ENG 4001 Research Project

Miniature Underwater Drone

Progress Report

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2023s1-EME.EE-DZA-UG-13492

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May 2023

Exclusive Summary

Traditional methods face limitations and safety risks, making underwater drones a necessary solution. Underwater drones have emerged as a vital technology for various applications in marine exploration, ecological monitoring, and underwater resource development. They provide access to challenging underwater environments, ensuring the safety of researchers. Equipped with sensors and cameras, these drones collect valuable data for ecological studies and conservation efforts. They offer a cost-effective alternative to traditional methods and demonstrate versatility and adaptability in underwater operations.

This project is to build an underwater drone from an existing project. To transmit signals between the user and the drone, two different ways are introduced in this report, one is acoustic communications and the other is radio frequency communication. This report finds out that some frequencies in radio frequency communication are commonly used, these belong to very-low frequencies and ultra-low frequencies. However, to transmit over long distances, acoustic communication is widely used instead of radio frequency communication, but underwater acoustic communication still faces several challenges due to the underwater environment.

This report also introduced the structure of the drone and the completion plan of the project. An acrylic cylinder is used as the hull of the drone and 3D printed parts will be used to carry the electronic parts and transmit power to achieve desired tasks. A camera will be used to observe the environment and electric boards will be used to collect data from sensors and compute results needed by actuators.

Finally, the completion plan specified in the report is as follows:

- Firstly, identifying desired features and capabilities of the drone, then designing the structures of the drone.
- Secondly, buying and assembling components and materials of the drone, then start testing the basic performance of the drone.
- Thirdly, improving the design of the drone to achieve or exceed the project requirements.

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1. Chapter 1: Introduction

An underwater drone is a robotic system capable of autonomously executing tasks in underwater environments. They are typically highly flexible and adaptable, equipped with various sensors and devices to achieve high-precision perception of the underwater environment and targets. The use of underwater drones avoids risks faced by divers and enables task execution in areas inaccessible to humans, such as the deep sea.

Key technologies in underwater drone development include underwater robot platform design, sensor integration and data processing, remote control, and communication. Through the application of these technologies, underwater drones can achieve efficient and stable operations, acquire critical information about the marine environment and resources, and provide strong support for marine scientific research, resource exploration, and environmental protection.

1.1. Background

The development of underwater drone technology has garnered significant attention due to its immense potential in various fields such as marine exploration, ecological monitoring, and underwater resource development. Traditional methods of underwater exploration and research face numerous limitations, including high pressures, low temperatures, high turbidity in deep-sea environments, as well as safety risks associated with human diving. The emergence of underwater drones offers a new solution to address these challenges.

The development of underwater drone technology will foster progress and innovation in the marine domain. They can be utilized in various applications such as underwater geological surveys, monitoring of marine pollution, and marine energy development. However, the application of underwater drones also faces challenges, including the complexity of the underwater environment, limitations in endurance capabilities, and requirements for high stability and precise control.

1.2. Project Aim

Our project aims to develop a reliable, efficient prototype drone that can undertake simple tasks such as underwater exploration in various underwater environments. Our underwater drone should have the capability to dive to an assigned depth, observe the environment with a camera and transmit data, allowing it to operate in shallow water, and confined spaces. Advanced objectives could include recharging water and collecting samples for analysis. The temperature project will only include the basic functions of an underwater drone, further techniques such as monitoring the health or temperature of the sea or water will not be included. After being developed, our project techniques could also be stored for further improvements and other projects.

2. Chapter 2: Literature Review

2.1. Existing project

Miniature underwater drone is a small compact submersible designed to operate underwater. The underwater drone is made in order to study radio frequency (RF) behaviour through water. This project was inspired by Lego-powered Submarine from Brick Experiment Channel on YouTube as shown in the **Figure 1**. The Lego-powered Submarine project started from the issue of maintaining a constant depth for a remote-control submarine [1]. The creator decides to implement PID control and utilizing the pressure sensor by using a Raspberry Pi as a microcontroller to measure the depth [1]. The problems encountered from the channel are the end caps for the submarine are hard to close, the propeller turn not strong and the submarine not able to maintain straight when it on the peak speed [1].

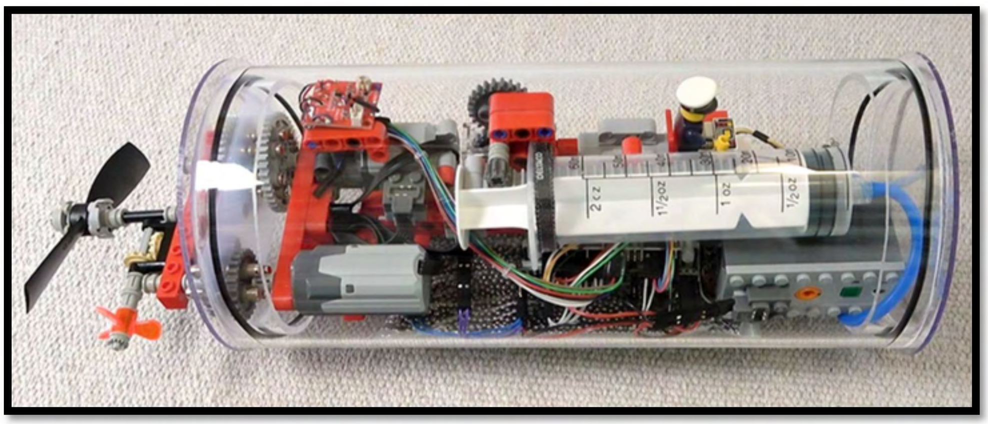

Figure 1: Lego-powered Submarine from Brick Experiment Channel [1].

2.2. Radio Frequency Communication

There are few types of radio frequency signals that can be used for underwater communication. These radio frequency signals are limited due to the high absorption and scattering RF waves in the water. In general, electromagnetic waves with higher frequencies such as used in Wi-Fi or Bluetooth are more severely attenuated in water. There are specific frequency bands that are commonly used for underwater communication. These frequencies fall within the very low frequency (VLF) and ultra-low frequency (ULF) ranges. VLF signals typically range from 3 kHz to 30 kHz, while ULF signals are even lower, ranging from 300 Hz to 3 kHz [2]. VLF and ULF signals can travel longer distances through water compared to higher frequency RF signals. They are used for various underwater communication applications, such as submarine communication, underwater data transmission, and scientific research. Acoustic communication, using sound waves, is the most common method for long-range underwater communication, as sound waves can travel much farther in water than RF waves. Sonar systems, underwater acoustic modems, and underwater acoustic beacons are examples of technologies that utilize acoustic signals for underwater communication.

2.3. Underwater Acoustic Communications

Acoustic communication is widely used for underwater applications due to its ability to transmit over long distances. It involves sending and receiving sound signals through the water. Acoustic communication system can be used to establish a communication link between the remote-controlled submarine. However, the data transfer rate for acoustic communication is relatively slow. The sound propagation of the acoustic communication travels differently in water compared to air due to differences in density and acoustic properties [4]. The speed of sound in water is much higher than in air, but it attenuates more rapidly over distance. Additionally, sound in water can be affected by factors like temperature, salinity, and depth. Underwater acoustic communication faces several challenges due to the characteristics of the underwater environment. These challenges include limited bandwidth, long propagation delays, signal attenuation, multipath interference, ambient noise, and Doppler shifts caused by the relative motion between the transmitter and receiver [5].

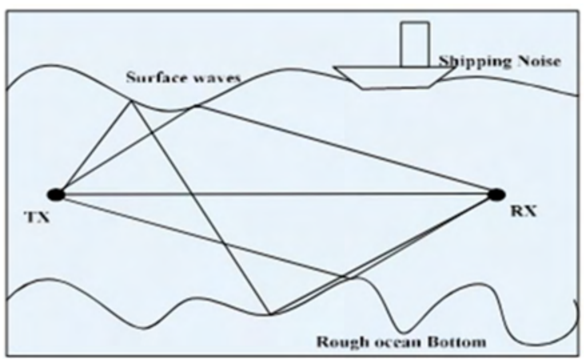

Figure 2: Underwater channel of multipath system [5].

Figure 2 shows the one of the phenomena in underwater acoustic communication where sound waves traveling through water reach the receiver via multiple paths due to reflections, refractions, and scattering from various objects and boundaries in the underwater environment. Sound waves can bounce off the seafloor, surface waves, underwater structures, or any other objects present in the water. These reflections can result in multiple copies of the original signal reaching the receiver at different times. Sound waves can change direction as they pass through water layers with varying temperature, salinity, or pressure. These changes in direction can cause sound waves to propagate along different paths and arrive at the receiver with time delays. Sound waves can scatter off objects such as suspended particles, bubbles, and marine organisms. The scattered waves can interfere with the direct path signal, leading to variations in signal strength and arrival time at the receiver.

2.4. Transmission Loss Radio Frequency Underwater

Transmission loss underwater is the depletion of strength of sound signals as it propagates through water. It occurs due to various properties that affect the transmission of sound waves in the underwater environment. The transmission loss (TL) in decibel (dB) can be obtained based on the Thorp's formula for attenuation [3]:

$$TL = 20 \text{ Log } (r) + \frac{0.11 \frac{f^2}{1 + f^2} + 44 \frac{f^2}{4100 + f^2} + 2.75 \times 10^{-4} f^2 + 0.003}{1000}$$

Where r is the distance in meter, r is used to get the spherical spreading factor while f is the frequency in kilohertz (kHz).

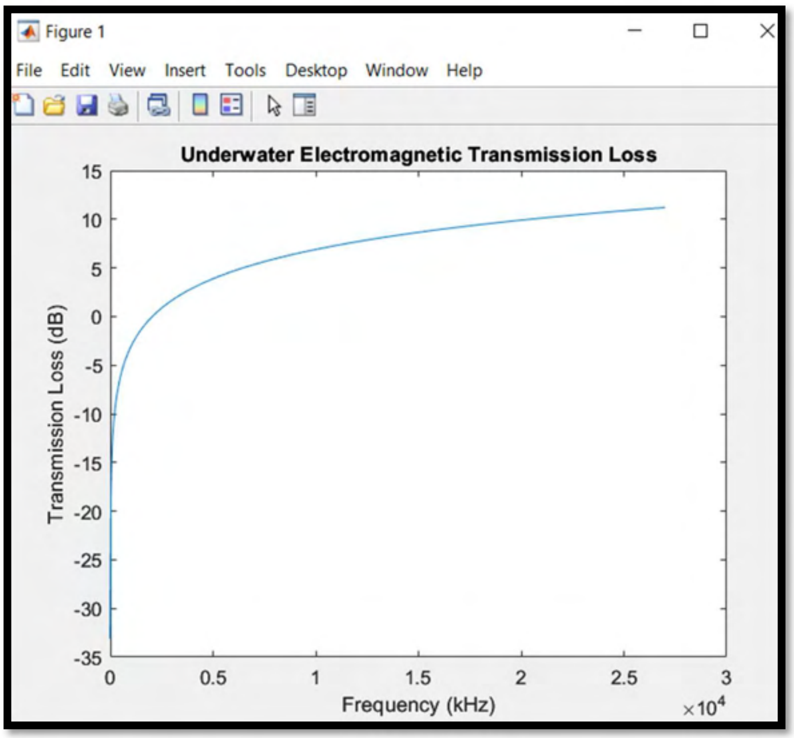

Figure 3: Transmission loss against frequency.

Figure 3 shows the result of transmission loss with different frequency underwater for 10-meter constant range by based on the Thorp's equation. The x-axis of the plot represents the frequency in kilohertz (kHz), ranging from 1 kHz to 27 MHz. The y-axis represents the transmission loss in decibels (dB). Absorption coefficient increases as the frequency increases [3]. It is important to note that this simplified model may not capture all the complexities and variations of transmission loss in different underwater environments. Viscosity and ionic relaxation in water contribute to sound absorption. Viscosity primarily affects the medium frequency range [3]. Sound absorption is influenced by factors like frequency, salinity, temperature, pH, and depth [3].

3. Chapter 3: Approach and Method for Completing Miniature Underwater Drone

3.1. Approach for Miniature Underwater Drone

To build the mechanical parts of the drone, including the hull and internal structures, the following methods are introduced:

The hull will consist of an acrylic cylinder. One side will be fully sealed by a hemisphere cover, while the other side will be capped by a cover with a diving hole. The diving hole side will be used to attach the transmission structure, which will transmit power from the motors inside the hull using magnets. To ensure the hull is properly sealed, it can be submerged at a designated depth for several days before installing the electronic components. This reduces the risk of water damage to the electronics.

Inside the hull, 3D-printed parts will be used to secure the electrical devices and the syringe for controlling diving movements. The syringe, driven by an electric motor, adjusts the drone's weight by taking in water to increase weight or expelling water to reduce weight. Furthermore, a counterweight will be installed at the bottom of the hull to prevent the drone from flipping upside down.

3.2. Method to Build Miniature Underwater Drone

The design and construction of a miniature underwater drone employ a methodology aimed at facilitating remote exploration and data collection in clear aquatic environments. The initial step involves the careful selection of a lightweight and water corrosion-resistant frame material, such as carbon fiber or reinforced plastic, capable of accommodating essential electronic components. These components include microcontrollers, batteries, motors, and sensors. Propulsion in underwater drones typically relies on propellers, which should be chosen based on desired maneuverability and speed, favouring efficient and durable brushless motors.

For regulating the movement of the drone and processing sensor data, a control system is necessary, which can consist of a microcontroller or a single-board computer like Arduino or Raspberry Pi. The control system must possess waterproof capabilities or be housed in a water-resistant casing. Various sensors, such as depth sensors, temperature sensors, and pressure sensors, can be integrated into the drone to gather data about the underwater environment. Additionally, a waterproof camera is indispensable for capturing images or videos for analysis purposes.

The selection of suitable batteries with adequate power and runtime is of utmost importance, with lithium-polymer (LiPo) batteries being commonly used due to their high energy density. The power system must be meticulously designed to ensure efficient power distribution while minimizing the risk of short circuits or water damage. The design process entails creating a detailed drone design that considers component placement, weight distribution, and hydrodynamics. Computer-aided design

(CAD) software can be employed to generate 3D models as prototypes, facilitating functionality verification, performance simulation, and necessary adjustments.

Once the design is finalized, the drone is assembled by integrating the components into the frame. The propulsion system, control system, sensors, and cameras are securely mounted, and all connections are made watertight using waterproof adhesives or O-rings. Thorough testing is then conducted to ensure the drone's stability, buoyancy, and maneuverability in a controlled water environment. The control system and sensors undergo calibration to guarantee accurate readings and reliable performance, with adjustments made as necessary based on the test results. Critical components and connections are suitably waterproofed to prevent water damage and maintain the drone's functionality.

An implemented buoyancy control system and ballast mechanism enable adjustment of the drone's depth to maintain proper buoyancy. During the design phase, the maximum depth and pressure ratings of the components used are taken into consideration to ensure the drone's ability to withstand the intended operating depth.

4. Chapter 4: Project Progress

4.1. Mechanical

There are 3 parts needed in mechanical design: diving control, transmission, and drone hull. Firstly, the 3D model building of diving has been finished and drawings of diving control are attached in appendix. Secondly, for the hull of the drone, the outer side drone body have not been produced due to huge volume counterweight needed and limited space inside the drone. The platform used to carry the electric devices will be drawn after the devices have arrived. Thirdly, the design of drone power transmission will be started after the diving control.

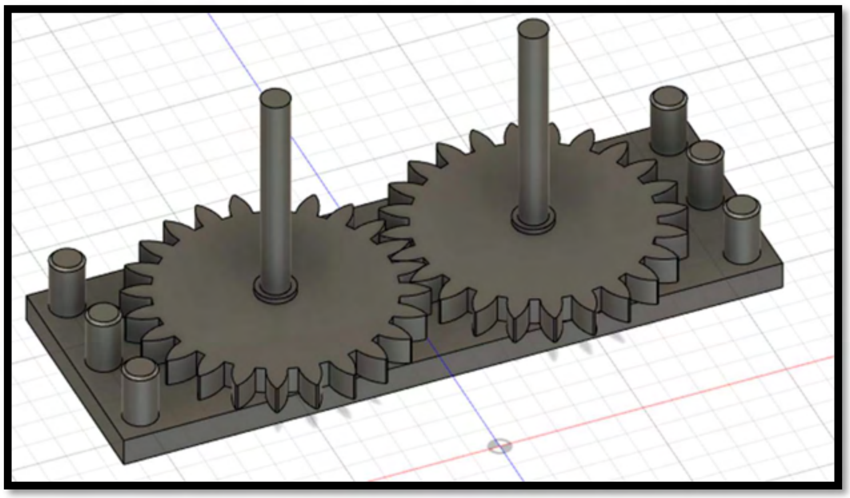

Figure 4: View of syringe transmission without upper board.

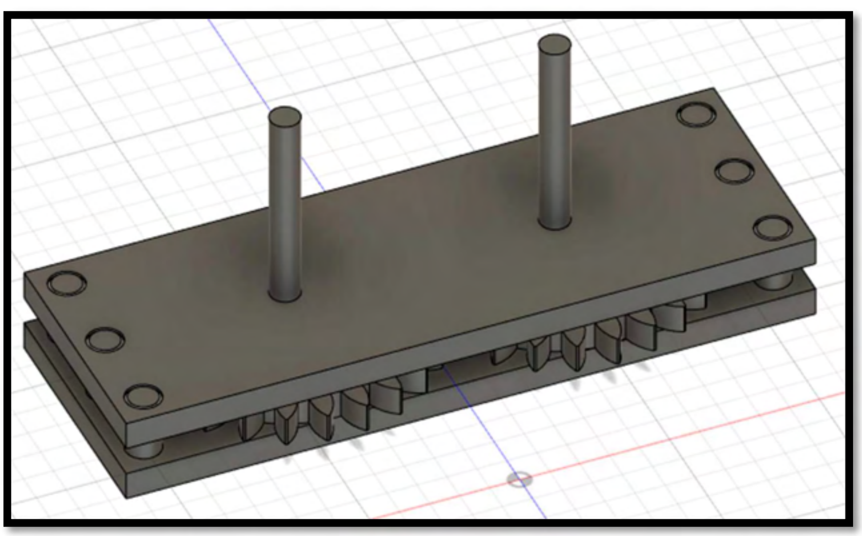

Figure 5: View of syringe transmission with upper board.

4.2. Electrical

The primary objective of the progress achieved in the development of the electrical and electronic systems for a miniature underwater drone is to ensure the overall functionality and performance of the drone in an underwater environment. The design phase of both the electrical and electronic systems has been successfully concluded, encompassing power distribution, communication interfaces, control circuitry, and electronic components. The completed designs serve as the foundation for the overall functionality and performance of the drone's electrical and electronic systems, as depicted in **Figure 6**, generated using Eagle Software.

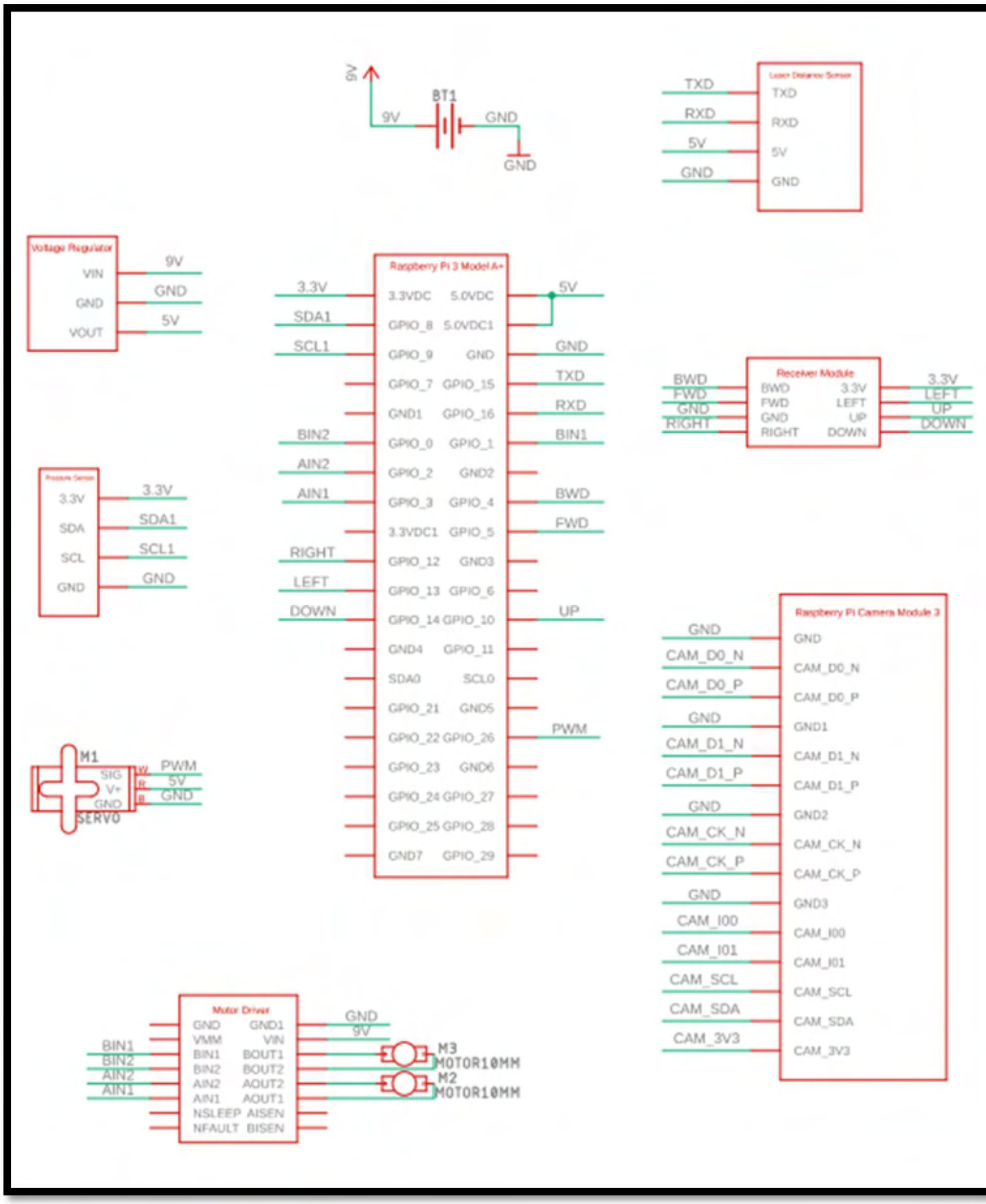

Figure 6: The schematic for the miniature underwater drone.

Power distribution assumes a critical role in the design, with the selection of a 9V Lithium-Ion battery as the primary power source. To regulate the voltage and ensure compatibility with the drone's components, a voltage regulator has been integrated to step down the voltage to 5V, serving as the power supply for the Raspberry Pi 3 Model A+.

Control circuitry plays a pivotal role in the successful operation of the drone. Two DC motors have been selected to drive the drone, enabling both turning and forward movement by connecting them to the propellers. A motor driver has been incorporated into the system to effectively control these motors. Additionally, a servo motor has been included to facilitate control over the diving system's components, allowing for precise manipulation of the drone's buoyancy.

Efficient communication between the drone and the operator is of utmost importance to ensure seamless operation. In this case, the system integrates two sensors to facilitate data collection. A laser distance sensor has been chosen to enable accurate distance measurements, ensuring safe navigation and obstacle avoidance. Moreover, a pressure sensor has been incorporated to provide essential data for monitoring underwater conditions. These sensors enhance the drone's situational awareness and enable intelligent decision-making during its missions. Furthermore, the installation of a camera enables high-quality visualization of the underwater surroundings, expanding the drone's functionality and facilitating data analysis.

Additionally, a receiver module is utilized to establish effective communication between the drone and the transmitter. This module allows the drone to receive commands from the transmitter, enabling real-time communication and precise control over the drone's movements and operations. All the components used in this project are listed in the appendix as depicted in **Table 1** below.

A rigorous testing phase will be undertaken before integrating them into a complete circuit to ensure the reliability and functionality of each component and prevent potential faults or malfunctions. This thorough testing process serves to validate the performance and durability of the electrical and electronic systems.

5. Chapter 5: Completion Plan and Conclusion

5.1. Completion plan

In the completion plan for the miniature underwater drone project, a sequential series of phases will be undertaken over the semester to ensure the successful development and evaluation of the drone. The initial phase entails the clear definition of the project's scope and objectives, where specific features and capabilities to be incorporated into the drone are identified. This step establishes a cohesive direction for the project, emphasizing the need to comprehend precise requirements and expectations to be met by the drone.

Following the definition of project scope and objectives, the design phase commences. This phase involves a comprehensive analysis of project requirements and specifications, encompassing a thorough examination of the drone's functional and technical aspects. Critical factors including size, weight, manoeuvrability, and payload capacity are meticulously evaluated during the design process. The primary goal is to devise a detailed design plan that incorporates these considerations effectively. Additionally, a 3D computer-aided design (CAD) model is generated to simulate the drone's performance and finalize the design.

Concurrently with the design phase, the selection of materials, sensors, and propulsion systems is conducted. These selections are based on the project's objectives and performance standards, ensuring compatibility with the overall design, and contributing to the drone's optimal functionality.

Upon completion of the design phase, the prototype development phase commences. During this stage, the required components and materials are procured for the construction of the drone. The team assembles the drone according to the finalized design, ensuring the proper integration of all subsystems. Initial testing is conducted to verify fundamental functionality, encompassing motor control, buoyancy, and communication systems. This facilitates the identification of any initial issues or performance limitations that require rectification.

Based on the test results, the design undergoes an iterative process, incorporating modifications as necessary. This iterative approach ensures the resolution of identified issues or limitations and the enhancement of the drone's performance. Safety measures, such as waterproofing and redundant systems, are also implemented during this phase to augment the drone's reliability and robustness. The fully assembled prototype is subjected to comprehensive testing to validate its functionality and ensure compliance with the project requirements.

Following the prototype development phase, the drone's performance is evaluated in real-world conditions. Test scenarios are devised and executed to assess the drone's manoeuvrability, stability, speed, and responsiveness to various commands. The accuracy and reliability of sensors and data collection capabilities are evaluated, with any areas for improvement identified for necessary modifications to enhance overall performance. Testing and evaluation are repeated until the drone successfully meets or surpasses the project requirements.

Lastly, a detailed documentation of the project is compiled, encompassing the development process. This documentation includes information regarding design decisions, encountered challenges, and iterative improvements implemented throughout the project. It serves as a valuable resource for future reference, offering insights for similar projects. Additionally, the documentation incorporates recommendations for further enhancements or suggestions for future research and development in the field of miniature underwater drones.

5.2. Conclusion

In conclusion, the emergence of underwater drone technology presents a promising solution for diverse applications in marine exploration, ecological monitoring, and underwater resource development. These drones offer autonomous operation in otherwise inaccessible underwater environments, minimizing risks to human divers and enabling efficient data collection and task execution. The literature review highlights various projects and technologies in the field, including PID control and pressure sensors for depth maintenance in remote-controlled submarines. Communication poses challenges due to water absorption and scattering, but options such as VLF, ULF signals, and acoustic communication through sound waves have been explored. The design and construction of a miniature underwater drone encompass mechanical and electrical aspects, with considerations for hull design, diving control, power distribution, sensors, and communication interfaces. The project progress demonstrates advancements in these areas, with 3D models, electrical system design, and thorough testing for stability and accurate data collection. The completion plan emphasizes a phased approach, from defining project scope to prototype development, testing, and evaluation. Despite challenges in underwater communication, ongoing technology advancements in platform design, sensor integration, remote control, and communication systems contribute to the growth and innovation of underwater drone technology. The progress achieved in the mechanical and electrical aspects of the miniature underwater drone project brings us closer to harnessing its capabilities and unlocking new possibilities in underwater environments.

6. References

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Appendix 1: A Diving Control Drawings

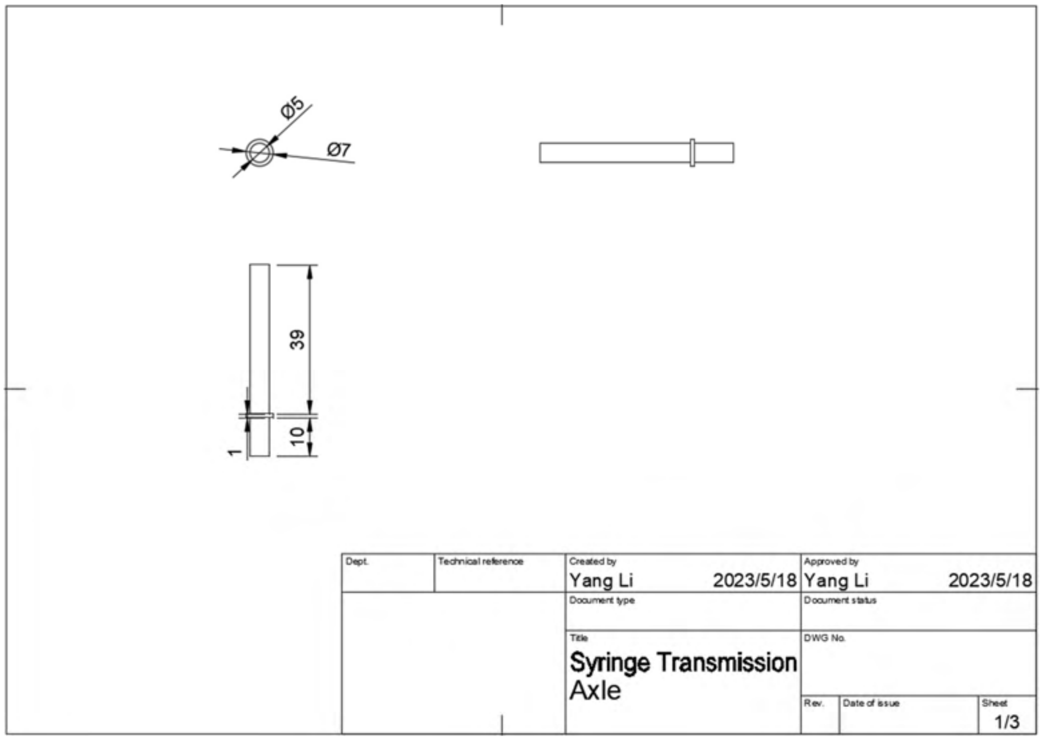


Figure 7: Syringe transmission axle.

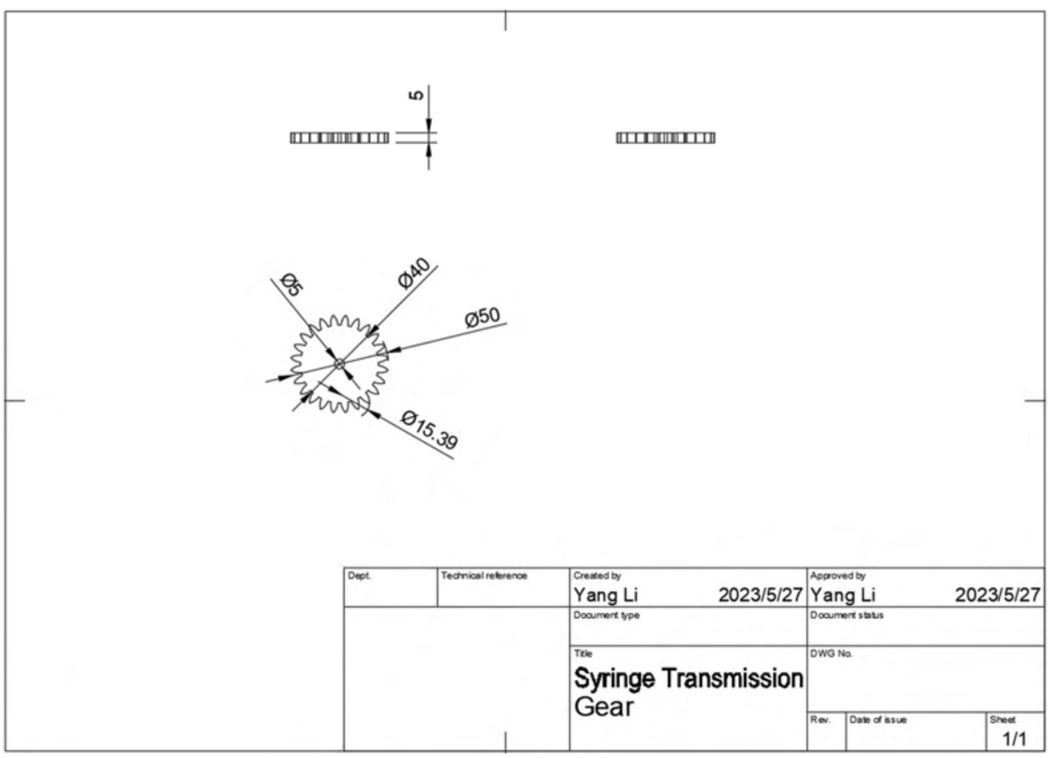


Figure 8: Syringe transmission gear.

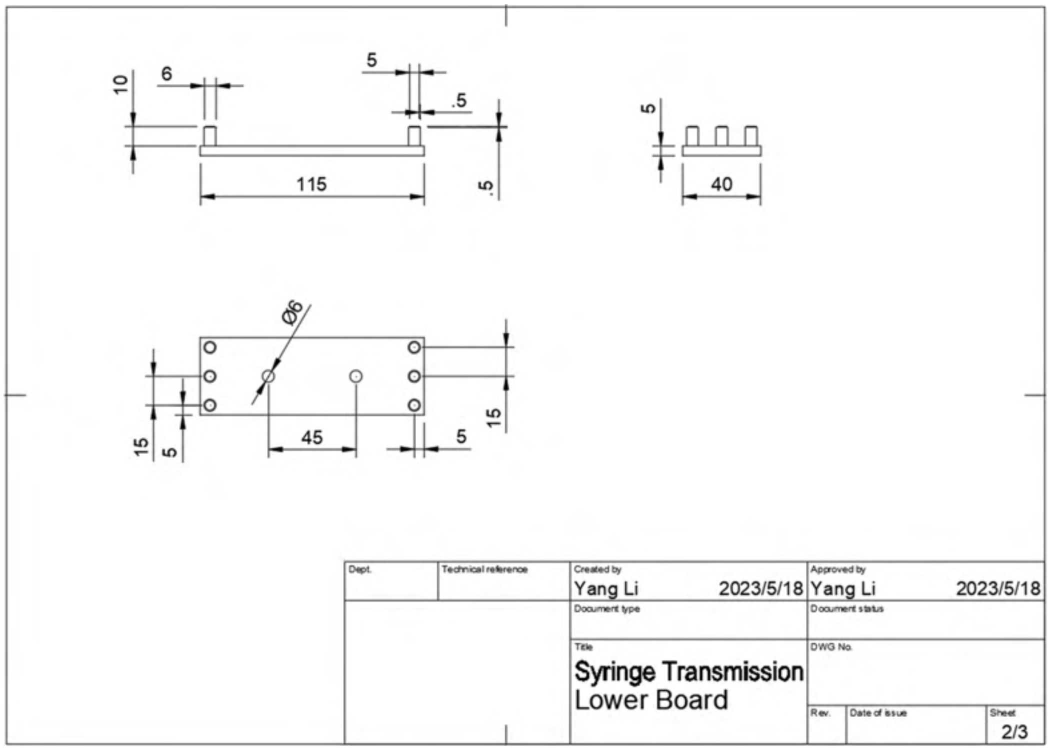


Figure 9: Syringe transmission lower board.

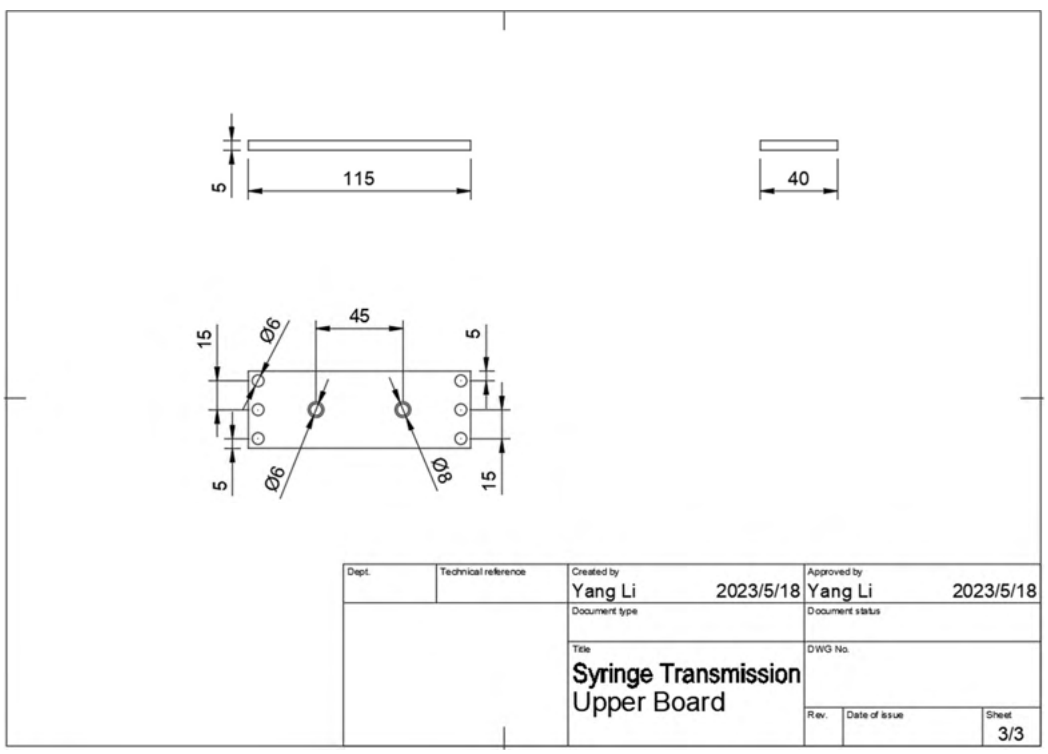


Figure 10: Syringe transmission upper board.

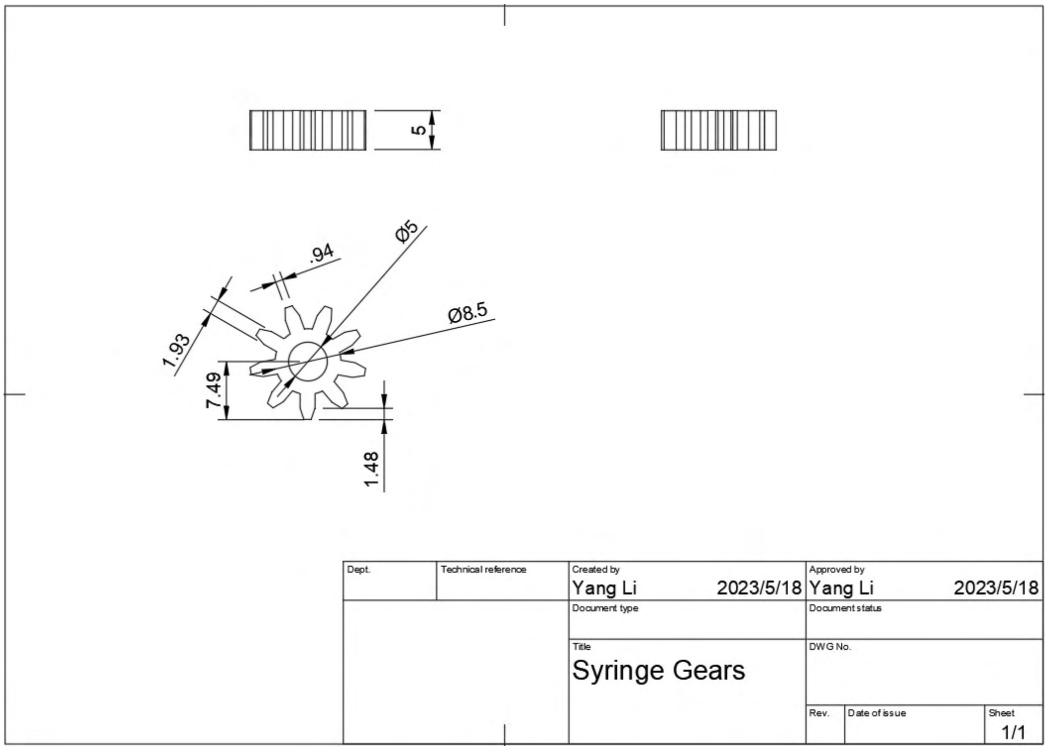


Figure 11: Syringe gears.

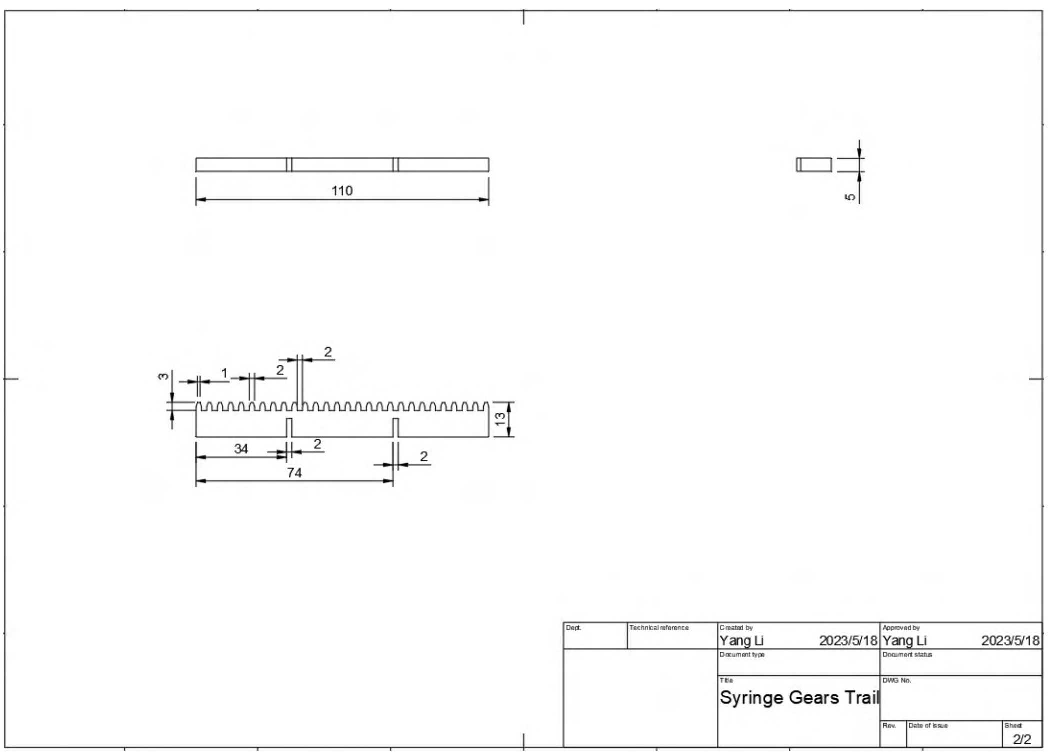
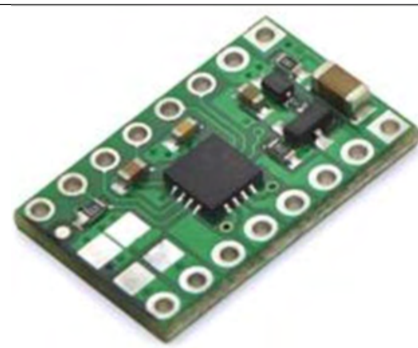


Figure 12: Syringe gears trail.

Appendix 2: Components used in the project

No.	Name	Description	Figures
1.	Single-board computer	Raspberry Pi 3 Model A+	
2.	Pressure Sensor	Honeywell Piezoresistive Pressure Sensor	
3.	Laser Distance Sensor	TF Mini LiDAR (ToF)	
4.	Li-Po Battery	2200mAh 7.4v 2S 30C Soft Case LiPo Battery	

5.	Servo Motor	Metal Geared 15Kg Standard Servo	
6.	DC motor	RS PRO Geared, 24.6 W, 3 to 7.2 V dc, 107.3 gcm, 22356 rpm, 2.3mm Shaft Diameter	
7.	Motor Driver	DRV8833 Dual Motor Driver Carrier (1.2A and low voltage)	
8.	Mini Camera	Raspberry Pi Camera Module 3	

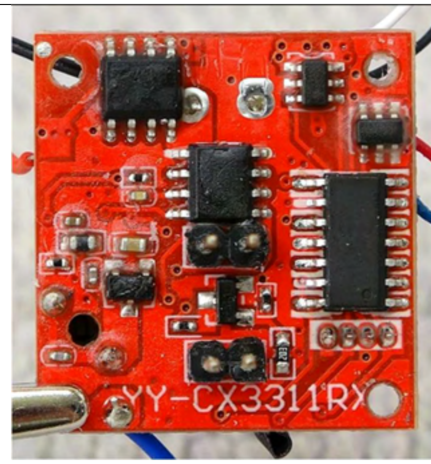
9.	Voltage Regulator	Pololu 5V Step-Up/Step-Down Voltage Regulator S7V8F5	
10.	Receiver module	27 MHz controller dissembled from a toy submarine	

Table 1: Listed components used in the project.