# MODULAR SELF-NAVIGATING UNMANNED SURFACE DRONE FOR MARINE APPLICATIONS

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# APPROVAL SHEET

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# ABSTRACT

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The project is motivated by the desire to explore the potential benefits of modularity coupled with autonomy. Developing a water surface drone leveraging an ESP-32 microcontroller and incorporating autonomous navigation powered by GPS and magnetometer sensors to create an easy to use and modular system by minimizing complexities, ensuring smooth operation and simplified troubleshooting. Testing procedures will evaluate the drone's accuracy in reaching designated target positions, providing quantitative insights into its navigational reliability. This project includes information on how to create said drone allowing anyone to reproduce it and use the drone as they see fit as it is modular by nature, some parts can be replaced or swapped out or even add new components to fit users intended use. Given the correct components, mapping lakes and rivers or monitoring ocean conditions for scientific research becomes a much easier task.

# Contents

# Chapter 1

# Introduction

This chapter has seven parts: (1) Background of the Study, (2) Statements of the Problem, (3) Theoratical Framework, (4) Conceptual Framework, (5) Scope and Limitations, (6) Significance of the Study, and (7) Definition of Terms.

Part one, Background of the Study, gives an overview as to which the research problem was anchored.

Part two, Statement of the Problem, identifies the main problem and enumerates the specific problems which the study hoped to answer.

Part three, Theoretical Framework, discussed the relevance of the variables in the identified theory, concept or principle to the research problem.

Part four, Conceptual Framework, presents the paradigm of the study.

Part five, Scope and Limitations, specifies the scope and coverage of the study in terms of purpose, research design, research instruments and statistical tools employed in the study.

Part six, Significance of the Study, presents the possible contributions and the specific application of knowledge that might be gained from the result of the study.

Part seven, Definition of Terms, contains the conceptual and operational definitions of key terms used in the study.

## Background of the Study

As the ocean covers over 70% of the Earth's surface, presenting a vast and complex environment ripe for exploration and study. Sea surface drones offer a valuable tool for navigating water bodies, collecting data, and conducting research across various disciplines. Unmanned surface vehicles (USVs) equipped with autonomous navigation capabilities have become pivotal in various applications, particularly in water environments.

Early USVs were also called ASC; Autonomous Surface Craft (ASCs) which were first developed at the MIT Sea Grant College Program in 1993 and were designed for various missions. Aptly named ARTEMIS,the vessel was a scale replica of a fishing trawler used as a platform capable of testing the navigation and control systems required by an ASC. Later on a new ASC ACES(Autonomous Coastal Exploration System) was developed during 1996 and 1997(Justin E. Manley 2008)

Further adaptation of USV in the early 20th century saw the development of remotely controlled USVs used for mine detection and target practice. World War II further spurred advancements, with nations utilizing USVs for reconnaissance and explosive delivery. Post-war, oceanographic research embraced USVs for data collection and underwater exploration. Notably, the bathyscaphe Trieste, equipped with a rudimentary autopilot, famously reached the deepest point in the Earth's oceans in 1960( National Museum of the U.S. Navy)

The 1990s witnessed a surge in commercial applications, with USVs employed for offshore oil and gas exploration, pipeline inspections, and aquaculture monitoring. The 21st century has seen a continued proliferation of USVs, with advancements in sensor technology, autonomous navigation systems, and communication capabilities propelling their capabilities further.

However, while traditional methods for marine data collection involve time-consuming, expensive, and potentially risky manual operations,

unmanned surface vehicles (USVs) offer a compelling alternative. These vehicles promise efficient, cost-effective, and safe data collection across vast areas. However, current USV technology faces three key hurdles: high cost due to complex hardware and software, limited accessibility due to user interfaces and maintenance requirements, and navigation challenges in dynamic aquatic environments. This study aims to address these limitations by developing a modular unmanned surface drone with a focus on simplified maintenance, affordability, and interchangeable components that can be easily switched.

Empirical testing conducted as part of this research, quantifying the water surface drone's ability to reach predefined target positions, serves as a critical quantitative assessment of the system's accuracy. The results obtained will offer data ensuring the navigational reliability of the drone.

The drones modular design enables adaptation on sea applications based on specific needs, seamlessly integrating communication modules, lifesaving equipment, or various sensors as required. This adaptability ensures tailored responses to emergency situations and varied data collection demands.

## Statement of the Problem

How accurate is the Modular Self-Navigating unmanned surface drone when moving from point of origin to the user inputted coordinates?

## Hypothesis

Drone accuracy will be high and can effectively navigate to the user supplied coordinates.

## Theoratical Framework

From a control systems perspective, the drone leverages feedback mechanisms and advanced algorithms to achieve autonomous navigation and mission execution. This dictates the drone's ability to gather environmental data, make real-time decisions, and dynamically adjust its actions based on sensor readings and mission parameters. Furthermore, the modular design aligns with the principles of modular robotics, emphasizing the benefits of independent, interchangeable components. This enables tailored configurations for diverse tasks, offering adaptability to various environments and operational needs. Additionally, the drone can be understood through the distributed systems theory, which emphasizes the coordination of multiple agents towards a common goal. In this context, the modular components act as individual agents collaborating to make the sea surface drone function. This theory guides the design of communication protocols and inter-module coordination algorithms, essential for seamless collaboration and collective task execution. By integrating these theories, drone development can benefit from established principles in control, modularity, and distributed systems, leading to a robust, adaptable, and efficient platform for maritime operations.

## Conceptual Framework

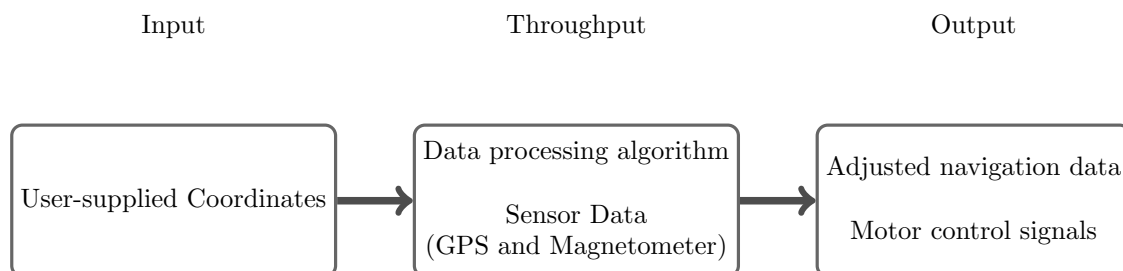Input                    Throughput                    Output



Figure 1.1: Conceptual Framework

Figure 1.1 shows the conceptual framework on how the drone functions. To discuss briefly; user provides geographical coordinates or destination data to the ESP-32 onboard the sea surface drone. Magnetometer and GPS sensors collect real-time data regarding the drone's current position, orientation, and the magnetic field. The ESP-32 employs a navigation algorithm that processes user input and sensor data from gps and magnetometer.

Continuous feedback loop adjusts the drone's path in real-time based on the latest sensor data, ensuring adaptability to various sea disturbances.

## Objectives

General Objectives:
– To design an ESP-32 based water surface drone with autonomous navigation capabilities using GPS and Magnetometer

Specific Objectives:
– To construct an easy to use and maintainable water surface drone system
– To test the accuracy of the sea surface drone to reach the target

## Significance of the Study

Developing a modular water surface drone equipped with autonomous navigation capabilities holds significant value. The widespread adoption of such drones requires accessible construction and upkeep, making them viable tools for various users. Evaluating the drone's accuracy in reaching target positions offers crucial empirical data, validating its reliability and paving the way for more practical applications. This project contributes to the progress of sea surface drone technology, potentially impacting research initiatives in oceanography, environmental monitoring, and more. Furthermore, being easy to reproduce fosters broader use, democratizing

access to this technology.

## Scope and Limitations of the Study

The research concentrates on assessing the accuracy of the drone's navigation, particularly in reaching user-provided coordinates, with a focus on real-time adjustments and adaptability to various water disturbances. The drone is limited to a navigation algorithm that checks and corrects for its navigational pathing on loop. Said algorithm is only designed for relatively small distances as it doesn't take into account the curvature of the earth and the distance measured by the algorithm is assuming a straight line and not a part of the Great Circle.
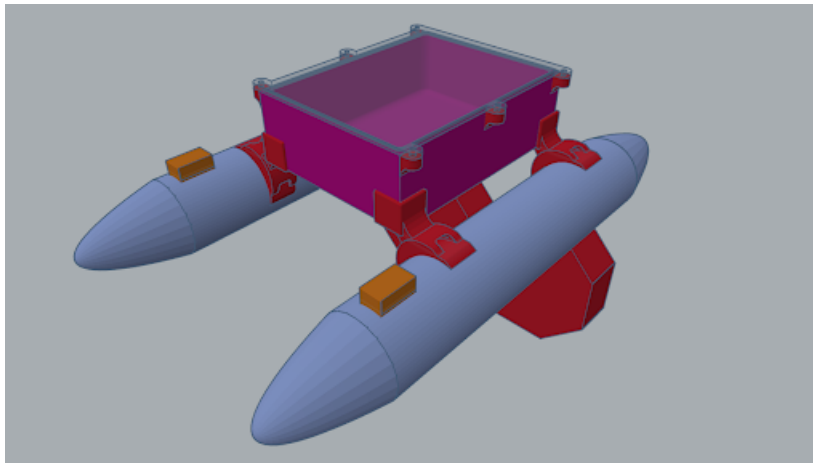


Figure 1.2: CAD Model

The study does not consider the potential challenges posed by capsizing due to strong tidal waves or encountering large obstructing objects in the ocean. Furthermore, the research does not extensively explore the intricate legal and regulatory frameworks governing unmanned surface drones, instead prioritizing an in-depth examination of the technical aspects related to navigation.

While the study's primary focus is on navigation accuracy, the drone is inherently modular(Figure 1.2). This modular design enables the

replacement of various components to meet the specific requirements of future users, enhancing its versatility and adaptability in different scenarios.

## Definition of Terms

- **ESP32** – low-cost, low-power system-on-chip (SoC) microcontrollers designed by Espressif Systems. Widely used in various applications such as IoT (Internet of Things), home automation, wearables, and industrial automation due to its versatility, low cost, and built-in Wi-Fi and Bluetooth connectivity. It is commonly programmed using the Arduino IDE or the Espressif IDF (IoT Development Framework).

- **Shroud** – refers to 3d printed components that covers and protects the propeller from marine debris. Secures brushless motor in place.

- **Pontoon** – refers to 3d printed components; Provides the drone with enough buoyancy to keep afloat on water.

- **Enclosure** – refers to 3d printed waterproof containers housing electronic components.

- **Bracket** – refers to 3d printed components; Design includes 6 pieces connecting the shroud to the pontoon and the pontoon to the enclosure.

# Chapter 2

# Review of Related Literature

The relevance of unmanned sea drones in the modern era is paramount due to their significant role in enhancing maritime operations, surveillance, and data collection while minimizing human risk. These autonomous platforms contribute significantly to various domains such as environmental monitoring, security, and underwater exploration. Navigational systems play a crucial role in the effectiveness of these drones.

Unmanned sea drones employ diverse navigation systems to ensure precise and effective operation. Inertial Navigation Systems (INS) utilize accelerometers and gyroscopes to calculate the drone's position by continuously measuring changes in velocity and orientation. Acoustic positioning systems leverage underwater sound waves for localization, particularly useful in subsea exploration. Additionally, Doppler Velocity Logs (DVL) provide real-time velocity measurements by analyzing the echoes of sound waves off the seafloor. These navigation systems collectively contribute to the autonomy and adaptability of sea drones in challenging marine environments. However, the magnetometer and GPS stand out as critical components due to their roles in determining heading and ensuring accurate global positioning, respectively, forming a foundational framework for the seamless navigation of unmanned sea drones.

The incorporation of Global Positioning System (GPS) and magnetometer technologies significantly contributes to improving autonomous navigation of water drones in maritime environments. This review explores the current state of research and developments in utilizing GPS and magnetometers for precise and reliable open sea navigation. Various studies have explored the application of GPS technology in drones.

## Prior Arts

- **An Autonomous Boat Based Synthetic Aperture Sonar [1]**

  Earlier innovators such as Silva et al. (2007) introduced the Synthetic Aperture Sonar (SAS) system mounted on an autonomous boat, specifically designed for mapping and characterizing shallow water environments. Drawing inspiration from Synthetic Aperture Radar (SAR), this SAS system leverages the combined processing of transmitted and received signals by a moving probe to generate high-resolution images. Unlike traditional narrow-aperture systems, the proposed SAS requires simpler hardware and boasts lower operational costs, making it suitable for various applications like bottom tomography, river navigability assessments, and infrastructure inspection. The key innovation lies in utilizing a floating platform instead of submersed platforms, enabling accurate position and velocity control through satellite navigation systems. This, in turn, enhances the quality of sonar images by providing precise motion compensation for the synthetic aperture technique. Silva et al. (2007) further emphasize the tight integration of GPS receivers (with carrier phase processing), compass, and inertial navigation system (INS) to achieve positioning and attitude accuracy below the acoustic wavelength used. This high-precision data feeds into a back-projection algorithm that generates absolute-coordinate images, facilitating seamless integration with other geographic information systems. Overall, the presented SAS system offers a promising solution for cost-effective and high-resolution mapping of shallow water environments, showcasing the potential of integrating advanced navigation technologies with sonar imaging techniques.

- **Navigation, guidance, and control of an overactuated marine surface vehicle [2]**

  Further innovations by Đula Nađ, Nikola Mišković, and Filip Mandić

9

(2017) proposed an optimal control strategy based on a PID controller to address course keeping during unmanned surface vessel navigation. The authors employ a combination of mathematical modeling, data analysis, simulations, and experiments to validate the effectiveness of their approach. Their findings demonstrate that the proposed PID control strategy can ensure course stability for unmanned vessels, making it a viable solution for autonomous navigation tasks.

- **Research on a course control strategy for unmanned surface vessel [3]**

Recognizing the limitations of traditional GPS and pre-built maps. Luo et al (2021) address the challenge of precise course control for unmanned surface vessels (USVs) in dynamic environments by proposing an optimal control strategy based on a PID controller. This approach leverages readily available onboard sensors, including odometry, compass readings, and occasional landmark measurements, to maintain course stability under the influence of wind, waves, and currents. Through a combination of mathematical modeling, simulations, and experiments, Luo et al. (2021) demonstrate effectiveness of their PID control method, showcasing its ability to track desired trajectories even in challenging scenarios. Their work offers a promising avenue for robust and adaptable navigation of USVs in real-world conditions, laying the groundwork for further exploration of sensor fusion and control algorithms for autonomous maritime operations.

- **Autonomous urban localization and navigation with limited information [4]**

Some studies avoided relying on gps entirely, such as Chipka and Campbell(2018) proposing an algorithm for autonomous urban navigation with minimal reliance on traditional GPS or pre-built maps. Chipka and Campbell's (2018) approach utilizes an extended Kalman filter to localize the vehicle based on odometry, compass readings, and occasional landmark measurements. Navigation is

achieved through a compass-based control law. This method demonstrates promising success rates in simulated urban environments under various conditions, suggesting a potential pathway for robust autonomous driving even in situations where GPS or detailed maps are unavailable. However, further testing and refinement are necessary to assess its real-world feasibility and extend its capabilities to handle more complex scenarios.

- **Autonomous unmanned merchant vessel and its contribution towards the e-navigation implementation: The MUNIN Perspective [5]**

On a broader scale;within the European Union, the MUNIN project develops a concept for an unmanned dry bulk carrier during deep-sea voyages..introduced by Burmeister et al. (2014), the MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) project, which investigates the feasibility of autonomous unmanned merchant vessels (UAMVs) and their potential alignment with the goals of e-Navigation, focusing on enhancing maritime safety and efficiency. While initially appearing to conflict with e-Navigation's emphasis on ship-to-shore cooperation, MUNIN effectively bridges this divide through its built-in automation features. Firstly, its advanced sensor module surpasses traditional systems in both redundancy and accuracy, potentially mitigating human errors in data interpretation and providing more dependable navigation information, a fundamental aspect of e-Navigation. Secondly, MUNIN's centralized architecture enables real-time monitoring of the vessel's status and surroundings from shore, enabling proactive intervention and improved situational awareness, in line with e-Navigation's objective of enhanced shore-based support. Lastly, MUNIN's automation directly addresses e-Navigation's goal of reducing seafarer workload by automating routine tasks, thus optimizing operational efficiency and easing crew pressure, potentially fostering a safer maritime environment by reducing fatigue. Although acknowledging the ongoing research and development needed for UAMV viability, Burmeister et al.

(2014) conclude that MUNIN's innovative approach provides valuable insights and advancements that could significantly enhance the broader e-Navigation framework.

## Synthesis

Unmanned sea drones for modern maritime operations offer enhanced surveillance and data collection while minimizing human risk. These platforms use various navigation systems like Inertial Navigation Systems (INS), acoustic positioning, and Doppler Velocity Logs (DVL), with GPS and magnetometer technologies playing critical roles in precise positioning and heading determination. Recent innovations, like the Synthetic Aperture Sonar (SAS) system on autonomous boats, highlight the integration of advanced navigation technologies for high-resolution mapping in shallow water environments. Additionally, optimal control strategies based on PID controllers are proving effective in ensuring stability and course control for unmanned vessels, showcasing advancements in autonomous maritime navigation.

Moreover, initiatives like the MUNIN project explore the feasibility of an autonomous unmanned merchant vessels (UAMVs) aligned with e-Navigation objectives, focusing on safety, efficiency, and reduced seafarer workload. By integrating advanced sensor modules and centralized automation, these projects aim to enhance navigation accuracy, shore-based monitoring, and operational efficiency. Such endeavors address current navigation challenges and pave the way for safer maritime operations by reducing human error and fatigue, offering insights into the future of autonomous maritime navigation within the broader framework of e-Navigation.

|  | Prior art 1 | Prior art 2 | Prior art 3 | Prior art 4 | Prior art 5 | Proponent's study | Remarks |
|---|---|---|---|---|---|---|---|
| GPS / Magnetometer based | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | Navigation algorithm is highly reliant on GPS / Magnetometer data |
| 3d printed materials | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | Uses PETG (Polyethylene Terephthalate Glycol-Modified), a material known for its water resistance |
| ESP-32 microcontroller | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | Utilizes an ESP-32 microcontroller |
| Water surface drone | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | Built for water surface applications |
| Modular design | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | Modular components are designed to be easily detached or replaced. This allows for quick upgrades, replacements, or modifications |

# Chapter 3

# Methodology

This chapter shows the process of designing, testing and troubleshooting tools and equipment, construction and wiring procedure.

Now that the design is in place, the purchase of material will follow, then the construction of the device and lastly the performance, functionality, and reliability will be tested.
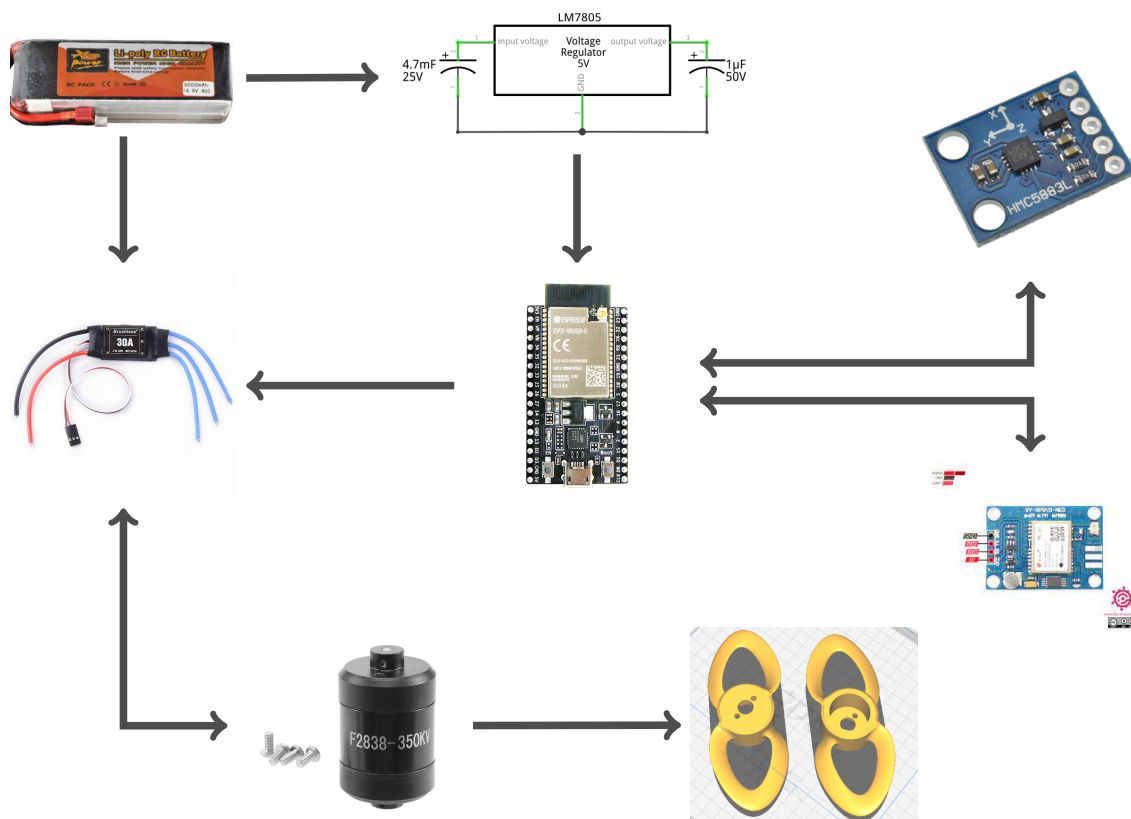
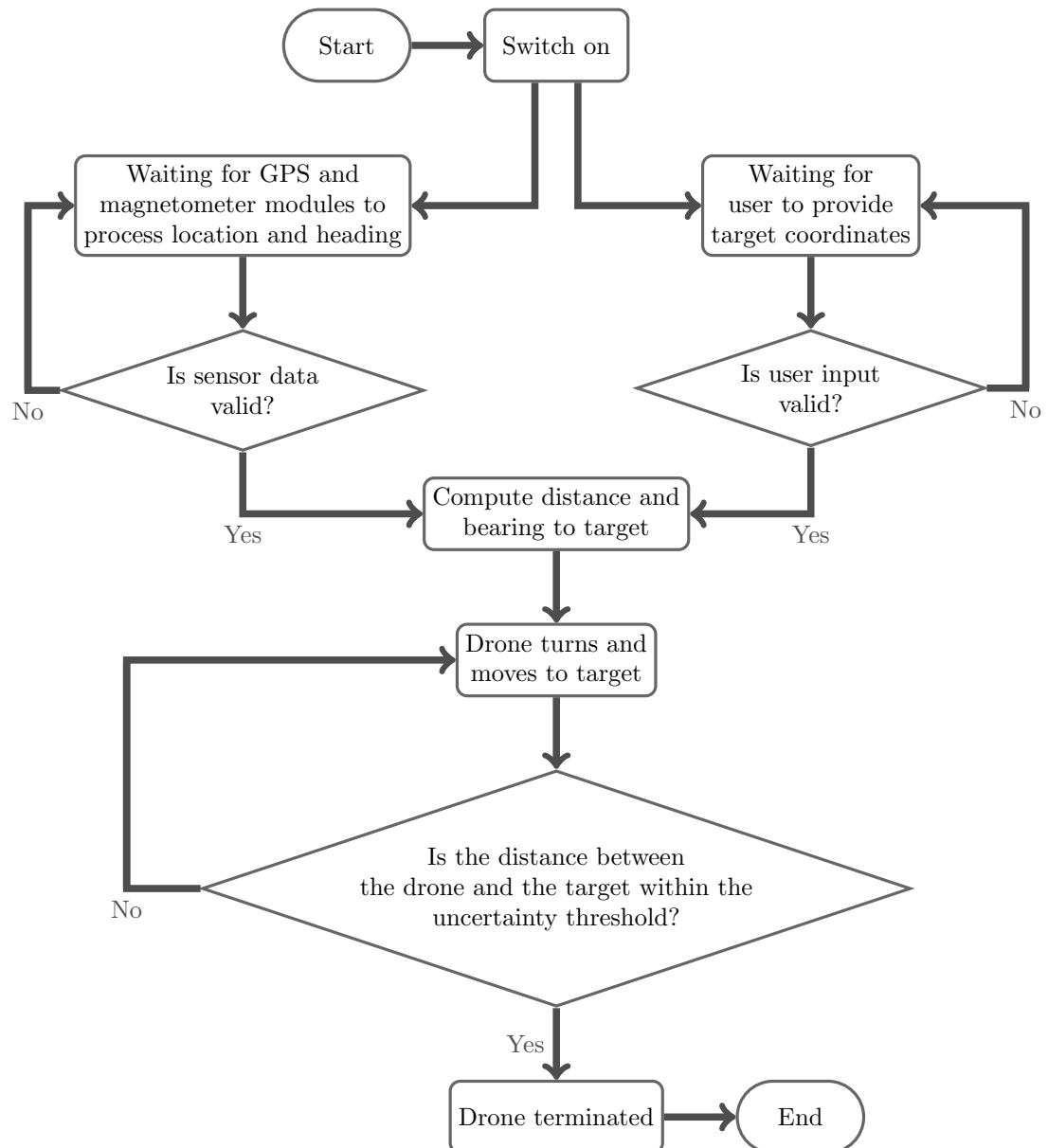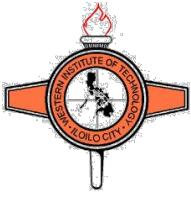## System Design



Figure 3.1: System Design

## Flowchart



Figure 3.2: Flowchart

## Navigation algorithm

1. Get target location $X_t$ from the user

   $X_t$ is acquired from the user by specifying its geo-coordinates in the *Latitude-Longitude* format. Latitude values denote the angular distance relative to the equator, with positive values indicating locations north of the equator and negative values indicating locations south of the equator. Similarly, Longitude values represent the angular distance east or west of the Prime Meridian, with positive values corresponding to western locations and negative values signifying eastern locations. *Both Latitude and Longitude should be specified as decimal degrees.*

2. Get current location $X_c$ and current heading $\theta_c$ from GPS and magnetometer modules

   $X_c$ is acquired from the Global Positioning System (GPS) module. The module transmits NMEA sentences (refer to Section X.X todo for a detailed explanation) to the ESP32 microcontroller. Of these sentences, the GPGLL sentence is specifically processed to extract the latitude, north/south (N/S) indicator, longitude, east/west (E/W) indicator, and validity status. The latitude and longitude values are converted from the degrees-minutes-decimal minutes format (dddmm.mmmm) to decimal degrees for further calculations. Subsequently, the N/S and E/W indicators are used to determine the correct sign (positive or negative) for the extracted latitude and longitude values.

   In contrast, $\theta_c$ , is calculated based on the $X$ and $Y$ values obtained from the magnetometer module. This value represents the device's orientation relative to magnetic north. The calculation of $\theta_c$ requires the declination angle $\delta$ which is itself derived from the longitude component of the current location, $X_c$ . The declination correction accounts for the difference between magnetic north and true

geographic north. This correction is applied to the magnetic heading, denoted by $\boldsymbol{\theta_c}$ which is am azimuth value between 0 and 359 degrees, to obtain a value that represents the device's orientation relative to true north. A specific function is used during this correction process to ensure the resulting value remains within the 0-359 degree range and avoids overflow errors.

$$\text{let } \lambda_c = \text{longitude component of } X_c$$

$$\delta = (\underbrace{0.015}_{\text{constant used to approximate angle of declination}} * \lambda_c) + 1$$

$$\theta_c = \text{atan}_2(y, x) + \frac{180}{\pi} + \delta$$

3. Get the difference between between longitude and latitude components of $\boldsymbol{X_c}$ and $\boldsymbol{X_t}$

$$\text{let } \lambda_c = \text{longitude component of } X_c$$
$$\text{let } \lambda_t = \text{longitude component of } X_t$$
$$\text{let } \phi_c = \text{latitude component of } X_c$$
$$\text{let } \phi_t = \text{latitude component of } X_t$$

$$\lambda = \lambda_c - \lambda_t$$
$$\phi = \phi_c - \phi_t$$

4. Get bearing $\boldsymbol{\Delta}$ to target

# Bibliography

[1] Sergio Rui Silva, Sergio Cunha, Anibal Matos, and Nuno Cruz. An autonomous boat based synthetic aperture sonar. In *OCEANS 2007*, pages 1–7, 2007.

[2] Đula Nađ, Nikola Mišković, and Filip Mandić. Navigation, guidance and control of an overactuated marine surface vehicle. *Annual Reviews in Control*, 40:172–181, 2015.

[3] Zhigang Luo, Tonghui Qian, Xi Ye, Jiahui Huang, and Linwen Yu. Research on a course control strategy for unmanned surface vessel. *Journal of Physics: Conference Series*, 1948(1):012106, jun 2021.

[4] Jordan B. Chipka and Mark Campbell. Autonomous urban localization and navigation with limited information. *CoRR*, abs/1810.04243, 2018.

[5] Hans-Christoph Burmeister, Wilko Bruhn, Ørnulf Jan Rødseth, and Thomas Porathe. Autonomous unmanned merchant vessel and its contribution towards the e-navigation implementation: The munin perspective. *International Journal of e-Navigation and Maritime Economy*, 1:1–13, 2014.