RoboBoat 2019 - Technical Design Report

"Phantom II"

Embry-Riddle Aeronautical University

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1.0 Abstract

The Embry-Riddle RoboBoat 2019 team's purpose is deliver a new multi-year platform that navigates with precise omnidirectional steering. This purpose was met with a trimaran hull-shape with inline azimuth thrusters, modular amas, and a modular deck. The inline azimuth thruster steering solution was chosen for the expected enhanced maneuverability when navigating near buoys and approaching islands. The other critical design strategies were derived from the need for a large deck, stability, and high top speed. The platform was designed be modular so any required upgrades during development or during future years could be implemented without needing to build a new platform. The systems and software design is similar to last year's platform, with the exception of a new waypoint following navigation strategy designed for inline azimuth thruster steering. Two navigation algorithms for the in-line azimuth thruster configuration were developed in a simulated environment using Simulink called Primary and Fine Maneuvering, that prioritize traversal speed and navigation accuracy respectively.

2.0 Competition Strategy

This year, our purpose was to deliver a new multi-year platform design and precise propulsion system to complete current and future competition challenges.

Figure 1: "Phantom I" during a test in the ERAU Henderson Welcome Center pond.

The Embry-Riddle RoboBoat 2019 team has made many changes since last year in its personnel, platform, and strategy. This year's 10 person team includes one returning member and 7 freshman members new to collegiate robotics. With the opportunity to develop the foundation for a new 4-year-team of aquatic robotic engineers, the team decided to start from scratch by developing a new competition strategy and designing a new platform. This new strategy called for an iterative design with the first year's goal being completing the base platform. Future years will have an increased focus on peripheral systems such as quadcopter integration and advanced autonomy.

2.1 Competition Requirements

The platform design was derived from the interpreted requirements to complete each competition challenge. These interpreted requirements are categorized as hull and system requirements and are listed in the Challenge Requirements appendix.

The hull requirements include a large deck, stability with an elevated center of mass, high top speed, and high degree of maneuverability. A large deck is required to launch and recovery of a quadcopter, as well as future competition elements. Stability with an elevated center of mass is required to account for the sensors, systems, batteries, and quadcopter that must be located well above the waterline. High top speed is required to perform well on the Speed Challenge portion of the competition. High maneuverability is required to complete the Find the Path portion of the competition, as well as interacting with the islands in the Raise the Flag and Automated Docking portions of the competition.

The system requirements include enhanced obstacle perception, enhanced path planning, visual symbol perception, Enhanced obstacle perception is interpreted as detecting distance and color with a 360 degree view of the surrounding environment, and is required to complete the Find the Path portion of the competition as well as enhance general obstacle detection. Enhanced path planning is interpreted as environment mapping and boat position and orientation monitoring, and is required to complete the Find the Path portion of the competition. Visual symbol perception is interpreted as the ability to detect different colored Buoys, as well as obstacles.

In order to deliver on our purpose to design a platform that is capable of completing all future competition challenges, the platform is designed be modular so any required future upgrades or changes can be implemented without needing to construct a new platform.

A major result of this year's competition strategy was to design a new propulsion system that enables the platform to navigate in any direction. The inline azimuth thruster steering solution was chosen for the expected enhanced maneuverability when navigating near buoys and approaching islands, over the standard maritime rudder or differential thrust configuration.

2.2 Mission Strategy

Our mission strategy for RoboBoat 2019 was to set a challenge priority that will organize our development focus and will set our challenge attempt order at competition. This year's challenge priority was selected based on the complexity of the challenges and the unique system requirements for completing them. These specific requirements are listed in the Mission Strategy appendix.

1. Autonomous Navigation
2. Speed Challenge
3. Find the Path
4. Raise the Flag
5. Autonomous Docking

3.0 Design Creativity

The Embry-Riddle RoboBoat 2019 platform is called "Phantom II". We have returned to the trimaran hull shape, with some major differences from our trimarans from previous years. The most notable difference is the inline azimuth thruster steering solution. In addition to the experimental steering solution, the hull was designed to manufactured rapidly, and incorporates modular amas and top deck.

3.1 In-Line Azimuth Thruster Steering

The two in-line azimuth thruster configuration was chosen to satisfy the requirement of high maneuverability. The dual inline thrusters are mounted on the bottom of the hull. Each thruster is mounted on a bushing sealed with dual o-rings that houses the thruster cabling and keeps water from entering the hull, as depicted in Figure 2.

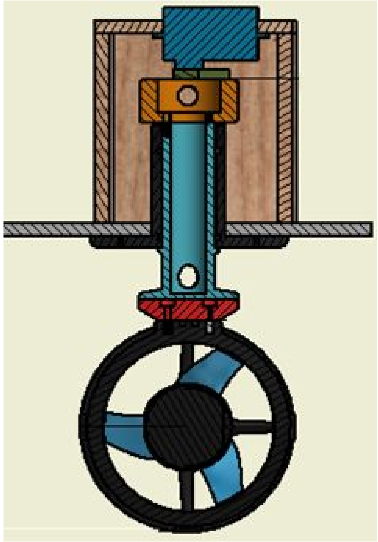

Figure 2: Section view of the 2019 azimuth motor mount design.

This thruster configuration enables "Phantom II" to traverse in any direction and in any orientation by turning and powering the thrusters independently, as depicted in Figure 3. The thrusters are positioned in-line with the hull, rather than both at the rear, so that the forward thruster is near the center of rotation of the hull. Thrusting from the center of rotation enables the boat to traverse in any direction with less torque imparted on the hull, increasing efficiency of pivot rotation and lateral traversal. In order to navigate with this unique thruster configuration, a custom navigation solution was developed that best utilizes the thrusters depending on situational requirements.

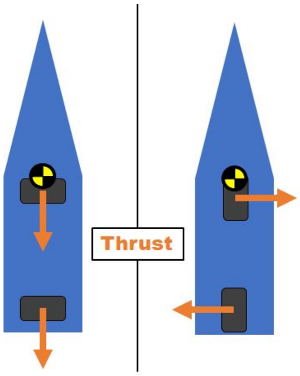

Figure 3: Thruster locations on the "Phantom II". Left shows both thrusters aimed backwards. Right shows both thrusters aimed in opposite directions.

3.2 Rapid Manufacturing

The “Phantom II” is constructed primarily from ⅛” plywood panels, with blue insulation foam used in the bow and amas. The plywood panels were laser cut in a jig-saw pattern so that the hull could be rapidly assembled precisely as designed. The panels corner interfaces were secured with hardware to ½” by 1 ½” wood beams or 3D printed blocks for obsolete angles at the bow. No adhesives were required to assemble the hull, with exception of the the insulation foam bow. Following assembly, the hull is coated with hardcoat and gelcoat. The results of developing this manufacturing process enabled us to manufacture the “Phantom II”, as depicted in Figure 4, at a cost of under $150 in under two weeks.

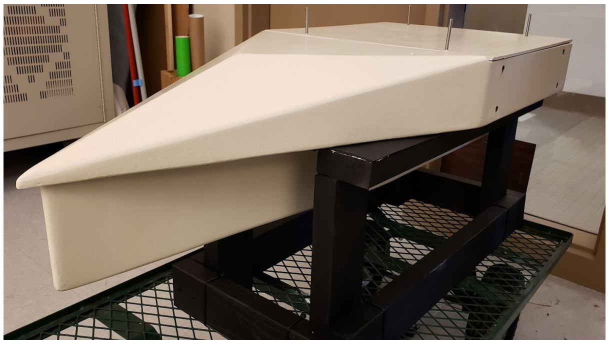

Figure 4: Phantom II Base Hull.

3.3 Modular Amas

The amas are designed to be modular and can be attached to the side of the central hull. This component was designed to be modular so the team can iterate with different types of materials and designs. Stability solutions being considered include varying ama spacing, canted ama positioning, and hydrofoil applications. This year the team is focused on ama spacing in order to create an initial and reliable ama setup that will serve as a default option as more experimental designs are created.

3.4 Modular Deck

The upper deck is designed to be modular and is be mounted at 4 hardpoints on the central cabin. This component was designed to be replaceable so the team can integrate future subsystems (e.g. Quadcopter and Heat Dissipation), without having to rebuild the platform. This year the deck is flat as the need for developing an initial reliable heat exhaust solution outweighed landing pad considerations for an unspecified quadcopter.

3.5 Systems and Software

The systems and software for this year's platform relies on a similar sensor suite as previous years' platforms. The enhanced obstacle perception and environmental mapping requirements are satisfied by using the Velodyne Puck LiDAR and a Microsoft LifeCam webcam. The Velodyne LiDAR builds a 3-dimensional map of the boats surroundings, and the Microsoft LifeCam provides forward object recognition and classification. The enhanced path planning requirement is satisfied by using the VectorNav VN-100 IMU and the Hemisphere A325 GPS to precisely monitor the boat's global position and absolute orientation.

4.0 Experimental Results

The navigation solution for the two in-line azimuth thruster configuration was developed using a custom hydrodynamics simulation. The simulated environment was created using Simulink and is meant to simulate the drag effects on the hull of the "Phantom II" as it moves in any direction and with any orientation on an X -Y plane. The purpose of this simulation was to develop an understand the dynamics of inline azimuth thrusters while the platform design is still in development.

4.1 Hydrodynamics Simulation

In order to simulate drag for forward, lateral, and rotational motion simultaneously, the drag profile was split into these three stated components and independently calculated. The forward component of flow velocity is used to determine the forward drag effect, the perpendicular component of flow velocity is used to determine the lateral drag effect, and the flow angular velocity is used to determine the rotational drag effect, as depicted in Figure 5. The simulation accounts for the parasitic drag effects as well as the hydrodynamic wave drag effect for each component of drag. Building this simulation environment enabled the team to develop navigation algorithms in an environment that accurately replicates the dynamics of the "Phantom II" as it reacts to the unique force and moment conditions generated from our unique thruster configuration.

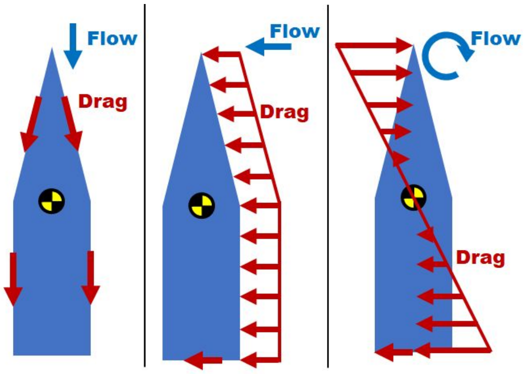

Figure 5: Parasitic drag components on the "Phantom II" considered independently. Left is Forward drag, center is perpendicular drag, and right is Rotational drag.

The navigation solution developed for the "Phantom II" combines two navigation algorithms that are employed depending on situational requirements. These navigation algorithms are called Primary, and Fine Maneuvering. The unique navigation algorithms combine gate logic and PID control loops that are specialized to meet two different situational requirements: high speed and precision navigation.

4.2 Primary Algorithm

The Primary navigation algorithm prioritizes speed and utilizes the rear thruster for steering and traversal to aim at and move towards a waypoint, and utilizes the front thruster to aid in steering during tight turns or provide additional thrust during long straight traversal, as depicted in Figure 6. This algorithm enables the "Phantom II" to move at its top speed by facing the next waypoint and maintaining this heading. This navigation algorithm is primarily employed during general navigation around the course and during the Autonomous Navigation and Speed Challenge portions of the competition.

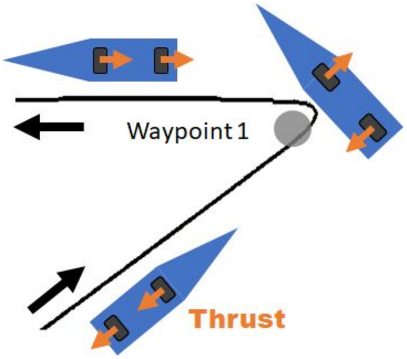

Figure 6: Representation of the thruster usage during the simulation of the primary navigation algorithm depicted in Appendix #.

4.3 Fine Maneuvering Algorithm

The Fine Maneuvering algorithm prioritizes precision navigation and utilizes the rear thruster for maintaining the orientation of the boat and utilizes the front thruster to traverse towards a waypoint, as depicted in Figure 7. This algorithm enables the "Phantom II" to move with precise control over its traversal and orientation by prioritizing orientation control above speed. This navigation algorithm is primarily employed during the Find the Path portion of the competition as well as interacting with the islands on the course.

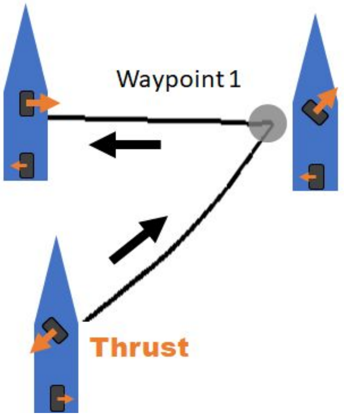

Figure 7: Representation of the thruster usage during the simulation of the fine maneuvering navigation algorithm depicted in Appendix #.

Simulated results confirm the expected differences in traversal speed and maneuvering accuracy. The Primary Algorithm is faster as it completes it waypoint simulation three times faster than the Fine Maneuvering Algorithm. The Fine Maneuvering Algorithm is more accurate as it has nearly zero waypoint overshoot as compared to the Primary Algorithm, most notably at waypoints 1 and 3, as depicted in Simulation of Primary and Fine Maneuvering Navigation Algorithm Appendices.

5.0 Conclusion

This year, our purpose is to deliver a new multi-year platform design that navigates with non-differential steering and test its capacity to meet competition requirements. All remaining critical design strategies were based on the requirements to complete this year's challenges. The "Phantom II" meets these requirements by incorporating inline azimuth thrusters, a trimaran hull-shape, and major modular hull components. The critical design choices increase maneuverability, increase deck size and stability, and enables future upgrades or changes to be implemented without needing to build a new platform, respectively.

6.0 Acknowledgements

The Embry-Riddle RoboBoat 2019 team would like to acknowledge all of our advisors and faculty, especially Dr. Eric J. Coyle, Dr. Christopher J. Hockley, Mr. Bill Russo, Dr. Charles Reinholtz, Dr. Patrick Currier, Timothy A. Zuercher, Marco Schoener, and David J Thompson, who were each able to contribute time, guidance, and support for the team. We look forward to making your proud this year and in the following years.

The team would like to acknowledge Angelo, President of Fiberglass Plus Inc. for graciously sponsoring our team and for his extraordinary fiberglassing services.

The team would like to acknowledge RelTek for sponsoring our team and working with us to get last minute materials.

7.0 References

[1] Final RoboBoat Tasks and Rules, AUVSI RoboBoat

[2] Datawave Marine Solution - Why You Want a Trimaran: Pros and Cons of Trimaran, https://www.youtube.com/watch?v=FjRSgUm03tk

[3] R. A. Royce, A. Mouravieff, and A. Zuzick, “Trimaran Resistance Artificial Neural Network,” *11th International Conference on Fast Sea Transport, Sep. 2011*.

[4] C. B. McKesson, *The practical design of advanced marine vehicles*. Lexington, KY: CreateSpace, 2014.

Appendix - Mission Strategy

Priority	Challenge	Justification
1	Autonomous Navigation	-Required
2	Speed Challenge	-Least number of unique requirements
3	Find the Path	-Unique requirements for this challenge apply to parts of both remaining challenges
4	Raise the Flag	-Embry Riddle Robotics Association has members with Quadcopter experience
5	Autonomous Docking	-Perceived as the hardest task and has requirements not shared with any other challenge

Appendix - Challenge Requirements

Challenge	Hull Qualities	System Capabilities
Minimum Requirements	● Basic Hull ○ Maintain Heading ● Basic Maneuverability ○ No minimum turn radius	● Basic Object Perception ○ Distance ○ Color ○ <2 objects simultaneously ● GPS Waypoint Navigation
Raise the Flag	● Large deck ● Stable with elevated CoM ● High maneuverability	● Quadcopter integration ● Visual symbol perception
Find the Path	● Small overall size ● High maneuverability	● Enhanced obstacle perception ● Enhanced path planning
Speed Challenge	● High top speed	
Autonomous Docking	● High maneuverability	● Underwater acoustic perception

Appendix - Simulation of Primary Navigation Algorithm

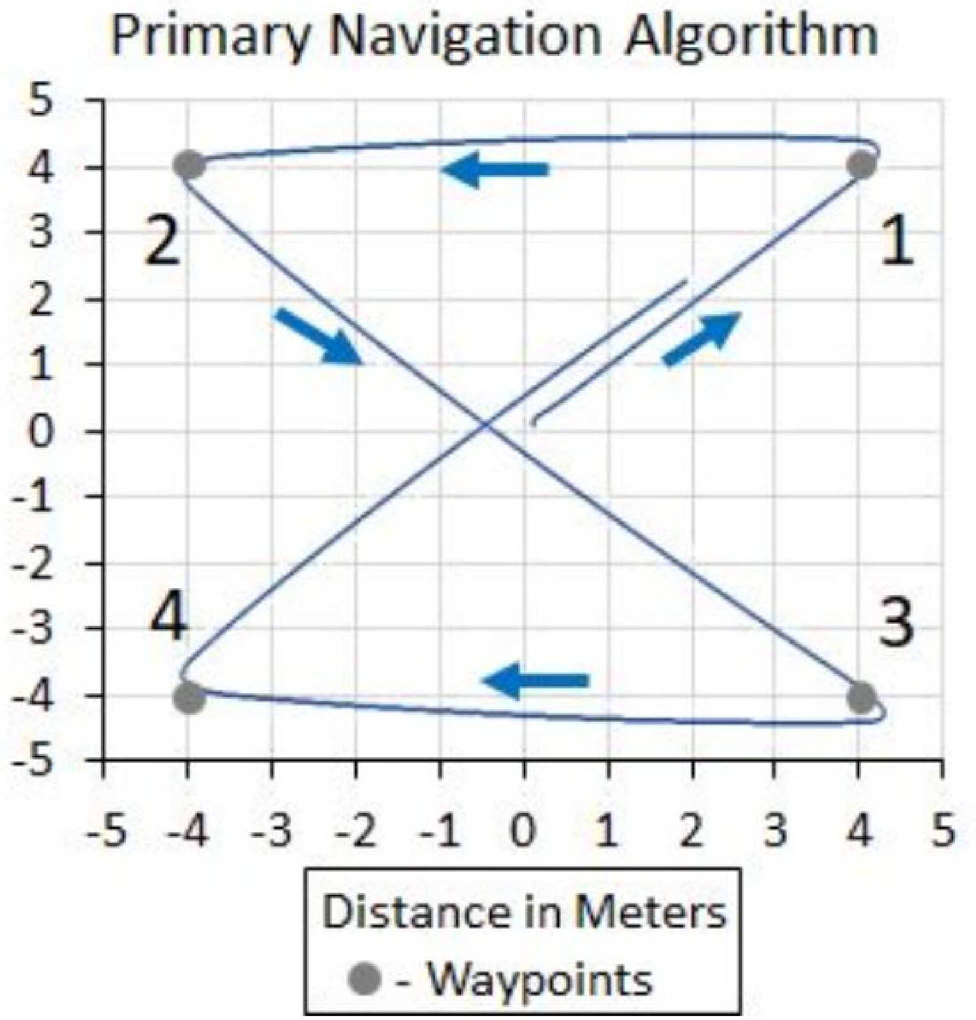

Figure #: Simulation of the traversal path of the [BOAT] following waypoints using the primary navigation algorithm.

Appendix - Simulation of Fine Maneuvering Algorithm

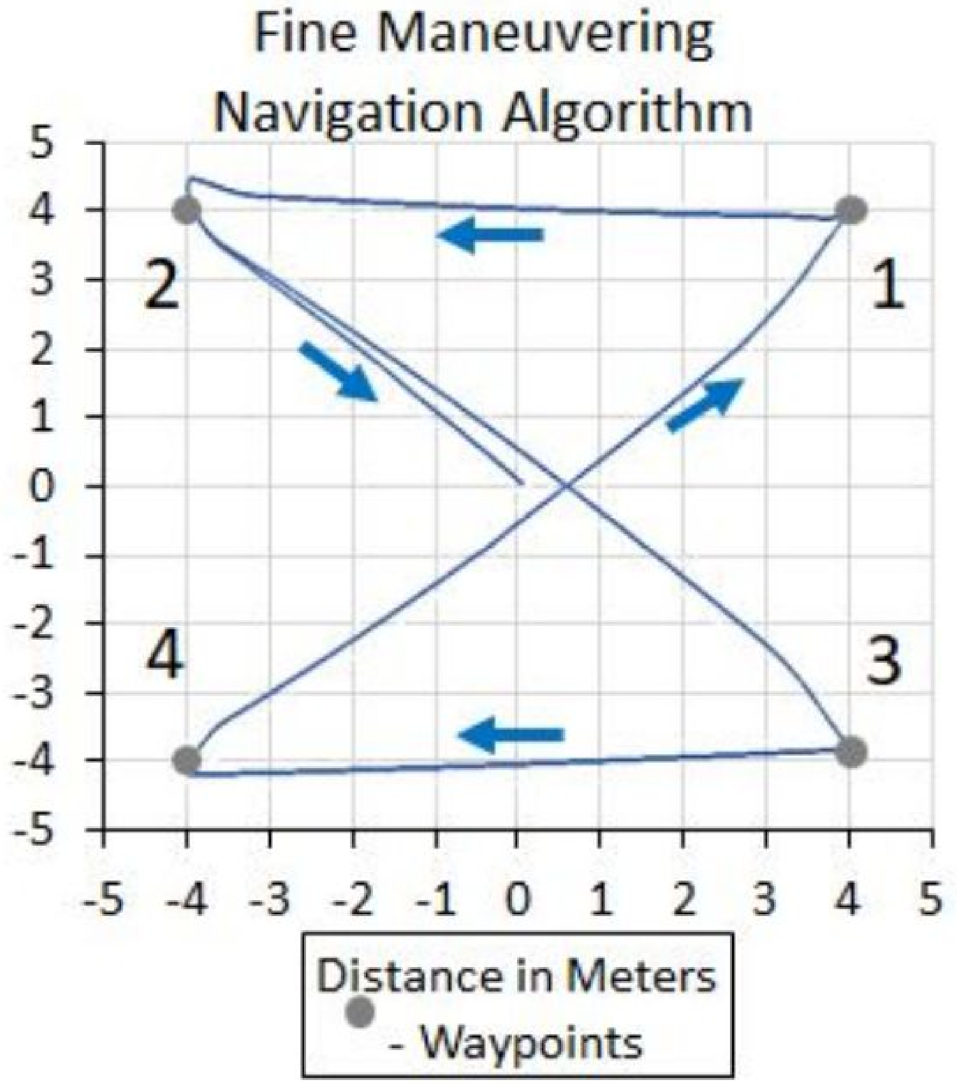

Figure #: Simulation of the traversal path of the [BOAT] following waypoints using the fine maneuvering navigation algorithm.

Appendix - Change Log

1st Design Iteration September 2018

- Trimaran
- 60x30x30”
- Axe Hull
- Central Hull 6 inch wide
- Amas 2 inch wide
- GPS LED LIDAR sensor stack center of boat
- Quadcopter flat deck aft
- 50 lbs weight estimate

2nd Design Iteration October 2018

- Dimensions changed to 50x22”
- Height change not calculated
- Amas 8.5” apart
- Central hull fineness ratio: 10
- Ama fineness ratio: 15
- Modular, flat hull
- Aft deck is 22x22” landing deck for quadcopter

3rd Design Iteration November 2018

- Central hull width changed from 5” to 8”
- Ama spacing decreased to 7”
- Amas 1.5” wide
- Overall dimensions remain the same
- Inline azimuthing thrusters

“Phantom I” Jan-Feb 2019

- Scaled down to 33x15”
- 22 lbs weight estimate

"Phantom II" Mar-Present

- Scaled up ~33%
- 3.5’ long
- 20x20” aft landing pad
- 7.17 fineness ratio
- External sponsor for gelcoating
- Rapid, machined construction
- Modular hull removed
    - Still flat bottom
- Front of boat rounded off
- Hard corners and edges rounded off