ECE 445/ME 470 Senior Design ZJUI

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Project Proposal

Submarine Model

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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

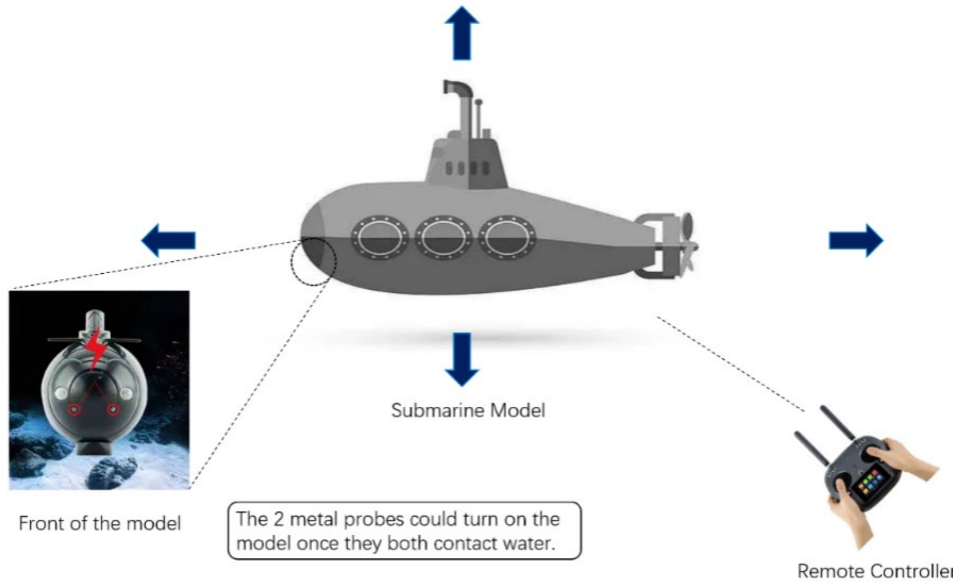

Figure 1 Visual Aid for Submarine Model [1][2][3]

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 handheld remote controller can be received by the MCU of model at least 50cm underwater and at least 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 with a propulsion system.
- 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

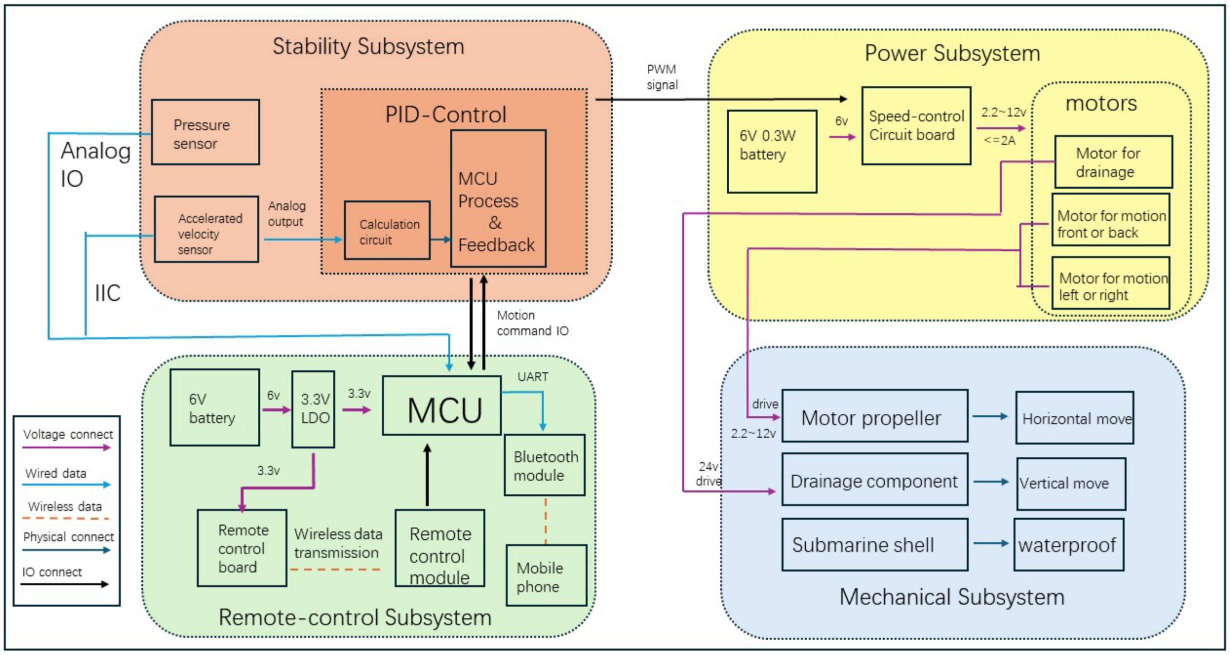

Figure 2 Block Diagram for Submarine Model

2.2 Subsystem Overview

2.2.1 Mechanical Subsystem

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.

2.2.2 Remote-Control Subsystem

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 from remote controller, the Control subsystem can generate control signals for controlling motors of the Power subsystem and ensure the stability of the submarine by calculating and controlling the Stability subsystem. Also, we could also interact and observe the real-time states of the submarine by Bluetooth module.

2.2.3 Power 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]

2.2.4 Stability Subsystem

The Stability subsystem is a crucial component designed to ensure the stable navigation of the submarine underwater. It plays a key role in facilitating the submarine's buoyancy, descent, and maintaining a stable hover at a specific horizontal plane. By processing data obtained from various sensors through the control system, the Stability subsystem collaborates with the power unit to achieve stable vertical movement of the submarine.

2.3 Subsystem Requirements

2.3.1 Mechanical Subsystem

1. Hull Structure: The hull material must be corrosion-resistant to simulate prolonged underwater exposure realistically. The shape and dimensions of the hull must adhere to common submarine design principles.

2. Control Surfaces (Fins and Rudders): Control surfaces must be adjustable within specified angles to simulate realistic steering. Materials used in control surfaces must be durable and resistant to water-induced degradation.

3. Propulsion Mechanism: The propulsion system must accurately simulate the power output and efficiency of common submarine propulsion methods. Adjustable thrust settings to mimic varying speeds and power usage.

4. Ballast System: The ballast tanks must fill and release water in a controlled manner to mimic buoyancy adjustments. Accurate representation of the impact of ballast adjustments on the submarine's depth.

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 meters to realize remote control. And the control signal will be delivered to the MCU control part. Also, we want to get the sensors' data from the submarine to our mobile phone by Bluetooth module. The detailed requirement is below: 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.

As for the requirement of MCU part, 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 a series of sensors like pressure sensor to measure depth and accelerate sensor to realize the function of stability. So the detailed requirements are shown below: 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. 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.

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.

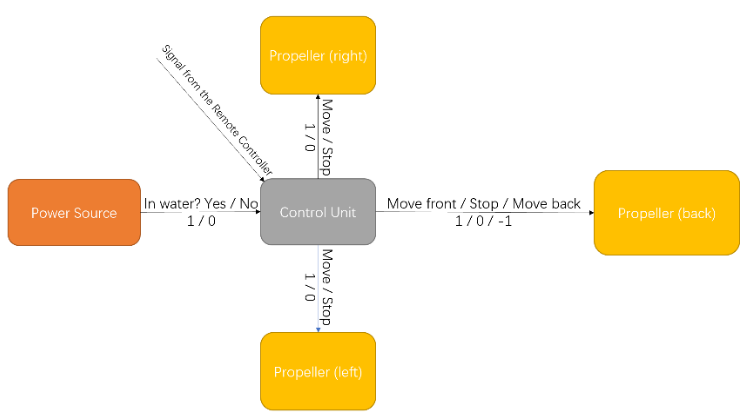

Figure 3 Block Diagram for Power Subsystem

2.3.4 Stability Subsystem

Stability control is paramount for submarines, directly influencing the balance and maneuverability of the submarine underwater. Achieving suspension 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. By designing algorithms and models, we can accurately measure acceleration and depth, ensuring that we obtain stable results.

2.4 Tolerance Analysis

2.4.1 Waterproofing and Submarine Appearance Tolerance Analysis

Conducting tolerance analysis for the waterproofing of the submarine is crucial. The dimensions and connections of key components must be tightly controlled to ensure that the hull does not leak during underwater operations. If waterproofing cannot be ensured, the submarine's internal electronic facilities will be severely affected or destroyed. Ingress of water may lead to circuit short-circuits, equipment damage, or complete failure. Tolerance analysis of submarine appearance involves the shape and surface treatment of components such as the hull, rudders, and sensors. These factors directly affect the hydrodynamic performance and attitude stability of the submarine.

2.4.2 Submarine Motor Tolerance Analysis

Tolerance analysis of submarine motors is crucial as they provide the propulsion for the submarine, directly affecting its hydrodynamic performance and attitude stability. Key components such as motor rotors, bearings, and electrical connections must undergo strict dimensional and performance control.

The goal of tolerance analysis is to ensure that each component of the submarine motor maintains consistent dimensions and performance characteristics during manufacturing, thereby guaranteeing the motor can provide effective and balanced propulsion. If there are dimensional deviations or performance instabilities during manufacturing, it may lead to reduced hydrodynamic performance or instability in the submarine's attitude, even resulting in serious consequences such as capsizing. Therefore, careful tolerance analysis and control of submarine motors are essential to ensure the submarine's safety and reliability. So, we need to ensure that the power provided by each motor is essentially the same and understand the precision of motor rotation.

2.4.3 Suspension Stability Tolerance Analysis

Tolerance analysis for suspension stability involves using accelerometer sensors to measure the translational acceleration of the submarine. By analyzing the acceleration data using mathematical formulas, the suspension stability of the submarine can be assessed:

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:

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

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 control the value of x, we can achieve this.

2.4.4 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:

$$\text{loss tangent} = \frac{\sigma}{\omega\varepsilon} \tag{2}$$

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:

$$E(z,t) = E_0 e^{-\alpha z} \cos\left(\omega t - \beta z + \varphi\right) \tag{3}$$

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

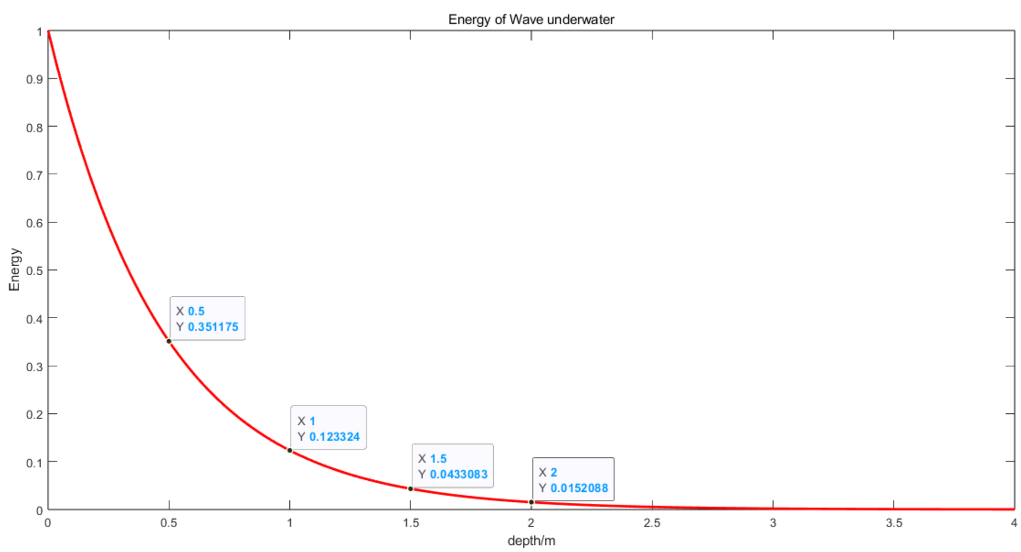

Figure 4 Energy decay simulation

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. Ethics and Safety

Analyzing the ethics and safety aspects of the project is crucial. According to the IEEE Code of Ethics [4], we should ensure that the project design, manufacturing, and testing processes adhere to the highest safety standards to protect the safety and health of project participants. In addition, we need to ensure that any collection, storage, and processing of personal data involved in the project adhere to strict privacy protection requirements to safeguard users' personal privacy rights. Submarines must avoid contaminating water quality during operations, and we will strictly control all emissions and waste to ensure environmental protection and preservation. At the same time, we will ensure that our project objectives are legal and comply with all relevant laws, regulations, and requirements to ensure that our activities do not violate any legal requirements or provoke unnecessary controversies.

In terms of safety, we will ensure the safety of circuits to prevent short circuits or electric shocks. We will take appropriate measures such as proper insulation and protective measures to ensure the stability and safety of the circuits. The main issue we face is the use of electrical equipment underwater, so we must ensure that various high-voltage electrical devices are kept away from our submarine model. Otherwise, this could lead to problems such as short circuits. So, we must ensure that high-voltage electrical equipment is permanently kept away from our facilities and properly insulated. Additionally, we will take measures to ensure that equipment such as motors does not pose a risk of injury to classmates' bodies, such as installing safety covers or implementing safe operating procedures.

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