Autonomous Sailboat

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1. Introduction

1.1 BACKGROUND

WRSC (World Robotic Sailing Championship) is an autonomous sailboat competition that aims at stimulating the development of autonomous marine robotics. Unlike the more traditional problem of autonomous RC vehicles, autonomous sailboats pose a more challenging control problem – dual-mode capability. In the event that the autonomous system cannot navigate a difficult environment (harsh winds, etc.), the user needs to be able to manually control the boat back to base. It would be difficult for the user to retrieve the boat otherwise. Furthermore, the convoluted steering system on RC sailboats presents a steep learning curve. Amateur users greatly benefit from this dual-mode capability and are less likely to potentially lose their sailboat to the wind or waves. In addition, autonomous sailboats attract great attention due to their possible infinite endurance [1].

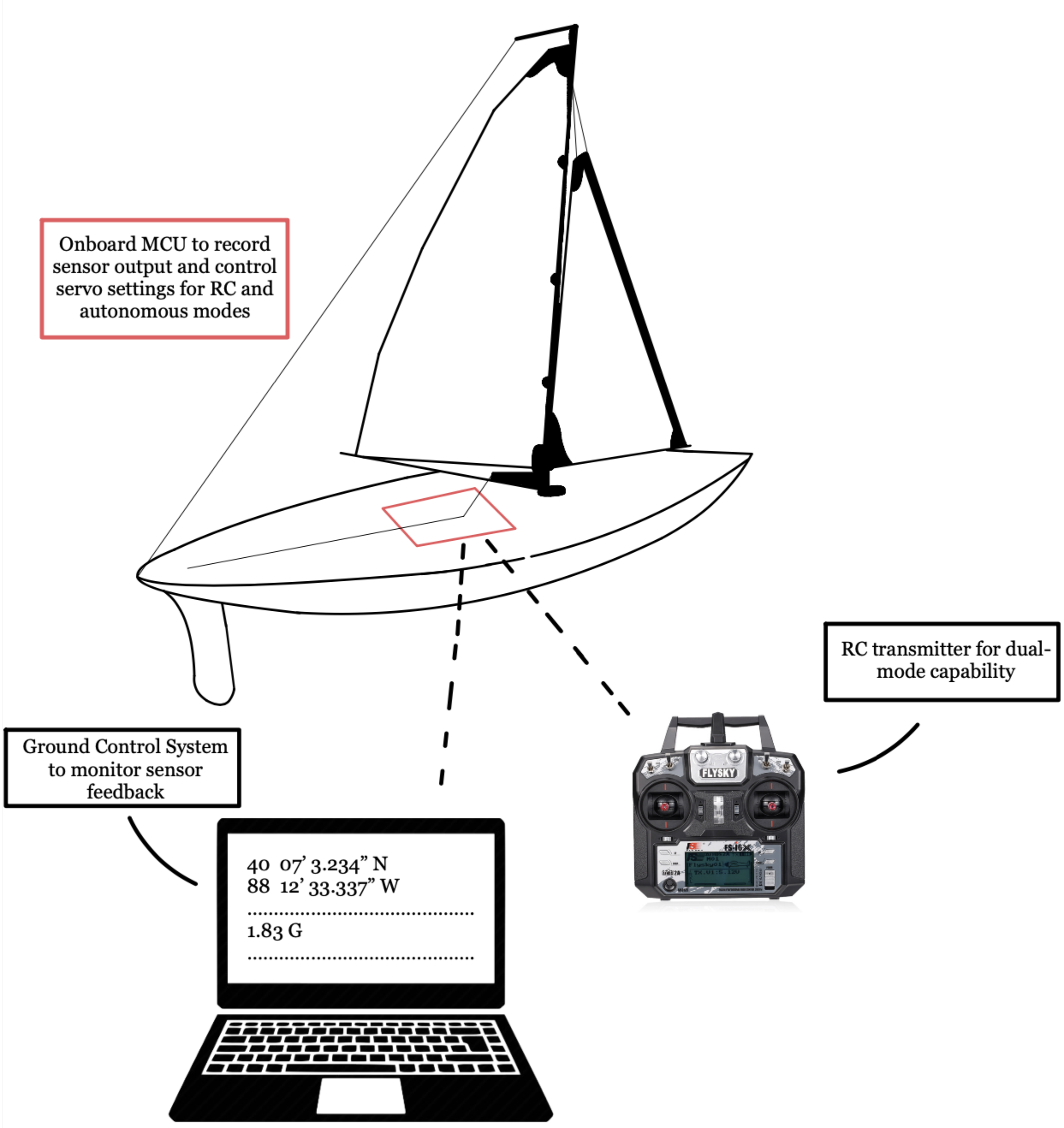
1.2 OBJECTIVE

Our project aims at developing an affordable autonomous sailboat design capable of sailing under radio control and maintaining its course in an autonomous mode. Other autonomous sailboat designs on the market utilize expensive autopilots such as the Pixhawk Flight Controller. Our design utilizes low-cost sensors and servos that will make it affordable and easy to install into any standard RC sailboat.

Being affordable, our design will be more marketable to amateur users who are not willing to spend the extra money on alternative systems. Thus, the sailboat will offer a “return to base” feature that would diminish concern of losing their boat via lack of steering ability. More experienced users will also benefit from this feature in the event of their sailboat losing signal to the wireless transmitter controller.

Users will also be able to monitor real-time sensor data that will be critical in revising the autonomous mode path planning algorithms and potentially useful in understanding manual control. This ground control system will receive this data from the on-board MCU via a telemetry transceiver. An RC transmitter will be used for manual steering and switching to and from the autonomous mode.

1.3 PHYSICAL DESIGN

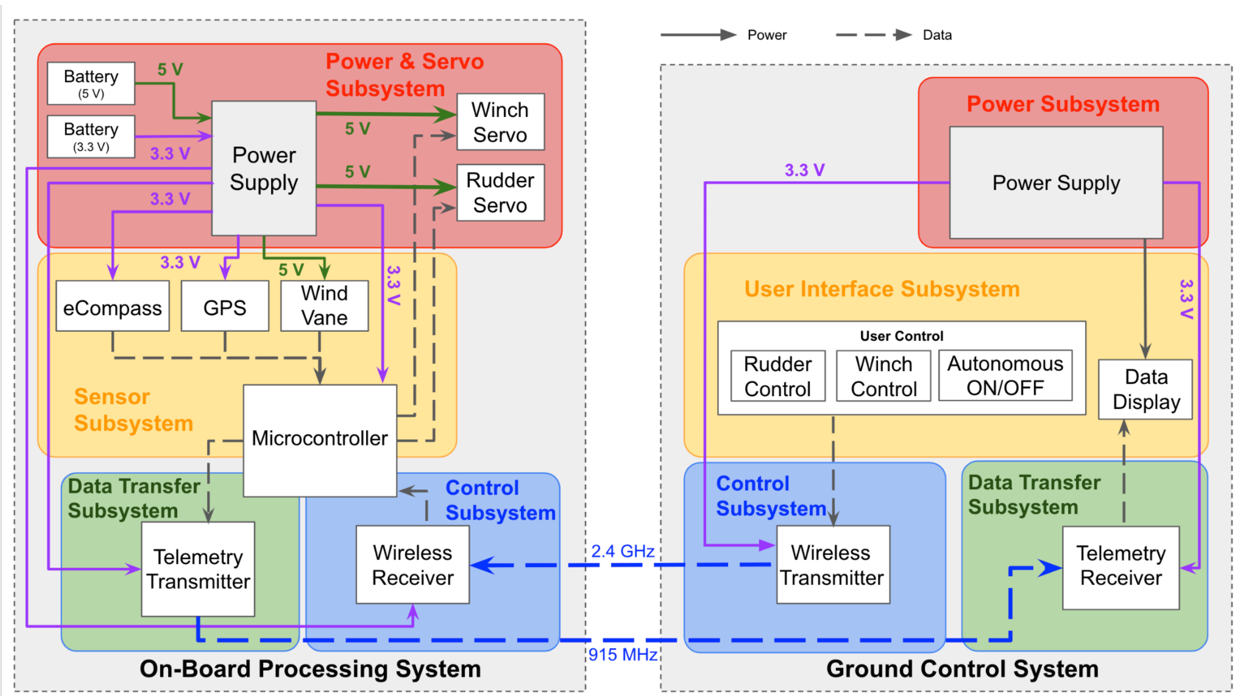


1.4 HIGH-LEVEL REQUIREMENT LIST

- The sailboat should have dual-mode capability; the operator can switch between a manual and an autonomous mode.
- The sailboat can record and transmit servo, sensor and position data back to base.
- When in autonomous mode, the sailboat should be able to maintain a compass heading.
- The operator should be able to use a “return to base” feature that guides the sailboat back to base.

2. Design

2.1 BLOCK DIAGRAM



2.2 ON-BOARD PROCESSING SYSTEM

2.2.1 Control Subsystem

Microcontroller:

The microcontroller will take data from all the sensors (GPS, Wind vane, Compass, Accelerometer) and use that information to compute the winch and rudder servos angles. When the system is operated in manual mode, it will adjust the winch and rudder servos angles according to the information received from the transceiver.

Requirement 1: Can adjust servos angles with a tolerance of ± 3º.

Requirement 2: Processor can calculate position, heading, wind speed and direction within a 5% margin of error.

Wireless Receiver:

The wireless receiver will receive user control inputs when in manual mode and send these inputs to the microcontroller that will then decide how to adjust the servos. This receiver will also receive the autonomous mode ON/OFF signal and return to base signal.

Requirement: Must accept signals of standard RC sailboat frequency of 2.4 Ghz.

2.2.2 Sensor Subsystem

GPS (NEO-6G):

The GPS will track the sailboat's position. It will send the position to the microcontroller so that it can operate the "return back to base" feature.

Requirement: GPS can locate the sailboat with a 4 meter precision.

eCompass (LSM303DLHC):

The eCompass will send the direction that the sailboat is taking to the microcontroller so that the system can adjust itself if it deviates due to some disturbances. It will also provide the acceleration data to the microcontroller so the user can track the speed of the boat.

Requirement: Can tell the direction the sailboat is facing with a tolerance of ± 10º.

Wind Vane (MA3 Miniature Absolute Magnetic Shaft Encoder):

The wind vane will tell the microcontroller what direction the wind is going.

Requirement: Can tell the direction the wind is going with a tolerance of ± 15º.

2.2.3 Power & Servo Subsystem

Battery:

The battery will be located at the board system, providing electricity to the power supply which will power all electrical components on the boat. The boat will contain two sets of batteries: a 3.3 V battery and a 5 V battery, due to certain components requiring different voltage levels.

Requirement: The batteries should provide the desired voltage with tolerance of ±0.2 V.

Winch Servo:

The winch servo is located near the front of the boat, and will be able to rotate the sails of the boat based on the controlling signal generated from the microcontroller, and powered by the power supply with 5 V electricity. This would allow the change in angle of the sails, allowing different maneuvers while sailing.

Requirement: Must provide around or at least 5.25 kg-cm of torque.

Rudder Servo:

The rudder servo is located at the rear of the boat, which will be able to rotate the rudder of the boat based on the controlling signal generated from the microcontroller, and powered by the power supply with 5 V electricity. This would allow the boat to change direction in which to travel.

Requirement: Must provide around or at least 1.83 kg-cm of torque.

Power Supply:

The power supply will connect to all electrical components that require electricity. For the board system, the power supply will pull electricity from the batteries and supply the components with electricity of the corresponding voltage level (pre-routed).

Requirement: Must provide 3.3 V with tolerance of ±0.3 V and 5 V with tolerance of ±0.2 V.

2.2.4 Data Transfer Subsystem

Telemetry Transmitter (GAMMA-915R-SO):

The telemetry transmitter will transmit servo, sensor and position information to the ground control system.

Requirement: Possesses a line of sight range > 10 kilometers.

2.3 GROUND CONTROL SYSTEM

2.3.1 Control Subsystem

Wireless Transmitter (FS-i6 Digital Proportional Radio Control System):

The wireless transmitter will transmit user inputs from the user control panel to the on-board processing system when autonomous mode is OFF. It will also send the autonomous mode signal ON/OFF and “return to base” signal to the on-board processing system.

Requirement: Must transmit at standard RC sailboat frequency of 2.4 Ghz.

2.3.2 User Interface Subsystem

User Control Panel:

The user control panel will contain mainly three knobs: a control for rudder, a control for winch, and a button to toggle autonomous mode for the boat. When autonomous mode is turned ON, the boat will travel autonomously on a predetermined route (controls on the rudder and winch from the user will be ignored). When autonomous mode is turned OFF, the user may use the rudder and winch control to manually control the boat's direction of travel.

Data Display:

The data display will be a screen providing and displaying real-time data collected by the sensors on the boat (relayed back through the transceiver module). This includes position of the boat (GPS), direction of the boat (compass), wind speed and direction (wind vane), and acceleration of the boat (accelerometer).

2.3.3 Power Subsystem

Power Supply:

The power supply will connect to the transceiver module and the data display and provide power to those components with required voltage. For the remote system, the power supply may pull electricity from any valid power source.

Requirement: Must provide a 3.3 V with a ± 0.3 V tolerance.

2.3.4 Data Transfer Subsystem

Telemetry Receiver (GAMMA-915R-SO):

The telemetry receiver will receive servo, sensor and position information to allow the user to view real-time data from the sensors via their laptop display.

Requirement: Possesses a line of sight range > 10 kilometers & USB Interface.

2.4 RISK ANALYSIS

The microcontroller is probably the block that poses the greatest difficulty to implement. It must take the data from the different sensors and use that data to compute the position that the sail and the rudder must take. The angles for the rudder and the sail must be PID controlled, because there are going to be perturbations (such as wind or water streams) that will make the angle change. PID control can be quite challenging because we will need to compute a model for the servos and make sure the model is correct. In addition, the microcontroller frequency will take a very important role in the PID control, if it is not fast enough the PID control will not work.

3. Ethics and Safety

3.1 ETHICS

There are a few ethics policies that we need to take into consideration with this project. Section 7.6 of the IEEE Code of Ethics I.5 states, “to seek, accept, and offer honest criticism of technical work… and to credit properly the contributions of others” [2]. As our project is not the first design for an autonomous sailboat, we ensure to credit any sources from previous projects and credit any resources we build upon [3]. Our project is a challenging assignment for the members of our team; we will strive to make use of any constructive criticism along the way.

3.2 BOAT SAFETY AND DATA PRIVACY

Furthermore, there are a few safety concerns our team needs to address. As the sailboat will have an on-board power supply, we must ensure that the casing of the power subsystem is completely waterproof and does not pose any risk for electrical shock. We will also ensure that wire connections from the servos to our waterproof casing are robustly secured to resist vibration and rolling as the sailboat may face on-board water exposure. Finally, our ground control system application will allow users to monitor the sensor data from the sailboat. Such data as the GPS coordinates of the boat, and hence user, poses a risk to their privacy. We will ensure that this application protects and does not monitor the user's data. Through ensuring safety we abide to uphold IEEE standards I.1; "to hold paramount, the safety, health, and welfare of the public… and to protect the privacy of others" [2].

3.3 TEAM SAFETY

Finally, our team will ensure to follow Lab Safety guidelines in testing our circuits and sensors. We will also abide by COVID-19 CDC recommended safety guidelines as we meet in person to work on the project.

References

[1] Silva M. F., Friebe A., Malheiro B., Guedes P., Ferreira P., Waller M. “Rigid wing sailboats: a state of the art survey.” Ocean Eng. 187, 106150, 2019 10.1016/j.oceaneng.2019.106150 [CrossRef] [Google Scholar]

[2] “IEEE code of ethics,” IEEE, Jun-2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 10-Feb-2022].

[3] S. Yang, C. Liu, Y. Liu, J. An, X. Xiang. “Generic and Flexible Unmanned Sailboat for Innovative Education and World Robotic Sailing Championship” frontiers in Robotics and AI, Mar-2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7990777/#B18. [Accessed: 10-Feb-2022].