# University of Missouri Students Underwater Robotics Foundation: *Tigris Maris* Design and Competition Strategy

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Abstract

Mizzou Students' Underwater Robotics Foundation (SURF) has designed, manufactured, and built an autonomous underwater vehicle (AUV) capable of performing a variety of underwater tasks. Mizzou SURF's AUV, named *Tigris Maris*, has been designed and built in a two-year time frame. This technical design report discusses the design of the submarine in regards to the scoring goal our team thought was practical for first-year RoboSub competitors. Some fluid dynamic analysis has been conducted, the results of which have been used to make the AUV as hydrodynamic as possible. This is because Mizzou SURF plans on completing the course as fast as possible, focusing on the simple tasks and making sure we have the basics mastered before attempting more complicated maneuvers in the future. With these plans, Mizzou SURF has built an efficient and well-performing AUV.

## I. Competition Strategy

Mizzou SURF is new to this type of engineering challenge. With the many challenges that come with having an entirely student-led team, decisions had to be made when it came to the scope of the project. We chose to focus our efforts on preparing for the tasks that could be accomplished using the fewest physical components; those involving motion of the vehicle, with a little manipulation of a game piece. Mizzou SURF plans to focus on the basics for their first competition. The basics consist of entering the journey to the realm of the undead (passing through the gate), following the path and expose to sunlight (surface in the octagon).

Once the initial scoring plan is completed and tested successfully, the software will begin to program a different path using more complex image recognition.

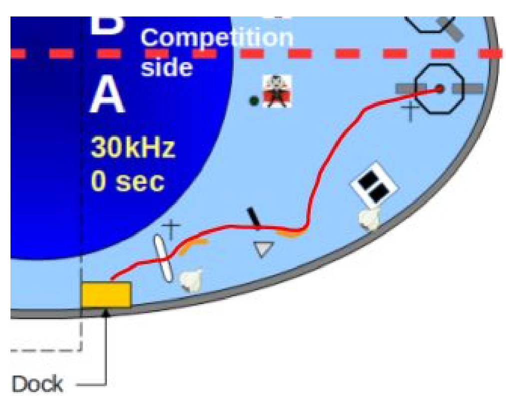


Fig. 1: Complex Competition Strategy.

This will only be attempted if the basic path has been completed successfully. In the more complex path, the scoring plan will begin with the coin flip, searching for the gate. Once the gate is located the sub will move toward the small section and pass through. After the gate, the sub will then follow the path as it does in the basic programming. At the end of the path, the sub will then search for a buoy. At this point, we will not aim for a specific picture and focus on making contact. After contact with the buoy has been made, the sub will proceed to the octagon to surface in the sunlight and end its run.

## II. Vehicle Design

### Mechanical

Our AUV consists of a ten-inch acrylic tube, capped on one end by a dome of the same material, and on the other end by an aluminum end cap. We machined the end cap out of a solid block of aluminum to allow for a custom fit onto our tube and to contain our wiring. Surrounding the tube we have a front and back plate also made from aluminum. The front plate contains 3D printed hydrofoils to create a more hydrodynamic shape for forward motion. The front and back plates each attach to a 3D printed ring that bonds them to the tube and the end cap respectively. Connecting the front and back plate are six one-inch aluminum extrusions that provide mounting points for our propulsion system and a variety of sensors.

Mounting the electrical systems within the central body tube is key to the operation of the AUV. This part consists of three triangular "rib" structures slotted for metal sheets to be inserted into the ribs. The rib structures include hinges that allow the electronics bay to be removed from the body tube and laid flat, allowing for structural or electronics work. Once the work is finished, the electronics bay will be folded back into the triangular structure and reinserted into the main body.

Another identifying feature of our sub is its propulsion system. The two tubes running from front to back are made of PVC pipe and 3D printed PLA. The tubes create more thrust off our horizontal brushless motors that each have a custom 3D printed PLA propeller. These two motors are used to propel the sub in the forward and aft direction while also controlling the yaw. The up and down directions, as well as the pitch and roll of the sub, will be controlled by the four Blue Robotics motors mounted below the main tube. Altogether, our sub supports a full 6 degrees of motion.

### Electronics

The AUV's power comes from 3 lithium-ion polymer batteries. Two four-cell lithium-polymer batteries are used to handle the high potential current draw of the motors. Another power line is powered by a three-cell Lithium-Polymer battery first fed through a DC/DC converter to supply 5V to the rest of the AUV's servos and CPU components. Lastly, the AUV has Neopixel LED strands powered directly from the 5V line that will relay warning signals in the event a critical condition is met. This may include dangerous heat levels, water leakage in the electronics bay, and other potentially catastrophic situations.

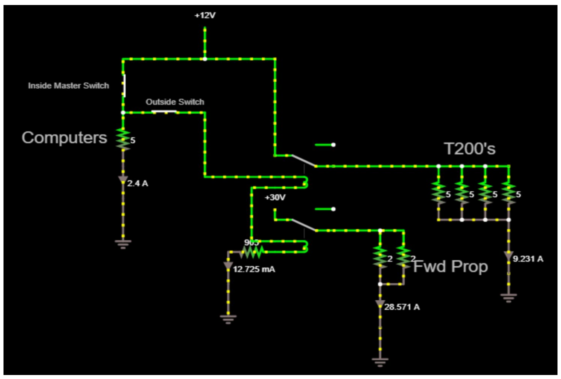


Fig. 2: Circuit Diagram for *Tigris Maris* 2019 and corresponding motor control.

## Software

The sub is very reliant on the software systems it has on board. The software is divided into four categories: image recognition, audio signal vector analysis, motor control, and navigation systems.

What has proven to be one of the most difficult parts has been motor control. Due to the fact that the sub is equipped with high current electronic speed controllers, there is little documentation, and proprietary pinouts make it a massive hurdle to overcome. This will likely continue to be a problem for seasons of RoboSub to come.

The image recognition is being done using a Tensorflow deep learning neural network, with the help of Keras to make the process easier to develop. A base image set to train the model has been made from 3D models and has had image post-processing applied to create a more realistic simulation of what will be seen in the water.

The audio signal vector analysis is done by simply comparing the signals received by six hydrophones oriented in various directions and pointing the sub in the direction of the source.

The navigation system will be pulling together all the data generated by the rest of the software stack. It will be responsible for doing the decision-making process for each task in the competition and mapping a route between the different tasks.

The software will be running on a networked group of four Raspberry Pi 3 Model Bs. This group of machines will communicate over ethernet to a SQL database running on one of the Pis. The Pis will be cooled by two 40 millimeter fans due to the heat generated by their processors, which will most likely be running near their limit. The Pis will each be equipped with a 64-gigabyte microSD card to store all of the data that they generate throughout the competition.

## III. Experimental Results

Mizzou SURF began testing in the spring of 2018. The first tests began with the new motors purchased for the forward thrusters. The goal of testing was to determine which propeller design would produce the most thrust for the AUV. The setup consisted of a submerged motor and propeller, ESC, fish tank, and batteries. This is how SURF began its design of the propellers that now reside on the sub. This also led the team to discover that much larger motors were needed to propel the sub at the competition.

Other mechanical experiments were conducted on a torpedo launching system. The original design consisted of a 3D printed barrel and a spring-loaded mechanism that would release the torpedo using the energy stored in the spring. Early testing showed that the barrel broke under the great stress from the spring. Because of this, a PVC barrel was manufactured and has proven successful thus far. However, due to time constraints, Mizzou SURF decided to discontinue development of the torpedo launcher and refocus its efforts elsewhere, and plans to implement a launcher at next year's competition.

During propulsion and torpedo testing, waterproof testing also began. This proved to be particularly challenging for Mizzou SURF. Many different leak tests were performed on complicated Mil-Spec connectors unfamiliar to most of the team. Eventually, leaks were found and mobility tests were able to begin.

Nearly all of the software on board the sub is an ongoing experiment. Due to the changing nature of the competition from year to year new software is constantly being thought up and tested. One of the biggest things that have been an issue for electrical, mechanical, and software teams, has been the motors that we are using for our main propulsion. The high current electronic speed controllers have been a challenge to work with for the software and electrical teams due to the odd nature of these devices. The mechanical team has been working hard to design the needed mounting solutions and propellers.

## IV. Acknowledgments

We would like to thank our support system, without which none of this would be possible. Our faculty advisor, Dr. Josiah A. Bryan, has been a steadfast supporter from the very beginning. Dr. Bryan continues to believe in our mission and provides opportunities to showcase and improve our organization.

Also responsible for the continued success of Mizzou SURF is the NASA-Missouri Space Grant Consortium. The funding and opportunity awarded allows for our organization to design, build, and test our AUV and the systems that go into the vehicle.

Next, we thank the Mechanical & Aerospace Engineering department of the University of Missouri College of Engineering for allowing us to create our student organization. They have provided us with support through funding, workspace, manufacturing assistance, and visibility for recruiting.

Lastly, Mizzou SURF would like to thank its devoted members. Without the long nights, long weekends and countless meetings we would not have anything to put in the water. We are forever grateful for everyone who has supported us and who continues to support our efforts to create *Tigris Maris*.

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Appendix A

| Subjective Measures | | | |
|---|---|---|---|
| | Maximum Points | Expected Points | Points Scored |
| Utility of team website | 50 | 50 | |
| Technical Merit (from journal paper) | 150 | 150 | |
| Written Style (from journal paper) | 50 | 50 | |
| Capability for Autonomous Behavior (static judging) | 100 | 25 | |
| Creativity in System Design (static judging) | 100 | 100 | |
| Team Uniform (static judging) | 10 | 10 | |
| Team Video | 50 | 50 | |
| Pre-Qualifying Video | 100 | 0 | |
| Discretionary points (static judging) | 40 | 40 | |
| Total | 650 | 475 | |
| | | | |
| **Performance Measures** | | | |
| | Maximum Points | | |
| Weight | See Table 1 / Vehicle | 18 | |
| Marker/Torpedo over weight or size by <10% | minus 500 / marker | | |
| Gate: Pass through | 100 | 100 | |
| Gate: Maintain fixed heading | 150 | 150 | |
| Gate: Coin Flip | 300 | | |
| Gate: Pass through 60% section | 200 | | |
| Gate: Pass through 40% section | 400 | 400 | |
| Gate: Style | +100 (8x max) | 400 | |
| Collect Pickup: Crucifix, Garlic | 400 / object | | |
| Follow the "Path" (2 total) | 100 / segment | 200 | |
| Slay Vampires: Any, Called | 300, 600 | 300 | |
| Drop Garlic: Open, Closed | 700, 1000 / marker (2 + pickup) | | |
| Drop Garlic: Move Arm | 400 | | |
| Stake through Heart: Open Oval, Cover Oval, Sm Heart | 800, 1000, 1200 / torpedo (max 2) | | |
| Stake through Heart: Move lever | 400 | | |
| Stake through Heart: Bonus - Cover Oval, Sm Heart | 500 | | |
| Expose to Sunlight: Surface in Area | 1000 | 1000 | |
| Expose to Sunlight: Surface with object | 400 / object | | |
| Expose to Sunlight: Open coffin | 400 | | |
| Expose to Sunlight: Drop Pickup | 200 / object (Crucifix only) | | |
| Random Pinger first task | 500 | | |
| Random Pinger second task | 1500 | | |
| Inter-vehicle Communication | 1000 | | |
| Finish the mission with T minutes (whole + factional) | Tx100 | | |

Appendix B

| Component | Vendor | Model/Type | Specs | Cost (if new) |
|---|---|---|---|---|
| Frame | McMaster-Carr | Connecting bars | 1" Aluminum Extrusion | $50 |
| | McMaster-Carr | Front & back plates | 1/8" Sheet Aluminum | $50 |
| Waterproof Housing | McMaster-Carr | Acrylic Body tube | 9" dia. x 24" long x 1/2" thick | $500 |
| | Plastic Guys | Acrylic Dome | 9" hemisphere | $98 |
| | McMaster-Carr | Aluminum Back Cap | Aluminum | $200 |
| Connectors | Glenair | Aquamouse | Shell size #10 | Donated |
| Thrusters | Blue Robotics | T100 Thruster | 5lbs of thrust | 4 x $119 |
| Motor Control | Blue robotics | Basic ESC | 30A | 25*4 |
| Propellers | 3D printed in-house | | PLA | N/A |
| Battery | Hobby King | Turnigy | 20Ah 4S | 3 x $150 |
| Converter | KNARCO | DC-DC Buck converter | 100W 5V | 28 |
| CPU | Amazon | Raspberry Pi 3 B+ | 1.4GHz quad-core ARMv8 CPU, 1 GB RAM | 4 x $37.42 |
| Internal Comm Network | Amazon | D-Link DGS-108 | 8 10/100/1000 Mbps ports | $29.99 |
| External Comm Interface | Generic | Cat6 cabling | 10gbps | 50.65 |
| Programming Language 1 | Python | | | |
| (IMU) | Grove | IMU 10DOF V2.0 | | $14.50 |
| Camera(s) | Logitech | C920 HD Pro | 1920 x 1080 | 3 x $60 |
| Hydrophones | Aquarian Audio | H1C Hydrophone | | 6 x $139 |
| Open source software | Keras/Tensorflow | Keras/Tensorflow | n/a | $0 |
| Team size | 24 members | | | |
| HW/SW expertise ratio | 7:1 | | | |
| Testing time: in-water | 3 hours | | | |

Appendix C

In the past two years since its inception, SURF has been extremely active in community outreach events. SURF first participated in the Youth Rocket Camp, hosted by the University of Missouri's Rocket Team. We showcased our skills in the aerospace field so that the children who participated could learn how to build water bottle rockets propelled by water vapor pressure. The Rocket Camp was three days over the weekend of May 5-7 and had 40 participants.

Mizzou SURF has also mentored a local FIRST Robotics team in SolidWorks and basic manufacturing techniques. SURF plans to continue this community connection throughout the upcoming years.

The next outreach that SURF participated in was Lab Exhibit Day hosted for Mizzou's Engineers' Week. SURF set up a booth with 3D printed visuals and a propeller test stand. Children got to play with small rubber band powered torpedos. Lab Exhibit Day hosted over 1500 children from schools all over mid-Missouri. SURF has done this event both years it has been a team.

Another outreach event SURF participated in was Mighty Machines in Jefferson City, Missouri. This event consisted of a day of learning for the children of Missouri's capital. SURF's AUV, along with many other large machines, gave these kids a window into the world of STEM, encouraging them to explore the field further.

One of the last events SURF participated in this past year was speaking to a range of local high school physics classes. These students are heavily interested in STEM and Mizzou SURF's goal was to educate them on college programs and how to stay involved while studying a heavy course load. Meeting and interacting with the students who could possibly be taking over our organization is vital for the SURF recruitment process and is beneficial to them and the university.

Another project that SURF plans to start is a day-long underwater engineering camp. This camp will be geared towards underrepresented communities in STEM and will teach the basics of engineering design and teamwork. We will have the children complete a small design project in groups and have them compete at the end of the day. This will challenge their skills while providing a fun and welcoming environment that will ensure engineering and STEM program retention. We want to increase the public profile of STEM within the community to enrich the community itself and provide kids with the tools to reach for their full potential, whether it is within STEM fields or anything else they decide to do in the future. We have started dialogues with local schools with which we are looking to market the camp