RoboBoat 2020 Technical Design Report

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RoboBoat 2020 – Technical Design Report

"Argo II," "Nautilus," and "Hercules"

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Abstract—This is the University of West Florida (UWF) Marine Robotics team submission for the 2020 RoboBoat competition. Initially, our team used an existing boat to prepare for the competition. The team abandoned the old amphibious autonomous surface vehicle (ASV) after encountering several issues. The team developed autonomous ground vehicle (AGV) in a tank platform to perform much of its testing and development saving a significant amount of time due to its flexibility of testing navigation and localization algorithms. A new boat design was developed to allow for an aluminum deck with all the systems attached. The deck transfers easily between the ASV and the AGV. The Robot Operating System (ROS) was chosen to provide a framework for the software used for autonomous operation.

I. Introduction

This is the UWF Marine Robotics team's first year to compete in the RoboBoat competition. Initially, our team used an existing boat, the "Argo II", shown in Fig. 1 to prepare for the competition. After encountering some issues with this platform, the boat's equipment was mounted on a wagon to accommodate testing and development strategies to prepare for the competition's challenges while a solution for the boat design was explored.

Fig. 1: "Argo II" in the UWF pool.

Graduating from the wagon, the team found a tank that was not being utilized. After some repairs, the tank was used to not only continue the project, but the systems on the tank were engineered to a point where it became the team's temporary autonomous test platform as an AGV. The AGV saved a significant amount of time because of its flexibility of testing navigation and localization algorithms. The land-based platform was so instrumental in our progress that a new boat design, "Nautilus," was developed to allow for an aluminum deck with all the equipment required for autonomous operation affixed. The deck could be transferred easily between the new ASV and the AGV providing the best of both platforms for testing and development.

II. Design Creativity

The goal of this project is to design, build, and program an ASV. More specifically, a robotic boat designed to compete in the RoboBoat competition, and the seven challenges included therein. Over the past two years, the team has researched both equipment and software requirements that would best achieve the goal of autonomous operation.

Fig. 2: Equipment testing using wagon platform.

A. Platform Design Approach

As the project developed, it was clear that the "Argo II" had issues with design and construction. The pontoons were not level and the motors mounts failed leading to leaks in the hull. The boat was designed around different equipment set creating challenges with mounting the new equipment set. These issues were all solvable; however, to continue the testing and development of strategies, the team turned to a wagon to mount the equipment as shown in Fig. 2 while solutions to repair and redesign the "Argo II" were developed.

The project quickly outgrew the wagon platform because it lacked a drive system. This limited the team's ability to move to testing and development of autonomous operations. A surplus heavy-duty tank by Super Droid Robots, "Hercules" (Fig. 3), was introduced to serve as a land-based platform or AGV. Because "Hercules" and "Argo II" both use a dual motor system, their drive systems behave in a similar manner. The tank uses a motor controller and brushed motors and the "Argo II" uses electronic speed controllers (ESC) and brushless motors; however upstream of these differences was identical.

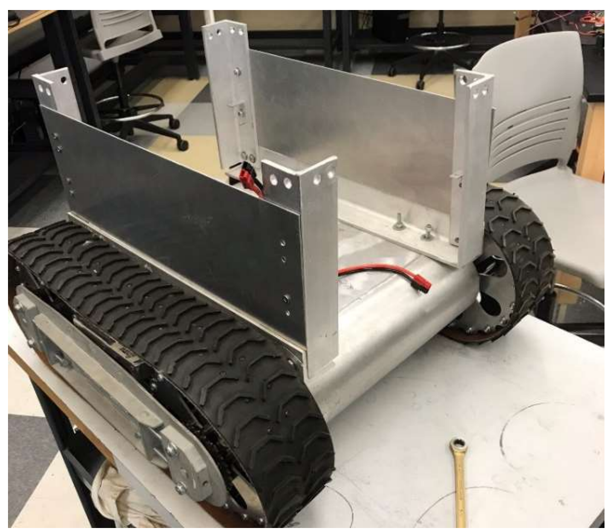

Fig. 3: "Hercules" initial configuration.

"Hercules" has saved the team valuable time in testing and development because of the shortened time it takes for deployment. The AGV can be set up and deployed within 15 minutes where the ASV takes well over an hour before any testing progress could start. The UWF pool staff were very supportive of our project, but there were limited times due to other university activities that utilize the pool.

Another benefit is the ability to safely watch at close range the behavior of the tank as it performs a task. Over the past semester, the systems used for "Hercules" were engineered to a point where it has now become a very mature test platform (Fig. 4).

The "Hercules" has also brought attention to our project. Although this was an unintended result, it is beneficial, nonetheless. The tank will continue to serve as a public relations tools for our project.

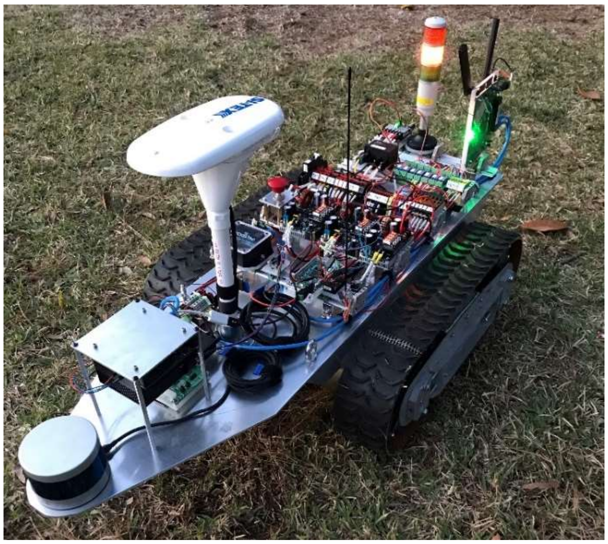

Fig. 4: "Hercules" near UWF Hal Marcus Building.

Even before the team finished building "Hercules," the discussion of how to transfer the systems to "Argo II" had begun. Unfortunately, the deck on "Hercules" would not fit in the existing ASV. At first there were only two options. Dismantle "Hercules" and install the components in "Argo II" or duplicate the bulk of the design on "Argo II" and move the major systems such as the computer, laser imaging, detection, and ranging (LiDAR), Global Positioning System (GPS), Compass, inertial measurement unit (IMU), and cameras between "Hercules" and "Argo II". The latter was the path chosen prior to the cancellation of the in-person portion of RoboBoat because the team did not want to lose their ability to use a land-based platform for test and development. Once it was clear the "Argo II" was not going to compete, the team contemplated a replacement vehicle.

A find of some used 8" pontoons resulted in the pursuit of a new ASV, "Nautilus." Fig. 5 shows a rudimentary view of the pontoons and the frame that will support an aluminum deck. According to Patrick J. Bray, Naval Architect in his discussion on stability, the greater the beam or width of the hull, the greater the boat's stability [1]. The maximum initial stability is achieved by separating the two pontoon as much as possible. In our case, the "Nautilus" beam will be 36 inches. Bray also stated that placing the weight as low as possible increases stability and have the heaviest weight towards the center of the boat will help with maneuverability. Therefore, the heaviest items such as the power system to include the batteries will be place in a centric location.

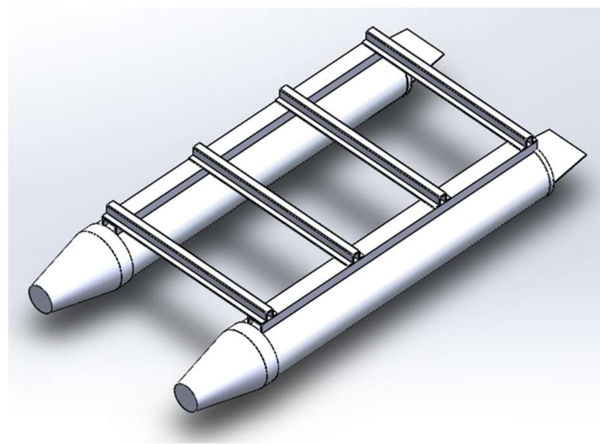

Fig. 5: "Nautilus" framework design.

The length of hull that is physically touching the water will be increased from the three feet for "Argo II" to four feet for "Nautilus" to further improve stability. That design decision may cause the ASV to exceed 70 pounds, however, stability is more important than the points we will lose due to weight. Fins at the rear of the outside pontoons where the motors are mounted will also increase stability while providing a level of protection for the motors. The wires for the motors will no longer penetrate at a location where it could result in hull leaks

On top of the "Nautilus" framework shown in Fig. 5 will be a sheet of aluminum about three by four feet. The deck will have the rear three feet covered by a five-inch-high housing constructed of 1/8-inch-thick aluminum separated into compartments for power, communication, and control. This housing will be configured to provide a level of shielding. The mounting system used to mount the components will be *Deutsches Institut für Normung* (DIN) rails. This was employed on the tank and made management of power and installing/movement of the other components much easier. All components are protected by breakers or fuses. A close-up of the power management system on the "Hercules" is shown in Fig 6.

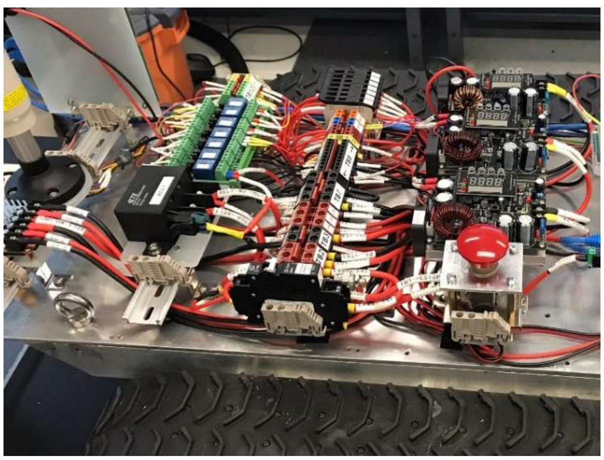

Fig. 6: "Hercules" power management system.

There was a time and economic cost involved with converting to DIN rails, but the savings came when team was not chasing issues with power and logic during the test and development phase. This has allowed the team to focus on solving the issue of autonomous operation rather than trying to determine why the ASV or AGV is not working.

The new deck will also have a flyover made from tubular aluminum towards the bow of the boat that will support the GPS and cameras. The LiDAR will be mounted on a portion of the deck that will protrude forward from the front of the deck to maximize its visibility. The team was in the midst of testing to determine the best LiDAR location when the university activities were suspended so completion of those tests will finalize its ultimate location.

A creative plan to install the camera system has been developed. It involves the creation of a flyover bridge fashion from aluminum tubing hold and acrylic case housing the cameras with the Jetson AGX Xavier computer mounted to the deck just underneath. The issue is the 30cm long cables that attach to the bottom of the Xavier. The Xavier is able to receive an enormous amount of data from the cameras, but the tradeoff is shortened cables. By mounting the Xavier upside down, the cameras can hover just above the bottom of the Xavier. A sealed flexible tube between the Xavier and the camera case will protect both components from moisture.

The "Hercules" will be refitted with cross members similar to the "Nautilus" so the newly constructed deck with all the systems attached can be easily moved between both platforms. Thus, one complete set of systems will support the platform that best supports our testing requirements

B. Software Design Approach

According to ROS.org, "…creating truly robust, general-purpose robot software is *hard*. From the robot's perspective, problems that seem trivial to humans often vary wildly between instances of tasks and environments. Dealing with these variations is so hard that no single individual, laboratory, or institution can hope to do it on their own. As a result, ROS was built from the ground up to encourage *collaborative* robotics software development [2]." ROS was chosen to provide a framework for the software used for autonomous operation. This gives the team flexibility to use software from various computer languages available as open source. ROS also provides the flexibility to unify

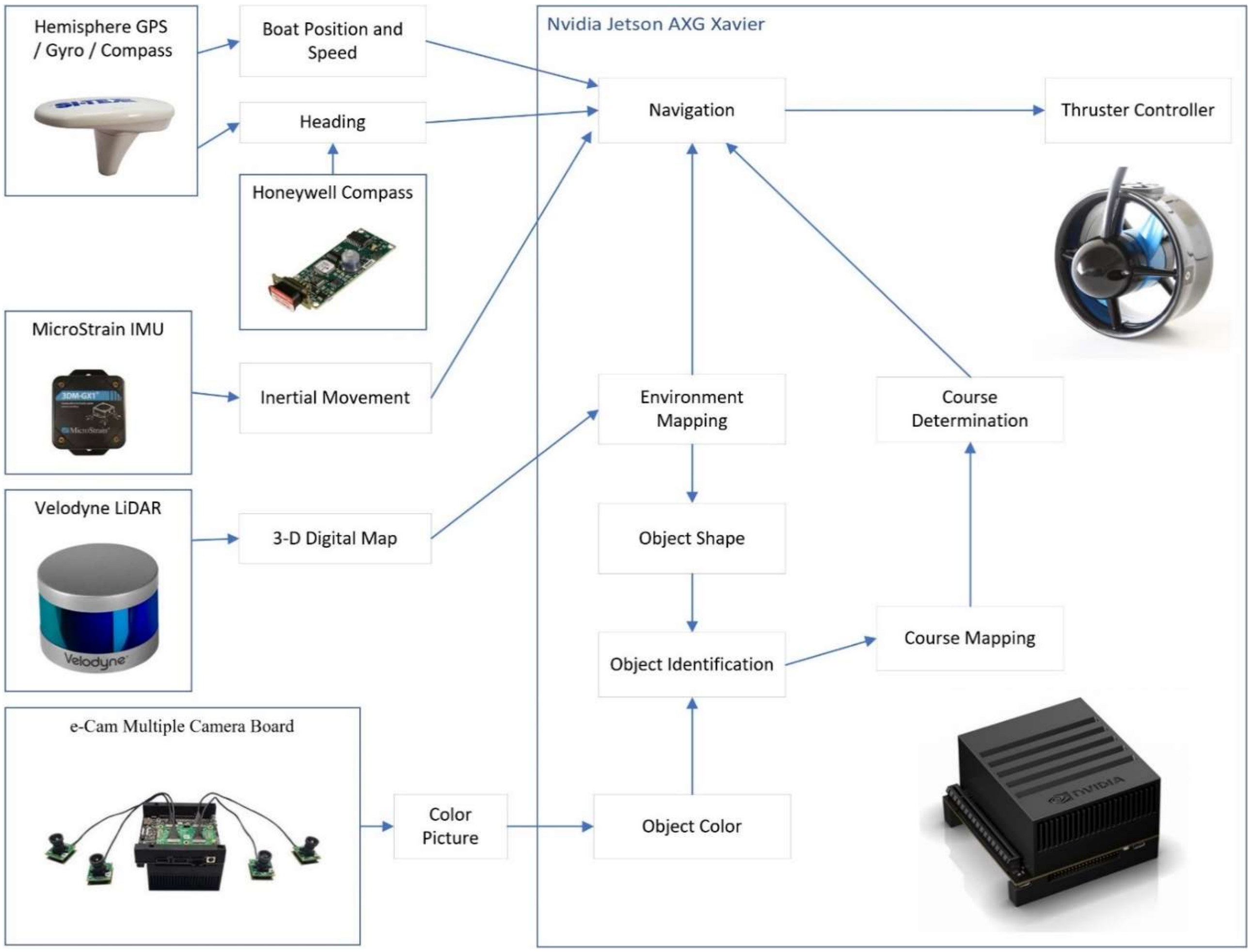

Fig. 7. Platform systems

equipment communications under one standard, as well as provides the means to simplify many of the more generic challenges that robotics software often faces. These challenges include timing issues, information containers, and compartmentalizing functionality. This, in combination with access to many interesting and unique open-source tools makes ROS the backbone of the software design approach for both the Hercules tank and Argo boat.

A certain degree of abstraction was focused alongside ROS to ensure that code that was developed for the tank would also run on the boat. This was made easier by the fact that sensors and components would remain mostly the same, so that the core, major differences between the two platforms could be designed inside of the same abstract bed as one another. It was very important for the project that designs on the tank be ported to the boat with minimal or no effort, so that the Hercules could remain a viable, justifiable test platform for rapid testing and prototyping of software.

C. Systems Design Approach

A systems approach was used to develop our vehicle to a point where it could accomplish tasks that will lead to completing the competition challenges. The team incorporated one component at a time and focused on retrieving the data it would provide into the overall platform operation. Eventually, there were several systems publishing information to ROS that allows the vehicle to map and navigate its environment as shown in Fig. 7. The order of components is not critically important. Important is becoming very familiar with configuring a component and understanding what data it can transmit and how that data can contribute to the current task. Based on this assessment, the level that ROS listens to the data can be set. As testing continues, the level of contribution for each component will change with each challenge.

D. Design Complexity

The complexity of a system component contributes to issues even when it is superior to other like components. A great example of this was our team choosing to use the STM32F407 high performance microcontroller to collect data from the GPS and supply it to the Nvidia Jetson AGX Xavier computer. The STM32F407 microcontroller would also be used to control the motors. The reason for this decision is the Xavier only has two serial ports on its 40-pin header. There were just more components than there were serial ports. In addition, there was a believe that the STM32F407 would allow the Xavier to focus on more important tasks such as collection of pattern recognition data.

One could say that the STM32F407 was like an Arduino microcontroller on steroids. This is a fair assessment, but with the power comes complexity, so much complexity. The team found itself writing drivers to process the serial connection to the GPS because the drivers did not exist. Over two semesters, we made progress and learned more about microcontrollers than we ever bargained for. Valuable information, but at the end those two semesters, the progress on the goal of creating an autonomous vehicle had come to a halt as the team focused all its time on the STM32F407 microcontroller. Fortunately, our mentors and department head convinced us to reassess the need for this component. The original problem was the Xavier only had two serial port connections. The solution that was missed; the Xavier has a PCIe slot that could be used to add multiple serial ports using a serial port card. As well, it turns out the Xavier is more than powerful enough to process the GPS, LiDAR, Compass, IMU, and Camera data and not miss a beat.

The serial port is a very old technology, the PCIe serial port card is also an old technology. The team was wasting valuable time solving a problem that has been solved. Once the team let the STM32F407 microcontroller go, our progress exploded. At each step, we now take a harder look at whether we are headed in the right direction. Especially when we hit a bump in the road. Better to fail fast and pick a new direction.

Sometimes complexity brings benefits that outweigh the complexity introduced into the system, but an honest evaluation needs to be performed. The team also needs to be willing to change directions; sometime this is difficult when significant resources have already been expended. However, a failure to redirect could lead to a failure to achieve the end goal.

Another lesson learned when considering a component. It is critical to check for available drivers, Robot Operating System (ROS) nodes, documentation, and supporting software. Building drivers or ROS nodes from scratch brings complexity to the project even when it appears to be a simple component.

III. Competition Strategy

Our approach to prepare for each of the seven competition challenges is very much like our approach to designing our vehicle. Start with one challenge and teach the vehicle to accomplish that task and then move on the next challenge while attempting to minimize complexity.

A. Complexity vs Reliability

If the vehicle's design is too complex, then this complexity will be inherited into the development of a strategy to complete a challenge. Data can be your friend, but your system can be overwhelmed with data when complexity results in too much data or conflicting data.

Since, we are using the Nvidia AGX Jetson Xavier computer, there is a temptation to use any and all available data since the Xavier is quite capable processing just about anything. However, this brings a complexity to the solution that can easily confuse ROS to point where it overthinks the problem leading to task failure. As complexity increases, so increases the statistical risk of failure. Even if the platform can achieve success, the complexity may prevent repeated success. Determining the simplest approach to the challenge is the only way to reduce statistical risk and increase the confidence of success.

Testing is critical to determining what data is needed and which is not. The algorithms utilized are also very important and can only be realized through testing and more testing.

As the approach for each challenge is developed, an assessment of what components were needed to complete the task was made in an attempt to find the sweet spot. Sometimes the solution is adding data, but sometimes is deciding not to listen as closely to some data. Finding the right balance of data from the components is key to reaching a solution to the task that can be duplicated.

B. Challenge Strategy

The approach for each challenge is different because the data needed is different and the use of that data is different.

The components required to complete the challenges include the GPS, LiDAR, compass, IMU, and cameras. The GPS is required to reach the start position to determine the ASV's speed and projected path based on the compass heading obtained using its dual GPS configuration. The LiDAR will be used to identify the buoy locations while the cameras will supply the color of the buoys to verify the proper orientation of the boat. The compass will also be used to maintain heading. Our compass is better at heading than the GPS so it will have a higher weight in the algorithm. The IMU will be used to account for unexpected drift. For maneuvering objects closer than three feet within the LiDAR dead zone, the IMU and compass become critical in ensuring the proper clearing of the obstacle. Data from these sensors will be published to ROS. ROS will use the inputs to calculate a path to complete the challenge. The correct balance of these components was still being tested when the university suspended operations.

1) *Mandatory Navigation and Obstacle Channel:* The mandatory navigation channel and the obstacle channel challenges will use the same algorithm to navigate between the red and green buoys. The strategy is for the LiDAR to identify the buoys. The camera will identify the color of the buoys based on the locations provided by the LiDAR data. A little math will provide a path for using the navigation data in ROS.

2) *Obstacle Field:* The Obstacle field challenge will start by circling with the field on the left of the boat while treating any balls less than four feet apart as a wall and entering the first opening greater than four feet. Once inside, the boat circle the center buoy while treating the balls on its right as a wall. Once the vehicle has circled the center buoy for more than 180 degrees it will begin to search for an opening greater than four feet on its right to exit the field.

3) *Acoustic Docking:* The acoustic docking challenge will use the hydrophone to determine the gate to approach. The camera will need to use open CV software to accomplish pattern recognition to locate the dock by determining the edge of the shapes in the data.

4) *Object Delivery:* The object delivery challenge will require a mechanical arm that will sling a foam ball supplied by a tube that has an actuator inside that pushed the next ball forward as the arm mechanism comes around. The components on the boat will be utilized to keep the boat in a zone predetermined to give the arm the best chance at hitting the center target.

5) *Speed Gate:* The setup for the speed gate is static so its algorithm can be simplified over the algorithm being used for the obstacle field challenge.

6) *Return to Dock:* This task is best accomplished by treating each challenge area as an obstacle and finding a path back to the GPS coordinate for the dock.

IV. Experimental Results

The team has committed much time to testing both hardware and software in the pursuit of achieving the goal of autonomous operation and the ability to complete the RoboBoat competition challenges.

A. Gazebo Autonomous Vehicle Simulation

A working simulation was created within Gazebo, a virtual robotic simulation software package that integrates well with ROS. Gazebo is limited in its ability to simulate non-traditionally wheeled robots such as the Hercules tank, but was a help in developing several key components of the overall ROS structure of the project. The Gazebo software can provide a physically accurate world and set of data necessary for various localization and navigation-based ROS packages as well.

B. ROS

The team's ability to expand ROS lies with theconstructsim.org website, which offers several of their courses for free [3]. Use of this training helped our team get our platform to a point where testing could take place.

All communication between components was unified and abstracted within a singular Robotic Operating System (ROS) executable operating on the Nvidia Xavier computer. The ROS navigation suite was implemented to provide a higher-level interface between sensor information, control algorithms, and locomotion drivers. Features such as obstacle avoidance, point to point navigation, and 3D mapping are being tested. Successful autonomous tests of the AGV has been accomplished albeit rudimentary implementation with issues that need to be addressed such as obtaining a far better IMU, as the project's GPS is only a superb inertial navigation system while moving. The tanks GPS component utilizes two GPS antennas to determine direction and movement**.** This allows for very accurate heading and velocity information to be inferred and compensates for the IMU's inability to provide a steady, accurate reading. However, when stationary, the Hercules tank suffers from serious noise and drift, primarily from the IMU. It is hopeful once this issue is solved, major progress will be made in the capabilities of the 'hands-off' autonomous mode of the Hercules tank.

B. GPS

The Hemisphere V104 Compact GPS has tested very well. It is a versatile GPS that has tested well as a GPS. Initially, this GPS was also going to serve exclusively as our compass. Because of its dual GPS configuration, it can provide the vehicle's heading. During testing this has been very effective when the platform is in motion; however, at a standstill, it is not able to consistently identify the vehicle's heading. As a result, a compass was added to our array of components.

C. Compass

The team found a Honeywell HMR3000 digital compass in the lab that belonged to a previous marine robotics team. A test of the compass showed it was operational. The compass is accurate and appears to be fast enough to solve the robot's compass needs. This compass will be incorporated into the ROS sensor data collection nodes to assist with navigation. Testing will show how to best use its data. Preliminary results show it is far better than the GPS at accurately providing the heading when the boat is static.

D. IMU

"Hercules" has been using a SparkFun 9DoF Razor IMU with mixed results. It is possible that there is interference from the other equipment that is contributing to this problem. Another possibility is the SparkFun IMU is not a good fit for this project. Just prior to the campus shutting down, the team found a MicroStrain 3DM-GX1 IMU. This unit has been readied for testing. The team is hopeful this IMU will have a better outcome.

E. Cameras

Once the cameras have been installed on our platforms, it will bring many changes to the algorithms used to complete the challenges. OpenCV boasts that their," …library has more than 2500 optimized algorithms, which includes a comprehensive set of both classic and state-of-the-art computer vision and machine learning algorithms. These algorithms can be used to detect and recognize faces, identify objects [4]." Via Open Computer Vision Library (OpenCV), we will train the vehicle to tell the difference between colors and shapes we anticipate. Particularly, training will need to take place for the acoustic docking challenge so the vehicle can distinguish the difference between a circle, cruciform, and a triangle. In other challenges, the camera system will be used to identify the color of the object the LiDAR is seeing to give confidence to the objects identity.

F. Hydrophone

The team has yet to test the Teledyne hydrophone. A search for opensource software has not met with success. The current plan is to attempt to either develop something internally or approach Teledyne about an academic grant or discount.

V. Conclusion

Over the past two years, the UWF team has made great strides toward creating a marine robotics program capable of competing in the RoboBoat competition. Our current plan of using both an ASV and AGV to assist with testing and development will result in success. More important has been that in the process, the students on this team continue to advance themselves towards becoming productive engineers because of the challenges placed before them.

Acknowledgements

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Appendix A—Component Specifications

Component	Vendor	Model/Type	Specs	Cost (if new)
ASV Hull form/platform	Self developed	N/A	3'x5' dual pontoon	Unknown
Waterproof connectors	Huayi-Fada Technologies	Varies with number of pins	IP68	Varies
Propulsion	Blue Robotics	T-200	https://tinyurl.com/t3cp9ma	2 x $200
Power system	Turnigy	4S 12C LiPo	4S1P, 14.8V, 10Ah	4 x $90
Motor Controller	Holybro	PikHawk 4	https://tinyurl.com/y9fh9y85	$200
Motor Controller	Blue Robotics	BESC30-R3	https://tinyurl.com/y26s9nzf	2 x $25
CPU	Nvidia	AGX Jetson Xavier	https://tinyurl.com/y92dbm8v	$700
Teleoperation	Linksys	EA6350 Dual-Band	https://tinyurl.com/y8s7cugr	$40
Compass	Honeywell	HMR3000	https://tinyurl.com/y7rhvvno	Unknown
Inertial Measurement Unit (IMU)	MicroStrain	3DM-GX1	https://tinyurl.com/yb26omhe	Unknown
Doppler Velocity Logger (DVL)	N/A	N/A	N/A	N/A
Cameras	e-con Systems	e-CAM130 _CUXVR	https://tinyurl.com/yb3dn9do	$700
LiDAR	Velodyne	VLP-16	https://tinyurl.com/y7vuot8v	$2,000
GPS	Hemisphere	V-104	https://tinyurl.com/y9ugsfak	$1,408
Hydrophones	Teledyne	Reson TC 4013	https://tinyurl.com/y9ltcgho	Unknown
Algorithms	ROS with local modifications			
Vision	OpenCV with local modification			
Acoustics	Will be internally developed			
Localization and mapping	ROS with local modifications			
Autonomy	Internally developed			
Team Size	5			
Expertise Ratio (hardware vs. software)	2:3			
Testing time: simulation	>60 hours			
Testing time: in-water	>2 hours			
Testing time: land	>20 hours			
Programming Languages	Python and C++			

Appendix B—Outreach Activities

The UWF Marine Robotics Team is committed to sharing our experience with the community. For example, we were provided the opportunity to share our project with state businessman and Florida congressional member during what is call "Capitol Day." The team was provided an area in the Florida capitol rotunda to display the "Argo II" (Fig. 8). Posters and video were also used to communicate the project goal to our audience.

The team has also presented the project to local engineers from local military bases.

The AGV gives the team an opportunity to demonstrate the project in environments without bodies of water such as local schools. Once it is safe to do so, the team looks forward to pursuing this option.

Fig. 8: "Nautilus" framework design.