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Group Number

Yachtonomous – An Autonomous Sailboat

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INTRODUCTION

Sailboats provide an environmentally-friendly and energy efficient alternative for aquatic transportation [1]. An autonomous sailboat presents a novel design challenge and provides further benefits by eliminating manual operation.

This project aims to demonstrate the feasibility of autonomous sailing vehicles on a reduced scope, focusing on the development of methods for navigation, localization, and control of autonomous sailboats, using onboard sensors and actuators, power, and wireless communications.

BOAT DESIGN

The boat uses a trimaran design to increase stability and area for electronics [2]. 3D printing reduced cost and provided more control over the design.

The mast is driven by a belt attached to a servo, and the rudders are driven by another servo attached with a linkage system. The mainsail is made of nylon and given a shape suitable to act as an air foil to provide propulsion.

ELECTRONICS

The boat uses an IMU, two rotation sensors, and several Bluetooth range sensors with RSSI measurements for localization. For actuation, two servo motors control the mast and rudder motion.

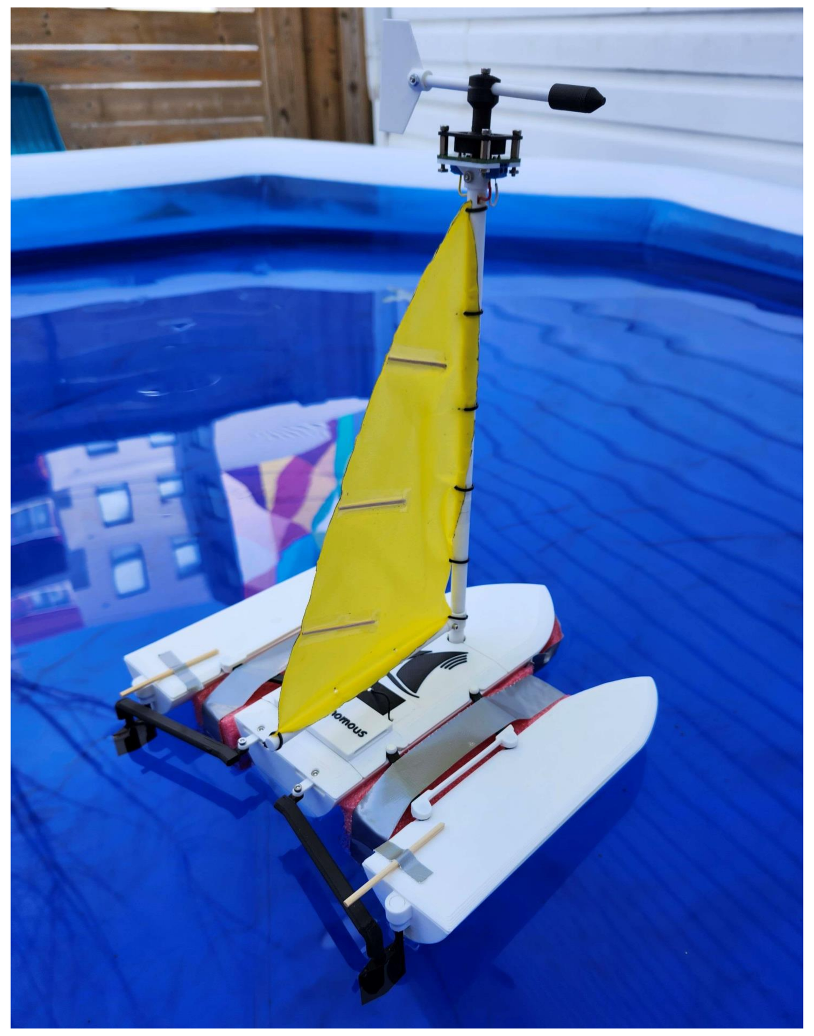
PCBs house and connect the MCUs, sensors, actuators, and power management, all powered by a 3.7V lithium-ion battery. Communication is achieved using I2C, PWM, Wi-Fi, and Bluetooth to send data between sensors, actuators, and controllers [3].

SOFTWARE

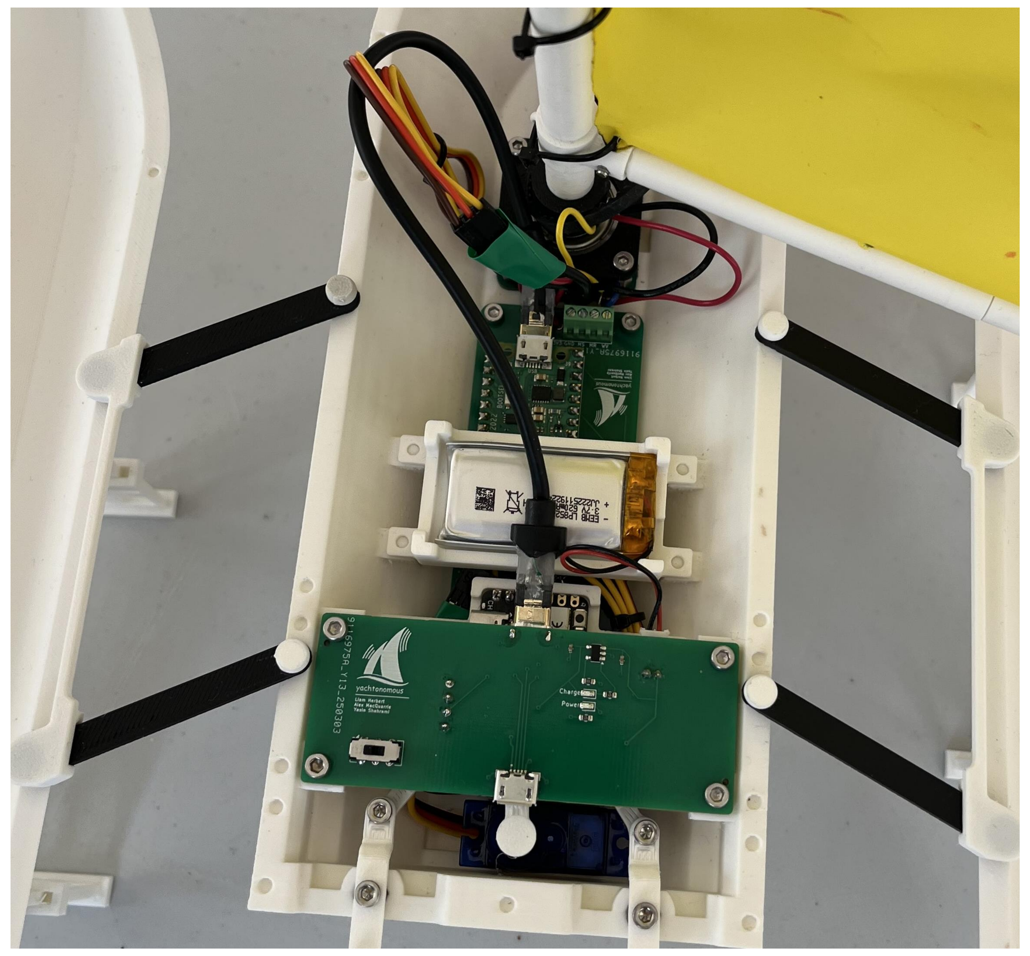
The boat's software is written in Python, MicroPython, and C++. The onboard Raspberry Pi reads from sensors, sends the sensor data over Wi-Fi to a PC, which runs navigation, localization, and control algorithms, to compute actuator inputs.

The custom navigation algorithm allows the boat to sail in any wind direction, while minimizing distance and number of tacks. Localization and feedback control are implemented using an Extended Kalman Filter, and Model Predictive Control, respectively [4].

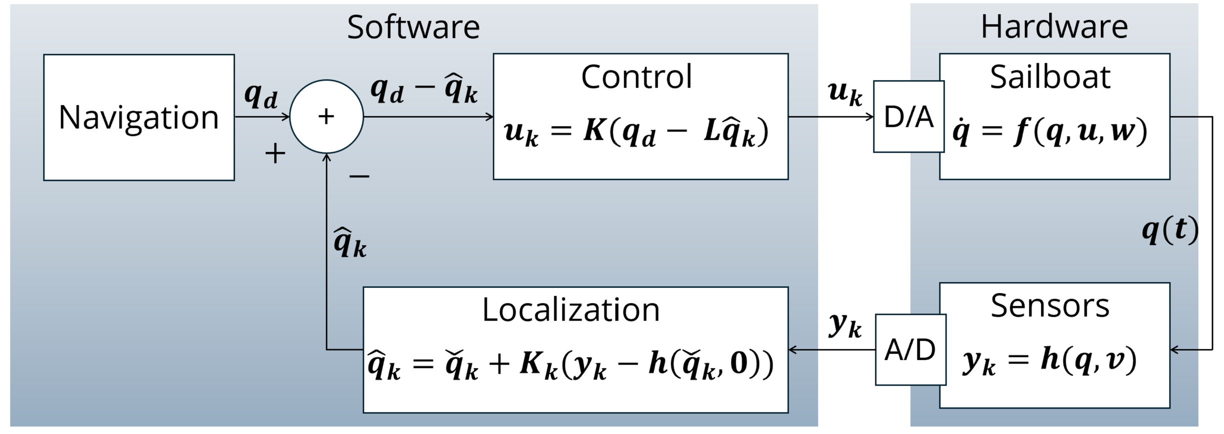
A software simulation environment was also completed to allow for testing and development, independent of the hardware.



(1) The boat in the test environment



(2) Electronics inside the main hull

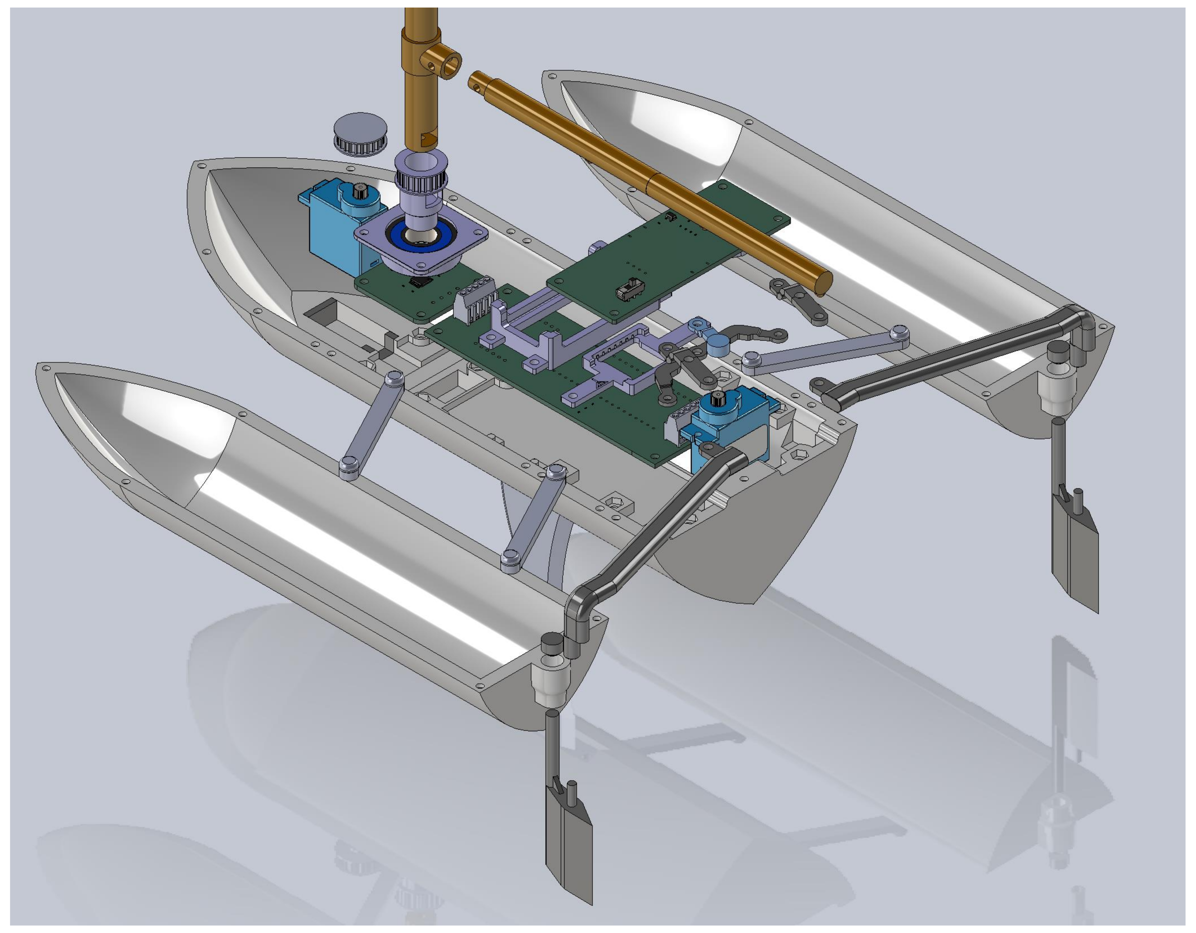


(3) Control block diagram

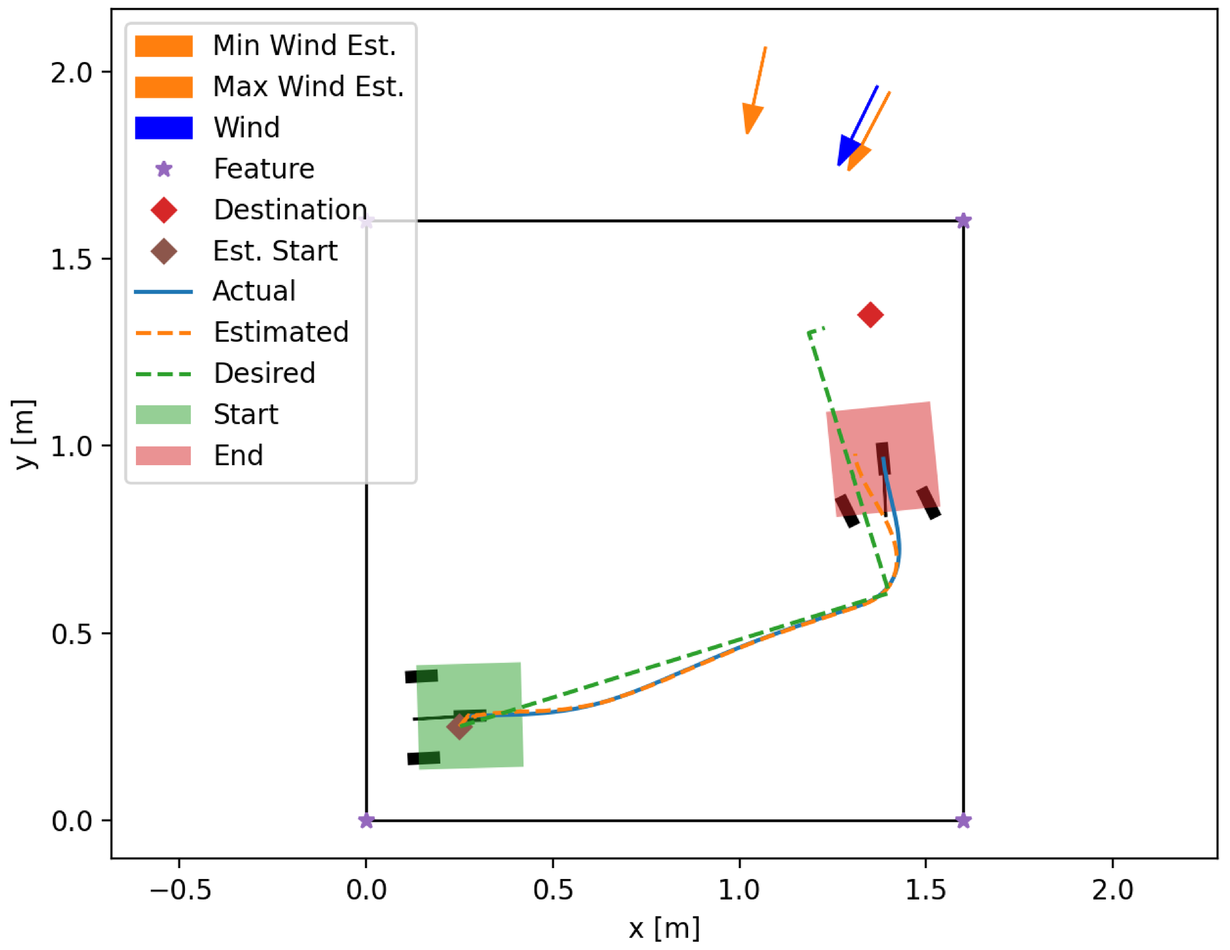
$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{\gamma} \\ \dot{\phi} \\ \dot{\eta} \end{bmatrix} = \begin{bmatrix} s\cos(2\eta - \gamma)\left(a\gamma^4 + b\gamma^2 + c\right)\cos(\theta) \\ s\cos(2\eta - \gamma)\left(a\gamma^4 + b\gamma^2 + c\right)\sin(\theta) \\ -\frac{s}{l}\cos(2\eta - \gamma)\left(a\gamma^4 + b\gamma^2 + c\right)\tan(\phi) \\ \frac{s}{l}\cos(2\eta - \gamma)\left(a\gamma^4 + b\gamma^2 + c\right)\tan(\phi) \\ \omega \\ \sigma \end{bmatrix}$$

x: Boat x position
y: Boat y position
θ: Boat orientation relative to x-axis
γ: Apparent wind angle relative to θ
ϕ: Rudder angle relative to θ
η: Sail angle relative to θ
ω: Rudder rotation rate
σ: Sail rotation rate
s: Maximum boat speed
l: Length between rudders and centre-board
a, b, c: Coefficients for boat speed relative to wind angle

(4) Kinematic model of the boat's motion



(5) SOLIDWORKS exploded assembly view



(6) An output from the software simulation

PERFORMANCE & RESULTS

Individual testing was completed for each subsystem before integration. All PCBs are fully functional and fit in the boat. After calibration, the sensors and actuators were tested and proved to be reasonably accurate. The software was fast enough to complete a control loop iteration in 30 milliseconds.

An inflatable test pool was used to test the boat's sailing ability in a variety of wind directions, with Bluetooth range sensors attached to the sides.

The boat struggled to sail in a straight line in most wind directions, but had some success sailing on beam reaches and broad reaches. The boat did not float as well as anticipated due to the weight of electronics, so external floatation was added.

CONCLUSIONS & RECOMMENDATIONS

Overall, the design and functionality of the boat was reasonably successful. While the boat struggled to sail in some directions, it was able to sail to the destination in others, demonstrating the overall feasibility of autonomous sailboats.

The main challenge was making a boat and sail that were aerodynamically functional. The boat could be further improved by modelling the boat's dynamics better, improving the boat and sail's aerodynamics, using servos with rotational encoders, and using I2C for the rotation sensors instead of PWM.

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