Heaven's light is our guide

Rajshahi University of Engineering & Technology, Bangladesh

Department of Mechanical Engineering

A project on

Development of safety systems for marine vehicles in Bangladesh perspective.

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ABSTRACT

Bangladesh is a country crisscrossed by an extensive network of rivers, making water transport a crucial mode of transportation. Traditional launches, which are often overcrowded and lack advanced safety mechanisms, are the backbone of this transportation system. Unfortunately, the country has faced recurrent accidents and collisions on its waterways, resulting in substantial loss of life and property. This paper presents the development of a safety system for marine vehicles in the context of Bangladesh, with the primary objectives of detecting obstacles on waterways, finding the optimum path for avoiding collisions, and retrofitting traditional launches with modern technology. To achieve these objectives, we utilized an Arduino-based system integrated with sensors and servo mechanisms. The system's obstacle detection capability relies on a sonar sensor, which can identify both static and dynamic obstacles in the boat's path. When an obstacle is detected, the system processes the information and instructs a servo mechanism connected to the rudder to steer the boat in a safe direction. Additionally, a gyroscope is employed to monitor the boat's tilt angle, providing real-time feedback displayed on an LCD screen to assist the boat operator in maintaining stability. Furthermore, a water sensor is incorporated into the system to detect overweight conditions, ensuring safe load limits are not exceeded during voyages. The results of our project confirm the successful operation of the safety system, presenting a significant step toward enhancing maritime safety in Bangladesh. By deploying this technology, traditional launches can navigate waterways more safely, mitigating collision risks and reducing accidents. The results of our project demonstrate that the developed safety system functions effectively as intended, enhancing the safety of marine travel in Bangladesh waters. However, we acknowledge that further improvements can be made to enhance obstacle detection and avoidance.

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Nomenclature

OW	Own Ship
TG	Target Ship
VTS	Vessel Traffic System
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea
HMI	Human-Machine Interaction
LRF	Laser Range Finders
LED	Light-emitting diode
LCD	Liquid-crystal display

Chapter 1
Introduction

1.1 Background

There are several rivers, canals, and waterway systems spread throughout Bangladesh. The inland waterways span almost 6000 kilometers of navigable channel. Additionally, Bangladesh has a lengthy Bay of Bengal shoreline in the southern region, which enabled Bangladesh to create the biggest delta in the world. This natural gift has facilitated easy access for people to all areas of the nation via waterways. Additionally, the majority of the population in this growing nation prefers it since it is cheaper. It is backed by the fact that nearly half of all goods are transported via inland waterways. One-fourth of Bangladesh's total passenger traffic and all significant freight traffic. This means of transportation makes a considerable contribution to Bangladesh's national GDP [1]. Thus, the use of waterways for communication is crucial. This route transports around 95 million travelers a year. But this significant means of transportation suffers from fatal accidents every year, costing a high number of lives. Approximately 5,500 people perished and 1,500 went missing in 658 launch incidents over the past 20 years (1994 to 2014). It has been discovered that the waterways connecting Dhaka and Chittagong to Barisal, Bhola, Chandpur, and Patuakhali are more accident-prone. These fatal collisions are caused by a lack of awareness, unrestrained operation of unfit vessels, overloading of passengers, hiring of unskilled crews, inadequate capacity of pertinent bodies, low standard maintenance of Inland Water Transport (IWT) channels, Technological barriers, poor weather forecasting, a profit-centered attitude on the part of vessel owners, and corruption [2]. Even though collisions pose a major threat to Bangladesh's marine safety, there has not been much research done on the subject. Accidents involving collisions are rapidly increasing in Bangladesh, along with the number of deaths [3]. Another research examined 156 collision events that occurred between 1981 and May 2007. According to the survey, collisions accounted for 39% of all accidents during that time [4]. However, recent research indicated that collisions accounted for the majority (60.3%) of accidents in Bangladesh's inland waterways from 2005 to 2015 [1].

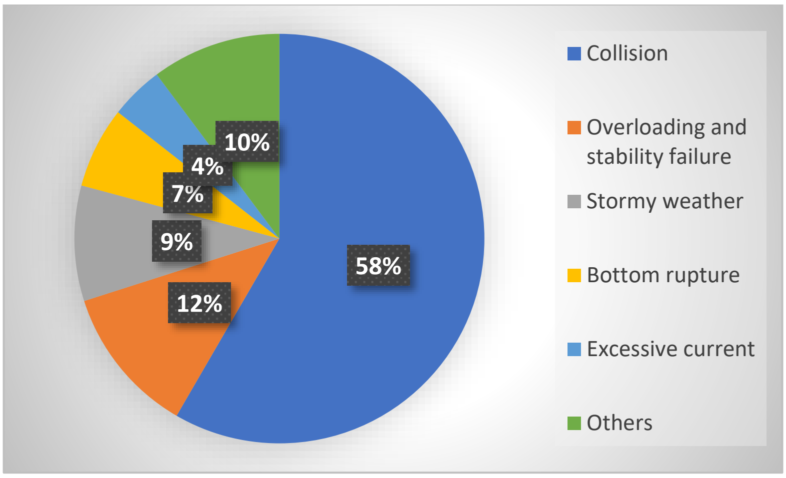


Figure 1.1: Percentage of accident types in inland waterways of Bangladesh [1].

From 2005 to 2017, Figure 1.1 depicts the total accident and collision accident pattern. According to analysis [5], accidents from 2005 to 2015 had a wave-like pattern. Along with the mentioned years, 2016 and 2017 were also included in the investigation, and it is fascinating to note that the trend is still being followed. To clarify this crucial topic, some in-depth study that considers socioeconomic aspects that contributed to the incidents is required.

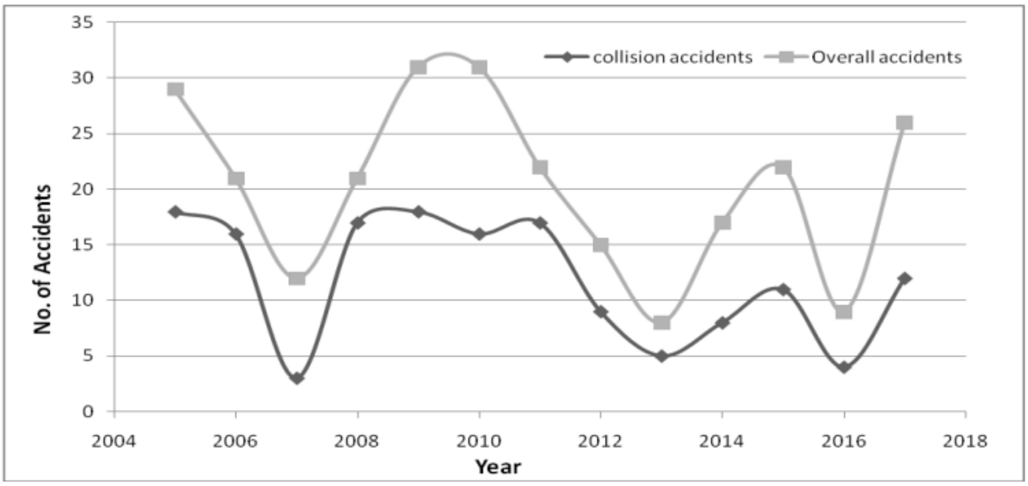


Figure 1.2: Yearly distribution of overall accidents and collision accidents [1].

Figure 1.2 demonstrates that collision-related incidents follow a similar trend to accidents. Both curves may be thought of as being similar, apart from the years 2009 and 2010. This graphical display illustrates the collision incidents' dominating pattern in Bangladesh's inland water transport.

Figure 1.3: Cargo ship Rupshi-9 hits ML Ashrafuddin in the Mahmudnagar area of Narayanganj.

A launch with at least 30 passengers aboard sank in the Shitalakkhya River after it was hit by a cargo vessel in Narayanganj on 20 Mar 2022, killing at least one person (Figure 1.3).

There are several studies of relevant literature that compile methods for avoiding collisions, such as [6]–[10]. These studies, however, have not highlighted the connections between the state-of-the-art techniques for manned and unmanned ships. Firstly, the reviews are either written with the intention of assisting humans in collision avoidance [9], [10]; or with the intention of constructing ASVs [6]–[8]. In these reviews, the debate across these two categories of papers is absent. Secondly, since these studies typically have diverse objectives, data on collision avoidance techniques is infrequently gathered or even disregarded. The review [10] described the collision risk assessment but neglected the techniques for conflict resolution; the papers [6] and [7] addressed the developments of ASVs in detail but placed less emphasis on conflict detection and obstacle avoidance; the review [10] concentrated on path planning techniques but only included a few studies related to reacting collision avoidance for unmanned vehicles. An update is required for the convenience of peer researchers due to the significantly growing amount of relevant publications. The limits of early ship collision avoidance technologies, particularly those developed between the 1950s and the early 2000s, were discussed in a literature study [9]. The identified shortcomings are summarized as follows, along with the constraints covered in other reviews: (1) Environmental factors are not considered when preventing collisions [8], [9]; (2) It is still difficult to incorporate regulations into collision prevention algorithms [6]–[8], such as the International Regulations for Preventing Collisions at Sea (COLREGs).

(3) Collision avoidance only takes into account static or semi-dynamic obstacles that move without changing headings [7], [9]; (4) highly ideal motion models are used in collision avoidance [8], [9]; and (5) balancing efficiency and effectiveness is disregarded [7]. Conflict detection is the process of determining whether and when the OOW should take evasive action. The key component of this process is a collision risk assessment, which sets off an event that either requests a human or a machine to identify potential collision hazards or provide a collision-free solution. In recent publications and literature reviews, these limitations have been extensively acknowledged and utilized. However, as new approaches and strategies emerge, certain restrictions have been solved and new difficulties have emerged.

This project presents a potential approach for enhancing maritime safety through the integration of human interaction with autonomous systems. The focus is on inland water vehicles, which often lack the advanced technologies found on larger ships. These vehicles play a crucial role in the transportation infrastructure of many countries, providing a cost-effective and accessible means of transporting goods and passengers. However, they also present unique challenges in terms of safety and navigation.

This approach is designed to handle four potential collision scenarios: static obstacles, head-on collisions, crossing paths, and overtaking situations. By effectively addressing these scenarios, the proposed system can significantly enhance the safety and efficiency of maritime navigation. Despite these challenges, this project presents a promising solution for modernizing inland water vehicles and enhancing their safety features. Through rigorous testing and analysis, it lays a solid foundation for future research in this area. It also provides valuable insights into how such systems can be scaled up for larger applications, paving the way for safer and more efficient maritime navigation in the future.

1.2 Problem Statement

Lack of contemporary technology and inexperienced crew are the primary causes of ship collisions. Therefore, the goal of this research is to identify an appropriate technique for avoiding launch collision and determining the best course utilizing current technologies.

The fundamental goal of an obstacle avoidance capability is to detect the presence of a surface obstruction on the vehicle's path in advance, in terms of both distance and time. Although stationary obstacles pose a hazard to the vehicle, they are merely a portion of the issue. Moving barriers are significantly riskier represented by swimmers, small boats, or canoes. In particular, not only for the integrity of the vehicle but the vehicle itself creates a concern for the safety of swimming individuals, and the safety of human beings.

For this reason, the obstacle detection sensor should have a field of view of at least 180 degrees and a field of action of around 100 meters to allow the vehicle to safely perform the required avoidance maneuvers. The vehicle will be able to recognize and steer clear of moving objects in this manner, including those that are discovered not just in front of it but also laterally and may possibly cross its path. Unmanned surface vehicles often have a significant sensoristic data to accomplish this task, such as a large number of fixed cameras (for covering 180 degree), X-band radar, and multi-beam laser. However, this method frequently yields a poorly integrated solution as well as a pricey, large system that is not appropriate for a small- to medium-sized vehicle.

The aim is to create a low-cost integrated system based on a limited number of lightweight, commercially available sensors and to make them function together to produce a navigation map of the 180 degrees surrounding the vehicle. Standard optronic systems for civil use, which often come with infrared cameras and laser range finders (LRF), might be a potential option that is already on the market. Unfortunately, none of them has demonstrated the ability to effectively address the collision avoidance issue. The key issue is that while these systems are often used for surveillance and are frequently monitored by a human operator, they are not appropriate for quickly scanning a large region. Secondly, every sensor in these systems is housed on a single actuating head. This presents a problem because the LRF must remain focused on the obstacle for a specific amount of time in order to provide a reliable reading, but by stopping cameras along with the LRF, the time to complete a 180-degree rotation increases to an unacceptable level, making it impossible to detect a crossing obstacle like a swimmer in time.

1.3 Theory

A thorough grasp of fluid mechanics concepts is necessary for the safe operation of marine vehicles, particularly in crowded or difficult waterways. These ideas are essential for maintaining the stability, control, and safety of boats.

Floating Body Principle:

This principle explains why marine vessels float that the buoyant force equals the weight of the displaced fluid. Collision Avoidance Systems keep track of the weight of the ship and its cargo to make sure buoyancy is balanced by using Archimedes' principle.

Floating body's principle is expressed mathematically as:

$F = \rho \times V \times g$ (Equation 1.1)

Where,

F = Buoyant force (N),

ρ = Density of the fluid (kg/m^3),

V = The volume of fluid displaced (m^3), and

g =Acceleration due to gravity (m/s^2).

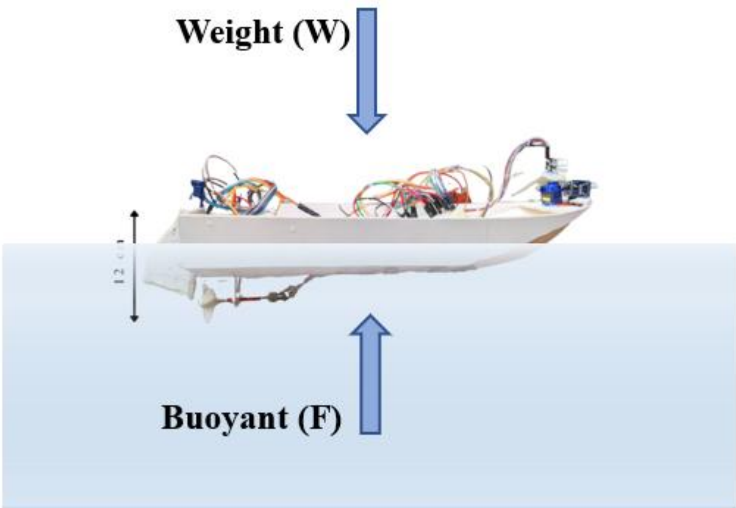


Figure 1.4: Application of Floating Body Principle.

The buoyant force F, which operates upward, is essential for a vessel's float. To sustain buoyancy, the vessel's weight must be less than or equal to the buoyant force.

Weight (W) $\leq$ Buoyant (F)

It's crucial to maintain vessel stability by distributing weight. Increased accident risk might result from tilting and instability caused by an unequal load or excessive weight.

To determine the minimum weight a boat can carry, we can use the equation:

$B = \rho \times g \times V$ (Equation 1.2)

Where,

B = Buoyant force, and

V = Volume of the submerged part of the boat's hull.

The minimum weight the boat can carry is equal to the buoyant force, which is the same as the weight of the fluid displaced by the boat. So:

Minimum Weight Capacity, $B = \rho \times g \times V$ (Equation 1.3)

This equation will give you the minimum weight capacity of the boat, based on its buoyancy and the submerged volume of the hull.

Floating Body Tilting Condition:

A floating body is stable if it deviates or tilts from its equilibrium position and has a resetting moment. As illustrated in Fig. 1.5, dead weight F_G and buoyancy F_A form a force couple with the lever arm of b, resulting in a righting moment. The measure of stability is the distance between the center of gravity and the point of intersection of the line of action of buoyancy and the symmetry axis. The point of intersection is known as the metacentre M,

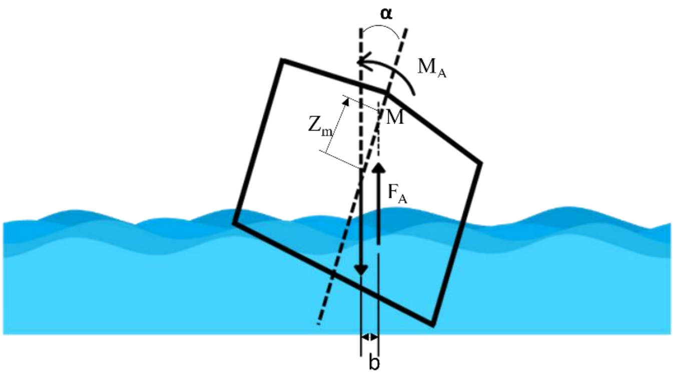


Figure 1.5: Tilting condition of a floating body.

and the distance between the metacentre and the center of gravity is known as the metacentric height, Z_m. The floating body is stable when the metacentric height Z_m is positive, indicating that the metacentre is above the center of gravity; otherwise, it is unstable. The position of the metacentre is independent of the position of the center of gravity.

1.4 Objectives

The objectives of the given case study topic can be stated as:

- To detect overweight & tilt.
- To detect and avoid obstacles on waterways.

1.5 Scope of the Project

This project aims to develop a safety system for marine vehicles in Bangladesh, with a specific focus on the development of an algorithm that can detect and avoid obstacles in the path of a ship. The study will also explore the use of center of gravity data of the ship and alert crew members in the event of overcrowding. The gyroscope sensor will also give data about roll, pitch, and yaw, which can be monitored to take corrective actions accordingly.

The scope of this study is centered on a technique designed for maritime navigation. This technique allows for the deactivation of the autonomous mode when a human operator assumes control of the ship. However, it also permits simultaneous operation of both the human operator and the autonomous system, with the human operator providing authentication for maneuvers. The system is also able to function autonomously to prevent collision scenarios in the absence of a human operator. Nevertheless, it is recommended that a human operator be consistently present to validate maneuvers.

This research is based on a prototype that is designed to effectively handle four primary scenarios: static obstacles, head-on collisions, crossing paths, and overtaking situations. The prototype incorporates a water level sensor and a gyroscope as a passive safety mechanism. The ultrasound sensor used in this prototype has a limited range, capturing data only within an angle of 180 degrees. The research aims to explore potential improvements and adaptations that could enhance the system's performance and reliability.

The algorithm developed a safety system that integrates with other systems for obstacle detection and avoidance, as well as monitoring the center of gravity to avoid overcrowding, and roll, pitch, and yaw data for balancing the vehicle. The developed algorithm is tested for the prototype built.

Chapter 2
Literature Review

2.1 Literature Review

Tor Arne Johansen et. al. [11] introduced a ship collision avoidance system, grounded in model predictive control. By adjusting the autopilot's course angle and propulsion speed, it generated a range of control behaviors. The system used simulated trajectory predictions to evaluate each behavior's compliance with international collision prevention regulations and potential collision risks. Based on these evaluations, the optimal control behavior was selected. The system's robustness was ensured by considering multiple scenarios, including factors such as ship dynamics, steering and propulsion systems, environmental forces, and obstacle dynamics. Simulations demonstrated the system's effectiveness in managing complex situations involving multiple dynamic obstacles and uncertainties related to sensors.

P. Chen et. al. [12] provided further information for readers. In the article, "collision risk" refers to the possibility or probability of a collision. The "expert-based method" and "model-based method," which are acknowledged, are the two main categories of literature. The first set of research directly applies knowledge from experts to determine collision risk. As a consequence, the calculated risk reflects what researchers think would happen in the case of a collision. A simplified model representing the physical process of collision is used by the second set of approaches to estimate the likelihood of an occurrence. The assessed risk is a conditional probability of collision as a result. Each group uses a variety of representations, such as numerical and graphical representations, to show the danger of collision to humans. While some researchers choose to express risk as a number, which is seen as a numerical representation, others prefer to depict risk as a two-dimensional map, such as rings of warning, action lines, etc., which is regarded as a graphical representation.

Rafal Szlapczynski et. al. [13] investigated the ship's domain to identify the last instance when a certain collision avoidance maneuver may be successfully conducted. To verify the situation MATLAB simulation has been implemented. The simulations include a whole range of common give-way interactions under different situations: head-on, crossing, and overtaking scenarios; maneuvers limited to course change and those combining turns with speed decrease; wide or constricted waterways and ultimately - in both favorable and limited visibility. It has been found that it is vital to describe when exactly a navigator needs to take action to avert domain violation. And it is maybe as vital to bring out circumstances where faster than normal or counter-intuitional measures should be performed. The article tackles both challenges, though indicated simulation findings are reliant on the dynamics of a ship, which has been employed in the simulations. Further study, employing a greater number of ship models, should be undertaken to allow further and more far-fetched assertions concerning the subject covered.

Cdr Kaosar Rashid et. al. [14] investigated the kind of activities necessary for preventing accidental events from the administrative viewpoint. The analysis has uncovered several alarming issues contributing to maritime mishaps. Along with unfit conditions, vessels are routinely overloaded beyond their permitted capacity, and passenger vessels often carry substantial cargo on the upper decks to earn extra income, which increases top-heaviness and instability. A considerable number of passenger vessels are in a state of disrepair with mostly non-operational mechanisms. Despite advisories to avoid marked risk-prone zones in navigation channels, these warnings are often ignored by vessel crews. Inland safety regulations are frequently disregarded, and the law enforcement mechanism in the Inland Water Transport (IWT) sector is ineffective. These findings underscore the urgent need for enhanced safety measures and stricter enforcement of regulations. The author recommended that large passenger ships, which can accommodate more than 200 passengers, should be equipped with an echo sounder (depth finder), compass, and GPS to ensure safe navigation.

The research conducted by Ning Li et. al. [15] explored the use of Particle Swarm Optimization and Genetic Algorithm for collision avoidance, as demonstrated through a MATLAB simulation. In head-on, crossing, and overtaking scenarios, the ship successfully avoids collisions safely and efficiently, with smooth avoidance paths. The uniform change in distance between the ship and the target ship meets safety standards. The minimum distance exceeds 5km, satisfying broad avoidance criteria. Post-avoidance, the target ship reverts to its initial heading trajectory with minimal deviation, fulfilling the economic requirements of collision avoidance. The findings from the analysis have demonstrated that the particle swarm genetic hybrid optimization algorithm proposed in this study can simultaneously meet the economic and safety needs of ship collision avoidance with a quicker convergence speed, seamless ship collision evasion path, less path distance, and navigating angle compared to another single algorithm.

Mohammad Tanvir Hossain et. al. [16] investigated contact type accidents of marine transport in Bangladesh utilizing fault tree analysis method. Based on the particular characteristics of the inland marine transportation system in Bangladesh, a fault tree is constructed to describe the chain of events leading to collision and sinking. The authors proposed that there is an urgency for the development of a robust and comprehensive database. It is imperative that all past accidents are thoroughly examined by the relevant authorities. The fault trees delineated in the study can serve as a foundational framework for these investigative procedures. Also, a direct study of accidents using an interactive system may serve the objective of both building an authentic and trustworthy accident database and upgrading the present fault trees. Such fault tree could be utilized as a foundation for detailed risk assessment.

Kang Zhou et. al. [17] conducted a study that utilized a quantitative approach to investigate the most effective collision-avoidance tactics in a two-ship crossing situation. The research involved the collection and analysis of data on ship dynamics, navigational techniques, and bunker usage to develop and assess possible collision-avoidance scenarios. The study provided a method for identifying collision hazards and calculating their values within a specific range. It was important to note that the rudder blades required a few moments to attain the proper angle.

In their research, R. Szlapczynski et. al. [18] conducted a thorough investigation into the use of the ship domain concept in maritime navigation and traffic engineering. The scientists ran simulations that covered the entire spectrum of common give-way contacts in various scenarios. According to the study, the ship domain was frequently employed as a safety condition in maritime navigation and marine traffic engineering. The simulation findings provided valuable insights into the utilization of the ship domain concept for determining distances required for collision avoidance maneuvers in give-way scenarios. However, there were limitations to the study. One limitation involved establishing the distance and timing at which a requested maneuver, preferred by a navigator, should be executed in order to prevent domain violations. Additionally, because COLREGS standards were not incorporated into the simulations, optimizing the trajectory in terms of factors such as energy usage and environmental conditions like wind and current was not possible.

A. Lazarowska et. al. [19] conducted an investigation and provided a comprehensive analysis of the use of a deterministic method in a decision support system for ship trajectory planning. The authors described a decision-support system for ships that had been created to tackle the challenge of avoiding collisions with both stationary and moving objects. The system aimed to achieve a new level of functionality characterized by complete autonomy. The experimental findings highlighted the significance of this contribution in advancing expert and intelligent systems. According to the author, autonomous systems represented the future direction of expert and intelligent systems. It was noted that computing time might increase in cases involving particularly complex issues.

Y. Liu et. al. [20] conducted a thorough investigation into the use of path planning algorithms for unmanned surface vehicle (USV) formations. The researchers developed a unique computer-based approach to address the challenge of USV formation route planning. This technique was grounded in the fast marching (FM) approach and was specifically designed for dynamic contexts, making use of the distinctive Constrained FM method. The Constrained FM approach proved capable of representing the dynamic behavior of moving ships within a short timeframe. Through a series of tests in a simulated scenario, the algorithm demonstrated its effectiveness in a demanding navigation environment. The advantages of engaging in USV formation activities included the ability to cover wide mission areas, enhance system robustness, and bolster fault-tolerant resilience.

Md. Jobayer Mia et. al. [21] addressed the characteristics of the incidents according to the accident data from 1995 to 2019. The data collected were analyzed based on a variety of variables, such as comparison of damage, the number of accidents every year, vessel category, regions prone to accident, and distinct investigation of the ten years accident data to determine whether any distinct changes to the trend took place. According to the survey, collisions were the most common form of accident, and passenger vehicles were the main contributing vessel types to the incidents. The study revealed that most maritime accidents occur at midnight, also passenger vessels accounting for 34% of incidents. The southern waterway, being the busiest, records the highest accident rate annually. Accidents peak during winter and heavy monsoons, with collisions causing 50.3% of them. Over the past decade, accident rates have risen, but fatalities have declined. The also suggested potential solutions. These include the use of artificial intelligence, enhancing awareness, and training more competent maritime professionals.

Chapter 3
Methodology

3.1 System Overview

The prototype is equipped with various components such as sonar sensor, Arduino microcontroller, servo motor, motor driver, gyroscope, water sensor. The system operates by utilizing ultrasound sensors to detect potential obstacles within the vicinity of the ship's domain. These obstacles could be either static or dynamic in nature.

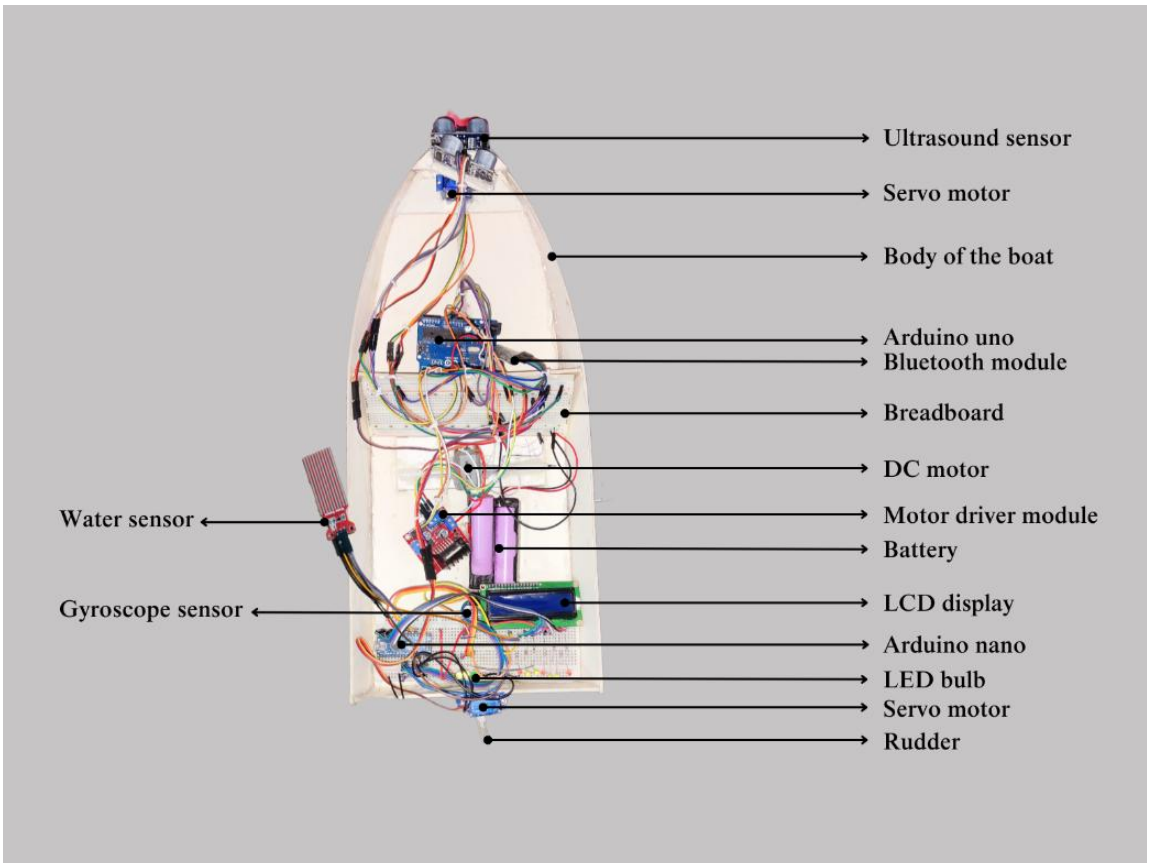


Figure 3.1: Overview of the boat.

The system is designed with one ultrasound sensor positioned at the front to detect obstacles ahead, and another that sweeps across a predefined range to locate obstacles. These sensors continuously scan the environment and relay data back to the processing unit. The processing unit then analyzes this data and based on its assessment, sends appropriate signal to the ship's rudder. If no imminent danger is detected, the vehicle continues its current path.

However, if a potential risk is identified, the rudder is actuated to steer the vehicle towards a safer path and then continue to previous direction.

A gyroscope serves as a critical component for detecting the boat's inclination, indicating how much it leans to one side. This is achieved by continuously measuring the angle of tilt in relation to the horizontal. The data collected by the gyroscope plays a pivotal role in making crucial decisions and issuing safety warnings. To ensure safety, a predefined

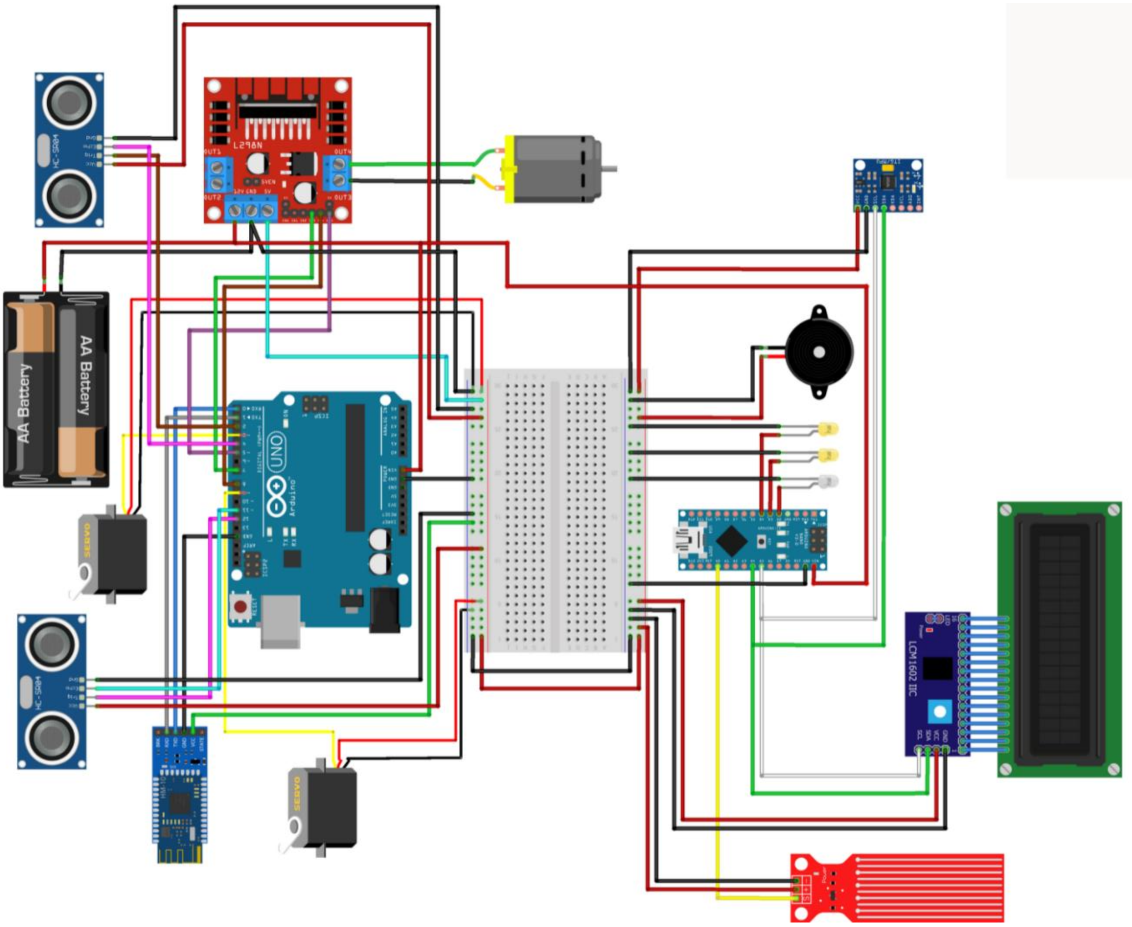


Figure 3.2: Circuit diagram of the system.

threshold of 30 degrees, either in a positive or negative direction of tilt, is established. If the gyroscope registers that the boat's inclination angle surpasses this limit, it signifies that the boat is leaning unsafely.

The gyroscope is interconnected with an LCD display. As soon as the gyroscope detects that the boat's tilt has crossed the 25-degree positive or negative threshold, it promptly transmits a signal to the LCD display. The LCD display promptly exhibits a warning message. This alert not only informs the sailor but also guides them in instructing the passengers to relocate to the opposite side of the boat, away from the direction of the tilt. This strategic movement helps the boat regain its balance, ensuring the safety of everyone on board. In essence, the gyroscope serves as a critical tool for maintaining the boat's stability and issuing timely warnings when necessary.

A water level sensor, integrated with an Arduino-based prototype boat, plays a pivotal role in ensuring the vessel's stability and the safety of its occupants. This sensor is designed to accurately measure the water level encountered by the boat as it navigates its course. The water level sensor is intricately connected to the boat's framework. Its primary function is to gauge the depth of water through which the boat is traversing. To convey critical information to the boat operator, the water level sensor is integrated with a set of LED indicators. These indicators serve as a visual representation of the boat's immersion depth.

Green LED (600mm): When the boat's immersion reaches 600mm, the first LED indicator, the green LED, illuminates. This signals a nominal water level condition.

Second LED (625mm): As the boat progresses further and immerses to a depth of 625mm, the second LED indicator activates. This provides a subtle warning that the boat is nearing its weight limit.

Third LED (650mm): At 650mm immersion, the third LED indicator comes to life, signaling that the boat has reached a critical water level and is approaching an unsafe weight condition. If the water level surpasses the 650mm threshold, the system triggers a buzzer. This audible alert unequivocally signifies that the boat has become overweighed and is potentially unsafe to operate.

In response to the buzzer activation, the boat's operator is prompted to take immediate action. They issue a command to the passengers, instructing them to disembark to restore the boat's safe buoyancy and stability.

3.2 Prototype Construction

3.2.1 Primary boat

The construction of the prototype boat is a critical aspect of this study. The boat is fabricated using a 3mm PVC board, chosen for its durability and lightweight properties. The individual components of the boat are meticulously assembled using a glue gun, ensuring a robust and secure structure. The primary boat incorporates the collision avoidance system described earlier in this study. This boat serves as the primary platform for testing and validating the proposed methodology for collision scenarios.

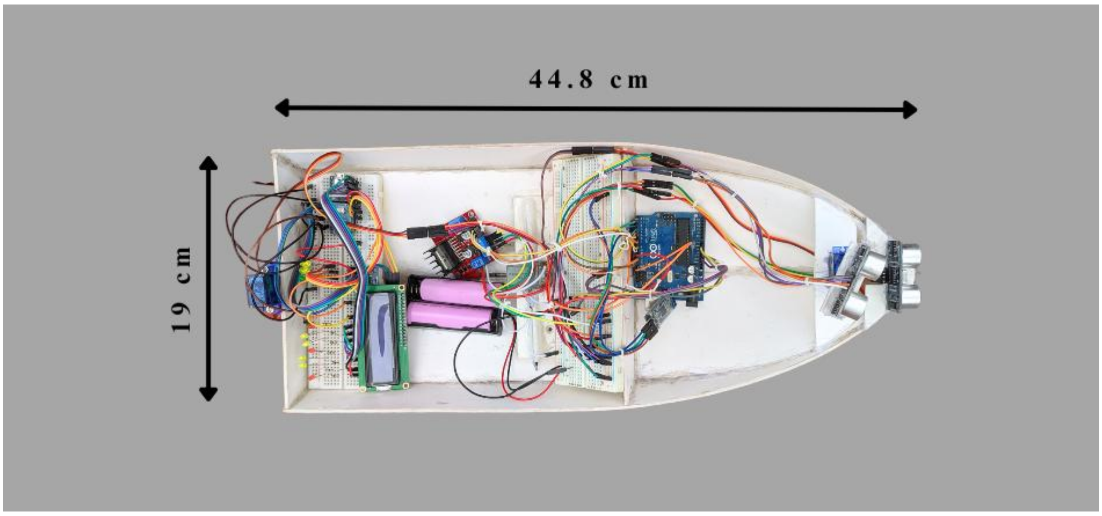


Figure 3.3: Top view of the primary boat.

The dimensions of the boat have been carefully selected to facilitate maneuverability and stability. The boat measures 44.8 cm in length, 19 cm in width, and 7 cm in height. With the inclusion of the propeller and rudder arrangement, the overall height of the boat increases to 12 cm.

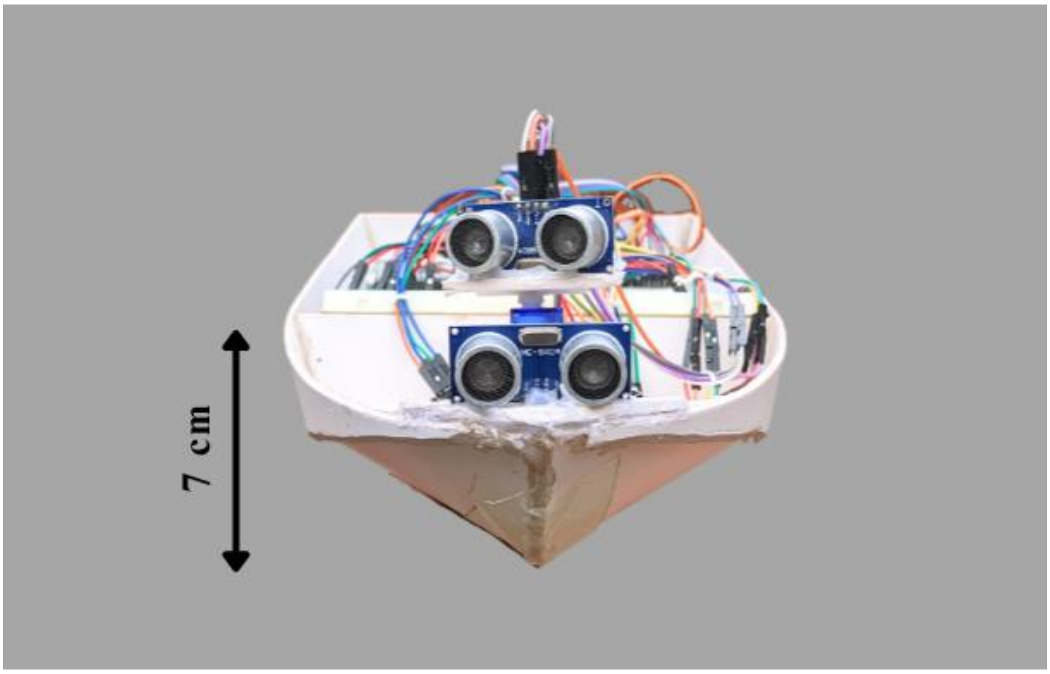


Figure 3.4: Front view of the primary boat.

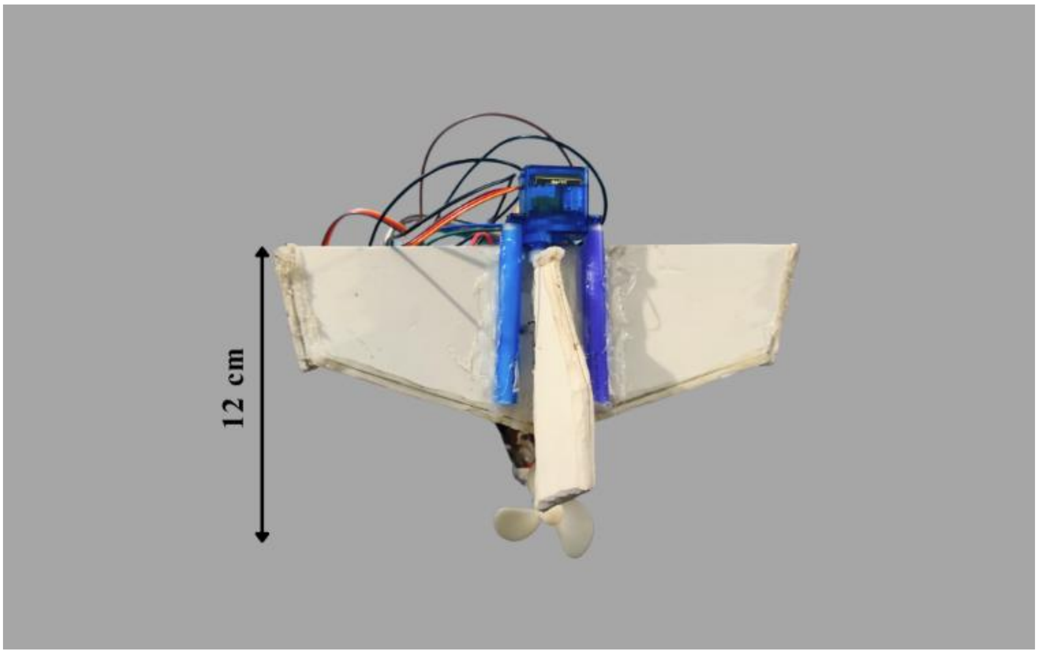


Figure 3.5: Back view of the primary boat.

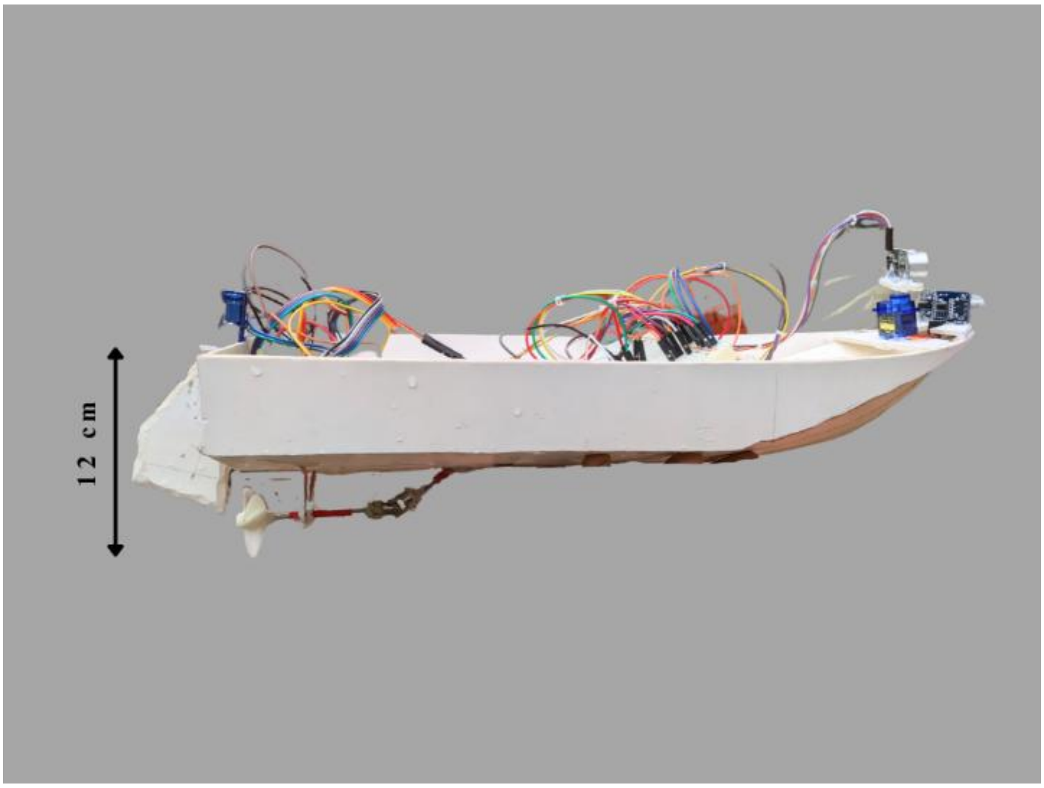


Figure 3.6: Side view of the primary boat.

These construction details are crucial as they directly influence the performance of the boat and, by extension, the effectiveness of the collision avoidance system. Future work could explore variations in these parameters to optimize the system's performance further.

3.2.2 Secondary Boat

The secondary boat, serving as the target vessel in this study, is also constructed from a 3mm PVC board. This material was chosen for its durability and lightweight properties. The components of this boat are assembled using a glue gun, ensuring a secure and robust structure.

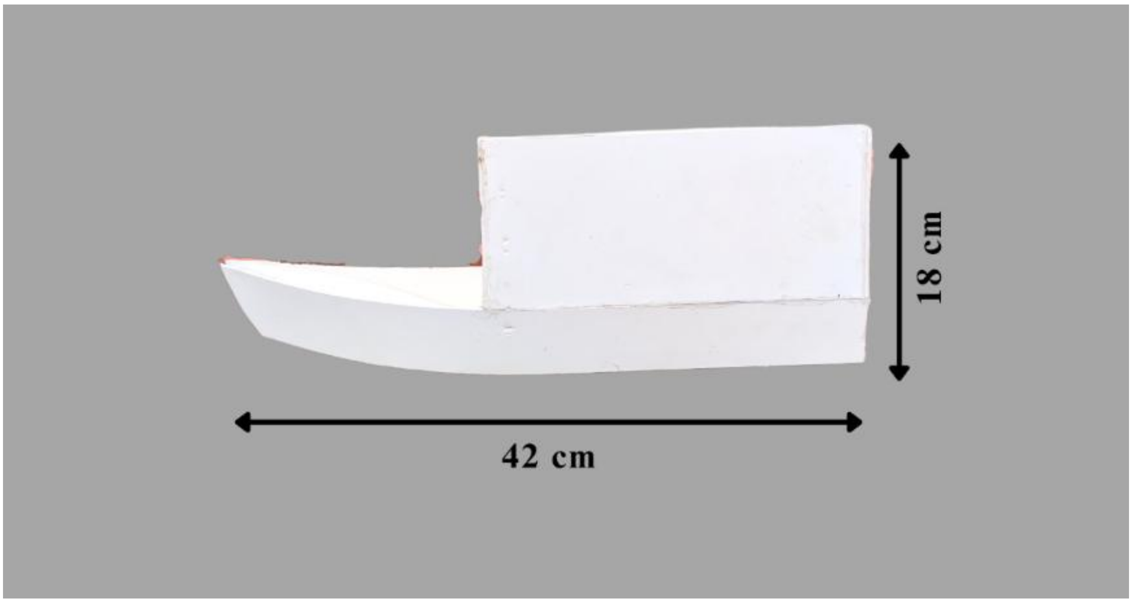


Figure 3.7: Side view of the secondary boat.

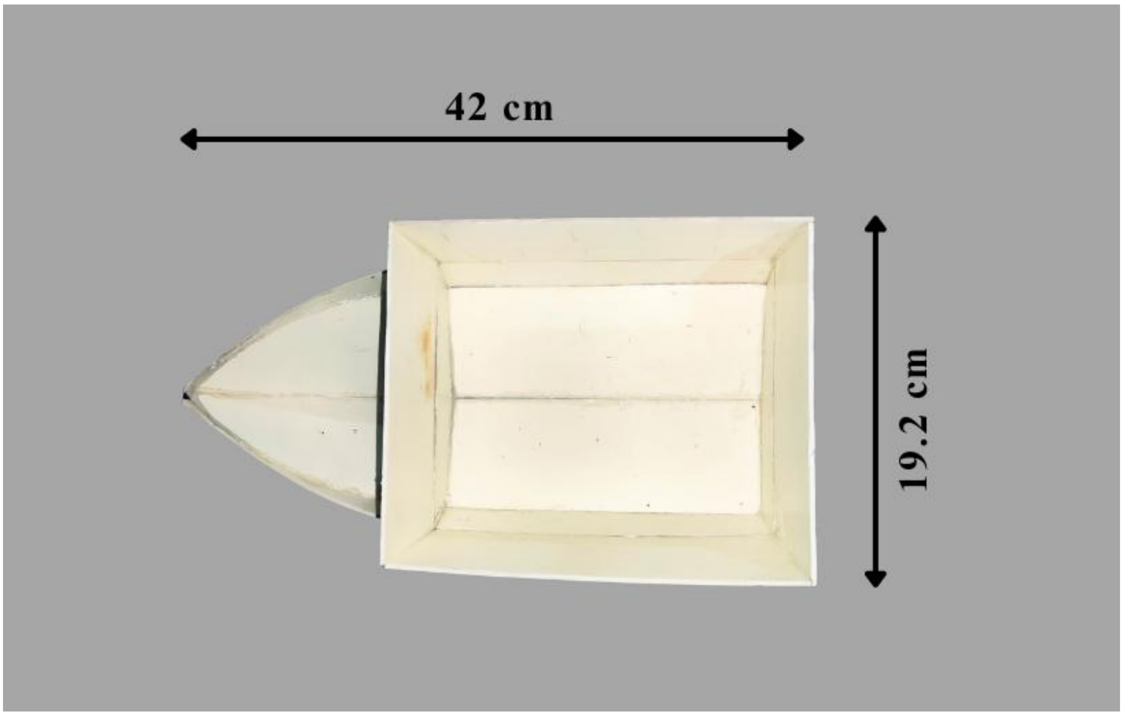


Figure 3.8: Top view of the secondary boat.


Figure 3.9: Front view of the secondary boat.

Unlike the primary boat, this secondary boat does not incorporate the automated system. Its primary function is to act as an obstacle in front of the primary boat during testing scenarios. The secondary boat is manually operated, providing a controlled environment for testing the collision avoidance system on the primary boat.

The dimensions of the secondary boat are carefully selected to facilitate detection by the primary boat's sensors. The secondary boat measures 42 cm in length, 19.2 cm in width, and has an increased height of 18 cm. This increased height enhances the visibility of the secondary boat, thereby improving detection accuracy. These construction details play a crucial role in the effectiveness of the collision avoidance system tested on the primary boat.

3.3 Mechanisms:

3.3.1 Power Transmission System:

Figure 3.10: Power transmission flowchart.

This power transmission system encompasses several key elements that work in harmony to convert electrical energy from a battery into mechanical motion, ultimately driving a propeller to create thrust for forward or reverse movement.

Battery

At the heart of the system is the battery, which serves as the primary power source. Typically, marine applications use high-capacity rechargeable batteries to provide the necessary electrical energy for propulsion.

Figure 3.11: Lithium-ion Battery.

Motor driver module (L298N)

The motor driver plays a pivotal role in controlling the electric motor. It acts as an intermediary, receiving commands and signals from the vehicle's control system. Through the motor driver, the motor's speed, direction, and power can be precisely regulated, allowing for responsive and efficient maneuvering.

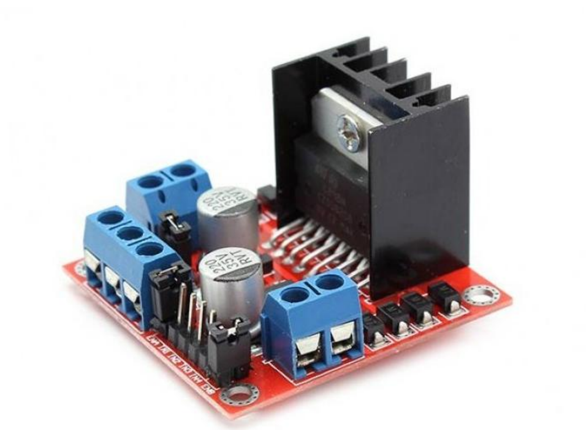


Figure 3.12: L298N motor driver.

The L298N Motor Driver Unit is a high-power motor driving component that is able to power both DC and stepper motors. This module contains two standard H-bridges and a 5V regulator. Up to 2 DC motors with direction and speed can be controlled by the Module [22].

The speed of a DC motor can be adjusted by Pulse Width Modulation (PWM). The average value of the input voltage is modified by transmitting a series of ON-OFF pulses. This average voltage is associated with the width of the pulses, which is termed the Duty Cycle. The average voltage provided to the DC motor rises with increasing duty cycle, increasing motor speed. The average voltage given to the DC motor decreases as the duty cycle shortens, which slows down the motor speed. Rotational direction of a DC motor may be altered by changing the polarity of its input voltage. H-bridge circuit is utilized for the purpose.

HM-10 Bluetooth module

The Bluetooth module is used to remotely power the dc motor for propulsion. The HM-10 Bluetooth module makes it possible for a project to communicate with another Bluetooth device, such as a mobile phone, using Bluetooth 4.0 (BLE 4.0). Standard voltages of 3.3V and 5V are used by the module to operate [23].

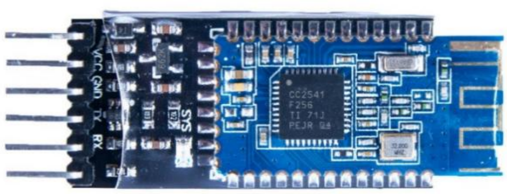


Figure 3.13: HM-10 Bluetooth module.

DC motor

A DC motor is an electrical machine that transforms electrical energy (Direct Current) into mechanical energy. A DC motor consists of armature, permanent magnet, frame, shaft, commutator, carbon brush. When the field coil of a DC Motor is powered, it generates a

Figure 3.14: DC motor.

magnetic field within the air gap. This magnetic field aligns with the radii of the armature. The magnetic field penetrates the armature from the North pole side of the field coil and leaves from the South pole side. The conductors situated on the opposite pole experience an equal force but in the reverse direction. These two opposing forces generate a torque, causing the motor armature to spin.

Universal Joint

To adapt the rotary motion of the motor for underwater propulsion, a universal joint is employed. This flexible mechanical joint provides versatility and allows for the transmission of motion even when the motor and propeller are not perfectly aligned. It ensures a continuous connection between the motor and the propeller shaft.

Figure 3.15: Universal Joint.

Shaft

The shaft in the boat serves as a conduit for transmitting the mechanical power from the motor to the propeller. It is a critical component in the propulsion system, converting the motor's rotational energy into thrust for forward movement. The shaft's operational efficiency directly impacts the boat's speed and maneuverability. For the shaft material stainless steel was selected.

Figure 3.16: Propeller shaft.

Propeller

The propeller is the final component of the system and is a critical part of marine vehicles. It is designed to efficiently convert the rotational motion from the universal joint into thrust. This thrust generated by the propeller propels the marine or aquatic vehicle forward or in the desired direction, making it a fundamental element for navigating water bodies.

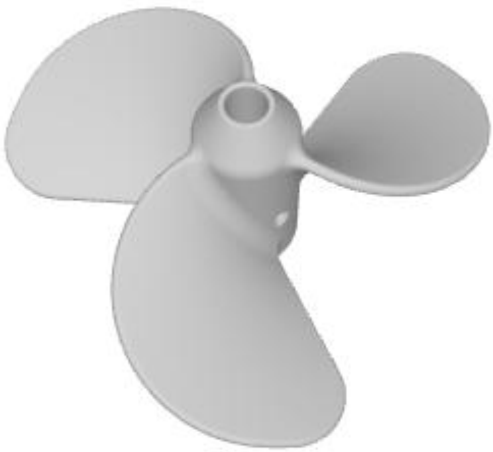


Figure 3.17: Propeller.

The design process involved creating a three-bladed propeller with a radius of 40 cm, ensuring optimal performance for the boat's size and purpose. Following the design phase, the propeller was brought to existence using 3D printing technology. Specifically, Stereolithography (SLA), a form of 3D printing technology used for making the 3D printed model. This advanced manufacturing technique allowed for a high degree of precision and complexity in the propeller's construction. Polylactic Acid (PLA), a biodegradable and bioactive thermoplastic aliphatic polyester derived from renewable resources, was used as the material for the propeller. PLA is known for its ease of use in 3D printing and its environmentally friendly properties.

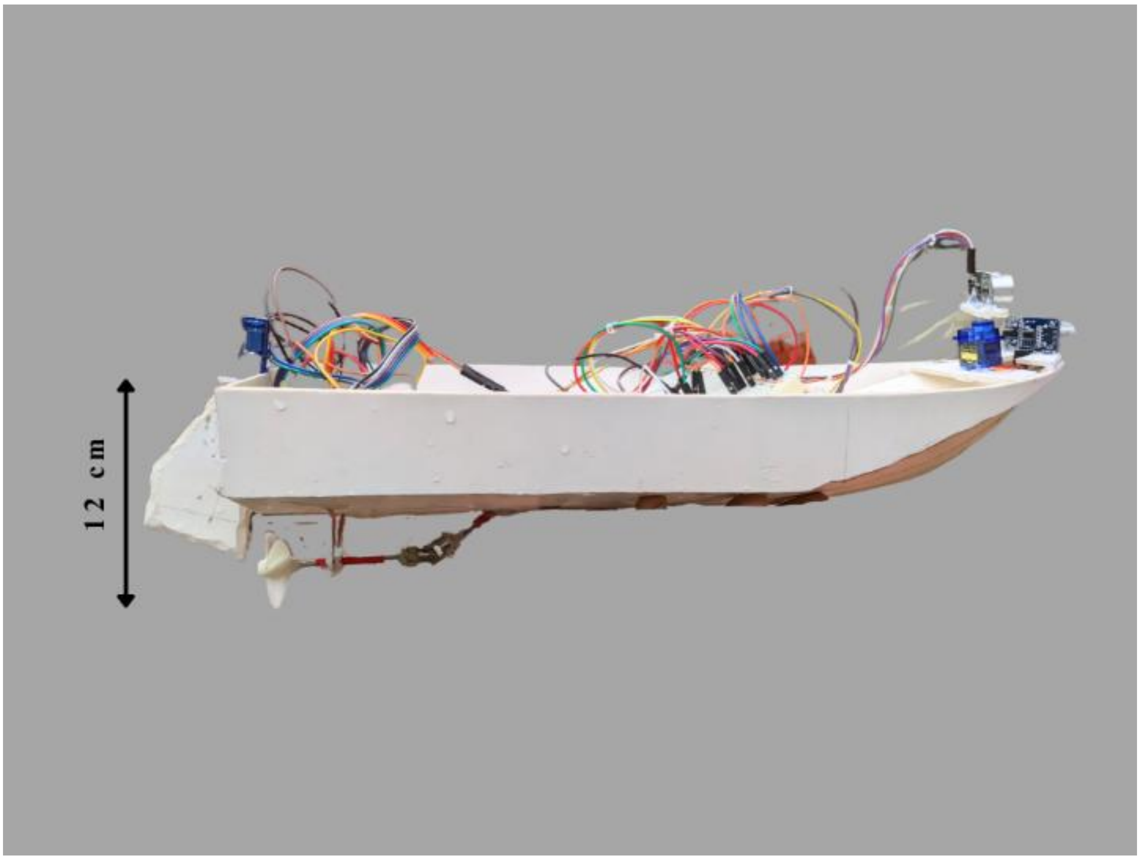


Figure 3.18: Power Transmission System.

Overall, this power transmission system represents a synergy of electrical and mechanical components, working cohesively to transform stored electrical energy into powerful propulsion. It is a vital part of marine technology, ensuring the reliable and controlled movement of watercraft, from boats to underwater vehicles, enhancing their functionality and safety on the open water.

3.3.2 Rudder Control Mechanism:

The rudder mechanism is a critical part of marine vessels, responsible for controlling the direction and stability of the boat by adjusting the angle of the rudder. This mechanism incorporates various components that work together to ensure precise and responsive steering in both manual and automated modes.

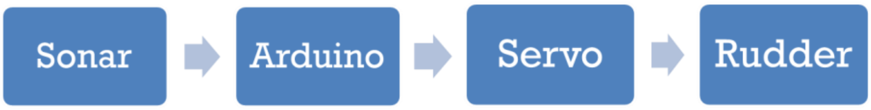


Figure 3.19: Rudder control mechanism flowchart.

Ultrasonic sensor (HC-SR04)

The sonar system, often referred to as an ultrasonic sensor in this context, is the primary input device for the rudder mechanism. It uses sound waves to measure distances between the boat and nearby objects, such as obstacles or other vessels. The sonar sends and receives ultrasonic signals to gauge the boat's surroundings, providing essential data for collision avoidance and navigation.

The HC-SR04 ultrasonic distance sensor is composed of two ultrasonic transducers. The first transducer functions as a transmitter, transforming the electrical signal into 40 KHz ultrasonic sound waves. The second transducer serves as a receiver, picking up the transmitted pulses. Upon receipt of these pulses, the receiver generates an output pulse, the width of which corresponds to the distance of the object in front. This sensor offers exceptional non-contact range detection from 2 cm to 400 cm, with a precision of 3 mm. As it operates at 5 volts, it can be directly connected to an Arduino or any other 5V logic microcontroller [24].

Figure 3.20: Ultrasonic sensor.

The measurement of distance from an object that reflects a signal back to the sensor can be determined by the duration of the received pulse. This concept is rooted in the fundamental equation of motion in physics, which relates distance, speed, and time (Equation 3.1).

Distance = Speed × Time (Equation 3.1)

Arduino (UNO)

Arduino microcontroller serves as the central processing unit for the rudder mechanism. It receives data from the sonar sensor and interprets it to make informed decisions regarding rudder angle adjustments. The Arduino processes the sensor data and sends corresponding commands to the servo motor, ensuring the boat's safe and efficient navigation.

Figure 3.21: Arduino UNO.

Arduino UNO is a microcontroller board based on the ATmega328P. It contains 14 digital input/output pins (of which 6 may be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power connector, an ICSP header and a reset button. It has everything required to support the microcontroller; just connect it to a computer with a USB wire or power it with an AC-to-DC converter or battery to get started [25].

It may be powered by a USB cable or a barrel connection that takes voltages between 7 and 20 volts, such as a rectangular 9-volt battery. It has the same microprocessor as the Arduino Nano board, and the same headers as the Leonardo board.

Servo Motor (SG90)

The servo motor is the actuator in the system, responsible for physically adjusting the boat's rudder. The Arduino sends control signals to the servo, instructing it to move the rudder to the desired angle. The servo's precision and responsiveness play a crucial role in ensuring the boat's ability to change direction accurately.

The SG90 Micro Servo Motor is a compact and lightweight motor with great output power. Servos feature a tiny DC motor coupled to the output shaft by gears. The output shaft powers a servo horn and is also coupled to a potentiometer (pot). The potentiometer gives position feedback to the error amplifier in the control unit, which compares the present position of the motor to the goal position. It can spin around 180 degrees (90 in each direction) and functions much like the regular ones but smaller [26].

Figure 3.22: Servo Motor (SG90).

It is a closed-loop control system that uses negative feedback to adjust the motor's speed and direction to achieve the desired result.

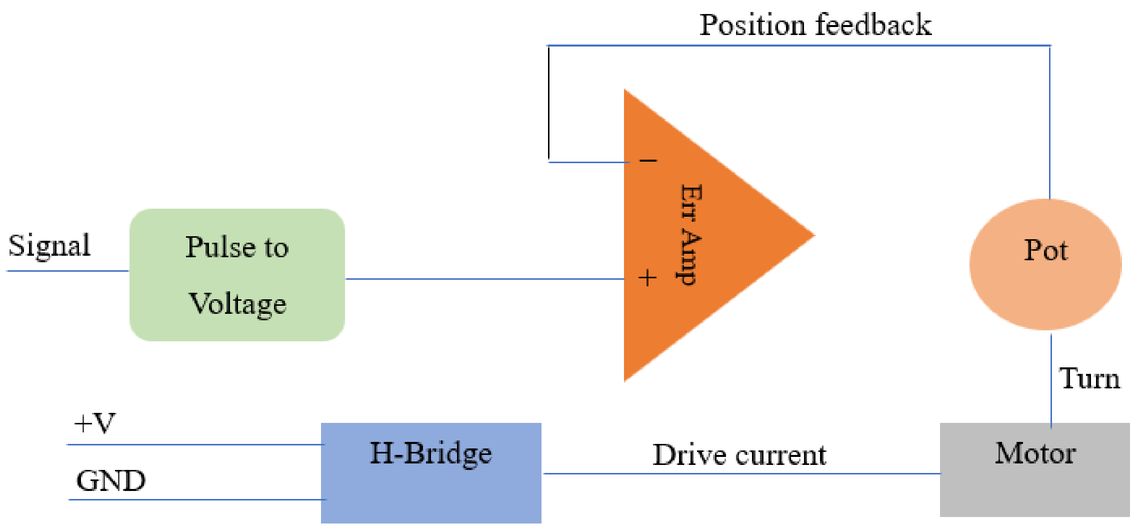


Figure 3.23: closed-loop control system of Servo Motor (SG90).

Position “0” (1.5 ms pulse) is midway, “90” (~2 ms pulse) is all the way to the right, “-90” (~1 ms pulse) is all the way to the left. It’s a fantastic alternative for novices who want to make items move without developing a motor controller with feedback & gear box, particularly because it will fit in tiny areas. It comes with 3 horns (arms) and hardware.

Rudder

The rudder is the mechanical component that controls the watercraft's direction. It is connected to the servo motor, and when the servo receives commands from the Arduino, it

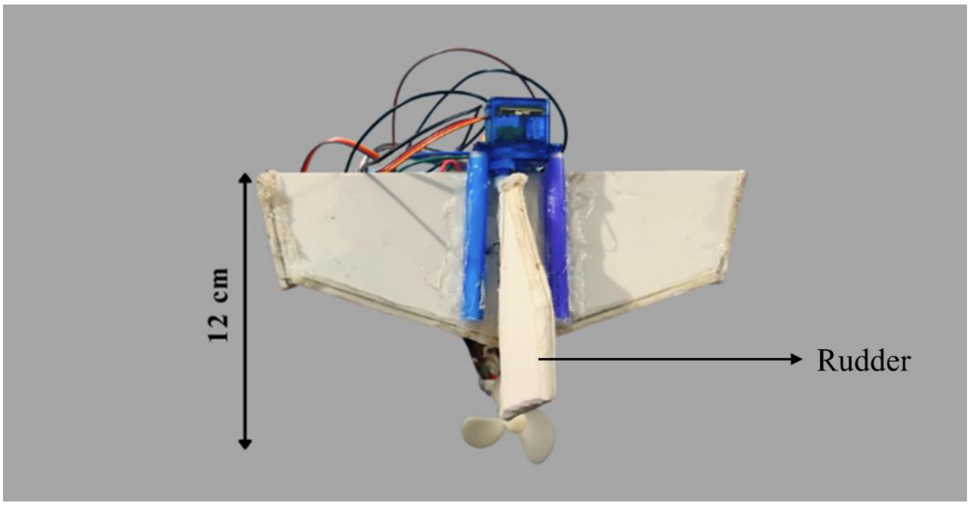


Figure 3.24: Rudder Control Mechanism.

changes the angle of the rudder accordingly. This action redirects the water flow, altering the boat's course to maintain a safe and collision-free path.

The rudder mechanism can operate in both manual and autonomous modes. In manual mode, a human operator can control the rudder's angle directly. In autonomous mode, the system uses input from the sonar to make real-time adjustments to the rudder, effectively avoiding obstacles and steering the boat along a designated course.

Overall, this rudder mechanism, enhanced with sonar technology and controlled by an Arduino, represents a significant advancement in marine safety and navigation. It enables watercraft to adapt swiftly to changing conditions, such as potential collisions or course corrections, making it a valuable addition to maritime technology.

3.3.3Tilt Mechanism:

Gyroscope Sensor (MPU6050)

The MPU6050 is a tiny, inexpensive, and low-power 6-axis Motion Tracking microprocessor. It is a Micro-Electro-Mechanical Systems (MEMS) that integrates a 3-axis gyroscope, a 3-axis accelerometer, and a Digital Motion Processor (DMP) in a compact 4mm x 4mm device. It is capable of sensing rotation or angular momentum across all three axes, static acceleration owing to gravity, and dynamic acceleration resulting from motion, shock, or vibration. MPU6050 unit comes with an inbuilt LD3985 3.3V regulator. The MPU6050 includes three additional 16-bit analog-to-digital converters that concurrently sample all three axes of rotation (along the X, Y, and Z axes). The rate of sampling may be set from 3.9 to 8,000 samples per second [27].

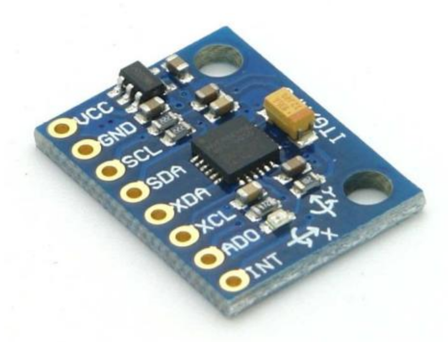


Figure 3.25: MPU6050 Gyroscope Sensor.

Working principle:

The MEMS Gyroscope operation relies on the Coriolis Effect. According to the Coriolis Effect, when a mass moves in a certain direction with velocity and an external angular motion is given to it, a force is formed, causing the mass to move perpendicularly. The displacement rate is proportional to the angular motion imparted. The MEMS Gyroscope comprises four proof masses and oscillates continuously. When the angular motion is applied, the Coriolis Effect induces a change in capacitance across the masses depending on the axis of the angular movement. The variation in capacitance is sensed and then turned into a reading.

MEMS devices are built on a silicon substrate in a similar way as single-chip integrated circuits, therefore the dimensions vary from just tens of microns to several millimeters. There are numerous varieties of MEMS gyroscopes that vary in their internal design, but all work based on the application of Carioles' force. Inside the sensor, there is a working body, performing reciprocating movements. Fig. 3.26 demonstrates the basic concept of Coriolis force. If the linear velocity and the Carioles force are known, the angular velocity can be calculated.

The MEMS sensor is made up of a proof mass (composed of four components M1, M2, M3, and M4) that is kept oscillating in order to respond to the coriolis action. They move inward and outward in the horizontal plane at the same time [27].

If the structure is rotated, the Coriolis force acting on the moving proof mass causes the vibration to shift from horizontal to vertical.

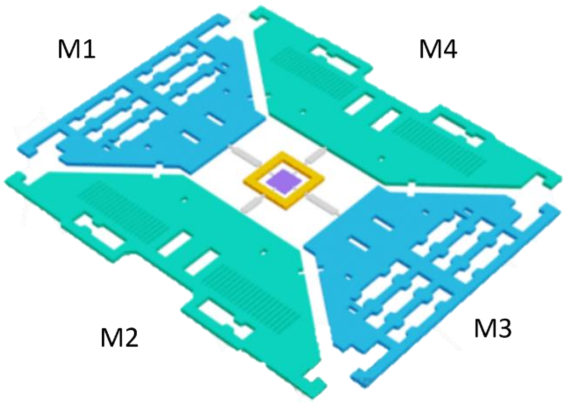


Figure 3.26: Proof masses of MEMS gyroscope [27].

There are three modes based on the axis along which the angular rotation is applied.

1. Roll Mode:

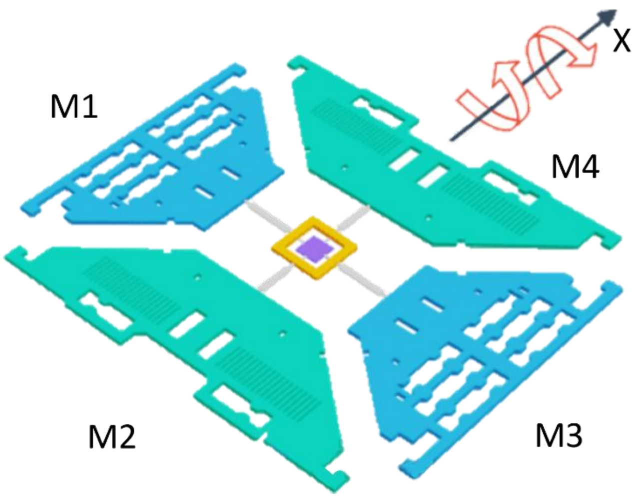


Figure 3.27: Roll mode of MEMS gyroscope [27].

Due to Coriolis effect, M1 and M3 to move up and down beyond the plane when an angular motion is applied along the X-axis. As a result, the roll angle changes.

2. Pitch Mode:

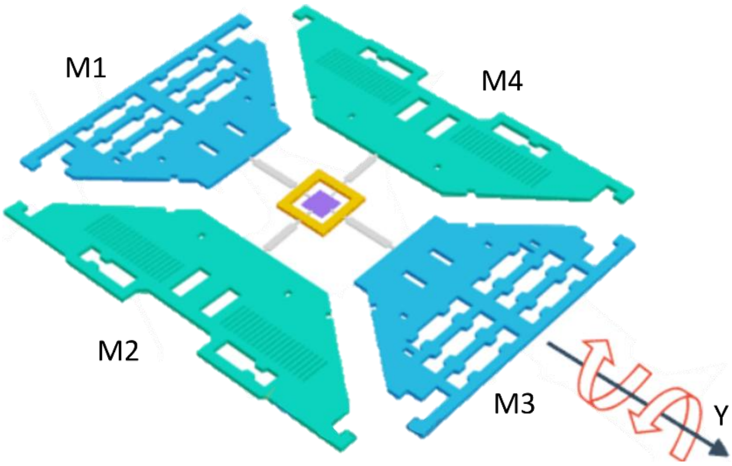


Figure 3.28: Pitch mode of MEMS gyroscope [27].

When an angular motion is applied along the Y-axis, due to Coriolis effect, M2 and M4 move up and down out of the plane. As a result, the pitch angle changes.

3. Yaw Mode:

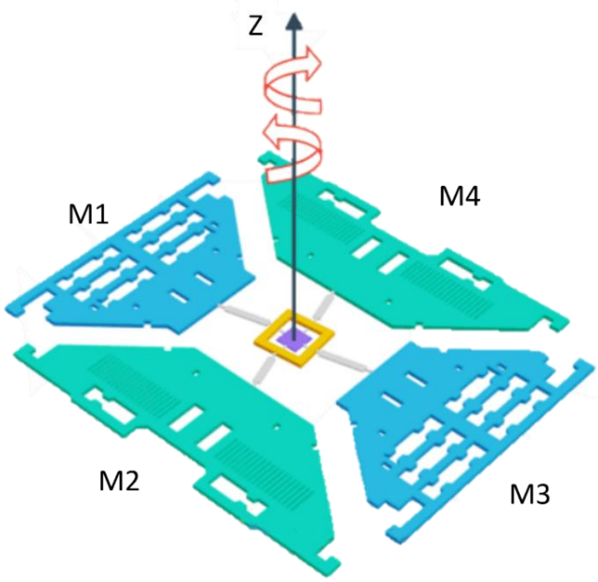


Figure 3.29: Yaw mode of MEMS gyroscope [27].

When an angular motion is applied along the Z-axis, M2 and M4 move horizontally in opposite directions. This results in the change of yaw angle.

Whenever the Coriolis effect is sensed, the constant motion of the driving mass will cause a variation in capacitance that is detected by the sensing mechanism and translated into a voltage signal. In the context of inertial navigation systems, the gyroscope sensor operates on the principle of maintaining orientation with respect to the Earth's rotational frame. This is achieved by establishing a reference along the horizontal axis. As the sensor deviates from this reference, it generates an output that corresponds to the angular displacement.

A graph was formed (figure 3.30) to find the presence of any deviations in the sensor's output. For this, voltage readings were recorded from the gyroscope sensor at every 10-degree interval over a range of 0 to 180 degrees. This process was then reversed, with measurements taken from 180 to 0 degrees. The deviations were found to be minimal.

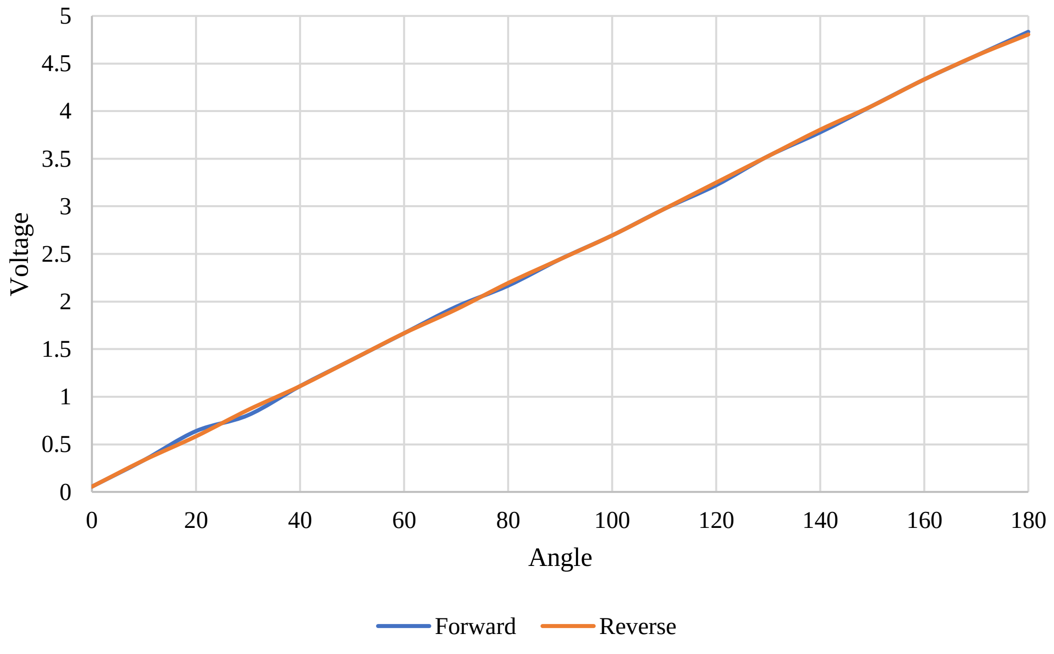


Figure 3.30: Voltage vs Angle graph in for forward and backward direction.

16×2 LCD I2C display

The I2C interface is used by this 216-character LCD Module with blue Backlight to connect to the host microcontroller. Projects needing the display of text, data, or ASCII characters of any kind employ this cost-effective LCD. Connect to the serial data line (SDA), serial clock line (SCL), Vcc, and ground (Gnd). This 5V DC device may be located at location 0x27/0x3F on the I2C bus [28].

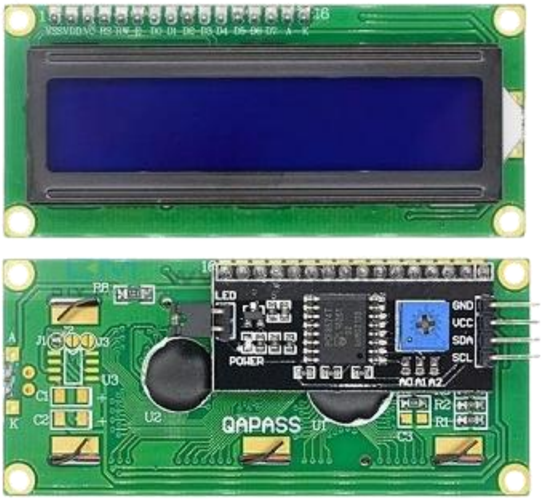


Figure 3.31: 16×2 LCD I2C display.

The gyroscope plays a crucial role in boat stability by detecting its inclination. It continuously measures the tilt angle relative to the horizontal, with a preset safety threshold of 20 degrees for the prototype.

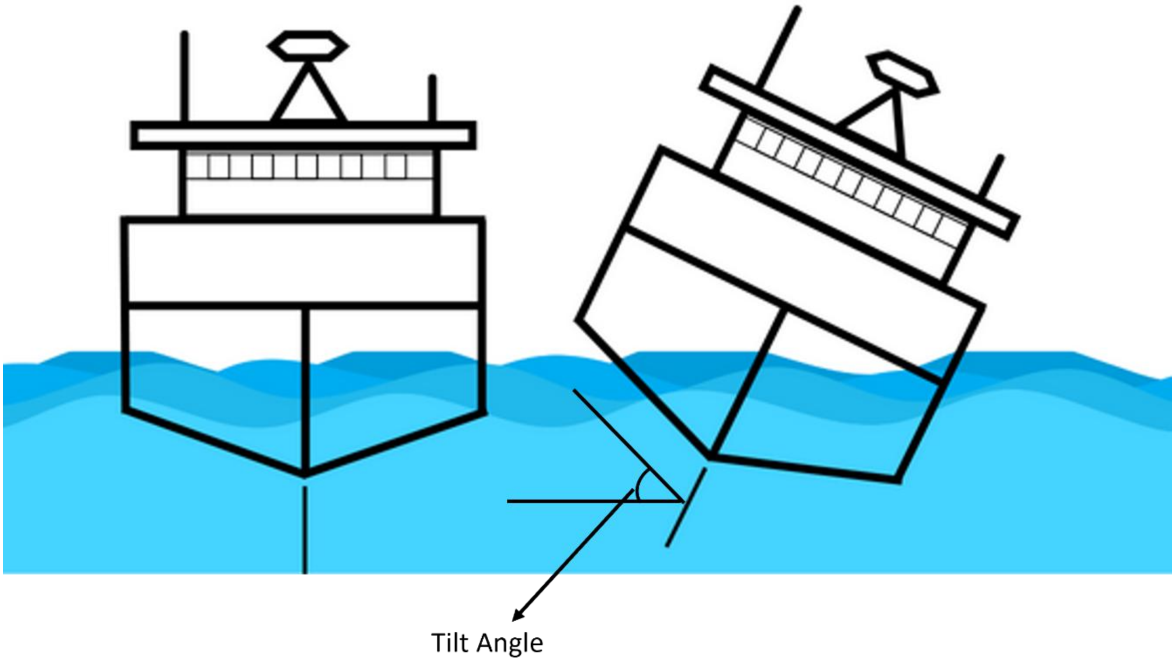


Figure 3.32: Tilt angle of boat.

Table 3.1: Tilt angle with status.

Tilt Angle (In Degree)	LCD Display Status
<20	OK
>20	WARNING

Tilt Angle <20 Degrees: OK

When the tilt angle of the boat is less than 20 degrees, the system displays "OK" on the LCD. This status indicates that the boat is within a safe range of tilt, ensuring stable and secure navigation. It is a visual confirmation that the boat is in a safe operational condition, and no immediate action is required.

Tilt Angle > 20 Degrees: WARNING

If the tilt angle of the boat exceeds 20 degrees, the system immediately responds by displaying "WARNING" on the LCD. This status serves as a critical alert to the boat's operator, indicating that the vessel's tilt has reached an unsafe level. When "WARNING" is displayed, it is an indicator for the operator to take necessary corrective measures, such as redistributing weight or adjusting the boat's balance to bring it back to a safe and stable condition.

3.3.4 Overweight Mechanism:

Water Level Sensor

The water level depth detecting sensor for Arduino has operation voltage DC 3-5V and operating current less than 20mA. The sensor is the analog kind which provides analog output signals proportional to the water pressure with its detecting area of 40x16mm.The water level sensor is a simple to use and cost efficient with high level/drop recognition sensor by having a sequence of parallel wires exposed traces detects droplets/water volume in order to estimate the water level [29].

Figure 3.33: Water Level Sensor.

To calculate the minimum weight capacity of the boat when it is immersed to a depth of 5 cm with a cross-sectional area of 44.8 cm (0.448 m) in length and 19 cm (0.19 m) in width, from equation 1.3

Minimum Weight Capacity, $B = \rho \times g \times V$ $\quad$ $(V = A \times d = w \times l \times d)$

Plugging in the values:

ρ = Density of water (approximately 1000 kg/m^3.)

l = Length of the boat (0.448 m)

w = Width of the boat (0.19 m)

d = Immersion depth (0.05 m)

g = Acceleration due to gravity (approximately 9.81 m/s^2)

Now, Maximum weight Capacity, $B = 1000\ kg/m^3 \times 0.448\ m \times 0.19\ m \times 0.05\ m \times 9.81\ m/s^2$

$$= 83.45\ kg\ m/s^2$$

So, when the boat is immersed to a depth of 5 cm with the given cross-sectional area, it can carry a minimum weight of approximately 8.5 kg.

In practical applications, the theoretical calculations for the minimum weight capacity of a boat, as determined by the displacement of water when the boat is immersed, may be affected by various factors. These factors can lead to discrepancies between theoretical and practical results. Some of the factors to consider include:

- Boat construction material and weight distribution
- Density of Water
- Water Conditions

The water level sensor is a device that monitors the liquid level in a stationary container that is too high or too low. According to the technique of measuring the liquid level, it may be classified into two types: contact type and non-contact type. The input type water level transmitter we call is a contact measurement, which turns the height of the liquid level into an electrical signal for output. It is presently a frequently used water.

LED

A light-emitting diode is a semiconductor device that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. The color of the light is determined by the energy required for electrons to cross the band gap of the semiconductor.

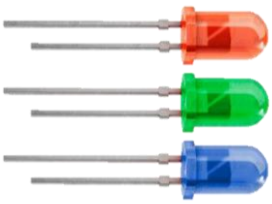


Figure 3.34: LED.

Buzzer

An audio signaling device like a beeper or buzzer may be electromechanical or piezoelectric or mechanical type. The main function of this is to convert the signal from audio to sound. Generally, it is powered through DC voltage and used in timers, alarm devices, printers, alarms, computers, etc. Based on the various designs, it can generate different sounds like alarm, music, bell & siren.

Figure 3.35: Buzzer.

The pin configuration of the buzzer includes two pins namely positive and negative. The positive terminal of this is represented with the '+' symbol or a longer terminal. This terminal is powered through 5-12 Volts whereas the negative terminal is represented with the '-' symbol or short terminal and it is connected to the GND terminal.

Figure 3.36: Overweight situation.

The system proposed has the ability to monitor the boat's immersion depth and provide real-time feedback ensures that the operator is well-informed about the vessel's safety and stability. It also considers the boat's specific design and purpose to provide context-appropriate feedback regarding immersion depth.

Table 3.2: Overweight data by water level sensor.

Boat immersed in water (cm)	**Turned ON**	**Status**
2	White LED	Ok
3	Yellow LED	Ok
4	Yellow LED	Full
5	Buzzer	Overweight

Boat Immersed in Water (2 cm):

At an immersion depth of 2 cm, the system activates a white LED, and the status displayed is "OK." This status confirms that the boat is operating under normal conditions, with no immediate concerns about its immersion depth. The white LED signal serves as a visual indicator of the boat's safe status.

Boat Immersed in Water (3 cm):

With an immersion depth of 3 cm, the system triggers a yellow LED, and the status remains "OK." This status indicates that the boat's immersion level is still within a safe range, and the boat's operation can proceed without issues. The yellow LED serves as an additional visual signal to reinforce the boat's safe condition.

Boat Immersed in Water (2 cm):

When the boat's immersion depth reaches 4 cm, the system activates another yellow LED, and the status is set to "Full." This status change indicates that the boat is becoming full in terms of its immersion, which can be a normal operating condition depending on the boat's design and purpose.

Boat Immersed in Water (2 cm):

If the immersion depth further increases to 5 cm, the system responds by activating a buzzer, and the status is displayed as "Overweight." This alert serves as a critical warning to the boat operator that the vessel is potentially overweight or overfilled, which can lead to instability and unsafe conditions. The operator should take immediate action to address the situation, such as redistributing the load or reducing the weight on the boat to achieve a safer immersion depth.

3.4 Methodology

System Flowchart:

The Collision Avoidance System for Marine Vehicles is a sophisticated maritime safety solution designed to enhance the navigation and security of watercraft in challenging conditions. This system incorporates various sensors and components to ensure the safety of the vessel and its occupants. The following flowchart illustrates the key operational steps and decision points within our Collision Avoidance System for Marine Vehicles.

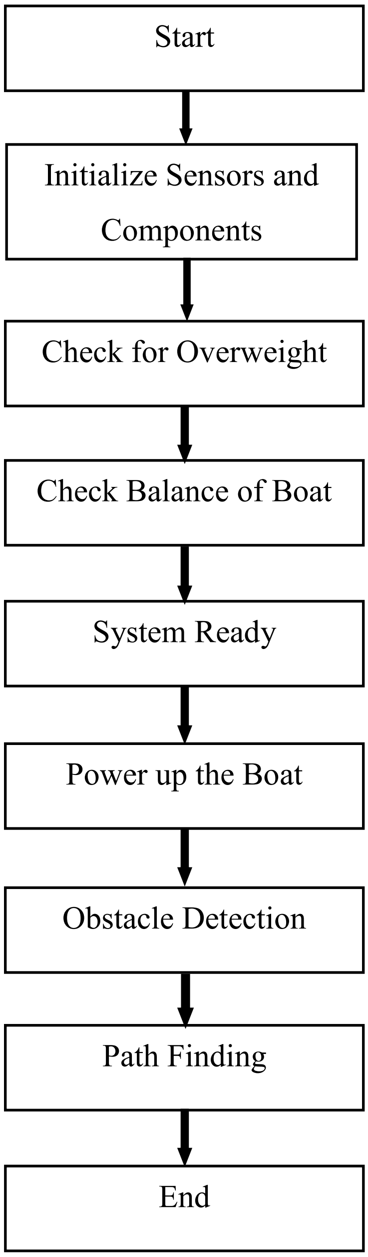


Figure 3.37: Methodology flowchart.

i. Start

- The beginning of the system's operation.

ii. Initialize Sensors and Components

Setting up and preparing the various sensors and components required for the system.

- Initialize Water Level Sensor: Configure and prepare the water level sensor.
- Initialize Gyroscope: Set up and calibrate the gyroscope for measuring tilt.
- Initialize LCD Display: Prepare the LCD display for showing information.
- Initialize Ultrasonic Sensors: Set up the ultrasonic sensors for obstacle detection.

iii.Check for Overweight

This step involves assessing whether the boat is carrying excess weight. It includes the following sub steps:

- Read data from the Water Level Sensor: Measure the water level to determine weight.
- Is the boat overweight? Check if the weight exceeds a certain threshold.
- If Yes, Buzzer is on and create sound to notify captain of the extra weight.
- If No, proceed to the next step: If the boat is not overweight, continue to the next stage.

iv. Balance the Boat

Ensuring the boat is level and stable. It includes:

- Read data from the Gyroscope: Gather information about the boat's tilt.
- Is the boat tilting? Check if the boat is leaning to one side.
- If Yes, display tilt information on the LCD: Provide feedback on the boat's tilt.
- Notify the captain to adjust weight distribution: Alert the captain to take corrective action.
- Wait for the boat to be balanced: Give time for adjustments to take effect.

v. System Ready

The system is prepared to move. It includes:

- Display "System Ready" message on the LCD: Indicate that the system is ready for operation.
- Wait for the captain's confirmation: Wait for a signal from the captain to proceed.

vi. Power Up the Boat

- Activate the boat's propulsion system.
- Start moving.

vii. Obstacle Detection Loop

Continuously monitor the environment for obstacles. It includes:

- Continuously read data from Ultrasonic Sensors: Gather distance information from the sensors.
- Is an obstacle detected? Check if any obstacles are in the boat's path.
- If yes, perform obstacle avoidance: If an obstacle is detected, take evasive action.

viii. Find a safe path

Determine a safe course of action to avoid obstacles. It includes:

- Adjust the boat's direction: Make necessary course corrections.
- If No, continue moving on the planned route: If no obstacles are detected, continue as planned.
- Repeat Obstacle Detection Loop: Continue monitoring for obstacles during the journey.

ix. Arrival at Destination

Determine whether the boat has reached its destination. It includes:

- Did the boat reach its destination? Check if the journey is complete.
- If yes, display "Arrived" on the LCD: Indicate successful arrival.
- If No, continue the journey: If the destination is not reached, continue traveling.

x. End

The conclusion of the system's operation.

This flowchart provides a clear overview of the system's logic, sensor integration, decision-making processes, and actions taken based on sensor data. It helps ensure that the collision avoidance system operates efficiently and safely in a marine environment.

This research proposes a technique based on the interaction between human operators and autonomous systems. The technique is designed for maritime navigation, where the autonomous mode is deactivated when a human operator takes control of the ship. However, both the human operator and the autonomous system can function simultaneously, with the human operator authenticating maneuvers. The system is designed to operate in autonomous mode to prevent collision scenarios when human isn't on board, but it is recommended that a human operator should always be present to validate maneuvers. This system is primarily designed to handle four potential collision scenarios: static obstacles, head-on collisions, crossing paths, and overtaking scenarios.

The algorithm in this system operates by continuously scanning the area in front of the vehicle, identifying potential paths, and taking necessary actions to avoid collisions. In the case of our prototype, when an obstacle is detected within a 1.5-meter radius, the model vehicle initiates appropriate maneuvers to navigate toward a collision-free path. This approach ensures safer navigation and reduces the risk of accidents.

Another essential component is the water level sensor, integrated into the Arduino-based boat prototype. It measures water depth as the boat moves. Three LED indicators provide a visual representation of immersion depth: green (at 600mm), second LED (at 625mm), and third LED (at 650mm). These LEDs signal normal, approaching weight limit, and critical immersion levels, respectively. If the water level exceeds 650mm, a buzzer sounds, indicating the boat is overweighed and potentially unsafe. This sensor system ensures vessel stability and passenger safety by monitoring water depth.

Chapter 4

Results and Discussion

4.1 Results

4.1.1 Tilt and overweight:

By determining the tilt of the boat, the gyroscope is essential to maintaining boat stability. It monitors the tilt angle in relation to the horizontal constantly and has a 25-degree safety threshold. A warning appears on the linked LCD display if the gyroscope detects the boat tilting above this threshold. Passengers are prompted by this notice to change their weight in order to balance the tilt, so insuring everyone's safety (Fig. 4.1).

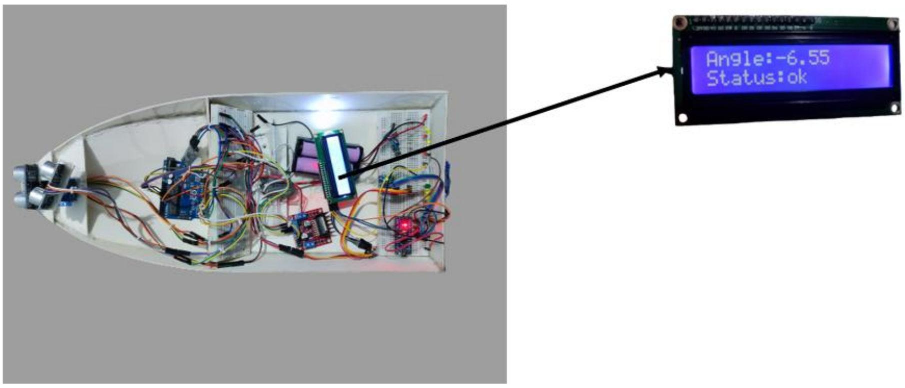


Figure 4.1: LCD showing gyroscope tilt Angle (< 25 Degree).

When the event of a boat tilt angle exceeding 25 degrees, a prominent warning sign is displayed on the boat's LCD screen. This warning serves as a visual indicator to alert the boat's occupants, crew, and captain of the critical situation.

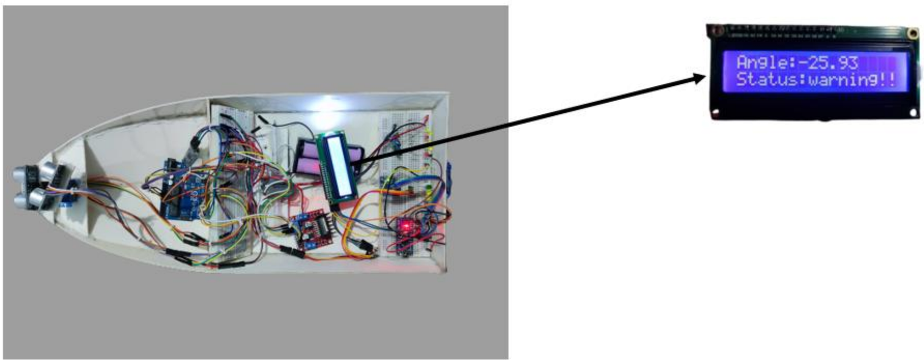


Figure 4.2: LCD showing gyroscope tilt Angle (> 25 Degree).

Fig. 4.2 shows As long as the boat's tilt angle remains below the 25-degree threshold, the "OK" sign will continue to be displayed on the LCD screen. This real-time feedback ensures that passengers and crew can focus on their activities without concerns about boat stability.

Table 4.1: Status of gyroscope sensor.

Tilt Angle (In Degree)	**LCD Display Status**	**Maximum water raise on the side of the boat (cm)**
<20	OK	3
>20	WARNING	5

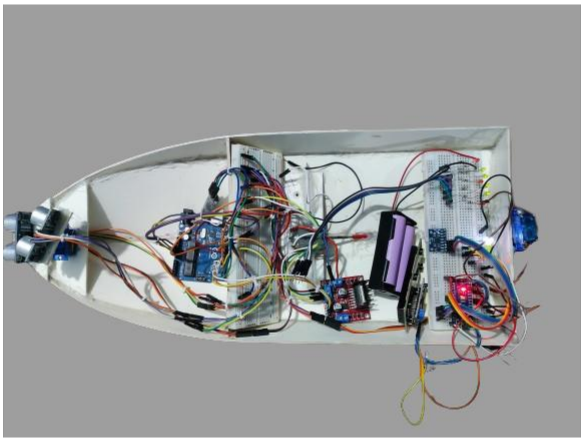
It is important to note that in practical applications, the minimum weight capacity for a boat is 8 kg. However, theoretical calculations suggest that the minimum weight capacity of a boat should be 8.5 kg. This is because various external factors can affect the displacement of water when the boat is immersed. (Table 4.2)

Table 4.2: Status of water level sensor.

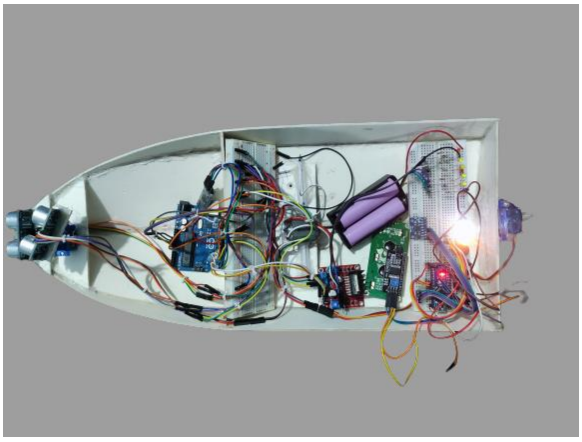
Weight (kg)	**Boat immersed in water (cm)**	**Turned ON**	**Status**
2	2	White LED	Ok
4	3	Yellow LED	Ok
6.5	4	Yellow LED	Full
8	5	Buzzer	Overweight

The Arduino-based boat prototype also has a water level sensor, which is a crucial component. As the boat travels, it gauges the water's depth. A visual depiction of immersion depth is provided by three LED indicators: green (at 600mm) (Fig.4.3 (i)), second LED (at

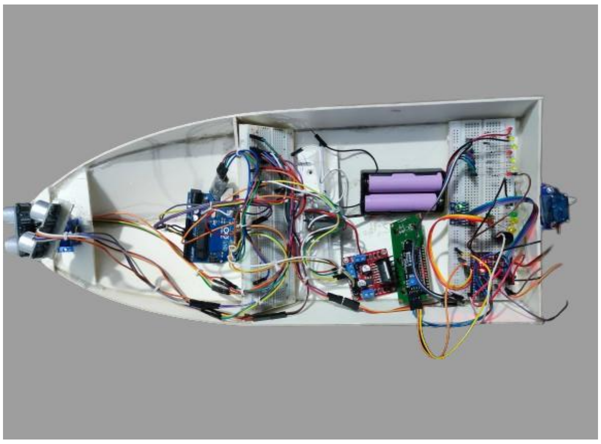
625mm), and third LED (at 650mm). These LEDs, in that order, indicate normal, nearing weight limit, and critical immersion levels. A buzzer sounds to indicate the boat is overloaded and possibly hazardous if the water level rises over 650mm (Fig.4.3 (iii)). By monitoring water depth, this sensor system guarantees ship stability and passenger safety.



(i)



(ii)



(iii)

Figure 4.3: Water Sensor Turning on LED Measuring Overweight.

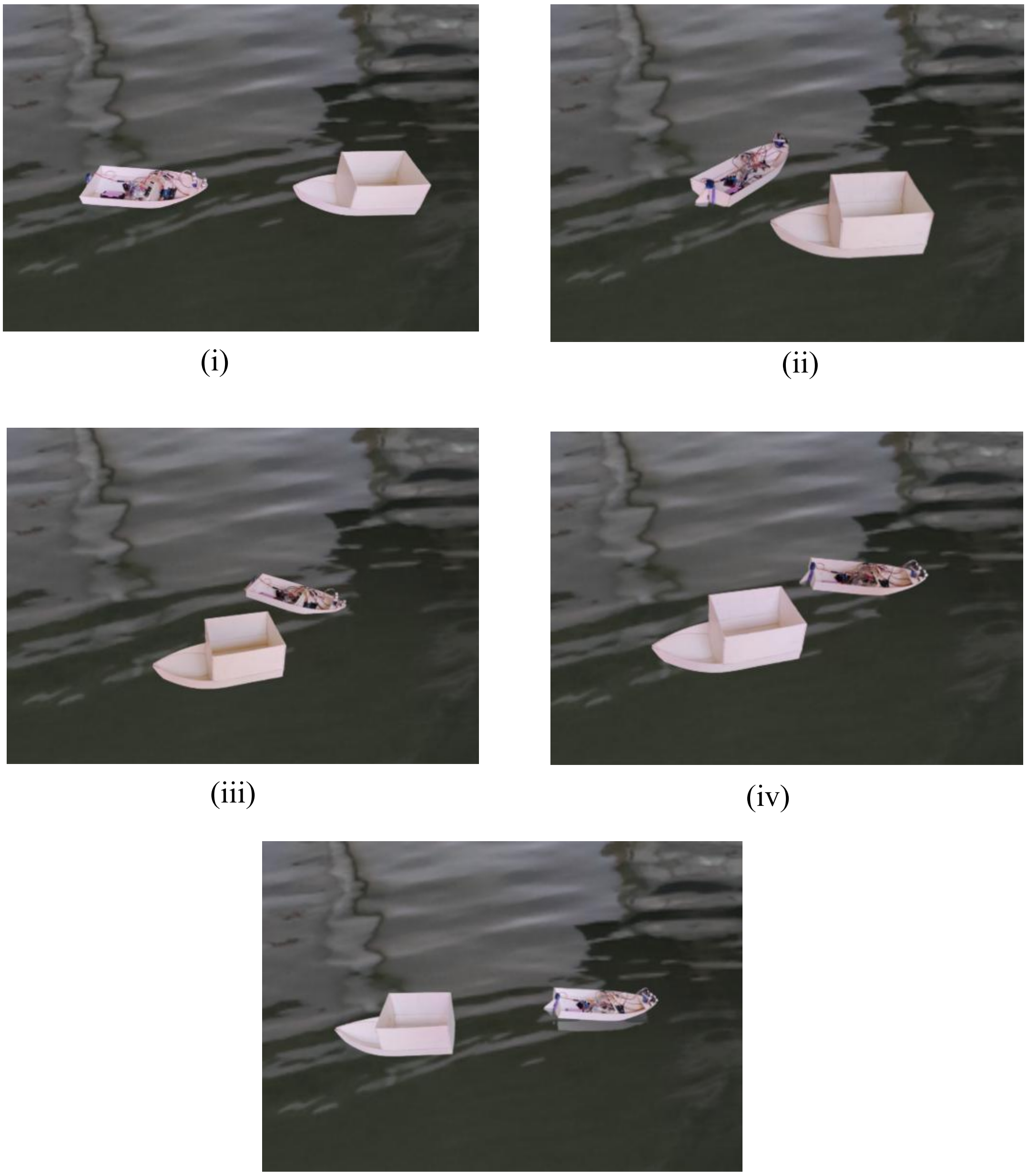
The collision avoidance system for maritime vehicles was created and tested under both static and dynamic settings. The technology proven its efficiency in boosting the safety of marine navigation in numerous conditions.

4.1.2 Collision avoidance

Static Condition:

In static situations, with the secondary boat staying motionless, the primary boat effectively recognized the existence of the secondary boat (Fig. 4.1(i)). Upon detection, the system actuates the servo mechanism attached to the rudder for avoidance (Fig. 4.1(ii)).

The algorithm effectively determined the ideal route and accordingly moving the rudder. As a result, the primary boat securely passes the stationary secondary boat (Fig. 4.1(iii)). This computation was based on the sonar sensor data and the relative locations of the vessels.



(i) (ii) (iii) (iv) (v)

Figure 4.4: Collision avoidance in static condition.

As a consequence of the optimum route computation, the rudder of the main boat was perfectly positioned to prevent any collision with the stationary secondary boat (Fig. 4.1(iii)). This proves the system's capacity to avoid collisions under static situations.

Table 4.3: Collision avoidance data for static condition.

No. of Attempts	**Actuation starting distance (cm)**	**Status**
1st	95	Failed
2nd	96	Success
3rd	100	Success
4th	95	Success
5th	100	Success
6th	100	Success
7th	100	Success
8th	100	Success
9th	90	Success
10th	100	Success

Motor speed = 2000 RPM

$$\text{Success Rate (\%)} = \frac{\text{Number of Successful Attempts}}{\text{Total Number of Attempts}} \text{ x } 100$$

$$= \frac{9}{10} \text{ x}100$$

$$= 90$$

So, the success rate is approximately 90%.

Dynamic Conditions:

In dynamic conditions, the collision avoidance system displayed robust performance in response to various scenarios involving the secondary boat's movement:

Head-to-Head Approach:

When the secondary boat was approaching head-to-head with the main boat, the sonar sensors recognized the imminent collision danger. The system rapidly provided signal to modify the rudder's position to prevent collision. This dynamic reaction successfully averted head-on accidents.

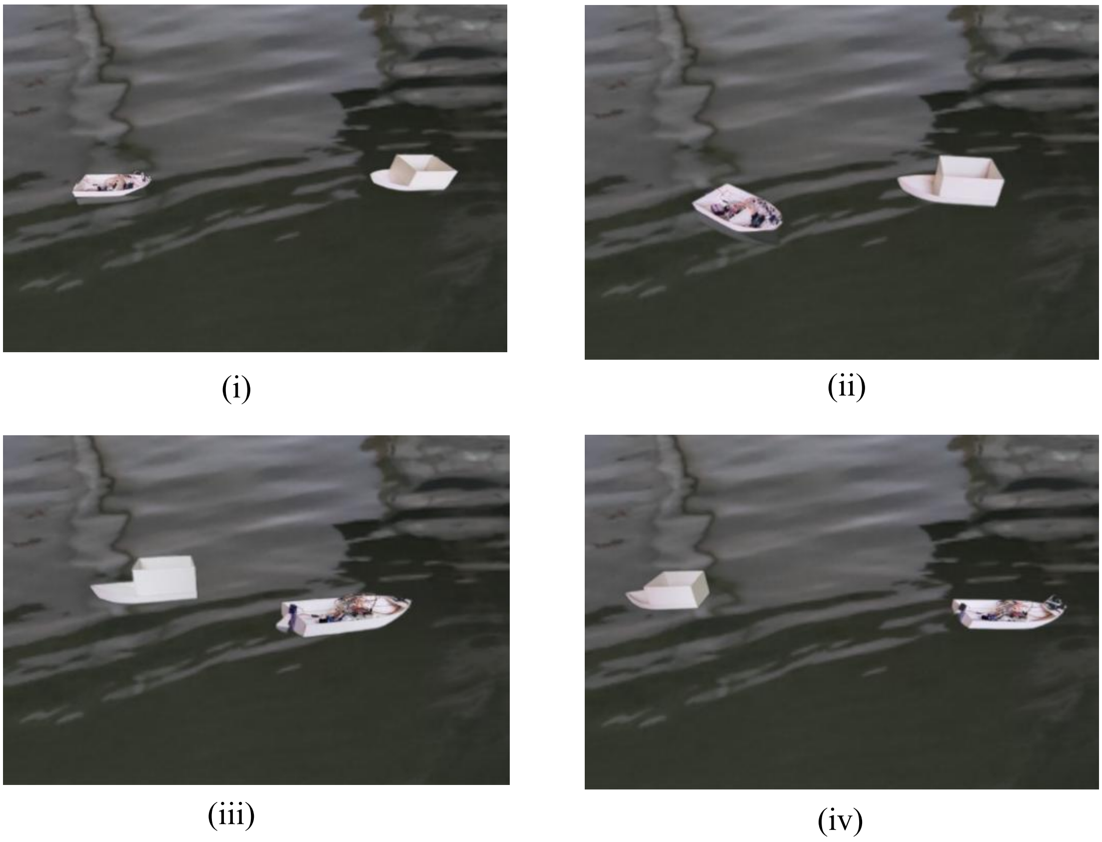


Figure 4.5: Collision avoidance in Head-to-Head Approach.

Table 4.4: Collision avoidance data for Head-to-Head approach.

No. of Attempts	**Actuation starting distance (cm)**	**Status**
1st	81	Success
2nd	76	Success
3rd	70	Success
4th	40	Fail
5th	78	Success
6th	68	Success
7th	35	Fail
8th	30	Fail
9th	78	Success
10th	75	Success

Motor speed = 2000 RPM

$$\text{Success Rate (\%)} = \frac{\text{Number of Successful Attempts}}{\text{Total Number of Attempts}} \text{ x } 100$$

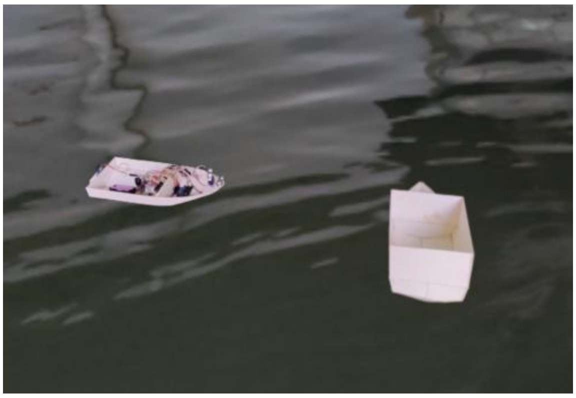
$$= \frac{7}{10} \text{ x100}$$

$$= 80$$

So, the success rate is approximately 70%.

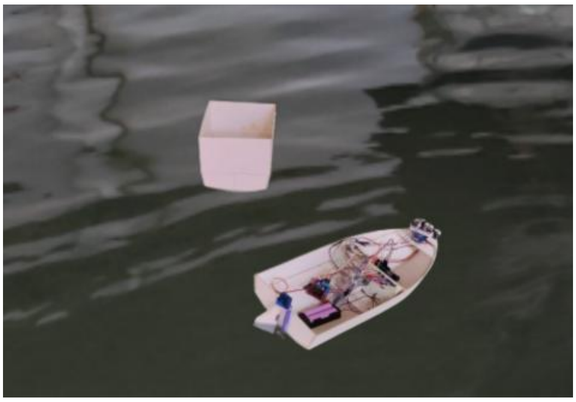
Crossing Approach:

In circumstances when the secondary boat approached from the right side of the main boat, the collision avoidance system identified the lateral hazard. The obstacle was detected by the sonar that was sweeping to find obstacle and collision free path. Then it instantly actuated the rudder mechanism to shift to an ideal position, guaranteeing safe passage. After passing the obstacle the primary boat went towards the direction it was previously going to. For this servo mechanism was actuated accordingly.



(i)

(ii)



(iii)

(iv)

Figure 4.6: Collision avoidance in crossing Approach.

Table 4.5: Collision avoidance data for crossing approach.

No. of Attempts	**Actuation starting distance (cm)**	**Status**
1st	100	Success
2nd	68	Success
3rd	26	Success
4th	83	Success
5th	85	Success
6th	77	Success
7th	70	Failed
8th	90	Success
9th	85	Success
10th	15	Failed

Motor speed = 2000 RPM

$$\text{Success Rate (\%)} = \frac{\text{Number of Successful Attempts}}{\text{Total Number of Attempts}} \text{ x } 100$$

$$= \frac{8}{10} \text{ x}100$$

$$= 80$$

So, the success rate is approximately 80%.

Overtaking Approach:

During overtaking maneuvers by the secondary boat, the system continuously monitored the relative positions of both vessels. When necessary, it adjusted the rudder's position to maintain a safe distance and prevent collisions during overtaking.

(i) (ii)

Figure 4.7: Collision avoidance in overtaking approach

Table 4.6: Collision avoidance data for overtaking approach.

No. of Attempts	Distance from obstacle (cm)	Status
1st	100	Success
2nd	98	Success
3rd	88	Failed
4th	95	Success
5th	97	Success
6th	100	Success
7th	100	Success
8th	100	Success
9th	85	Failed
10th	100	Success

Motor speed = 2000 RPM

$$\text{Success Rate (\%)} = \frac{\text{Number of Successful Attempts}}{\text{Total Number of Attempts}} \times 100$$

$$= \frac{8}{10} \times 100$$

$$= 80$$

So, the success rate is approximately 80%.

Overall Success Rate:

Table 4.7: Overall success rate.

Conditions	No. of Failed Attempts	No. of Successful Attempts	Success Rate (%)	Overall Success Rate (%)
Static	01	09	90	80
Head-to-Head	02	08	70	
Crossing	03	07	80	
Overtaking	02	08	80	

Thus, overall success rate for the primary boat is found to be 80%.

4.2 Discussion

In this project, we have proposed a methodology for collision avoidance and the implementation of safety systems, aimed at preventing accident scenarios that cost human life and assets. The prototype model developed has demonstrated satisfactory performance with 80% overall success rate in the four scenarios previously discussed.

Inland water vehicles, such as launches and ferries, are often not equipped with the advanced technologies found on larger ships sailing in the sea. Therefore, we have proposed a cost-effective solution to modernize these inland water vehicles. The system has undergone real-world testing and has provided reliable results, indicating its potential for automating dangerous scenarios. The algorithm employed in this project performs adequately under most conditions. However, its performance could be improved in more challenging scenarios. One limitation of our system is that it only scans the forward part of the vehicle using an ultrasound sensor. We attempted to use a 360-degree LIDAR sensor but encountered operational issues as it failed. As the project is based on Arduino, there are inherent limitations due to the sequential execution of code, which impacts system performance. Future work could explore ways to overcome these limitations and enhance system performance.

For the application of this system in real-world vehicles, hardware upgrades are necessary. The subsidiary safety systems, including the gyroscopic sensor and water level sensor, currently only provide warning signals without any actuation mechanism. A potential improvement could be the integration of an actuation mechanism that prevents the vehicle from starting if the water level sensor indicates a potential overloading scenario at the start of the journey. Currently a warning buzzer is included in the system to alert the crew. The warning signals can be customized for proper voice announcement on the vehicle or the crew on board needs to manually relay these warning messages to ensure the safety of all individuals on board. However, there are areas for improvement and potential expansion, particularly in terms of hardware upgrades, sensor capabilities, and system performance.

Chapter 5
Conclusions and Future Recommendations

5.1 Conclusion

The world of maritime navigation is a complex and challenging environment, where safety is of paramount importance. The vast expanse of the world's waterways, from the smallest inland rivers to the largest oceans, are traversed by a myriad of vessels, each with their own unique navigational needs. Ensuring the safe and efficient operation of these vessels is a task that requires a delicate balance of human skill and technological innovation.

In conclusion, this study presents a potential approach to enhance the safety of inland water vehicles by integrating human interaction with autonomous systems. The proposed methodology effectively addresses four potential collision scenarios and has demonstrated promising results in real-world testing. The system's design allows for simultaneous operation of human and autonomous modes, providing an additional layer of safety through human validation of maneuvers.

However, the study also identifies areas for improvement, particularly in terms of hardware upgrades, sensor capabilities, and system performance. The limitations of the Arduino-based system and the need for more advanced sensors for larger vehicles are acknowledged. Despite these challenges, the research provides a cost-effective solution for modernizing inland water vehicles, thereby contributing to the preservation of human life and assets. Future work will focus on overcoming the identified limitations and further enhancing the system's performance and reliability. This research lays a solid foundation for the development of advanced safety systems for maritime navigation.

Furthermore, this research holds significant implications for Bangladesh, as these waterways witness fatal accidents every year due to various factors such as lack of awareness, operation of unfit vessels, overloading of passengers, hiring unskilled crews, inadequate capacity of relevant bodies, low standard maintenance of Inland Water Transport (IWT) channels, technological barriers, poor weather forecasting, profit-centered attitude on part of vessel owners, and corruption.

The proposed system in this study addresses these challenges and enhance the safety of inland water transport in Bangladesh. By reducing collision incidents and improving navigational safety, this research could contribute to preserving human lives and assets in Bangladesh's inland waterways.

5.2 Future work

While this project project has made considerable steps in enhancing the safety of maritime vehicles in the setting of Bangladesh, there are various areas for future study that might further increase the system's efficacy and applicability.

1. Enhanced Computing Power: As technology advances, it is likely that more powerful computing hardware will become available. Future iterations of our safety system should leverage these advancements to process data more quickly and accurately, especially when dealing with complex navigational scenarios.
2. LiDAR Sensor Optimization: Future research should focus on maximizing the potential of LiDAR sensors for precise and reliable obstacle detection. This entails comprehensive calibration, seamless integration with other sensor data, and the development of advanced algorithms to fully exploit the 3D spatial information provided by LiDAR sensors.
3. Tilt Mitigation Mechanisms: Addressing vessel tilt is a critical aspect of future work. In addition to gyroscope-based tilt angle monitoring, efforts should be directed toward designing mechanisms capable of actively minimizing tilt or autonomously restoring the boat's balance. These measures are pivotal in accident prevention and overall safety enhancement.
4. Machine Learning for Obstacle Avoidance: Integrating machine learning models tailored specifically for obstacle avoidance is a promising avenue to enhance the system's performance. These models can be engineered to adapt and learn from historical data, enabling more informed real-time decision-making and, consequently, more accurate and effective collision avoidance strategies.

Although the present project marks a major step towards better maritime vehicle safety in Bangladesh, the highlighted future work areas comprise the necessity for diligent sensor development, greater stability mechanisms, and the introduction of flexible machine learning algorithms. These combined efforts seek to significantly improve the system's functioning and safety requirements, therefore contributing to safer and more efficient water transport in the area.

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