Autonomous Maritime Robotics Association: Team Unsinkable

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***Abstract* - Team Unsinkable representing Embry-Riddle Aeronautical University is using a custom-designed Autonomous Underwater Vehicle (AUV): Nautilus. Nautilus has tightly integrated mechanical, electrical, and software foundational systems, upon which sensory and manipulation modules can be added. Nautilus uses a camera with object detection software. All systems are powered through a custom power distribution module, with an intuitively designed emergency stop. These all allow the mechanical systems of the AUV to actuate and complete the assigned objectives through thrusters and manipulators. The design process and justification for certain design aspects are to be discussed within this paper.**

I. Competition Strategy

The strategy employed this season was to approach each task one at a time, in order of difficulty. The goal was to achieve complete reliability in the gate and buoy tasks first. Doing so would create a foundation that could easily be built upon in the future for more complex tasks. After the gate and buoy tasks, it is necessary to implement an arm to complete the next task. While the software team is troubleshooting gate and buoy tasks in the pool, the mechanical and electrical team can focus on the design of an arm and a dropper. Having different sub-teams work on different tasks ensured efficient use of time and allowed for testing to happen consistently while the next task element can be designed without any team falling behind. To ensure each sub-team is advancing and not falling behind, the executive board of the club implemented Agile Scrum through the program Trello. Trello allowed the team to see all of the goals for the season, the order of importance of each goal, and what is being worked on at any time. Scrum was implemented through Trello by setting up tasks that need to be completed in a two-week run. The team would meet once a week for a general meeting where an executive board member would go to each sub-team to either find out what is holding any member back from completing their goals or to check on overall progress. The first week of a run would start by moving completed goals into the archive and assigning new tasks to each member. The beginning of the second week would start by checking on progress and finding solutions to help members that are stuck on a task to be able to complete it in the time given. If a task can't be completed in two weeks, it can be extended into the next run.

The primary method used for autonomy was computer vision. Computer vision is what the team is the most familiar with and has the most resources for. While vision was a large focus, the team had discussed using more complex systems such as sonar and Doppler Velocity Loggers (DVLs) in the future. These systems were planned to be on board the AUV even while not operative to transition smoothly to using them in future years. It was planned to have the systems collecting data that could be used to develop them into the platform when the time comes. With a new and complex custom design, there was an issue raised regarding the reliability of the platform. Many precautions had to be taken and critical systems had to be planned meticulously in order to avoid failure. The team utilized faculty and graduate advisors to assist in all stages of development. Their advice guided the team during the design process and helped avoid possible issues in the design of the new platform. Many backup plans were created if one or more of the systems on board had failed. This included but is not limited to considerations of failure in power distribution, leaks, sensor failure, and software

II. **Design Creativity**

A. Software

1) Computer Vision Navigation Algorithm: Our AUV, Nautilus, implements a monocular image capture sensor, oriented toward the zero degree relative bearing. Using OpenCV, the multi-denominational visual data array communicates over Universal Serial Bus (USB) to the, Nvidia Jetson TX2, an embedded AI computing module. The raw visual data is then hastily published to the zero degree visual data ROS Topic, while simultaneously the data is made available for the embedded AI computing module. Nautilus uses a pre-trained Object Detection model available from the TensorFlow 1 Model Zoo. The top layer of neurons within the Deep Neural Network (DNN) was then tuned to specifically detect and bound specific images from a data set of nearly 1,000 images. The algorithm outputs the X, and Y coordinates of the object it detects within its field of view (FOV). The AUV has a constant FOV of 78°. This FOV is subdivided into seven defined areas of concentration. Three vertical segments and two horizontal segments make six areas that are defined as “out of bounds” and have relative bearings ranging from -36° (324°) to + 36°. The final segment is a small defined section in the middle of the AUV's field of view, this corresponds to the “dead ahead” relative bearing, ranging from -2.5° to +2.5° on the relative bearing. The algorithm uses the X, and Y coordinates of the object of interest with FOV and takes corrective action to bring the object of interest in line with the zero bearing.

2) Benefits of this Navigation Style: Using visual navigation on the AUV was a necessity. The lack of funding to secure more advanced sensors including a Doppler Velocity Logger (DVL) or a Sonar Imaging Array meant that the use of readily available monocular cameras was optimal for navigation and necessary for the tasks that required discernment between objects in physical space. The buoy and gate tasks are solely based on the effective localization of images and navigation to those images. Using the Computer Vision Navigation Algorithm, we could successfully fulfill those two task objectives for relatively low hardware costs.

B. Electrical

With a custom AUV design, it was determined that a custom power distribution board was also necessary. Its purpose is to handle the miscellaneous tasks on board the AUV, such as emergency shutoff, leak detection, voltage regulation, and power management. Initially, it was going to use an Atmel Atmega as its main processor, but because ethernet connectivity is a major factor in its design, we eventually switched to an Mbed NXP LPC1768 as the main processor due to its native ethernet capabilities and ease of use.

The reason for the ethernet connectivity is so that the subs main computer can gather data such as battery voltage, to calculate its remaining runtime; or immediate battery current, so the computer can calculate the most effective thrust values to output to the thrusters, so the electrical system is not overloaded from the thrusters current. Another reason the power distribution board supports ethernet is to allow the sub to be gracefully shut down. When the power switch is turned off, the sub will not immediately power down. Instead, the power distribution board will first tell the computers that they need to shut down and wait until they have successfully shut down before finally cutting power to the sub. We made this decision after observing how typically, flipping the power switch causes the power to the computers to be cut while they are running, and saying "There has to be a better solution." By allowing the computers to gracefully shut down, we mitigate any potential damage to the OS caused by the improper shutdown. Finally, the last use of the ethernet capabilities is to let the power distribution board receive statuses from the main computer and report them visually by numerous RGB LEDs around the enclosures. This lets us determine what the sub is doing with a quick glance.

Another key aspect of the power distribution board is to manage the thruster's emergency stop and the water intrusion detection. The emergency stop is set up in such a way that both the user and the software have the ability to activate it, however, they are set up in series so that one cannot override the other under any circumstance. This allows both the divers around it and the crew managing the base station to safely immobilize the sub in the event of an emergency while knowing that the sub cannot accidentally be rearmed by the other party or by the autonomous code. The power distribution board also monitors various leak sensors positioned around the sub that when triggered, activates a single-use kill switch that cuts power to the entire sub. This switch cannot be reset unless the batteries are removed which makes sure that the sub cannot accidentally regain power while flooded.

The last interesting design decision is the heat dissipation of the power regulators. Initially, we had onboard a network switch that included POE for use with our cameras. This switch required 48V which meant that the power distribution board had to contain multiple large, inefficient power supplies. We noted that these supplies got extremely hot and that to be cooled, we would have to mount the power distribution board to the aluminum connector box to dissipate the heat generated by these power supplies into the surrounding water. This severely limited the physical size that our power distribution board could be because of the little space available in the connector box, and as a result, the capabilities we could add. To solve this, we changed our cameras to smaller units that were not powered over ethernet. This allowed us to change the network switch to a much lower power device that does not require the power-inefficient power supplies. This change let us move the power distribution board out of the confined connector box and into a more spacious tube to be able to cool the remaining voltage regulators using the internal air circulation fans.

As of right now, the thrusters are controlled using an Arduino Mega because of its large number of PWM pins. Eventually, we plan to make an expansion module off the power distribution board that acts as a motor controller board. We also have a DVL installed for the purposes of data collection. While the data from the DVL will not be used for autonomous decisions this year, we plan on using the data we acquired to aid the DVL's software integration in the future. For the main computers, we have decided on an Intel NUC to control the sub and the various other tasks, and an NVIDIA Jetson TX2 for vision processing. As stated before, the cameras used previously were POE IP cameras, but this was eventually swapped out to higher resolution cameras from Leopard Imaging that talked over a MIPI interface directly to the Jetson.

C. Mechanical

Last year the focus was to have as modular a submarine as possible to ensure additional components can be implemented as we develop more advanced systems. The chassis of the AUV is built around a modular frame consisting of four rails arranged in a rectangle. This design allows the team to add, move, remove, or replace components as needed in order to achieve versatility in equipment configuration and to be able to assemble or disassemble the AUV efficiently. This modularity also allows the team to change configurations in a short period of time, so if any equipment becomes damaged and needs to be replaced at short notice, it can be done. This year, in addition to the modular aluminum frame of the submarine, further systems have been added to AUV including an arm, a torpedo system, and a dropper.

The dropper system was created intentionally as simply as possible due to limitations from the electronics configuration. The electronics configuration allows for access to only one hole on the backplate of the main enclosure. The dropper consists of two tubes, each containing a golf ball, which is both blocked by a plate attached to a servo. To drop a golf ball, the servo can swing the plate out from under one of the tubes while keeping the other tube covered. To drop the second ball, the servo simply swings the plate to the other side. This allows the team to have two attempts at landing the golf ball in the proper position while minimizing the complexity of the dropper system.

The torpedo launcher is one of the most prominent features of the sub, the large tube under the belly of the sub is the torpedo launcher. The torpedo launcher uses a custom spring launching mechanism that jets out the torpedo. It uses a servo to retain the torpedo against a compressed spring. When the servo is signaled to release, the retention mechanism goes off and the torpedo is launched outwards with the compressed potential energy of the spring. The servo mechanism is located on the outer side, this mechanism allows the team to easily reload the tube. As well, the spring is kept captive in the mechanism to prevent it from flying out when the torpedo launches, and to make reloading easier. The positioning of the launcher parallel to the forward axis of the sub allows us to aim by simply rotating the sub.

One of the biggest mechanical challenges while creating the sub, was developing the arm. The arm has 3 joints and can extend out 18 inches when fully expanded. The tip of the arm has a hinged claw that allows it to grasp various objects. A3 DOF (degree of freedom) arm was chosen in order to gain the flexibility in the operation of being able to position the end effector precisely in 3 dimensions without needing to precisely position the vehicle. A full 6 DOF arm was deemed unnecessary, as the competition objects do not need to be grasped from a precise angle, nor do they need to be rotated to any particular angle for any task. Dropping the three extra servos will reduce complexity in mechanical design, wiring, and code.

III. Experimental Results

Before replicas of the tasks that will be at competition could be created to gather data, the software sub-team chose to test code on images from Google. People wearing glasses were pulled from Google and used to train a network using TensorFlow. The purpose of choosing glasses as a dataset was simply due to how easily the dataset was acquired. Additionally, glasses are readily available which allows for easy testing of the network once it is trained. There was a confidence rate that was consistently above 80% using this method. This was used as a control to ensure that the neural network training procedure was being done correctly. Once the network became successful with detecting glasses on members of the team with a confidence rating of 90% or higher, the team could then construct a replica of the gate and buoys. Since the university pool has been closed for the last year for construction purposes, it has been difficult to gather data and perform tests.

The closest pool that we had access to was about a half-hour drive, so tests had to be thoroughly planned out ahead of time. Therefore, it was planned to have a test at the end of each run of Scrum, every other week. These tests gave the team a lot of insight as to what aspects of the software or mechanical design need to be changed or fixed. For example, the team ran into a lot of issues running demo scripts for the vehicle movement. After a lot of trial and error and consulting with people from Pixhawk, it was determined that the Pixhawk the team had inherited years ago was actually an illegitimate copy. The team also learned a lot about the logistics of working at a far away site, which helped prepare for the competition. Because the drive to the pool was very lengthy, it was imperative that all of the necessary tools, equipment, and spare parts were packed.

Through lots of mistakes of forgetting to pack seemingly insignificant items, the team was able to create an extremely detailed packing list and come up with a method to ensure that all necessary items were always present. Testing was a big obstacle for the team this year, due to the regular testing site at the university pool being closed for the past year. Regardless, the team did everything possible in order to get Nautilus in the water, even if it was only a few times.

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Appendix A: Component Specifications

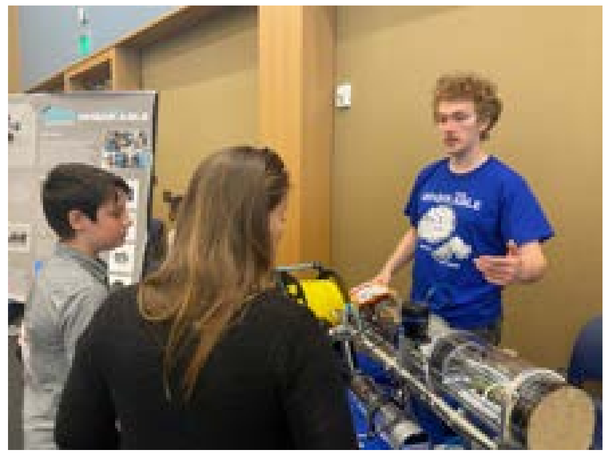
Component	**Vendor**	**Model/ Type**	**Specs**	**Custom/ Purchased**	**Cost**	**Year of Purchase**
Frame	Custom	Custom	Aluminum	Custom	~$225.00	2020
Waterproof Housing	Blue Robotics	6” Enclosure	6” Diameter Acrylic Tubing	Purchased	$600.00	2020
Waterproof connectors	Blue Trail Engineering	3-Pin Power & BlueROV Battery Conn.	Rated to 600 m depth, Max: 150VDC @ 12 Amps	Purchased	$430.00	2020
Thrusters	Blue Robotics	T-200	9.0 lbf of Thrust, @ 390 Watts 3.9 in. Diameter Water Lubricated Plastic Bearings	Purchased	$1,600.00	2019
Motor Control	Blue Robotics	Basic ESC	Bidirectional 30 amp ESC	Purchased	$320.00	2019
High Level Control	Pixhawk	PX4	L3GD20 3-Axis Digital 16-bit Gyroscope, LSM303D 3-Axis 14-bit Accelerometer / Magnetometer, MPU6000 6-Axis Accelerometer / Magnetometer, MS5611 High Precision Barometer	Purchased	$100.00	2019
Servos	LoBot	HiWonder	20Kg*cm	Purchased	$55.00	
Battery	Blue Robotics	The Lithium-ion Battery	14.8V, 15.6Ah 18650 lithium-ion cells	Purchased	$1320.00	
Regulator	MuRata	Multiple	12V 5V	Inherited	Inherited	Unknown
CPU	Intel	NUC Board NUC7i7DNBE	Quad-Core 1.90 Ghz	Purchased	$200.00	2020
Vision Processing Computer	NVIDIA	Jetson TX2	Dual-core NVIDIA Denver 2 64-bit CPU and quad-core ARM A57 Complex 1.33 TFLOPs | 256 Cuda Cores	Inherited	Inherited	Unknown
Internal Comm Network	Netgear	GS308	8 Ports Network Switch	Purchased	$20.00	2021
External Comm Interface	Blue Robotics	ROV Tether	150m BlueROV Tether	Purchased	$1,000.00	2021
Compass	Pixhawk	PX4	See Above	Purchased	$100.00	2019
Inertial Measurement Unit (IMU)	Pixhawk	PX4	See Above	Purchased	$100.00	2019
Manipulator	Custom	Custom		Custom	~$15.00	2022
Algorithms	Google	Tensorflow		Open	$0.00	2020

		Object Detection		Source		
Vision	Intel	OpenCV		Open Source	$0.00	2021
Open-Source Software	Open Robotics	ROS		Open Source	$0.00	2021

Appendix B: Outreach Activities

A. STEM Day at Embry-Riddle

Team Unsinkable also participated in Embry-Riddle's STEM day. Middle schoolers from all Volusia and Flagler counties were invited to Embry-Riddle to participate in STEM related activities and learn more about STEM related fields. Team Unsinkable hosted a booth with a variety of activities such as an electronics circuit workstation, an interactive neural network training activity, a TensorFlow demo, and a 3D printing demo. STEM Day was a wonderful opportunity to interact with some amazing young students who were passionate about learning and pursuing engineering. We appreciated the opportunity to teach young students about what we do and how it can make the world a better place.



B. Marine Discovery Center

On April 21st 2021, the sub was brought to the Marine Discovery Center in New Smyrna Beach, to show elementary school age children and their parents functional submarines, including piloting demonstrations in a small pool, and explain how they work. Once the demonstration was over, the team answered questions from both children and their parents. The purpose of this demonstration was to show how autonomous underwater vehicles can be used to help marine life.

C. Future Plans: Seaperch

Team Unsinkable is currently working out the logistics of implementing Seaperch at the nearby High School, to allow a team or teams to have the opportunity to participate in a robotics competition by giving access to our teams lab and resources to interested students.