Design and Implementation of an Arduino Mega Based Autonomous Sailboat for GPS Waypoint Navigation Using Wind Sensing and Real Time Control

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Abstract

This study demonstrates the development of an autonomous sailboat designed to navigate using predefined GPS waypoints, employing real-time sensor data to regulate its sail and rudder mechanisms. The system is anchored by an Arduino Mega microcontroller, which integrates various sensor modules and servo motors. Additionally, an SD memory card is incorporated for data logging purposes. Wind speed is quantified by measuring pulses from an anemometer, while wind direction is derived from analog signals provided by a wind vane. By synthesizing wind data with the vessel's heading and GPS coordinates, the system computes the requisite direction and distance to the target waypoint, subsequently adjusting the rudder orientation and optimizing the sail angle. The servo motors governing the rudder and sail are controlled via a PWM driver (PCA9685), ensuring precise positioning. Throughout the navigation process, all sensor inputs and control outputs are systematically logged onto the SD card for post-mission analysis. In summary, this system presents a cost-effective and practical approach to autonomous sailboat navigation, with potential applications in marine research, environmental monitoring, and educational robotics.

Keywords: Autonomous Sailboat, Wind Sensor, GPS-Based Navigation, Arduino Mega, PWM Servo Control, Embedded Navigation System, Real-Time Control

1 Introduction

1.1 Overview

Oceans play a significant role in global climate protection. Scientists argue that the ocean is one of the most frequently overlooked environments; however, it is amongst the most severely affected, making scientists and the population each time more interested in monitoring it. (Lovelock et al., 1986) In that way, long endurance autonomous monitoring of oceanic water is an important and difficult task due to several constraints imposed by the harsh environment of the seas. One of the biggest challenges is how to provide enough energy for an autonomous water vehicle for missions with an endurance of months or even years.

Therefore, the use of wind-propelled boats is a good alternative to missions that require long duration tasks, since the propulsion energy requirements are smaller when compared to boats propelled by motors. These boats are often called wind vane servomechanisms. (Belcher et al., 1982) Besides their great potential for sustainability, another main advantage of using sailboats instead of boats with a screwpropeller is that while the last consumes the greater part of its energy with propulsion, a sailboat uses wind for propulsion, thus reducing the required electrical energy, which increases its potentiality for payload (applications). Such feature makes the use of sailboats an attractive approach, mainly in cases of long running missions, where velocity is not an issue. For example, it can serve as a base station for other short-range underwater vehicles or a UAV team operating in a sea area. Simply by using solar panels and a battery for turning on servos/actuators for guiding the rudder and sail in the right positions, one can make a sailboat navigate autonomously not only for hours, but also for days, weeks or even months without human intervention. The type of actuators necessary for this kind of operation consumes much less energy than the ones necessary in a normal helix boat. (Ang, 2022 and Cristea, 2023) On the other hand, while traditional propelled boats can be more easily controlled due to their simplicity, there are some considerable differences when developing the control laws of an autonomous sailboat. In order to control the displacement of a robotic sailboat from a given position to another position within a navigable space, several issues and conditions should be addressed, such as wind direction, wind speed, boat heading and sea currents. A control loop for such a kind of boat uses the above-mentioned information to position the sail and the rudder with respect to the wind so that the boat can head and displace to the desired position. In such a system, sensors are used to obtain the wind speed and direction, which are provided to the control loop. Thus, needing some special strategy to get to a given target in that direction. (Wille, 2016)

This work discusses all of the issues related to this problem, proposing solutions for the control system, including a prototype that is currently fully functional. In the next sections, this text presents the problem in more detail, the overall system architecture, including the hardware and software of a typical sailboat, electronic components, the control law's modeling and implementation. Finally, experimental results are presented for testing the accuracy of the system.

1.2 Aim and Objectives

The aim of this project is to design, develop and implement an autonomous sailboat based on the Arduino mega 2560 platform that is capable of navigating water bodies using wind power and onboard sensors, with minimal human intervention, for applications such as environmental monitoring, marine research, and autonomous maritime navigation.

Objectives

This project aims to develop an autonomous navigation system for a sailboat that can determine its position and heading accurately and respond to changing conditions in real time. Using GPS for location, a compass for heading, and wind sensors for wind direction and speed, the system will continuously calculate the best course to follow and the sail adjustments required to preserve efficient movement toward predefined waypoints.

To achieve reliable control on the water, the project will implement an Arduino based control architecture that manages both sail trim and rudder position. The control logic will translate sensor readings into practical steering corrections and sail settings, helping the boat stay on course while making smarter use of available wind. Emphasis will be placed on stable actuation, smooth corrections, and robust behaviour when conditions shift, for example sudden gusts, minor drift, or temporary sensor interference.

In addition, the design will integrate wireless communication to enable remote monitoring and decision making during operation. This will allow real time status updates, logging of key navigation and sensor data, and, where required, a safe manual override function for testing, recovery, or operational safety.

Finally, the system will be tested and endorsed through structured trials in both controlled and real world freshwater environments. Performance will be assessed by how accurately and consistently the sailboat follows its waypoint route, how well it maintains heading under different wind conditions, and how dependable the overall system remains throughout extended runs, with results used to improve the control strategy and improve reliability.

Finally, the system will be tested and validated through structured trials in both controlled and real world aquatic environments. Performance will be assessed by how accurately and consistently the sailboat follows its waypoint route, how well it maintains heading under different wind conditions, and how dependable the overall system remains during extended runs, with results used to refine the control strategy and improve reliability.

1.3 Contributions of the Work

This work shows that autonomous sailing does not have to be expensive or complicated to get started. By using simple, widely available parts like an Arduino and off the shelf sensors, the project proves you can build a working system at a low cost. That makes it easier for students, researchers, and even hobbyists to learn, test ideas, and improve the design without needing a high budget or specialised equipment.

Another contribution is how the sensors are brought together and used for real decisions on the water. The boat does not rely on one reading or one device. It combines GPS for position, a compass for direction, and wind sensors for what is happening in the environment, then uses that information to adjust the sail and rudder in real time. This helps show how sensor readings can be turned into practical control actions, especially when conditions keep changing.

This project also adds value by tackling the real difficulty of navigation when wind is the only source of propulsion. With a sailboat, you cannot always go in a straight line to a waypoint, especially when the wind is against you. The work helps build understanding of wind aware navigation, including things like choosing the right sailing angle and using tacking when needed. That is an important step for anyone trying to design path planning methods for sail driven systems.

The field testing is another strong contribution. Instead of stopping at theory, the project takes the system into real aquatic environments and checks how it behaves in practice. These tests give useful feedback on stability, control response, sensor noise, and how reliable the boat is over a run. The results also help highlight what needs improvement for future versions, such as better handling of gusts, drift, or delays in steering and sail adjustment.

Finally, the project creates a good starting point for future environmental and marine monitoring work. Because the boat can run without fuel, it supports the idea of long duration, low impact platforms that can collect data over time. With further development, this concept could be used for tasks like water quality checks, wildlife observation, or collecting ocean data in a cleaner and more sustainable way.

Figure 1. The wind vane designed by Herbert Hasler

2 Literature Review

2.1 History of Autonomous Sailboats

The idea of automating sailboats started from the need to keep a steady course without constant human input. One of the earliest methods was simply tying the rudder or tiller in a fixed position to help maintain direction. Over time, more advanced systems were developed, like the wind vane, created by Herbert Hasler. (Fig. 1) This device uses a small fin that reacts to wind direction and adjusts the rudder through a system of ropes and pulleys, helping the boat stay on course with the wind.

Later on, electronic self-steering systems began to appear. These systems use sensors like compass, wind direction sensors, or GPS to control the rudder automatically. A noticeable step in this area was the invention of the Gyropilot by Elmer Sperry in 1911, which used a gyroscope to help the boat steer more like an experienced sailor. This kind of system introduced feedback control, which was further improved by Minorsky’s work on PID controllers. (Fig. 2)

In recent years, more advanced methods, using artificial intelligence, have been developed for rudder control. Techniques like fuzzy logic and Artificial Neural Networks (ANNs) allow the system to adapt to changing conditions at sea without needing constant manual adjustments. According to Stelzer, AIbased systems can often steer more smoothly than traditional PID controllers, especially during complex maneuvers like tacking or jibing. (Stelzer et al., 2011) A good example is the RoboSail project, which started in 1997 and used machine learning and agent technology to create a self-learning autopilot.

Figure 2. Gyropilot designed by Elmer Sperry

As mentioned in Stelzer's work, the evolution from mechanical to intelligent systems has made autonomous sailboats much more capable, allowing them to make decisions and adapt to the environment with very little human involvement.

2.2 Navigation Methods

Over the past two decades, the autonomous navigation field has experienced great progression toward full automation. These improvements are mainly based on GPS and compass sensors, employing basic methods such as Line of Sight (LOS) or Velocity Made Good (VMG) algorithm to lead the boat efficiently while adjusting sail and rudder positions through PID controllers or finite state machines. (Brito er al., 2012 and Lekkas, 2013 and Puschl, 2018). In other scenarios, like upwind navigation, heuristic tacking algorithms are utilized. Additionally, it worth mentioning that with the progression of AI and related fields, machine vision has turned to a key aspect in this section. (Bertram, 2008)

2.3 Power Management

Renewable energies are the main source for autonomous sailboats since they are mainly for longduration missions. Solar panels are the most popular choice among the manufacturers due to their simplicity and efficiency. (Tuna et al., 2015)

However, they are other power supply systems used as well. They benefit from combining solar with wind or wave energies to raise their working life span in various weather conditions.

(Röhr & Bruns, 2009) On the other hand, energy-aware control systems are also widely implemented to react based on energy level of the boat. Figure 3 shows an example of solar panels used on a sailboat.

2.4 Control System Evolution in Autonomous Sailboats

Designing an appropriate control system for boats is among the key elements to reach autonomy. In the early stages control algorithms were mainly utilized for calculating the proper sail and heading angle for navigation in various scenarios such as harsh weather and etc. For instance, Neveu et al. designed an autopilot system based on a simple PID controller which demonstrates that early-stage use of lowcomplexity models for sailing autonomy. (Neveu et al., 2008)

As the field matured, it is observed that more sophisticated models such as fuzzy and hybrid controllers were employed in order to control the sail and rudder in gusty or low-wind environments with high precision.

Figure 3. Employing solar energy on boats

Model Predictive Control (MPC) has also played a crucial role in modernizing the sailing industry. Xuefei et al. proposed an MPC-based system which is able the to optimize the control inputs over a predictive time horizon while considering physical constraints, such as limited turning radius and sail angle range. (Xuefei et al., 2019)

With the buttress of recent developments in artificial intelligence and machine learning, adaptive and learning-based control strategies have turned into hot spots of research and development. Chen et al. developed a reinforcement learning approach adapt rudder and sail configuration based on environmental feedback, enabling autonomous adaption to changing sea states without explicit environmental modelling. (Chen et al., 2024) The spread of intelligent agents in sailing scenarios can increase the overall systems efficiency which will result in more eco-friendly transportation.

3 System Design

3.1 Sailboat

Figure 4 shows the autonomous sailboat used in our project. It features a single mainsail with a wind sensor mounted on the extension at the stern, which allows for accurate wind direction and speed measurements. The boat is equipped with a custom-built rudder control system and sail adjustment mechanism, both actuated by servos. The keel and bulb design provide stability during navigation. The sailboat is mounted on a portable stand for ease of testing and transport, making it ideal for controlled experiments in both indoor and outdoor environments.

Figure 4. The components of sailboat used in this project

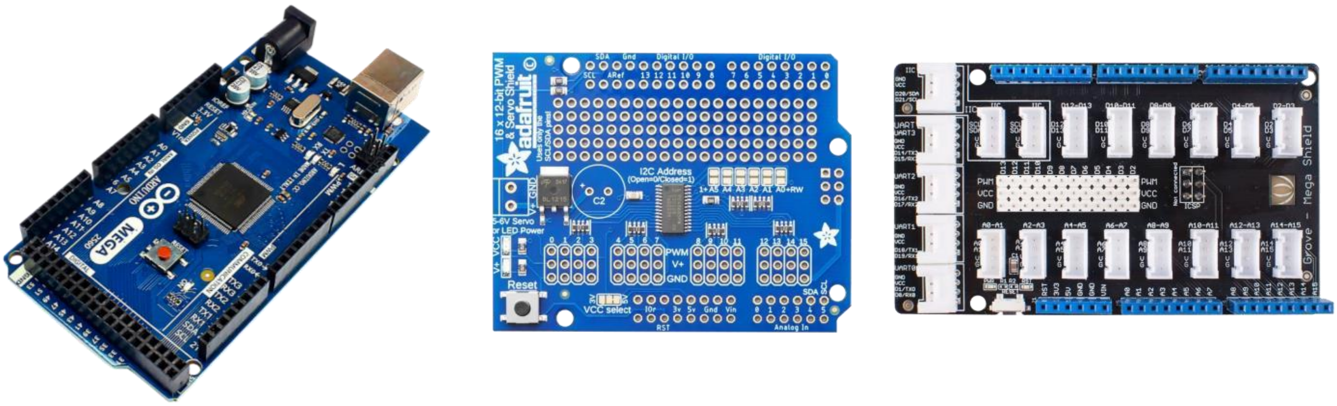

Figure 5; a. Arduino Mega 2560, b. Adafruit 16-Channel 12-bit PWM & Servo Shield, c. Grove - Mega Shield

3.2 Microcontroller, Sensors, and Actuators

3.2.1 Arduino Board

The Arduino Mega 2560 is a microcontroller board that serves as the core processing unit in the proposed system. (Fig. 5a) The operating voltage of this board is 5V, which can be powered by normal commercial power banks and batteries. Also, the addition of 54 digital I/O pins and 16 analog input pins enables the user to have sufficient freedom in system architecture, using various sensors and actuators. While comparing the Arduino platform with other competitors such as Raspberry Pi, the fact that Arduino has its own customized development environment and a vast repository of libraries and packages makes it stand out. Additionally, the lower power consumption and hardware-level control of the Arduino make it more appropriate for tasks that require precise timing, such as PWM signal generation for servos and reading sensor inputs with minimal latency.

3.2.2 Shields

The Grove - Mega Shield and Adafruit 16-Channel 12-bit PWM & Servo Shield are extension boards for Arduino Mega. These integral components are responsible for streamlining sensor integration and actuator control. (Fig. 5b-5c)

The Grove - Mega Shield simplifies wiring by providing plug-and-play compatibility with the Arduino board, allowing for easy connection of various Grove modules, such as GPS, compass, etc., without the need for soldering or using a breadboard. On the other hand, the Adafruit 16-Channel 12-bit PWM & Servo Shield extends the ability of the Arduino board in order to control multiple servos or PWM-driven devices. The I²C protocol is utilized in this component to enhance PWM control. The integration of these components makes the prototyping and design procedure both efficient and robust.

3.2.3 GPS

In this project, the GY-GPS6MV2 GPS module was used in order to provide accurate real-time positioning for the system. This module is designed based on Ublox NEO-6M GPS chip which can offer up to 5 Hz refresh rate and 2.5 meters precision. For seamless connection to the satellites, it uses a ceramic antenna. The cold start period for this sensor to start collecting GPS data is normally between 10 to 15 seconds. Additionally, the compact size of this module turns it to a great option in terms of spacing in the boat. (Fig. 6)

Figure 6. GY-GPS6MV2 *GPS module*

3.2.4 Wind Sensor

Accurate wind sensing is a key factor for the reliable operation of autonomous sailboats, as it directly influences navigation decisions such as sail positioning, rudder control, and course optimization. The ability of the vessel to maintain its heading relative to wind direction, known as apparent wind angle, depends heavily on precise, real-time wind measurements. Wind sensors used in these systems typically include wind vanes, which measure wind direction, and anemometers, which quantify wind speed. These devices provide continuous environmental data that is processed by onboard micro controllers to dynamically adjust the sail trim and rudder angle, thereby ensuring efficient and responsive movement. In this project, the employed wind sensor is Anemometer-SKU7911 which can be deployed easily on the stern of the sailboat, without interrupting the sail and rudder activation mechanisms. (Fig. 7)

3.2.5 SD card Module

An SD card module in an autonomous sailboat serves as a local data logger, allowing the Arduino to store mission-critical data during operation. This is particularly useful when no real-time communication is available. SD Cards as used in the projects serves the purpose of:

- Date Logging: Records GPS position, heading, wind angle, and sensor data over time.
- Mission Replay: Enables post-mission analysis and debugging by examining stored logs.
- Power Efficiency: Data is stored passively without requiring constant transmission.

The Kwmobile micro-SD card reader module has the data logging responsibility in the proposed system design. It is compatible with various microcontrollers and works with 5V input voltage. (Fig. 8)

Figure 7. Anemometer-SKU7911

Figure 8. Kwmobile micro-SD card reader module

3.2.6 Actuators

In this project, the HS-785HB and HS-5645MG servos were employed to control the sail and rudder, respectively. (Fig. 9) The HS-785HB is a winch-style servo designed for applications requiring extended rotation, making it ideal for sail control. It provides up to 3.5 turns of rotation and is capable of handling the continuous adjustments needed for precise sail trim in response to changing wind conditions. For rudder control, we used the HS-5645MG, a high-torque digital servo known for its speed, precision, and durability. It features a metal gear train and programmable functionality, offering reliable and responsive steering control even under dynamic loading. Together, these servos provided robust and accurate actuation, ensuring stable and efficient autonomous sailing performance.

3.2.7 Compass

The CMPS12 sensor is a digital compass that provides heading, pitch, and roll information for the boat's navigation to describe orientation in 3D space. The sensor uses a 3-axis magnetometer, gyroscope, and accelerometer to obtain this data. The module runs internal algorithms to correct errors caused by PCB tilting. It requires a minimum of 3.3V and a maximum of 5V to operate. The CMPS12 is automatically calibrated. The sensor uses I2C or serial communication. The pinout of the sensor can be seen in the image. For this project, this module is used in serial mode, therefore the MODE pin was connected to ground. (Fig. 10)

Figure 9. HS-785HB and HS-5645MG Servos

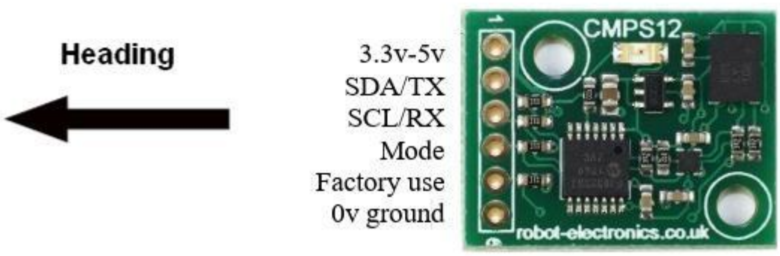

Figure 10. CMPS12 sensor

3.2.8 Battery

The battery is the primary power source for all electrical components of the autonomous sailboat, including the Arduino, sensors, and servos. For this particular project, a power bank is used to provide power to the Arduino microcontroller, with servo shields included to deliver appropriate voltage level to each component.

3.3 Mission Safety and Remote-Control Module

In the process of designing the autonomous sailboat, safety considerations, in case of the system failure, have been applied. For this purpose, a controller and a receiver are paired together and programmed to take the lead of the boat's action when the user tends to. Flysky FS-R6B radio receiver, is added to the circuit, which is responsible for accumulating data sent by the user via the controller. For the rudder and sail control, in the proposed circuit, channel 1 and 3 are utilized. (Fig. 11)

3.4 Wiring

The wiring diagram, (Fig. 12), illustrates the complete electrical architecture of the autonomous sailboat system, showcasing the integration of multiple sensors and actuators with the Arduino Mega 2560 and Adafruit 16-channel PWM Servo Shield via the Grove Mega Shield. The wind sensor and anemometer are connected via I²C (SCL: D21, SDA: D20), while the GY-GPS6MV2 GPS module and CMPS12 compass are interfaced through Serial2 and Serial3, respectively. The SD card module is connected via SPI (CS, SCK, MOSI, MISO) for onboard data logging. The FlySky receiver is wired to digital pins D2 and D3 for manual override capabilities.

Figure 11. Remote controlling system

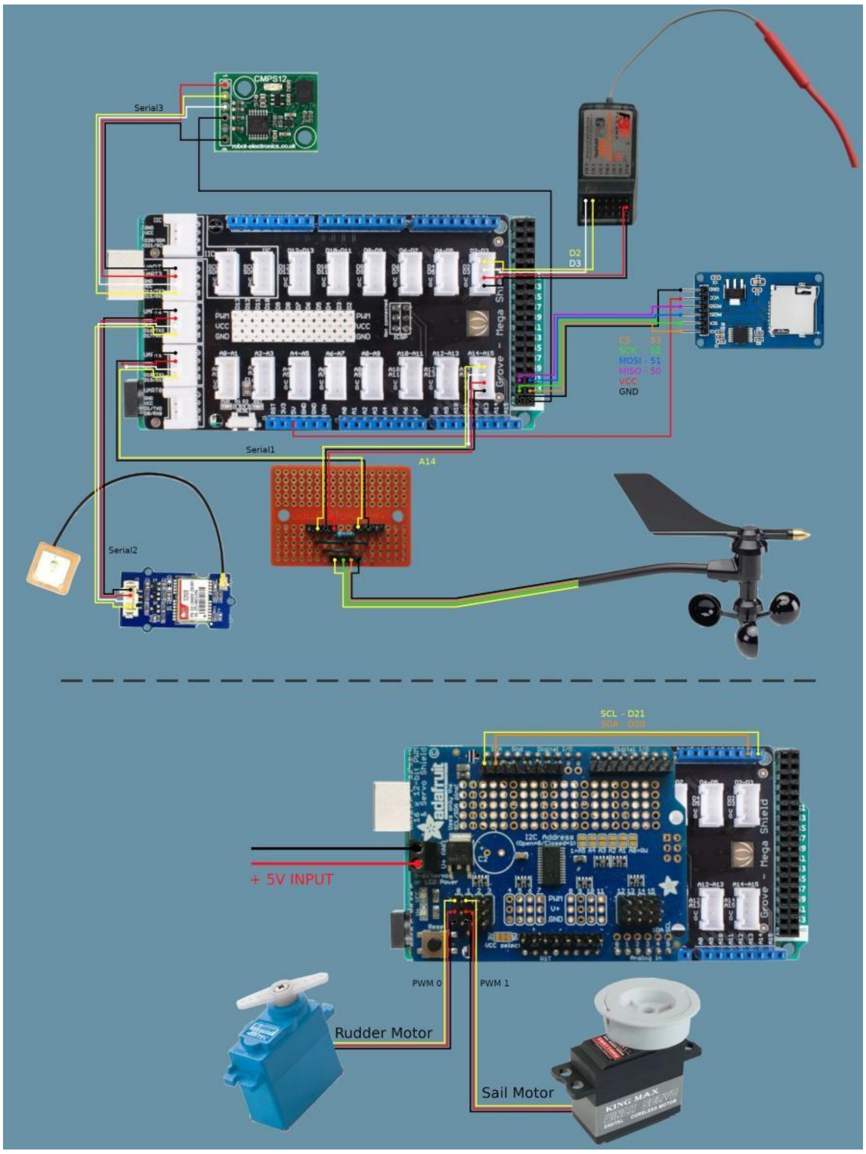

Figure 12. Wiring Diagram

The sail and rudder are actuated using HS-785HB and HS-5645MG servos, connected to PWM ports 1 and 0 of the Adafruit servo driver, which is powered by the external 5V supply. Communication between the Arduino and the servo shield is handled over I²C, ensuring synchronized and efficient control of navigation actuators. The system is designed to be modular, robust, and well-organized for both lab testing and real-world deployment.

3.4 Structural Design

3.4.1 Circuit Box

According to Fig. 12, it is vivid that the physical size of the circuit and components are noticeable. Since the sailboats operate in humid and wet environments, there should be a cover designed for them. Fig. 13 demonstrates the electronics enclosure which is specifically designed to protect and organize the Arduino board, sensors, and other electronic components used in the system. It serves as a protective housing that shields sensitive electronics from environmental factors such as water, dust, and physical damage, while also allowing for secure mounting and proper cable management. This enclosure ensures

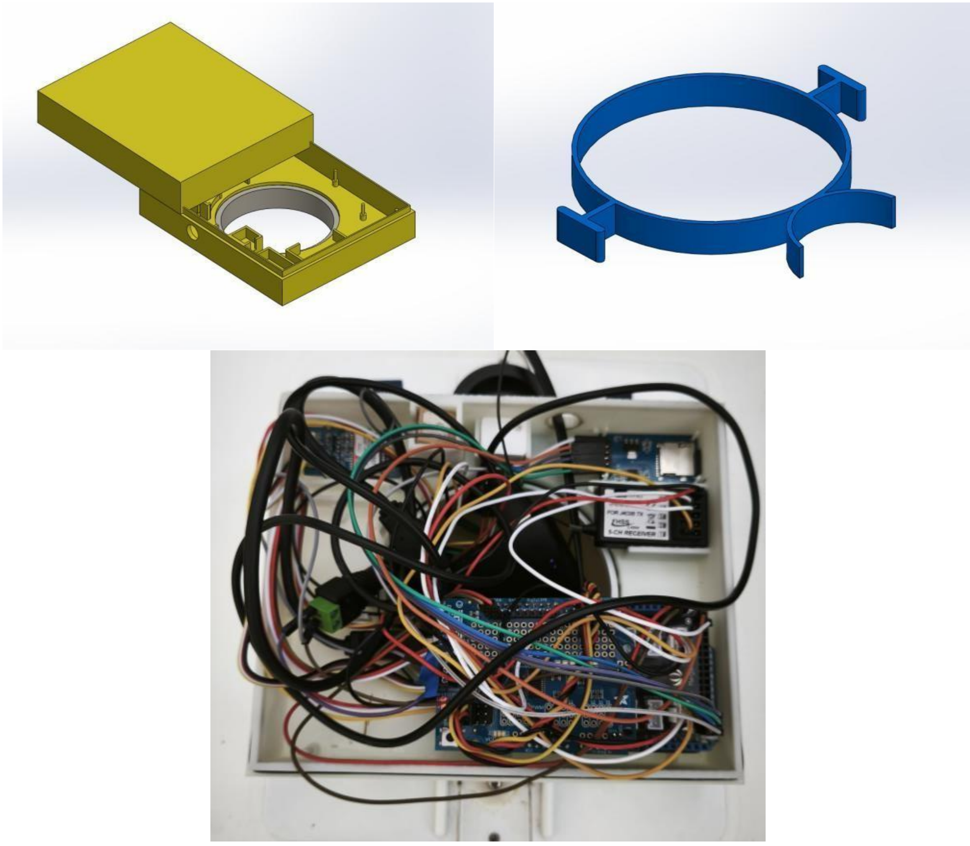

Figure 13. 3D printed box for physical enclosure of electronics

that the internal components remain stable, accessible for maintenance, and safely isolated from external elements, especially in outdoor or marine applications like autonomous boats. The box is designed in Solid works software and 3D printed with Polylactic Acid (PLA) filament.

3.4.2 Wind Sensor Stand

In order to get precise result from the wind sensor, the process of installation and mounting of the sensor must be performed respective to the fluid mechanics aspects. Any disturbance in the air flow before reaching the sensor may cause rising of error in sensor output. Accordingly, it has been decided to mount the wind sensor in front of the boat's body, meaning the wind sensor will collect the air flow data prior any disturbance caused by the sail or other components. For this purpose, a stand for this sensor has been designed by Aston University's members. This design is shown in Fig. 14.

Figure 14. Wind Sensor Stand

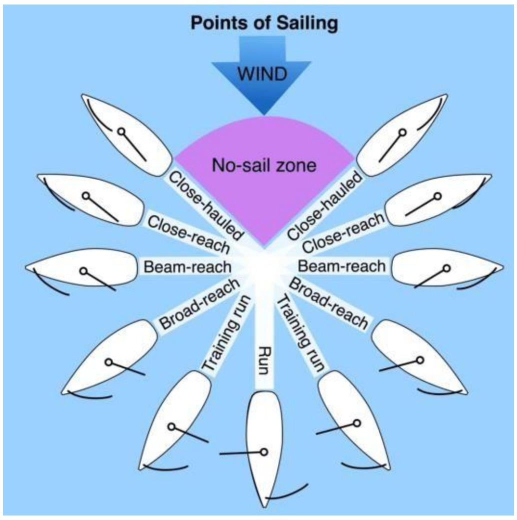

Figure 15. Sailing dynamics diagram

4 Dynamics and Control

4.1 Sailing Dynamics

Understanding the dynamics of sailing is crucial in the system systems, as it enables the control logic to plan optimal headings and sail configurations based on prevailing wind directions, maximizing speed and efficiency while avoiding the no-sail zone. (Tipsuwan et al., 2023)

Sailing dynamics are fundamentally governed by the interaction between the sailboat's heading and the direction of the wind, a relationship described through the "points of sail". As illustrated in the Fig. 15, the wind blows from the top of the diagram, and the surrounding circle represents various sailing angles relative to it. Sailing directly into the wind (0°) or within the adjacent "no-sail zone" (approximately 30– 50° on either side) is ineffective, as the sails cannot generate sufficient lift to propel the vessel forward. Outside this zone, the boat can begin to harness wind power efficiently. The closest effective angle is called close-hauled (\~45° to the wind), where the sail acts like an airfoil, generating lift much like an airplane wing.

As the angle between the wind and the boat increases, the sailing mode transitions from close reach to beam reach (90°) and then to broad reach. These modes allow for fast and efficient movement, with lift still being the primary driving force. When sailing at larger angles past 135° toward 180°, the boat enters running or downwind mode. Here, the sail no longer generates lift but instead relies on drag-functioning more like a parachute catching the wind from behind. (Setiawan et al, 2020)

4.2 Control Algorithm

4.2.1 Development Platform

It was mentioned in the last sections that an Arduino Mega 2560 is utilized as the processing unit in this project. (Ismailov, 2022) Thus, the required programming section has been developed in Arduino Integrated Development Environment (IDE). The Arduino IDE primarily uses a variant of C++ for programming, however, the additional packages and libraries in this platform makes it ideal for more robust and efficient programming. The main used libraries are: wire.h, Adafruit_PWMServoDriver.h,

TinyGPS++.h, SD.h which are built-in features developed for the platform. (Barrett, 2022)

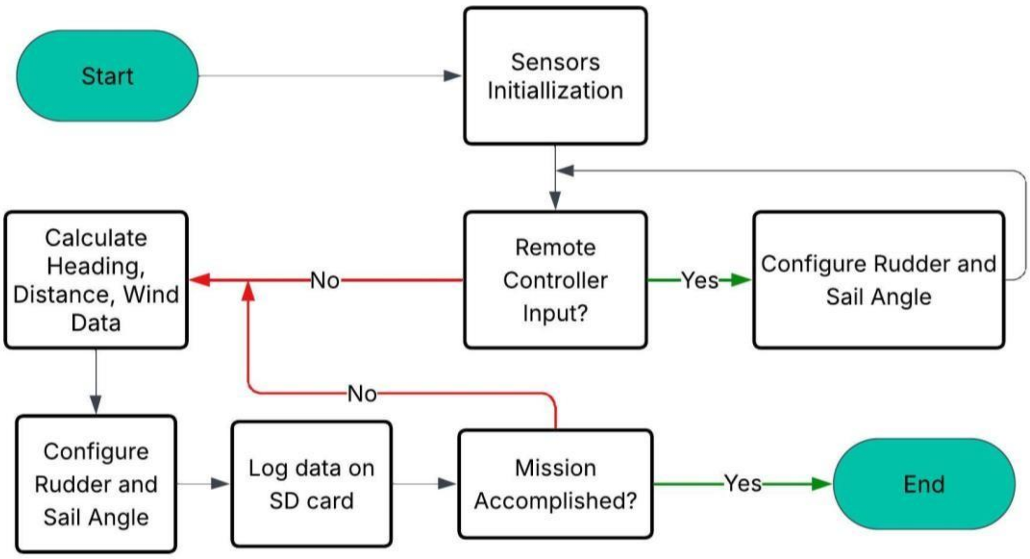

Figure 16. The control strategy flowchart

The flowchart in Figure 16 outlines the operational process for a sailboat's autonomous navigation system, starting with the "Start" phase where the system initializes by gathering data from sensors. This initial step ensures all necessary inputs, such as environmental conditions, are ready for the journey. From there, the system checks for remote controller input; if present, it configures the rudder and sail angle accordingly to steer the boat effectively. This adaptability allows the system to respond to realtime commands, ensuring the sailboat can adjust its course as needed to reach its destination.

If no remote input is detected, the system calculates heading, distance, and wind data to determine the best path forward. It then configures the rudder and sail angle based on these calculations, logging all data onto an SD card for later analysis. The process continues with a check to see if the mission— reaching the destination—has been accomplished. Once the sailboat arrives, the system concludes with an "End" state, marking the successful completion of the journey. This structured approach ensures the sailboat navigates efficiently and records its progress throughout the trip.

5 Testing and Validation

In this section, the experimental results of testing the sailboat performance are reported. The tests took place in two conditions; dry test and water test.

5.1 Dry Test

The control system gathered data using an onboard SD card module that kept a running log of important details during some dry outdoor tests. This included stuff like GPS latitude and longitude, compass heading, wind speed and direction, rudder angle, sail angle, and system timestamps. To mimic real movement, the sailboat was artificially moved around an open outdoor space, hopping between waypoints while keeping the sensors active and the actuators responding in real time. Figure 17 shows roughly the path that the boat was carried and relatively the system reacted.

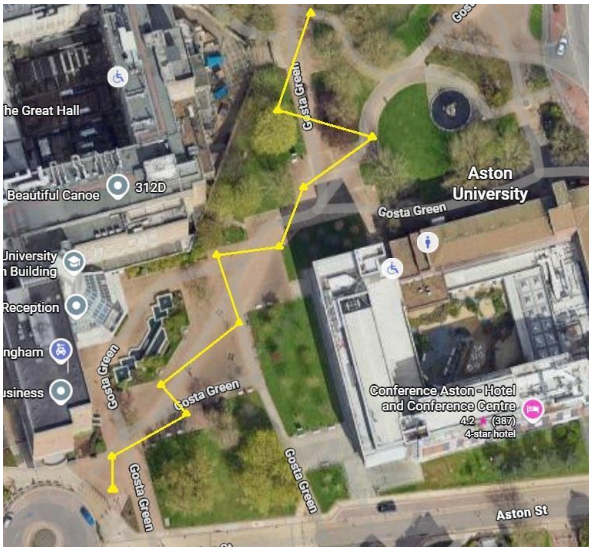

Figure 17. the artificial waypoints for the boat's navigation

Table 1 shows a sample of data from dry test. *GPS Latitude, GPS Longitude, Heading, Bearing, Distance, Wind Direction, Wind Relative, Rudder, and Sail* are the outputs that each 100 milliseconds were written on the SD card. Also, the trend that the rudder and the sail angle changed are shown in Figure 18.

Table 2: SD card sample data

GPS Lat.	GPS Long.	Heading	Bearing	Distance	Wind Dir.	Wind Rel.	Rudder	Sail
52.473018	-1.954050	~ 60	299	21.73	~ 95	18-35	45	43-60
52.473022	-1.954090	~ 150	301	19.19	~ 95	30-55	45	45-60
52.473068	-1.954227	~ 150	302	8.52	~ 95	190-220	75	90
52.473083	-1.954267	~ 300	307	5.24	~ 95	90-100	135	90

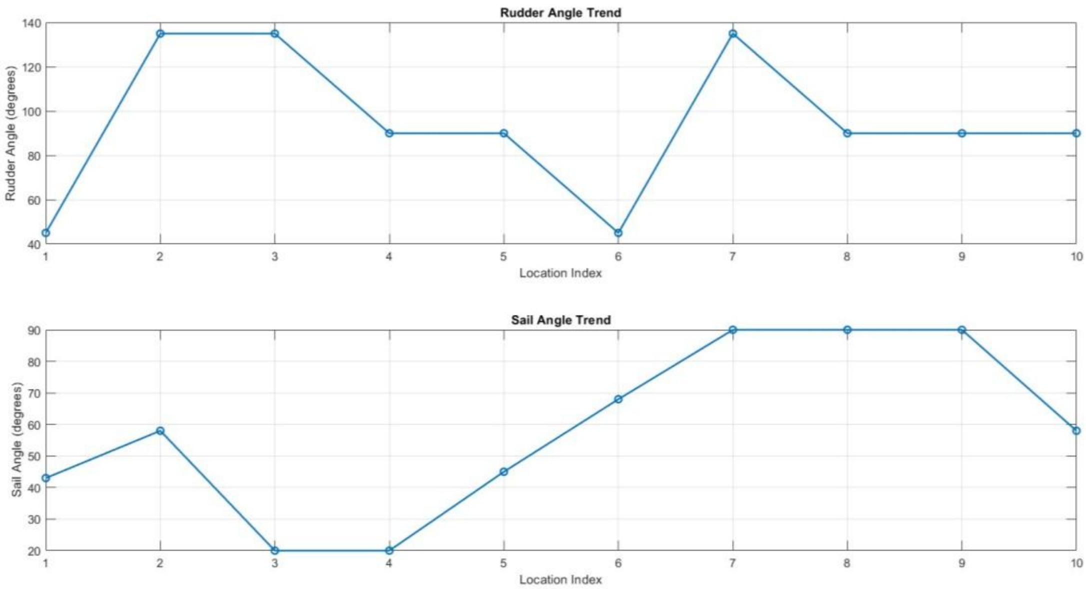

Figure 18. The rudder and the sail angle trend

5.2 Water Test

The final section of the project was dedicated to the water test. Although there is various limitation about the accessible environment for the best state of testing, a successful result was achieved. In figures 19 and 20 the result for a short distance water test is demonstrated.

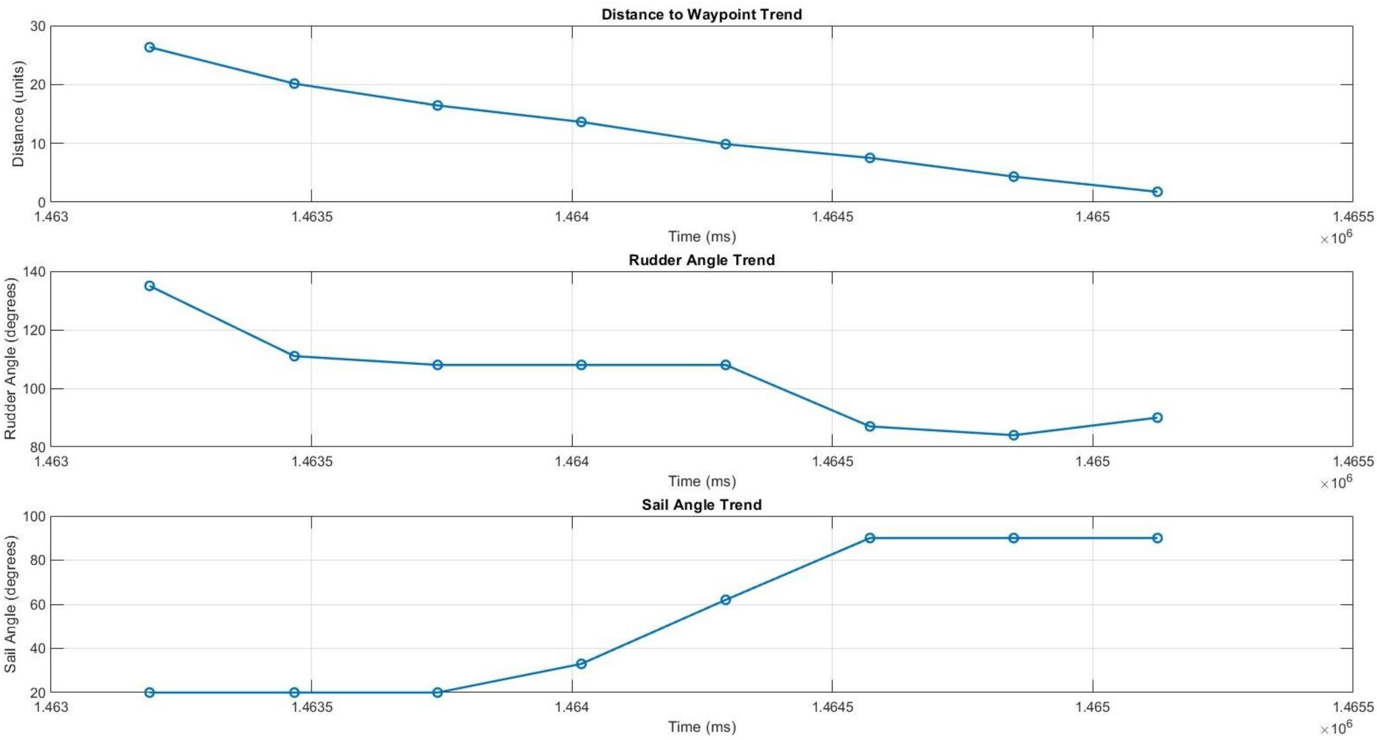

Figure 19. Water test result

Figure 20. Water test at Birmingham water canal

5.3 Outcome

After reviewing the SD card data and the sailboat's performance across various parameters, it’s clear that the outcome is successful. The steady decrease in distance to the waypoint, combined with the adaptive adjustments in rudder and sail angles, demonstrates effective navigation and control throughout the journey.

5.4 Challenges

However, this project successfully accomplished its mission, there were various challenges that limited the success throughout the process. The lack of accessible proper testing environment is among the most important ones. For instance, the canals that were used for testing are limited in width, which makes it hard for sailboats to move free enough. On the other hand, the utilized sensors, mainly the GPS sensor, was not accurate enough and throughout the test, the precision were highly concerning. It is suggested to upgrade mentioned sections for better results in future works.

6 Conclusion

The primary objective of this project was to design and evaluate an autonomous sailboat system capable of maintaining a consistent heading and position under varying environmental conditions. The results indicate that the system successfully met its core objectives. Key findings reveal that the sailboat sustained a stable heading throughout the trial, underscoring the effectiveness of the rudder control mechanism. Additionally, the stable wind angle readings suggest that the system adeptly adapted to shifting wind conditions. The subtle adjustments in rudder and sail angles further highlight the system's ability to self-regulate, optimizing its sailing performance and reinforcing the robustness of the control system in maintaining course stability.

However, the project faced certain constraints, including limited time and resources, which influenced the scope of the work and identified several avenues for future enhancement. To address these limitations, future iterations could benefit from testing the system across a broader range of weather conditions to assess its resilience in challenging scenarios. Incorporating additional or higher-quality sensors, coupled with advanced filtering techniques, could enhance data accuracy. Moreover, exploring adaptive control strategies—such as machine learning or self-tuning controllers—might improve the system's responsiveness to dynamic environmental changes, paving the way for a more sophisticated and reliable autonomous sailboat.

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