ECE 445/ME 470 Senior Design ZJUI

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Design Document

Submarine Model

By

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1. Introduction

1.1 Problem

The innovation of our "submarine model" UAV expands the boundaries of traditional UAV functionality, offering a versatile and transformative solution for various industries and applications that require underwater exploration, monitoring, and intervention capabilities. This versatile UAV can provide students with unique learning experiences, expanding their scientific knowledge and skills through field exploration and data collection. For instance, students can utilize the UAV for activities such as underwater ecosystem research and water quality monitoring, deepening their understanding of marine and aquatic environments.

1.2 Solution

Our solution is to divide each function of the submarine into different subsystems: stability subsystem, power subsystem, remote-control subsystem, and mechanical subsystem. Each subsystem is designed, experimented, and verified separately, and finally these subsystems are merged and coordinated and integrated using MCUs to realize the complete submarine functions. In the stability subsystem, we will use the traditional stepper motor and silk rod to form a transmission to push the injector to realize the control of submarine sinking and floating. In the power subsystem, we will use variable speed motors and propellers to drive the submarine. For the remote-control subsystem, we will use a remote controller to transmit direction commands to the submarine, and a Bluetooth module to transmit the data received from the sensors back to the user. For the mechanical subsystem, we will use acrylic tubes for the hull of the submarine and 3D printed parts to fix all the components of the hull. For the sensor subsystem, we will use different sensors to detect the three-dimensional velocity, acceleration and underwater depth position of the ship's body, forming a closed-loop control system. Compared with the existing and market submarine models like [2], our solution can better improve the motion performance of the submarine, make the ship better suspension function, and better simulate the function of the submarine. The existing submarine model in market can not float stably and easily in the water. We utilize our control system and stability subsystem to make better performance.

1.3 Visual Aid

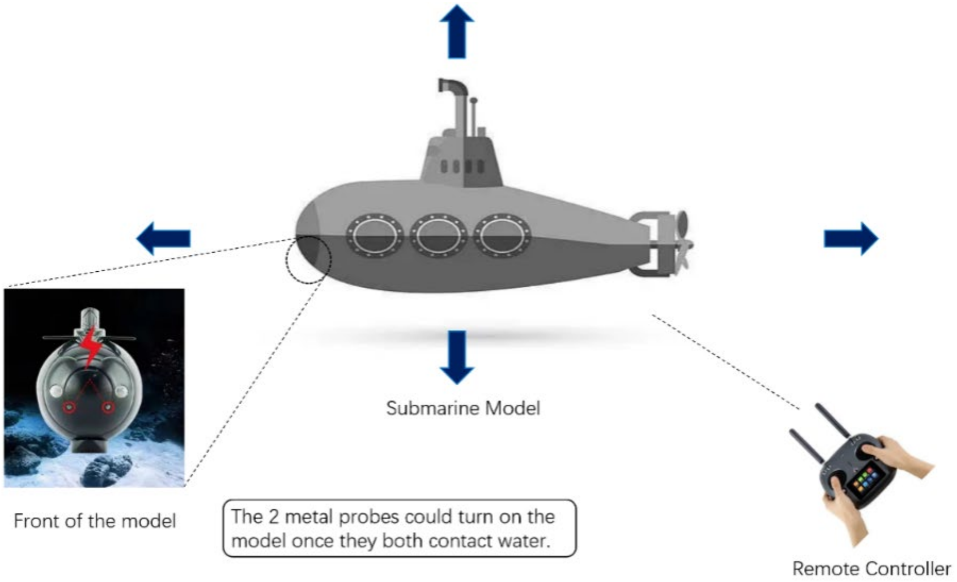

Figure 1 Visual Aid for Submarine Model [1][2][3]

1.4 High-Level Requirements

- The submarine model shows good waterproof performance (i.e. the device is still dry after staying underwater for 10min).
- Considering the attenuation of TEM wave in the water, the signal from the remote controller can be received by the model at least 50cm underwater and within 1m from the remote controller (i.e. the submarine model shows obvious respond to the remote controller).
- The submarine model can float at a certain height (within 0.5m) stably, sink to 0.5m depth and resurface.
- The submarine model can move according to the commands from a remote controller (i.e. move at least 20cm front, back, left, and right at a speed that is recognizable with human eyes).

2. Design

2.1 Block Diagram

Figure 2 shows that our submarine can be divided into mainly four subsystems. The Mechanical subsystem serves as the submarine model's foundational component, functioning as the outer shell and providing waterproof capabilities. The drainage component of the mechanical part is closely linked to the Stability subsystem, which is responsible for the submarine's vertical movement. Additionally, the mechanical part's propellers are closely interconnected with the Power subsystem, which handles the propulsion of the submarine. The Control subsystem serves as the central hub that connects and coordinates the operation of all other subsystems. It plays a crucial role in managing the functioning of various modules and receiving remote commands. Once the Microcontroller Unit (MCU) receives control instructions, the Control subsystem can command the directional movement of the Power subsystem and ensure the stability of the submarine by calculating and controlling the Stability subsystem. Stability control is paramount for submarines, directly influencing the balance and maneuverability of the submarine underwater. Achieving buoyancy aims to ensure that the submarine can maintain a specific depth in the water and stabilize its floating when required. Effective control of the buoyancy adjustment system is crucial to maintaining the submarine's balance in the water, allowing it to descend to the desired depth while maintaining a suspended state. We also need to ensure that the submarine can descend rapidly and in a controlled manner when necessary. By adjusting the ballast tank and other systems, the submarine can achieve descent to the desired depth [2].

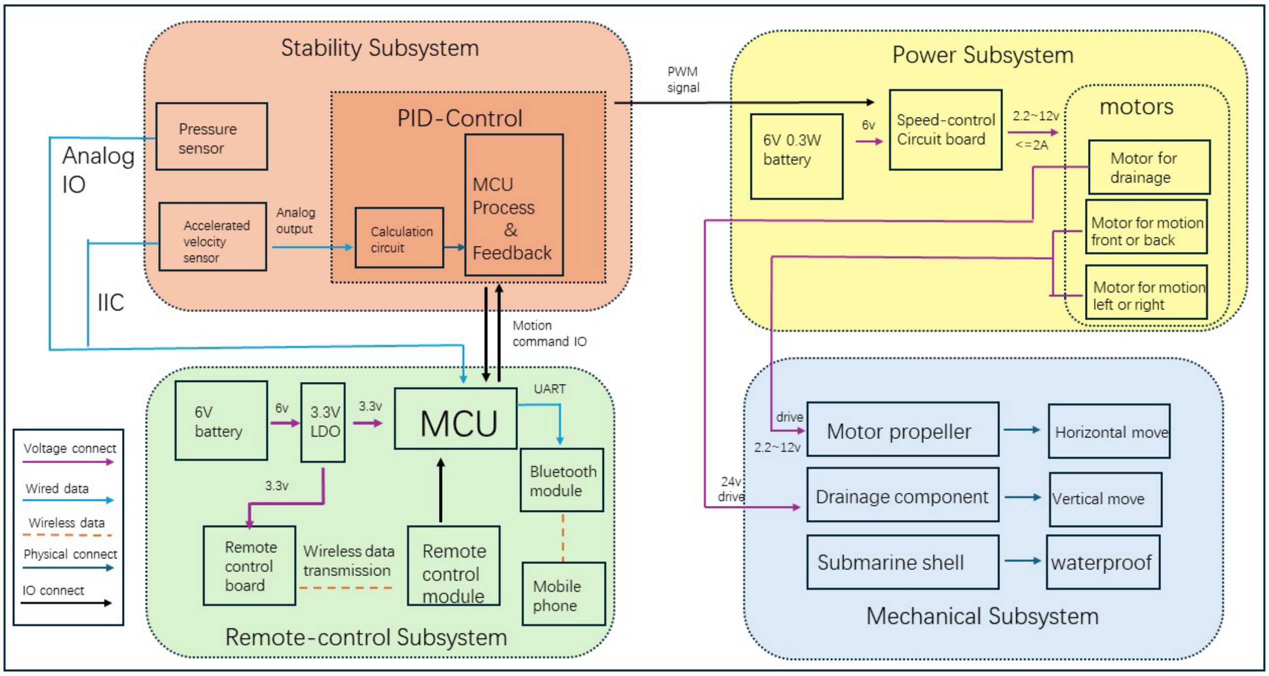

Figure 2 Block Diagram for Submarine Model

2.2 Physical Design

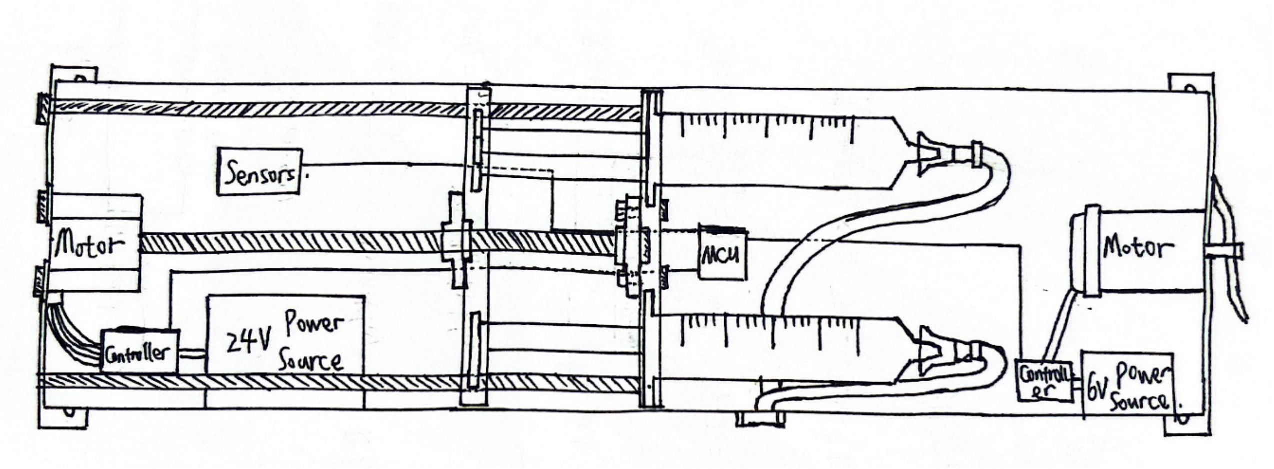

Figure 3 Submarine Model

2.3 Subsystem Requirements and Verifications

2.3.1 Mechanical Subsystem

The mechanical subsystem primarily comprises two components: the hull structure and the ballast system. Regarding the hull, its pivotal roles encompass isolation and immobilization. It's imperative to ensure that all hull components, excluding the ballast system, are effectively shielded from external water. Simultaneously, stability within the hull must be maintained. To achieve this, we propose utilizing a 100 mm diameter (approximately 3.94 inches), 40 cm long acrylic tube as the hull framework. A 110 mm diameter (about 4.33 inches) cover plate will be cut to seal the hull, and waterproof glue and o-rings will be employed to ensure water resistance at the junction between the cover plate and the hull. Additionally, 3D printed parts will be utilized to secure circuit boards, motors, and other components within the hull.

The net weight of the submarine model was approximately 1.4 kg (shown in Figure 4). We need to add counterweights (shown in Figure 5) to balance the whole model and make the total weight approximately equal to 3.14kg.

For the ballast system, we plan to employ a combination of 42-60 stepper motors and silk rods to actuate injectors for water absorption and drainage. A T8 trapezoidal screw will facilitate the push-pull mechanism, while a T5 screw will be utilized to affix the syringe to the motor.

Figure 4 Submarine Model

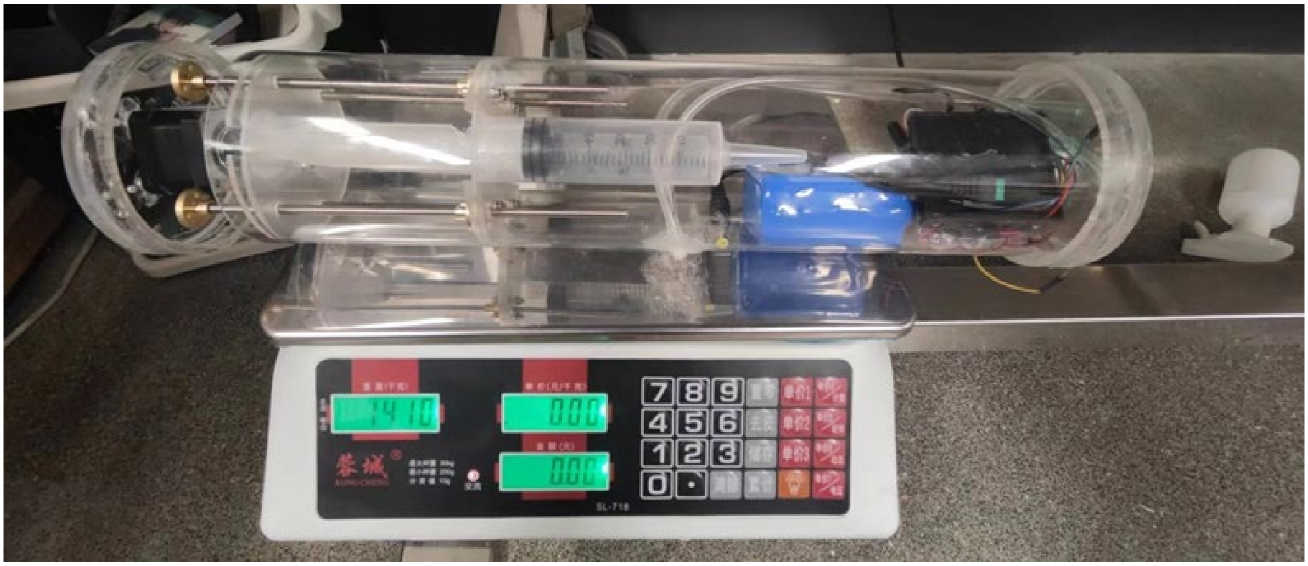

Figure 5 Net weight for submarine model

Figure 6 Counterweights

Requirements	Verifications
1)The submarine hull can make sure that everything except the ballast system, is isolated from the outside water. 2)The submarine hull and its components can be kept relatively stationary in motion and rest. 3)The submarine ballast system can implement stable and fast water intake and discharge. 4)The submarine can keep its balance while floating in the water. 5) The submarine can float and sink completely and remain suspended.	1) Submerge the cabin underwater, first stand still for 10s, then move back and forth randomly and vigorously for 10s to detect any water ingress into the hull of the boat 2) Submerge the cabin underwater, first stand still for 10s, then move back and forth randomly and vigorously for 10s, to detect whether there is any displacement of the parts inside the vessel 3) Turn on and operate the stepper motor and observe whether the screw can drive the end of the syringe in a smooth push-pull motion and observe whether the syringe body is offset from the motor. 4) During all these tests, the hull pitch Angle is maintained at

Table 1: Requirements & Verifications for Mechanical Subsystem

2.3.2 Remote-Control Subsystem

The control part mainly consists of MCU process and remote control. As for remote control, we need to use remote control module to give the order of motion to submarine. We need to control distance at least 50 centimeters to realize remote control. And the control signal will be delivered to the MCU control part. As for the requirement of MCU part, we need to use 3.3V battery to drive the chip and we need use low power mode to provide continuous work. The MCU needs to have enough ability to process the signal from remote control module and generate control signal to drive the motion of motors. MCU control is also required to process the data of velocity and accelerated velocity to realize the function of stability. We use STM32F103ZET6 chip as the MCU of submarine. And the remote-control RX-Q8 module is combined with transmitter and receiver. The command is sent with 433MHz electromagnetic wave, and the experiment shows it can work under 50cm water. This module is integrated with an 8-pin decoder, which can output 0 or 3.3V according to the transmitter. These eight pins will connect with the GPIO pins of MCU, such that MCU can receive the command of remote controller.

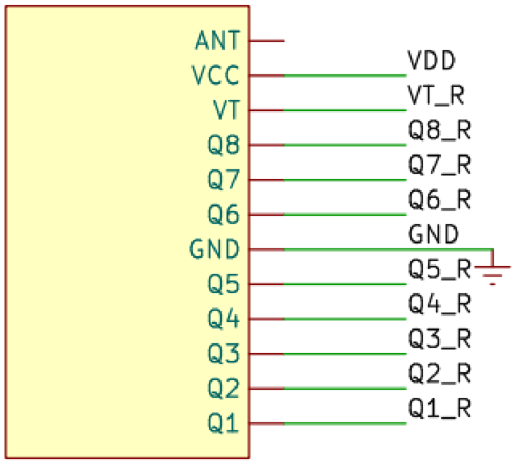

Figure 7 Remote-control module RX-Q8 circuit Schematics

In addition, we plan to use HC-08 chip, a Bluetooth 4.0 chip to transmit sensors' data from MCU to our mobile phone to illustrate the state of the submarine. The MCU is connected to Bluetooth module by UART interface. We can just use RXD and TXD pin foot to communicate about what data it sends. Then module can send data to our mobile phone.

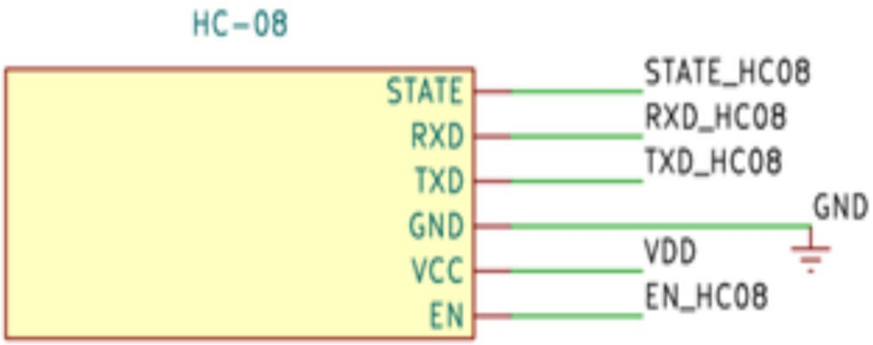

Figure 8 Bluetooth module HC-08 circuit Schematics

Requirements	Verifications
1) The Submarine can receive the motion command through transmitter under 50 cm water. 2) Submarine can send the sensors' data to mobile equipment, and we can demonstrate the states of the submarine in mobile devices.	1) a) If submarine can move according to the remote controller, the below test can pass. b) Connect the LEDs with output decoder pins of remote-control module. If receiver receive the motion command, corresponding LED should light up.

	c)put the submarine underwater around 50 centimeters, press the command button, observe whether the corresponding LED light within delay 2s. 2) a) Put submarine underwater around 50 centimeters. Our mobile device can receive the data and show the sensors' data like depth of submarine and accelerate data. b) Use the program in MCU that send sentences to mobile devices continuously. Gradually sink the submarine underwater. Observe the received data on the mobile device and measure the depth that we cannot receive the sentences by ruler, compare the measured depth with target depth 50cm.

Table 2: Requirements & Verifications for Remote-Control Subsystem

2.3.3 Power Subsystem

The power part is to power the whole model to move properly. It includes a battery (0.3W, 6V, AA battery*4), speed control circuit board (output voltage 2.2V-12V, <=2A), at least 3 motors (9-88 rpm) to move front or back, left or right and enable the tank to pump in or out water respectively and corresponding propellers to motivate the model to move. Besides, it also contains a protection switch to ensure the system is on only when the model is inside the water. To achieve this, 2metal probes act as the switch. When the model sinks into the water, the water between the probes serves as a conductor and thus the circuit is on [2].

The motors are controlled by the remote controller so there is a connection part which works as switches based on the output signal of the receiver of the remote controller. Moreover, as the propellers should be in the water, the waterproofing problem should be carefully handled, as a connection part with the cover part.

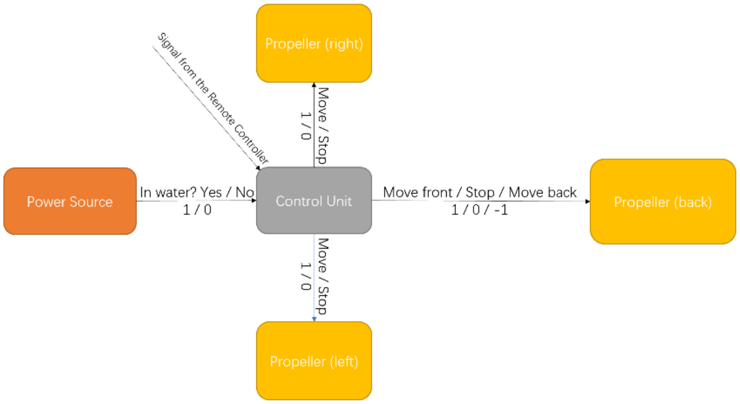

Figure 9 Block Diagram for Power Subsystem

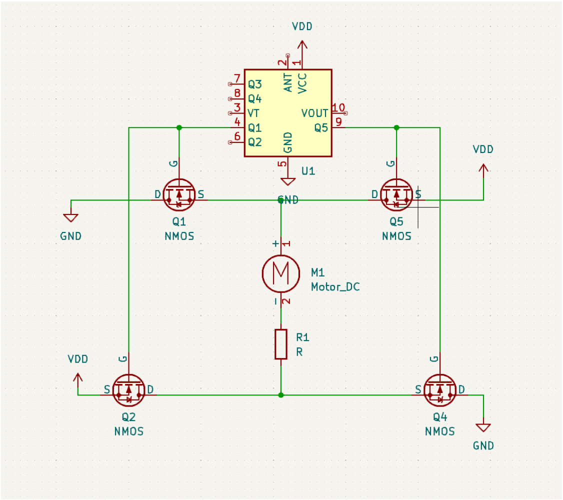

Figure 10 Circuit Diagram of Power Subsystem (V1)

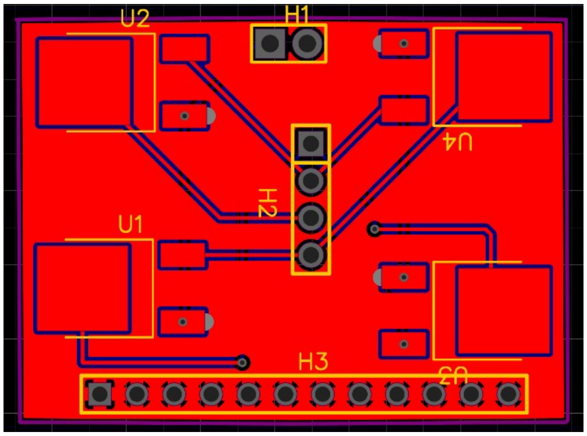

Figure 11 PCB Design of Power Subsystem (V1)

Requirements	Verifications
1) The control unit can respond properly according to the signal received (0V-0± 0.1V, 1V-3.3±0.1V). 2) The propellers can work under the output voltage range (1V-6V) of the power source. 3) The connected parts of propellers and motors should have good waterproofing abilities (50cm under water). 4) The propellers react as the remote controller commands.	1) Measure the output signals of the control unit with signal controlled using an oscilloscope and compare them with data in theory. 2) Power the propellers with certain voltages to see if they reach the spinning speed of 88rpm. 3) Immerse the connected parts in the water 50cm under water for 10s and then see if the device inside the model is dry. 4) Press the buttons on the remote controller and see if the propellers work as expected.

Table 3: Requirements & Verifications for Power Subsystem

Updated on April 12th: The circuit in Figure 7 did not work as expected. Here is the revised version.

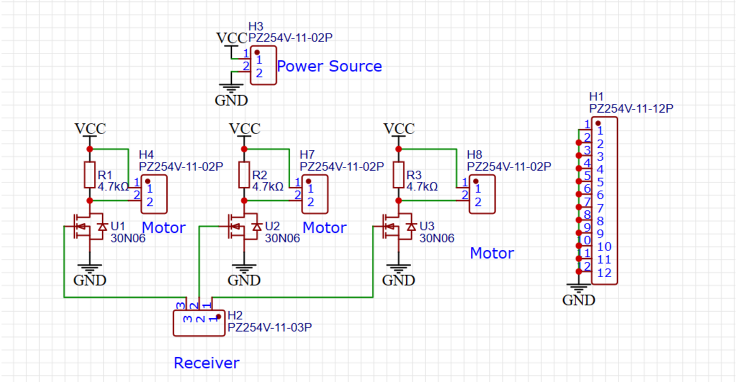

Figure 12 Circuit Diagram of Power Subsystem (V2) [4]

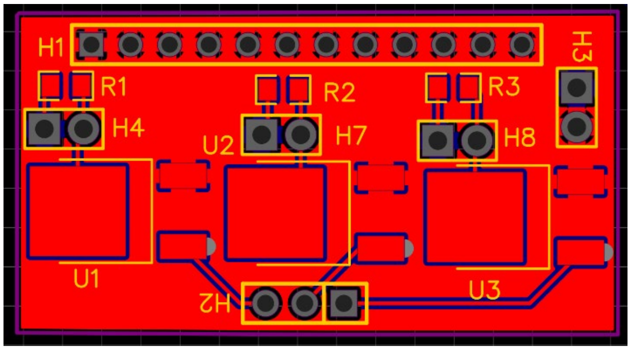

Figure 13 PCB Design of Power Subsystem (V2)

Update on April 18th: The revised one passed all tests.

2.3.4 Stability Subsystem

In our design, the purpose of the stability subsystem is to ensure the stable navigation of the submarine underwater. This subsystem plays a crucial role in facilitating the submarine's buoyancy, controlling its descent, and maintaining a stable hover at a specific horizontal plane. We achieve this by processing data obtained from various sensors and collaborating closely with the power unit through the control system to achieve stable vertical movement of the submarine.

To meet the high-level requirements set forth for the submarine's operation underwater, it is imperative to provide a highly detailed and quantitative block description of the Stability subsystem. We must understand how the stability subsystem contributes to the overall design objectives, including ensuring stable navigation, controlling descent, and maintaining hover stability.

Stability control is paramount for submarines, directly influencing the balance and maneuverability of the submarine underwater. Achieving buoyancy aims to ensure that the submarine can maintain a specific depth in the water and stabilize its floating when required. Effective control of the buoyancy adjustment system is crucial to maintaining the submarine's balance in the water, allowing it to descend to the desired depth while maintaining a suspended state. We also need to ensure that the submarine can descend and in a controlled manner when necessary. Adjusting the tank and other systems allows the submarine to descend to the desired depth.

Expanding on this, our primary objective is to develop a sophisticated stability control system that not only ensures the submarine's equilibrium but also enhances its maneuverability underwater. This entails implementing advanced algorithms and control mechanisms to precisely regulate the submarine's buoyancy in real-time. We aim to achieve a fine balance between buoyancy and weight distribution, enabling the submarine to maintain its desired depth effortlessly.

Furthermore, our focus extends beyond passive buoyancy adjustments. We intend to integrate active control mechanisms that allow the submarine to adjust its depth when needed. This involves optimizing the performance of the ballast tank system and incorporating responsive actuators to facilitate swift and precise movements underwater.

Through meticulous design and rigorous testing, we aim to develop a stability control system that not only meets but exceeds the stringent requirements of submarine navigation. By ensuring seamless integration with other subsystems and employing robust verification procedures, we strive to deliver a solution that enhances the overall performance and safety of the submarine.

For this part, we will use MPU-6050 sensor. Because we found in our calculations that the accelerometer we're using measures the value of gravitational acceleration, and because the direction of gravity cannot perfectly align with the xyz axes, we need to manually confirm the direction of gravitational acceleration. So we choose to use the sensor MPU6050 using the MCU. This sensor not only measures linear acceleration but also has three gyroscopes, which can be used to calculate the values of its Euler angles. In this scenario, we can calculate the direction of gravitational acceleration under the initial conditions and then correct the subsequent direction of acceleration.

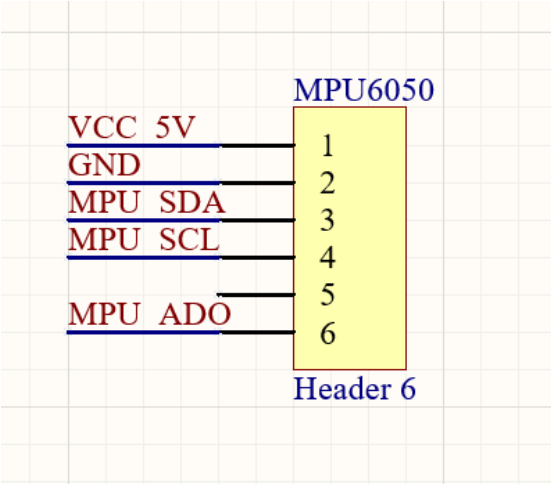

Figure 14 MPU6050 Pin Plan

For MPU6050, SCL and SDA are the digital output of I2C. It will output digital signal related to the accelerator of the chip. The I2C part and the MCU pin plans can be seen in the MCU part below.

In addition, we also intend to use a simple water pressure sensor. This sensor can provide analog signal output indicating the current water pressure at the submarine's position. This can help us understand the current underwater depth, aiding in achieving the stability of the submarine during submersion.

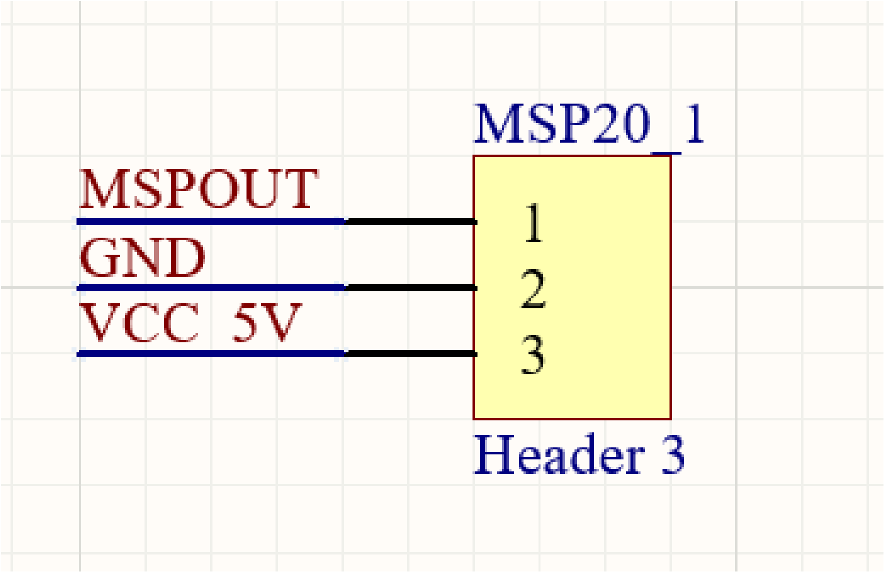

Figure 15 MSP20 Water Depth Pin Plan

In this figure, the MSPOUT pin is the analog output pin, and the output of this port will increase as the water pressure rises. Based on our measurements, we found that the output analog voltage values are roughly proportional to the depth. Through the corresponding relationship, we can determine the relationship between the required voltage and the depth.

Requirements	Verifications
1) The submarine's diving depth should be ensured. It should be able to descend to at least 8cm below the water surface and still float back to the surface. 2) The error range in suspension should be ensured. The vertical variation in suspension should not exceed 12 centimeters and should be maintained for at least 5 seconds. 3) The submarine should be able to descend to the specified depth. The error should not exceed 20 centimeters.	1) Measurements should be taken using a ruler or other length measuring tools. 2) Measurements should be conducted using a timer and length measuring tools. Measurements should be taken at different heights, either randomly or at regular intervals of depth. 3) Measurements should be taken using a ruler or other length measuring tools.

Table 4: Requirements & Verifications for Stability Subsystem

2.3.5 Microcontroller Unit Subsystem

Microcontroller unit subsystem is the core subsystem to handle the data process. We selected STM32F103ZET6 as our MCU. We use MCU to receive the decoded command from remote controller, collect acceleration data and pressure data from sensors. MCU also takes responsibility for sending sensors' data through Bluetooth module HC-08. MCU connects some sensors like acceleration sensor ADXL345 through IIC interface and connects pressure sensor though analog IO. Figure shows the correct use of IIC interface measured by oscilloscope. The yellow line is SCL signal and blue line is SDA signal.

Figure 16 **IIC interface measurement by oscilloscope**

MCU sends data to HC-08 module through UART interface (RXD and TXD). MCU subsystem will be used to calculate the PID algorithm and generate PWM waves to control the speed and direction of motors. So, the speed control module A4988 is connected to MCU through GPIO. Through these sensors' data and calculations, the submarine should achieve the functionality of floating stably. Figure shows the circuit schematics of A4988, and Figure shows all the electric module connect with MCU.

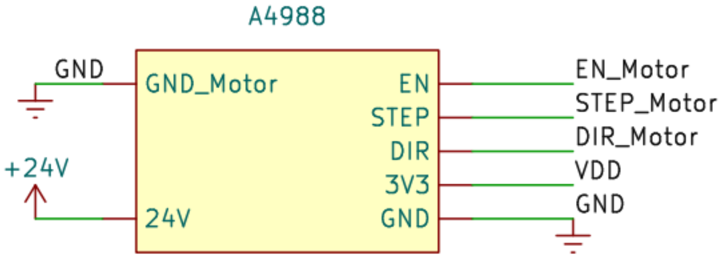

Figure 17 **Speed control module A4988 circuit Schematics**

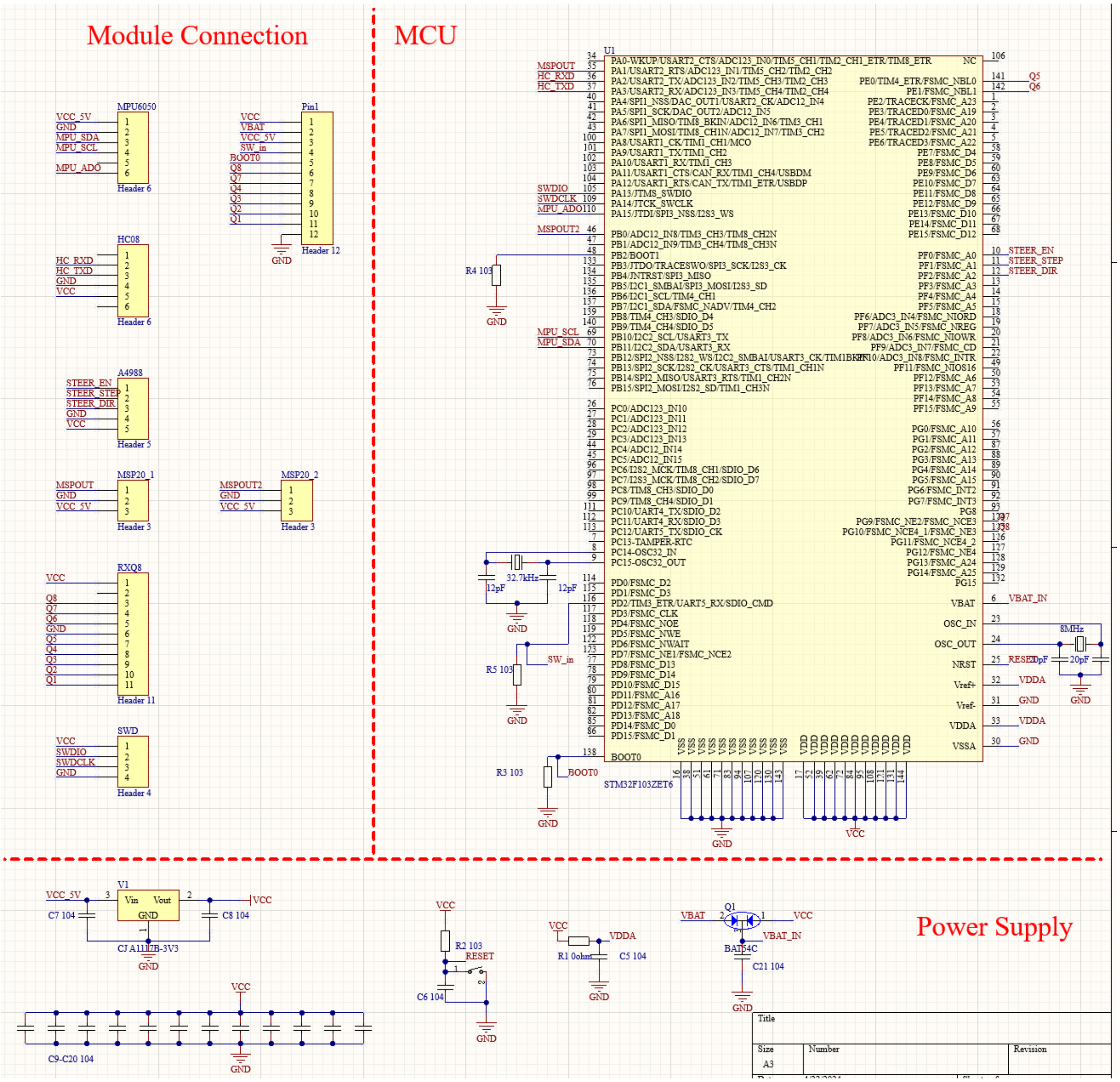

Figure 18 MCU subsystem circuit Schematics

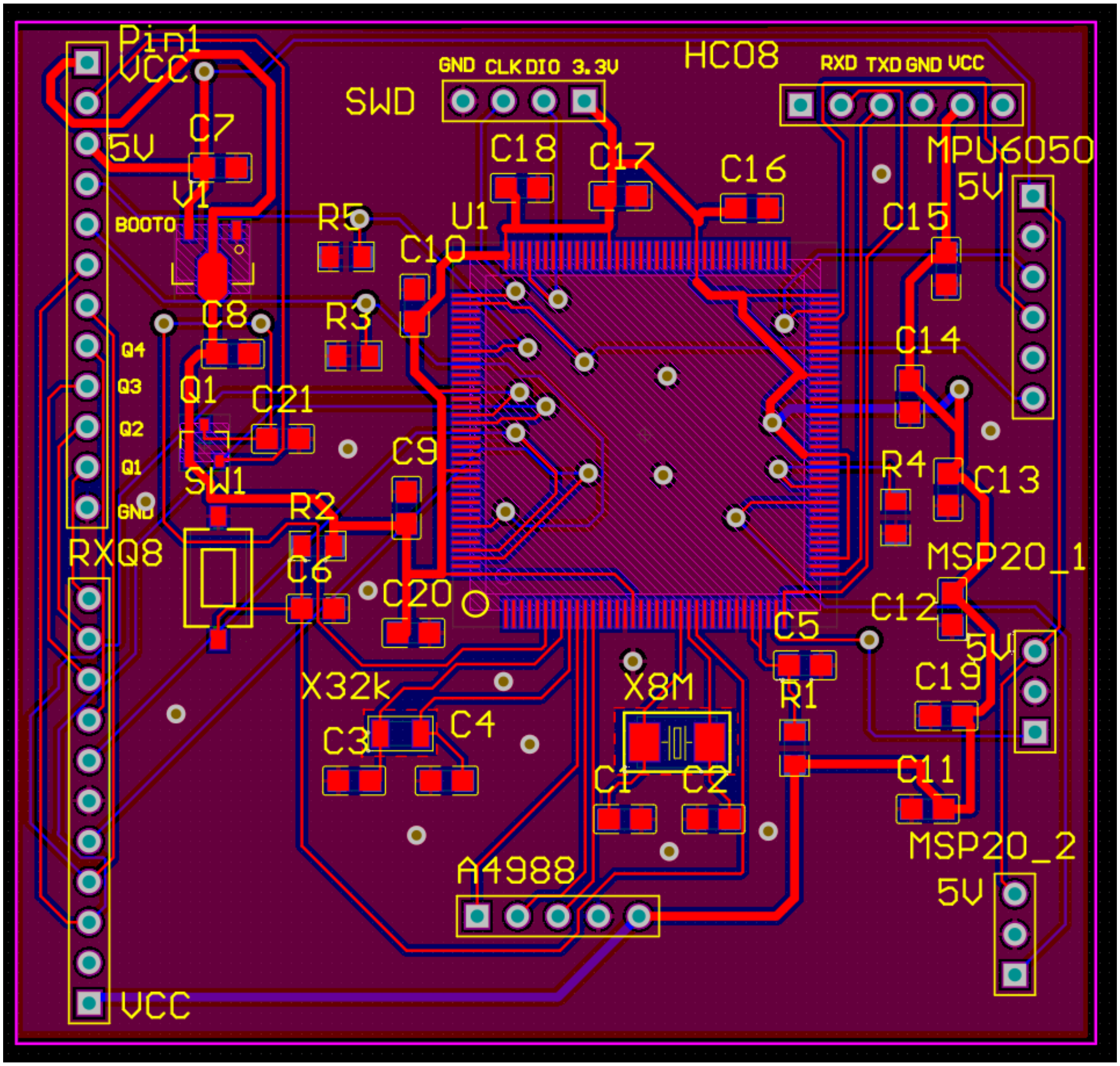

Figure 19 PCB Design of MCU subsystem

Requirements	Verifications
1) In general, MCU should ensure all the interfaces (IIC, UART, ADC) and sensors work. MCU can read data, process all the data, and output some data. MCU need generate PWM waves to control the speed of motors. Meanwhile, all the electric components need 3.3V power supply and 3.3V IO connect, MCU need output appropriate voltage. 2) MCU need process remote control signal and generate motor control signal, so the motor could react according to the remote controller.	1) a) We plan to connect all the sensors to MCU pins. We can measure the outputs of sensors by oscilloscope and determine the functionality works. b) Test the ADC interface with pressure sensors. Connect pressure sensors with MCU. Pressure sensors can generate varied voltage value linearly between 0V and 5Vaccording to the varied pressure, and MCU could read the data with ADC, demonstrated by sending data to mobile devices.

The drainage motor should drive tank suck or expel the water according to the remote command. 3) The data needs to be processed quickly enough to ensure the quick reaction of the submarine. The reaction should not be realized more than 3s.	c) Test the UART interface of Bluetooth module. And Bluetooth module can be tested by receiving correct data like sentences in mobile phone. d) Test PWM signal generated by MCU to control motor speed. The oscilloscope can display the PWM waves and record the frequency of PWM and speed of motors, then compare the relationship between frequency and motor speed. e) Test the voltage connect between components by voltmeter and compare the voltage value with the desired value according to datasheet. 2) a) Put the submarine underwater around 50 centimeters, we can press moving up, down, front, back, left, and right button, record the rotation of motors and its direction, compare the motion with the button press. b) press the button 5, MCU should generate control signal to drive motor rotate and causing the submarine's ballast tank to suck in water so that the submarine could dive. c) press the button 6, MCU should generate control signal to drive motor rotate in counter direction and causing the submarine's ballast tank to expel water so that the submarine could surface. 3) The code needs optimized enough. We can test the efficiency that the submarine can implement command within delay 3s. We can test delay by record the time between pressing the command button and the reaction moment of the submarine.

Table 5: Requirements & Verifications for Microcontroller Unit Subsystem

2.4 Tolerance Analysis

2.4.1 Waterproofing and Submarine Appearance Tolerance Analysis

Ensuring the waterproofing of the submarine is of utmost importance, necessitating comprehensive tolerance analysis. Precise control over the dimensions and connections of critical components is imperative to prevent any leaks in the hull during underwater operations. Failure to maintain adequate waterproofing can result in severe damage or destruction of the submarine's internal electronic systems. Water ingress poses the risk of circuit short-circuits, equipment damage, or complete system failure, compromising the submarine's functionality and safety.

Moreover, tolerance analysis of the submarine's appearance extends beyond waterproofing to encompass the design and treatment of key components such as the hull, rudders, and sensors. The shape and surface finish of these elements directly impact the submarine's hydrodynamic performance and attitude stability. Ensuring tight control over these factors is essential for optimizing the submarine's maneuverability and effectiveness underwater.

At the same time, the overall weight of the hull should be kept within 3.02kg to 3.14kg. Of course, we have a counterweight with an accuracy of 0.02kg to help us carry out the counterweight of the hull. At the same time, after calculation, the position of the diving bin needs to be within 1.3cm of the center of the ship, so as to ensure that the pitch Angle of the hull is maintained at the maximum and minimum load is restricted at ±10∘ .

2.4.2 Submarine Motor Tolerance Analysis

Given the crucial role of submarine motors in providing propulsion, conducting tolerance analysis for them is indispensable, as it directly impacts the hydrodynamic performance and attitude stability of the submarine. Components such as motor rotors, bearings, and electrical connections must undergo rigorous dimensional and performance control to maintain waterproofing, operational continuity, and so forth.

The primary objective of tolerance analysis is to uphold consistent dimensions and performance characteristics across all components of the submarine motor during manufacturing. This ensures that the motor can deliver effective and balanced propulsion, essential for optimal submarine operation. Deviations in dimensions or performance during manufacturing can compromise hydrodynamic efficiency or lead to instability in the submarine's attitude, potentially culminating in severe consequences such as capsizing. Hence, meticulous tolerance analysis and control of submarine motors are imperative to safeguard the submarine's safety and reliability.

Therefore, it is imperative to ensure uniform power delivery from each motor and comprehensively understand the precision of motor rotation. This approach guarantees the submarine's propulsion system functions seamlessly and contributes to its overall effectiveness and safety.

2.4.3 Suspension Stability Tolerance Analysis

To meet the requirements for the normal operation and suspension of the submarine in water, we need to provide a highly detailed and quantitative block description for the analysis subsystem related to suspension stability. This subsystem utilizes accelerometer sensors to measure the acceleration in all three directions (x, y, z) of the submarine, which is crucial for assessing its suspension stability. This task will be quite complex, so our first step in the design approach is to fulfill the basic buoyancy and suspension requirements. This will not demand too much in terms of stability since it is just the initial phase of the design. Then, in the second step, we aim to achieve suspension and maintain a fixed position below the water surface. This will be more challenging but highly valuable. Additionally, in subsequent design phases, we can utilize the translational acceleration for other control purposes.

The accelerometer sensors provide data on the submarine's acceleration, which is then analyzed using mathematical formulas to evaluate its suspension stability. Specifically, we make certain assumptions:

assume the submarine mass is m, the acceleration due to gravity is g, the depth of the submarine is h, the density of water is ρ, the volume of the submarine excluding the tanks is V_0, and the volume of the tanks is $S \times x$, where S is the cross-sectional area of the tank and x is the drainage height of the tank. We control the value of x through the motor. Thus, we can have:

$$\rho g(V_0 + S \times x) = mg - m\ddot{h} \tag{1}$$

Assume $\dot{y} = \frac{\ddot{h}}{g}$, $y(t = 0) = 0$, which means that the submarine's initial vertical velocity is 0. Thus, we can have $y(t = +\infty) = 0$. By controlling the value of x, we can achieve this. We can use a PID system for this part.

The control of the drainage height x is achieved through the motor, allowing us to adjust it as needed. By controlling x and analyzing the accelerometer data, we can effectively assess and adjust the suspension stability of the submarine.

To further validate and support our design decisions, our plan includes relevant data analysis and considerations regarding the motor and chip components. This involves calculating the motor's rotational speed and minimum rotation increments, among other factors. Additionally, we will analyze from the perspective of the control system to ensure its stability. This will ensure that our design decisions are justified and aligned with the overall design goals dictated by the high-level requirements.

2.4.4 Euler Angle Tolerance Analysis

In the previous section, we mentioned that we will use Euler angles to transform acceleration or other vectors into different coordinate systems.

Euler angles are a way to describe the orientation of a rigid body in three-dimensional space. They consist of three angles: roll, pitch, and yaw. Roll describes rotation around the longitudinal axis (the x-axis); pitch describes rotation around the lateral axis (the y-axis); yaw describes rotation around the vertical axis (the z-axis), and they together, these angles uniquely describe the orientation of an object in three-dimensional space.

Assume the Euler Angle is (θ, ϕ, ψ) for the axis of (x, y, z), then if we want to transfer (0,0,0) to (θ, ϕ, ψ), we have:

$$Rx = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -sin\theta \\ 0 & sin\theta & \cos\theta \end{bmatrix}, Ry = \begin{bmatrix} cos\phi & 0 & sin\phi \\ 0 & 1 & 0 \\ -sin\phi & 0 & \cos\phi \end{bmatrix}, Rz = \begin{bmatrix} cos\psi & -sin\psi & 0 \\ sin\psi & cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

The new vector from the original vector (a, b, c) will be:

$$\begin{bmatrix} a' \\ b' \\ c' \end{bmatrix} = RxRyRz \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{3}$$

Based on this algorithm, we can transform any vector into any Euler angle configuration. If we take the initial gravitational acceleration as a reference, we can adjust subsequent acceleration vectors using Euler angle transformations to accommodate changes in the direction of gravity. If the gravity we measure is (g_x, g_y, g_z), we need to turn it to $(0,0,g_0)$. With this method, we can transform all scenarios into a unified coordinate system.

2.4.5 TEM wave transmission distance Tolerance Analysis

TEM waves will decay through water, so we need to analyze how much power of TEM waves will decrease through 0.5m water. In our design, we use 433MHz transmitter and 2.4GHz Bluetooth module. Assume the transmitter is on the surface of water. After looking up the datasheet of tap water, tap water has the parameters below: $\sigma = 0.05S/m$,$\epsilon_r = 81$, $\mu_r = 1$. Then we calculate:

$$\text{loss tangent} = \frac{\sigma}{\omega\varepsilon} \tag{4}$$

The loss tangent is 0.0256 for 433MHz wave and 0.004623 for 2.4GHz, so both are imperfect dielectric.

The propagation constant for imperfect dielectric $\alpha = \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}}$=1.04647, which is irrelated to frequency.

Because the energy of electromagnetic waves is proportional to the intensity of the electric and magnetic fields, which is the strength of the wave vector, so we can get:

$$E(z,t) = E_0 e^{-\alpha z} \cos(\omega t - \beta z + \varphi) \tag{5}$$

and the energy is proportional to $e^{-2\alpha z}$, where z is the depth underwater.

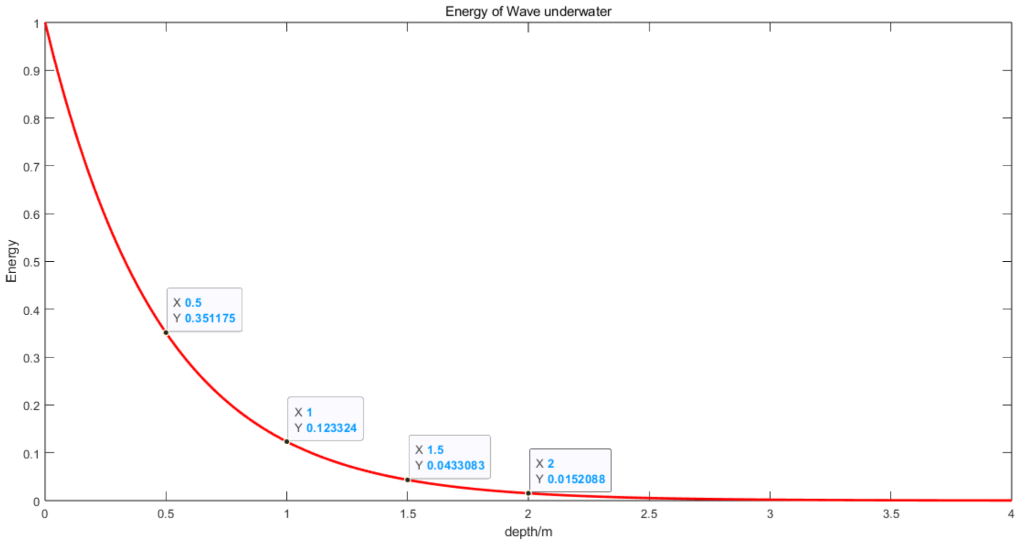

Figure 20 Energy decay simulation

To receive the valid data, we will receive 35% power under 0.5m water and we cannot transmit data through tap water exceeding 2 m with around 1.5% power.

3. Cost and Schedule

3.1 Cost Analysis

- Labor = $18/h * 10h * 12 weeks * 4 members = $8640
- Cost Table

Bought				
Description	Manufacturer	Part	Quantity	Cost
Governor motor set	Hancheng flagship store	Propeller 1.0	1	20.34
AA battery	Huatai	Propeller 1.0	12	4.95
130 motor	Telesky flagship store	Propeller 1.0	1	2.4
ADXL335 Chip	Analog Devices	Sensor 1.0	1	29.8
ADXL345 Chip	Analog Devices	Sensor 1.0	1	9.5
STM32F103ZET6	Jiendi store	MCU1.0	1	47.88
remote control module	wanhong store	remote control 1.0	1	28
BMP280 Chip	zave store	Sensor 1.0	2	9.6
MSP20 Chip	Studing store	Sensor 1.0	2	58.4
Silicone O-rings	lingnan store	Waterproof	6	6.14
Waterproof glue	tiantiantemai store	Waterproof	1	8.44
T5 Trapezoidal lead	chuanxiang store	Sink tank	4	44
Medical infusion tube	biduoshi store	Sink tank	4	12.79
60ml syringe	biduoshi store	Sink tank	5	22.88
24V lithium battery	zhongli store	Sink tank	1	69.8
42 step motor	huayang store	Sink tank	1	52.29
Motor driver	jiaxinwei store	Sink tank	1	10.19
Acrylic tube	jiabo store	Hull	1	120
Submarine model	luoerle store	Model	1	113.28
HC-08 Chip	HC store	Bluetooth 1.0	1	8.8
			Total	679.48

Table 6: Cost Table

- Total: $8640 +￥679.48 = ￥63,041.272 = $8734.14

3.2 Time Schedule & Milestone

Week 1	March 11-14
Cover	Design and purchase shell and sink tank, prepare for underwater sealing testing.
Remote Controller & MCU	Do the working test of the remote-control module 50cm underwater. Learn for ADXL345 sensor.
Stability & Sensors	Testing the Basic Properties of Sensor Chips: MSP20 and MPU-6050
Propeller	Power system and motor purchase; Conceive of magnetohydrodynamic thruster.
Week2	March 15-21
Cover	update shell and sink tank design.
Remote Controller & MCU	Test the IIC interface and ADC interface for sensors using oscilloscope.
Stability & Sensors	Writing code for activating sensor; Attempt to connect the sensor with MCU and use MCU to control the sensor.
Propeller	The propeller part completes individual test.
Week3	March 22-28
Cover	Underwater sealing testing, design and assemble ballast system.
Remote Controller & MCU	Use MCU output PWM signals to control the speed of motor. Realize the connection of MCU and ADXL345 sensor (acceleration sensor).
Stability & Sensors	Testing the Sensor for water depth; Integrate Sensor with the MCU.
Propeller	Complete waterproofing Test and connection with remote controller.
Week4	March 29 - April 4
Cover	Solve the leak problem and test ballast system. Consider the distribution of the center of gravity.
Remote Controller & MCU	Realize the control speed of motor by remote controller. Integrate acceleration sensor and speed control module.
Stability & Sensors	Integrate depth and acceleration sensor for PID system.
Propeller	Design the PCB of the propeller-control circuit and print the PCB.
Week5	April 5 -11
Cover	Complete installation of shell and sink tank, prepare for sinking and floating experiment.
Remote Controller & MCU	Integrate the remote control with the motor speed control. Study and writing the code for Bluetooth module HC-08.
Stability & Sensors	Using MCU code to control the Sensor (MPU6050). Get data and try to calculate velocity.
Propeller	Test the printed PCB circuit.
Week6	April 12-18
Cover	Complete Sinking and floating experiment. Try Fluid simulation modeling.
Remote Controller & MCU	Test the use of Bluetooth Module and design the PCB to integrate the connection between MCU and modules. Complete sink test with remote control in the submarine.
Stability & Sensors	Collect data about sensors (water depth sensors); Write code to try calculating speed to use PID.

Propeller	PCB tests passed. Complete remote controller part. Feasibility test of propellers with magnets passed.
Week7	April 19 - 25
Cover	Design electronic component fasteners and improve tail power system (High-power motor).
Remote Controller & MCU	Complete the PCB design of MCU subsystem and prepare to solder and test the printed PCB.
Stability & Sensors	Calculate acceleration and velocity and obtain correct outputs using the MCU. Use Filter to Remove Noise
Propeller	In-water test complete.
Week8	April 26 – May 2
Cover	Complete assembling.
Remote Controller & MCU	Solder the electronic devices on PCB and test the work of MCU subsystem on PCB. Add PCB circuit in the body of the submarine model.
Stability & Sensors	Complete the algorithm design and make the submarine reasonably stable
Propeller	Reverse circuit design.
Week 9	May 3 - 9
Cover	Hull beautification and prepare for the final demo.
Remote Controller & MCU	Test the remote control in the whole system and prepare for the final demo.
Stability & Sensors	Adjust parameters and further optimize algorithms and outputs
Propeller	Reverse circuit test.

Table 7 Time Schedule and Milestone

4. Ethics and Safety

Analyzing the ethics and safety aspects of the project is paramount. Adhering to the IEEE Code of Ethics [5], we must ensure that the design, manufacturing, and testing processes of the project strictly adhere to the highest safety standards to safeguard the well-being and health of all project participants. Moreover, it is imperative to guarantee that any collection, storage, and processing of personal data involved in the project strictly comply with stringent privacy protection requirements to uphold users' rights to personal privacy.

In addition to safety concerns, environmental considerations are also integral. It is imperative that submarines operate without contaminating water quality, and we will implement rigorous controls over all emissions and waste to ensure environmental protection and conservation efforts are upheld.

Furthermore, it is essential to ensure that our project objectives are lawful and align with all pertinent laws, regulations, and requirements. This is to ensure that our activities remain within legal boundaries and do not incite unnecessary controversies or contravene any legal mandates.

In terms of safety, prioritizing the safety of circuits is paramount to prevent short circuits or electric shocks. We will implement stringent measures, including robust insulation and protective measures, to ensure the stability and safety of the circuits. Additionally, comprehensive measures will be taken to mitigate risks associated with equipment such as motors, ensuring they do not pose any threat of injury to classmates. This may involve installing safety covers, implementing safe operating procedures, and adhering to strict safety protocols to mitigate any potential hazards.

Another risk is that we are combining electricity and water. We must ensure that high voltage, such as 220V, never gets anywhere close to our experimentation with water. Due to the unique situation of submarines, waterproofing and electrical issues are of paramount importance. We need to utilize high-quality waterproof materials and sealing techniques to ensure the submarine's hull, critical components, and all connections have excellent waterproofing performance. Additionally, regular waterproof performance testing and inspections should be conducted to promptly identify and rectify any potential leakage issues. Contingency plans should be considered to address emergencies or unforeseen events. Regarding the electrical system, certified electrical components and wiring should be used to ensure the reliability and stability of the system. Furthermore, strict electrical safety standards, including proper waterproofing and insulation measures, must be implemented to prevent short circuits and electrical shock accidents. By adhering to these safety measures and recommendations, we can effectively address waterproofing and electrical issues in submarine design, thereby maximizing the safety of team members and equipment.

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