TEAM PHANTOM 2021

Embry-Riddle Aeronautical University

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Abstract— **Team Phantom of the Robotics Association at Embry-Riddle (RAER) has spent this competition season continuing to improve on the trimaran Phantom II platform that has been used for the last two years. Development has strongly focused on a complete overhaul of the electrical and software systems on the Autonomous Surface Vessel (ASV), with a new central computing system and all new software. Additionally, a great deal of effort was put into improving accommodations for the quadcopter UAV needed for the Object Delivery challenge. This involved major physical modifications to the aft deck and outer hull structures, as well as design for an object dropper to be mounted to the UAV. While COVID-19 restrictions did delay progress and testing, great progress was made, ensuring Phantom II will remain competitive for years to come.**

I. COMPETITION STRATEGY

Having performed suitably in the past two competition seasons, the Phantom II ASV design was left largely unchanged from the 2020 season. However, several significant redesigns were made to the system. The mechanical team worked towards optimising task completion surrounding the quadcopter UAV and in particular focused on recovery of the UAV. The control systems team chose to embark on a complete systems overhaul; the main programming language of the ASV was changed from NI Labview to python-based ROS, and the main computing unit was changed from an Intel NUC to a Jetson Xavier AGX. Consequently, nearly all of the code which had already been developed in LabView needed to be re-written in ROS.

It was hoped that this development strategy would increase the capability of the Phantom II platform overall, but retain many of the same strengths enjoyed by the ASV in the 2019 and 2020 competition seasons. Given the proven stability and seaworthiness of the platform, it was expected that once electrical and software overhauls were complete, the ASV would be able to retain the ability to complete many of the competition challenges that rely solely on navigation and obstacle avoidance. Specifically, the Navigation Channel, Speed Gate, Obstacle Channel, Obstacle Field, and Return to Dock challenges were expected to be the primary tasks which the ASV would aim to complete in a competition trial. These challenges were therefore almost exclusively seen as software and sensing challenges, as the ASV was already capable of meeting physical requirements of navigation on the water.

Considerable further effort was made to make the Phantom II platform compatible with the Object Delivery challenge. This seemed to be more easily attainable than the Acoustic Docking challenge, as the team had successfully implemented a UAV in the 2019 competition season, which could be used in a similar manner to deliver objects to the target area this season. Additionally, the team made attempts to make quadcopter operation from the aft deck of the ASV more flexible by adding provisions for the UAV to return to the deck of the ASV after its flight. It was hoped that recovery of the UAV by the ASV would prove unique to the Phantom II design, and distinguish it from other ASVs competing in the competition.

II. DESIGN CREATIVITY

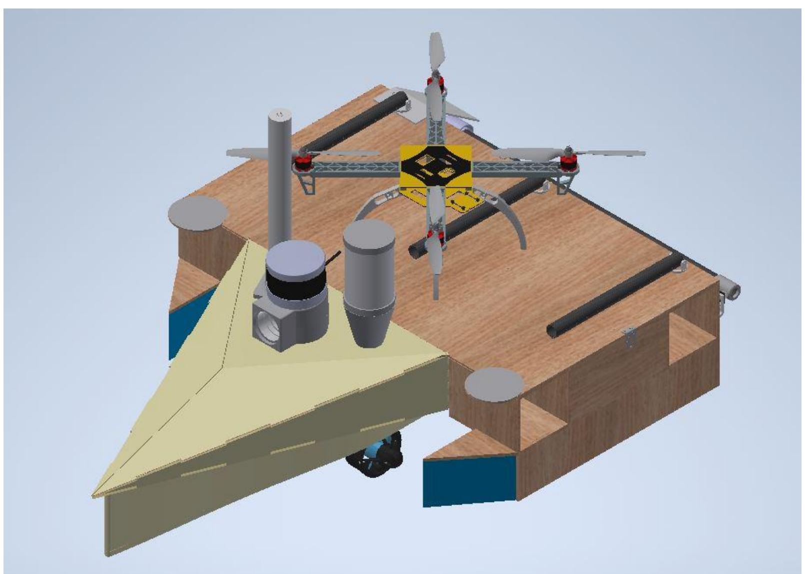

Figure 1 - CAD rendering of current configuration of the Phantom II

As last year's platform was retained for competition this year, a majority of the changes to the platform revolved around modifying and fine tuning the subsystems already on the ASV. These changes revolved around better integration of the quadcopter onto the ASV, as well as performing minor repairs and remaking parts that had deteriorated over time. Development of other subsystems to tackle more competition tasks was secondary to these changes, as the software and electrical revamps were to take the entire year to complete. In other words, it was expected that the control systems subteam would be so busy with its own work, adding entirely new subsystems (namely a hydrophone for the Acoustic Docking challenge) was given less attention.

A. Top Deck

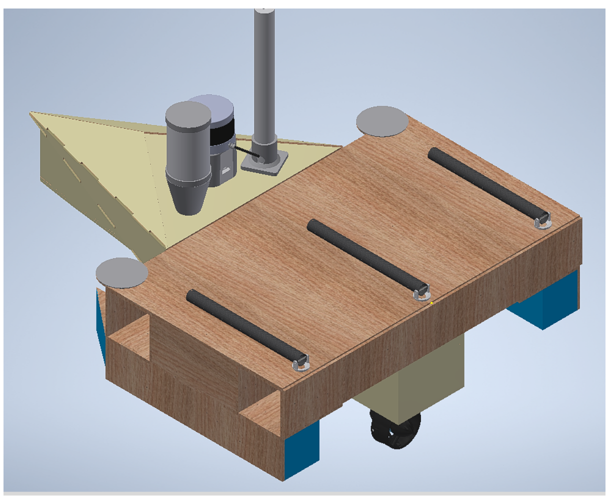

Figure 2 - Expanded Deck aft view

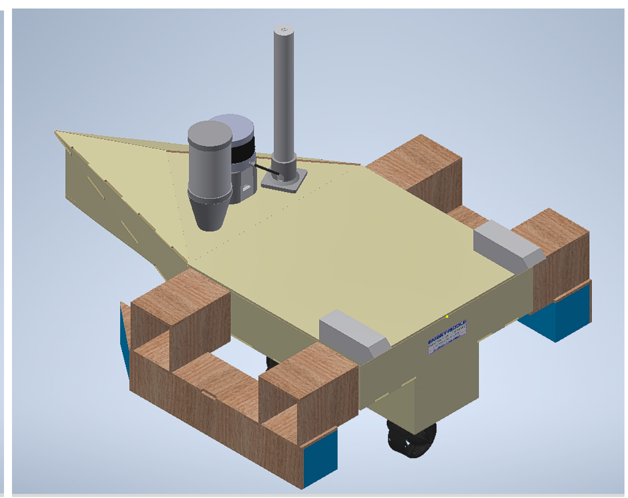

Figure 3 - Previous Top deck configuration

In order to better facilitate the quadcopter recovery, a redesign of the quad landing area was necessary. By working closely with Embry-Riddle's own National Science Foundation (NSF) Cyber Physical System Challenge team, integrating the quadcopter UAV with the ASV was much easier, as their expertise proved crucial in design and implementation of the quadcopter and recovery system. To reduce the chances of a failed landing resulting in the quadcopter falling off the boat (both during ASV maneuvering and UAV recovery), the width of the deck was increased, from 28 inches to 32 inches, which provides a larger area (see Figures 2&3). This width increase creates some overhang, which resulted in a rebuild of the outer hulls, or amas, to provide better support. The final design change on the plate itself was integration of the GPS mounts into the plate itself. Previously they had been mounted on the ASV using a C channel bracket. The new top deck has locations for the GPS mounts on the forward most corners of the deck to ensure accurate readings, more stable and durable mounting, and more aesthetically pleasing integration.

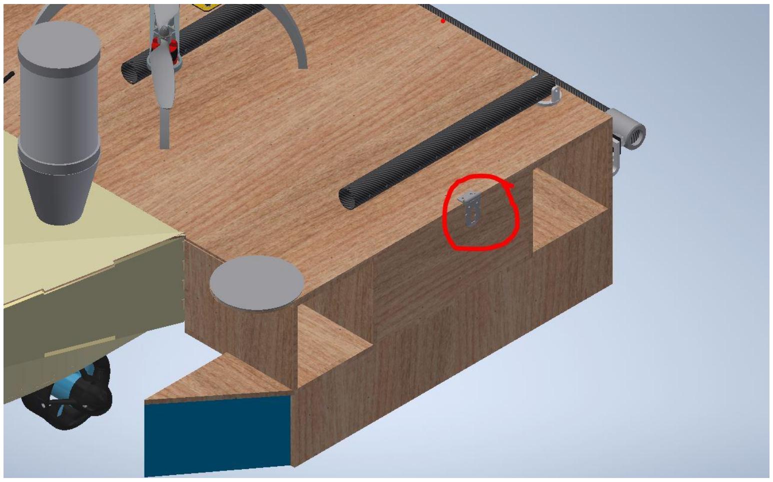

Figure 4 - Position of the port side hasp

In order to ensure a smooth landing, several smaller design changes were made in conjunction with the larger top deck. First, the method of securing the top plate to the hull was revised. Previously, four large eye bolts had fastened the top deck panel down to the hull. This also provided Phantom II with four hardpoints to which the harness could be attached, however, these eye bolts consequently protruded through the surface of the deck. Therefore, to secure the new top deck as well as replace the hardpoints provided by the eye bolts, three hasps were placed on the port, starboard, and rear edges of the deck (see Figure 4). This required the addition of wooden panels mounted to new amas so that the hasps could be fastened to the hull without drilling into the gel coat of the hull. Figure 2 shows the position of these wooden panels, located between the mounts on either side of the deck as well as a long panel flush with the stern of the ASV.

Finally, the rather large and square vents were redesigned to be a flatter design (see Figure 5). While they have a larger footprint on the deck, the reduced height decreases the likelihood that the UAV will be fall over if a leg lands on one of the vents.The new vents are half the height of the former design, and will connect to a duct under the deck that runs toward the forward section of the electrical bay, where the Jetson, voltage regulator (with its heat sink), and batteries are located. This was done to better ventilate this area of the electronics bay, which generates most of the heat produced by the ASV. The vents are baffled to keep water out, and each one contains a fan (one pushing air out, the other pushing air in) to facilitate airflow.

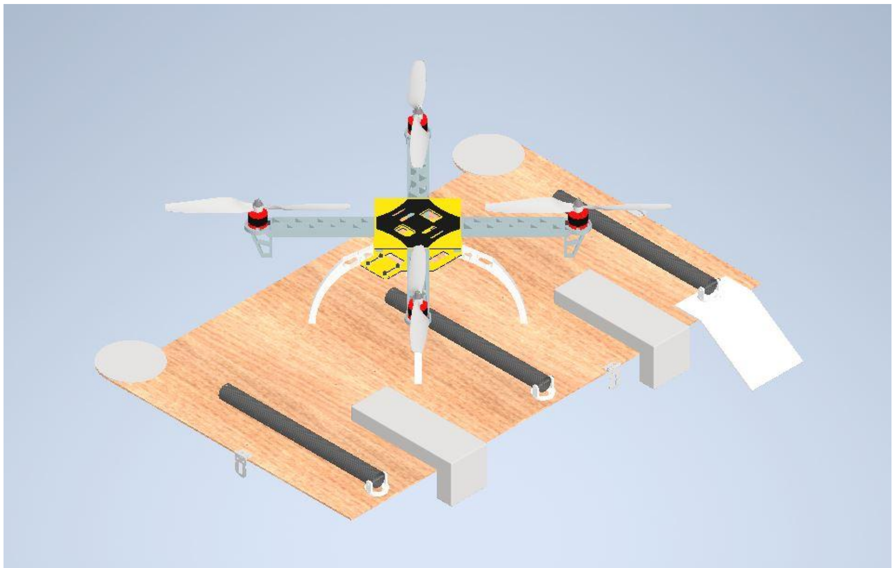

Figure 5 - New vent design

B. Ama Rebuild

As part of the widened deck included significant overhang from the central portion of the boat hull, the amas would support the overhang of the top deck to reduce flex in the top deck structure, especially under load if the quadcopter landed off center. As the quality of the coating on the amas developed from last year were fading, a new set of amas was made, with minor design changes focused on better supporting the top deck. This included widening the mounting supports and adding an extra plate along the edge of the amas to facilitate a mounting and locking mechanism to replace the eye bolts used previously. All of these design changes could not be done without rebuilding a new set of amas from the ground up, as the entire ama assembly is glued together.

C. Object Dropper

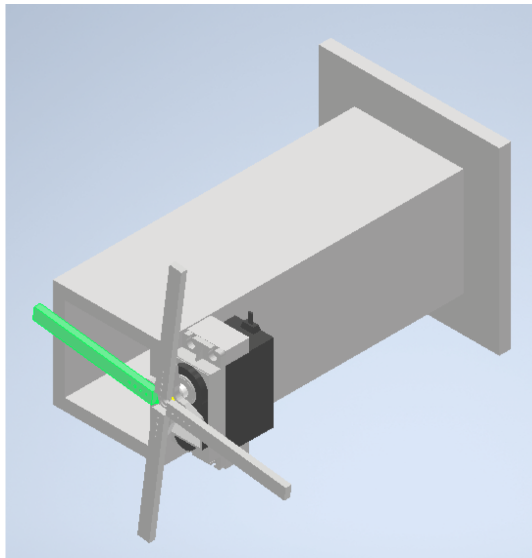

Figure 6 - Concept for the object dropper to be installed on the UAV

To make the Phantom II platform compatible with the Object Delivery challenge, an object dropper was developed for use on the quadcopter UAV. The dropper was designed and constructed to be as simple as possible. This would serve to minimize the payload weight the UAV would need to carry, as well as allow for adaptability of the system as the details of this challenge became more clear. Ultimately, the design selected was a 3D-printed module (see Figure 6). The dropper is to hold its payload objects in a rectangular tube, which will be suspended vertically from the bottom of the UAV. Attachment to the UAV was made with tie wraps, which wound through holes in the flange of the module and the frame of the UAV. A servo motor fitted to the bottom of the tube to retain the objects, which would be released by turning the servo arm once the quadcopter was over the drop area.

D. Software

Up until this semester, Team Phantom used a custom piece of in-house developed software, known as Minion Core. This software was originally developed for the 2014 Maritime RobotX Competition, when other pieces of software, such as ROS, were still in their infancy. As a result, for several years, all of Emrby-Riddle's RoboNation competition vehicles relied on Minion Core for autonomy. This however presented many issues, the main being the specificity of the software unique to ERAU, as well as the language it was written in: NI LabVIEW. Not only was the software unique, but the programming language was not included in any of the ERAU curriculum or coursework. This resulted in a low interest rate in software development of the vehicle, as well as development progress of a piece of software which was argubally limited in many ways. Finally, Minion Core is set to be abandoned by the Embry-Riddle RobotX team and replaced by ROS in the coming years. As a result of these challenges, Team Phantom made the decision to pivot from the Minion Core Framework to Robot Operating System, or ROS. This has many benefits, the main benefit being that existing modules and software has been written for the various sensors and modules of Phantom II by the support community, in addition to well documented solutions to problems and unexpected errors. This not only allows for quicker development cycles, but also permits knowledge learned for competition to easily be learned by new members. While the software development is still ongoing, significant progress has been made, and a fully functional vehicle will likely become viable in the next few months.

E. Electrical Redesign

Since last year, the core design of the electrical system has stayed consistent. However, the team has created a unified Printed Circuit Board or PCB, that allows for all of the core functionality of the vehicle to be integrated into a single unified source. This new system allows for vehicle simplification, as the previous electrical system was plagued with many stray voltage regulators, POE injectors, as well as boards and devices to control sensors and key systems. The new design unifies all power, data, and sensor systems where possible.

Further changes were made to the onboard computer systems. Previously, the Minion Core software suite required two independent computer systems. The first computer, an Intel NUC running a Windows operating system, was needed for core vehicle operations and communication purposes. Another a standalone Nvidia Jetson TX2, which allowed for object detection and recognition, was needed for obstacle avoidance and processing of imagery data. Because of the departure from Minion Core (and consequently Windows), further simplification of the vehicle became possible with the combination of the two systems into a single Nvidia AGX Xavier. This not only allows for future expansion of the vehicle and its systems, but also promises to keep the vehicle competitive for 2-3 additional years without any major notifications to the core operating functions.

III. EXPERIMENTAL RESULTS

Figure 7: Picture of the quadcopter, having landed directly over the IR beacon in a test.

As the aft deck was being constructed, a landing method for the drone was refined. Team Phantom coordinated with fellow students from Embry-Riddle's National Science Foundation (NSF) Cyber Physical System Challenge team, who use quadcopter drones of similar configuration in their own competition. Traditionally, this team has used an infrared-guided system to land its quadcopters autonomously on relatively large and stationary landing pads. The system used an infrared (IR) camera mounted to the quadcopter, which was able to detect and center over a beacon placed in the landing area. Once a landing sequence was initiated and the beacon was located by the IR camera, the quadcopter would be guided to the landing zone by the beacon. This process had proven quite successful in the NSF team's own competition, and it was hoped that this system could be used to land the quadcopter directly on the aft deck of Phantom II with minimal modification. However, its accuracy had not been proven or tested on Team Phantom's own airframe.

Experimental flights with the NSF team proved that the quadcopter was able to land with near perfect precision over the beacon (see figure 7). At the time of testing, the ASV was still under modification, and testing was conducted on land in an open field. However, the quadcopter setup intended for use with Phantom II was used for the first time.

In initial testing, autonomous landings over a stationary beacon were attempted. Out of three attempts, the quadcopter landed directly over the target twice, just inches from the beacon. Only the first attempt failed due to a calibration error with the controls. Next, a simulated moving landing zone was also tried, and the beacon was moved across the ground on a towel as the quadcopter attempted a landing. These landings were performed with similar success, though admittedly less precise than when the beacon remained stationary. Further testing will be needed to determine whether IR homing is practical over bodies of water, which may reflect IR radiation from sunlight or other natural sources, thus interfering with the IR camera's identification of the beacon.

IV. ACKNOWLEDGEMENTS

The Embry-Riddle RoboBoat 2020 team would like to acknowledge all of our advisors and faculty, in particular: Dr. Eric J. Coyle, Dr. Christopher J. Hockley, Mr. Bill Russo, Dr. Charles Reinholtz, Dr. Patrick Currier, and David J Thompson, who were each able to share endless amounts of time, guidance, knowledge, and support to our team. We would also like to acknowledge ThunderPower, which has provided the Robotics Association at Embry-Riddle with its LiPo batteries for many years. Finally, we would like to acknowledge and thank VectorNAV for their extraordinary donation of a new VN-300 for us to use.

V. REFERENCES

[1] Roboboat 2021 Rules and Tasks Description, Robonation RoboBoat

APPENDIX A:

Component	Vendor	Model/Type	Specs	Cost (If New)
ASV Hull	Developed	N/A	Sealed and laser-cut plywood	Inherited
Amas	Developed	N/A	Sealed and laser-cut plywood, insulation foam	
Fiberglass Exterior	Fiberglass Plus	Marine Gel Coat	http://www.fiberglassplusinc.com/gelcoats.html	Inherited
Waterproof Connectors	N/A	N/A	None, waterproof connections were hand made with silicone sealant	N/A
Propulsion	Blue Robotics	T200 Thruster	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster/	Inherited
Power systems	Thunder-Power	6S LiPO	5000mAh	Inherited
Motor controls	RC Electric	30A ESC	https://www.amazon.com/RC-Brushless-Electric-Controller-bullet/	Inherited
CPU	NVIDIA	Jetson Xavier AGX		$800
Teleoperation	FRSky	QX7	https://www.amazon.com/FrSky-Taranis-Channels-Transmitter-Controller/dp/B072559WH9	Inherited
LIDAR	Velodyne	Puck	https://velodynelidar.com/products/puck/	Inherited
IMU and GPS	VectorNav	VN-300 Dual Antenna GNSS/INS	https://www.vectornav.com/products/vn-300/specifications	Inherited
Camera	Point grey Research	Blackfly USB3 w/ 1920x1200 fixed focus lens	https://www.flir.com/products/blackfly-usb3?model=BFLY-U3-23S6C-C	Inherited
UAV Specification				
Aerial Vehicle Platform	Amazon	DJI Flame Wheel F450 ARF	4x E300 ESC (15A) 4x E300 Motor Integrated PCB Wiring	Inherited
Propellers	Amazon	O-XOXO Propellers	Self-tightening	Inherited
Camera	Amazon	GoPro Hero 7 Silver	4K30 Video Quality Stabilized Video 10 MP Waterproof	Inherited

Antenna	RobotShop	Here 2 GNSS for Pixhawk 2.1	https://www.robotshop.com/en/here-2-gnss-pixhawk-21.html	Inherited
LIDAR	lightware	LW20/B	https://lightwarelidar.com/collections/lidar-rangefinders/products/lw20-b-50-m	Inherited
Pixhawk	RobotShop	Pixhawk 2.1 Standard	https://www.robotshop.com/en/pixhawk-21-standard-set.html	Inherited
Landing Gear	Amazon	F450 F550 multicopter Landing Gear Kit	https://www.amazon.com/Xiangtat-multicopter-Anti-Vibration-Multicopter-Quadcopter/	Inherited
Raspberry Pi	Amazon	3 Model B Board	https://www.amazon.com/Raspberry-Pi-MS-004-00000024-Model-Board/dp/B01LPLPBS8?ref_=ast_bbp_dp	Inherited
IR-Cable	Ir-lock	IR-LOCK to Pixhawk2.1 Cable	https://irlock.com/collections/ir-markers/products/ir-lock-to-pixhawk2-1-cable	Inherited
IR-lock Sensor	Ir-lock	IR-LOCK Sensor	https://irlock.com/collections/ir-markers/products/ir-lock-sensor-precision-landing-kit	Inherited
IR Beacon	Ir-lock	MarkOne Beacon 3.0	https://irlock.com/collections/ir-markers/products/markone-beacon-v3-0-beta	Inherited
Power Management	Castle creations	CC BEC PRO SWITCHING REGULATOR	http://www.castlecreations.com/en/accessories-5/cc-bec-pro-010-0004-01	Inherited
Software				
Programming Languages	Robot Operating System (ROS), C++			
Vision	TensorFlow			
Inter-vehicle communication	Ubiquiti	Bullet M2	https://store.ui.com/collections/wireless/products/bullet2	Inherited
3D Modelling and Drafting	Autodesk Inventor			
Team Information				
Team Size	10 students, 4 faculty advisors			
Expertise Ratio	0.40			
Testing time: simulation	0			
Testing time: in-water	0			

Testing time: flight	2