water without introducing new risks to the aquatic ecosystems. To achieve this goal, we have taken steps to ensure the robot's operation does not harm local wildlife. The skimming mechanism, for example, has been designed to avoid trapping fish or other animals. Furthermore, we want to make an effort to avoid using components that could contribute to more pollution. We use only the components necessary for keeping the robot lightweight and functional, while also staying within our budget. We're being careful about our choices so we avoid creating more waste while we clean up the water.

In terms of safety, our system must follow safety standards to prevent injuries or malfunctions during testing and future use. All electronics will need to be waterproofed to avoid possible short-circuiting, and the battery will need to be managed carefully to avoid overheating. We also need to comply with the regulations regarding the use of remote vehicles on public water bodies, such as those set by the U.S. Coast Guard. We want to make a robot that not only helps clean up the environment but does so in a safe and responsible way.

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