Mizzou Student Underwater Robotics Foundation Robosub Technical Design Report

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Abstract* — After the competition in 2019, Mizzou SURF learned many lessons. One of the biggest was our sub design. The sub was far too heavy and large to perform competition tasks. For competition season 2021 we have scrapped our last sub to make Jelly, a sub that is small and nimble. Jelly is the prime example that the best things come in small packages. Jelly's compact design and hydrodynamic hull powered by 8 thrusters allows Jelly to glide through the water as high speeds while being accurate enough to perform tasks. On the software side, it was decided that the pre-made software solutions we had used on our previous sub were greatly limiting our capacity. Instead, we opted for a much more hands-on approach by using a PWM servo board and writing our own motor control software. This allowed much more freedom in programming the sub and made issues much easier to troubleshoot.

I. COMPETITION STRATEGY

The first task of the competition is for the sub to navigate through the starting gate. For extra points, our team would opt to flip a coin to determine our submarine's starting position. The planned placement of Jelly's motors and cameras allow Jelly to see and navigate in nearly all directions. Jelly will submerge and 'crab walk' through the gate rather than turn to face it. Jelly's will only be trained to recognize pictures necessary for bootlegger tasks. This will risk losing points if Jelly does not successfully pass on the bootlegger side of the gate, but saves time in training Jelly to recognize images. To increase the likelihood of Jelly passing on the bootlegger side, Jelly will be trained to navigate closer to the side with the bootlegger picture. While going through the gate on the bootlegger side, Jelly will yaw and pitch 360 degrees for style points.

To reach the next two paths, Jelly must be able to follow the orange path. Jelly's cameras will recognize the orange color of the paths and keep them in one camera's view to ensure Jelly correctly reaches the next tasks.

For the 'Make the Grade' Buoy challenge, Jelly's cameras will recognize only the tommy gun image and bump that buoy. For the 'Collecting Bins' challenge, Jelly's two hands allows our sub to hold a marker and remove the lid simultaneously. Jelly's camera will recognize either the whiskey bottle or the barrel image, so it will drop the markers in the appropriate bin.

Jelly's two hydrophones allow Jelly to navigate to the 'Survive the Shootout' challenge. Once Jelly gets close enough to recognize the images in the challenges, the camera will take over for navigation. In this task, Jelly will recognize the G-man image and attempt to shoot through it. Since Jelly has two torpedo launchers, one will be launched through the G-man image and one through the larger opening. If Jelly is unsuccessful at launching through the smaller opening at the G-man, this strategy makes it more likely that Jelly can recoup points by making it through the larger opening.

Using the same navigation strategy in the last challenge, Jelly will first rely on hydrophones to reach the center of the octagon in the 'Cash or Smash' challenge. Jelly's two hands allow it to grab multiple bottles. Once bottles have been grabbed, Jelly will return to navigating via the camera, recognize the dollar sign image, and move the bottles to that table. Jelly will then resurface in the octagon and Jelly's run will be completed.

II. DESIGN CREATIVITY

Once scrapping our old sub, we devised a list of design constraints we want to have to create the best sub that we can. The first design constraint was that Jelly's main frame must be able to fit in a 62 linear inch box. This first constraint allows us to take Jelly on the plane as checked luggage with little to no disassembly. Not only does this ensure that we have the sub on time for testing at the competition (if it happened to be in-person) but it was also a good practice to replicate commercial AUV's that will travel the globe with its engineers collecting data wherever it is needed. On top of transportation, the small body allows Jelly to be more hydrodynamic and move through the water with ease. The second constraint that we set was a weight constraint. Our last sub was extremely heavy which hurt in the competition and our backs, so we wanted to keep our submarine's weight under 48.5 lbs. The weight constraint was set to get us points in the competition for the weight and gaining a small edge over the other teams. With these two constraints, we got to work building Jelly.

Fig. 1 Jelly

The first thing we focused on was the propulsion system. The propulsion system we thought that best matched our competition strategy was a vectored ROV with four vertical thrusters. We chose this design because it gave Jelly the most power in all directions and is a supported frame configuration for ArduSub ran on the Pixhawk mini mounted in the electronics board. This configuration provides Jelly with the power needed to move quickly from task to task, the precision to perform the tasks, and streamlined our programming through ArduSub, which we originally planned to use. We got a main plate and mounted the rotors in this configuration then extended the mounts for the corner rotors to allow Jelly to sit comfortably on any surface. Later, we added hydrophone mounts to the legs of the angled horizontal thrusters to use space between the legs and the front of Jelly.

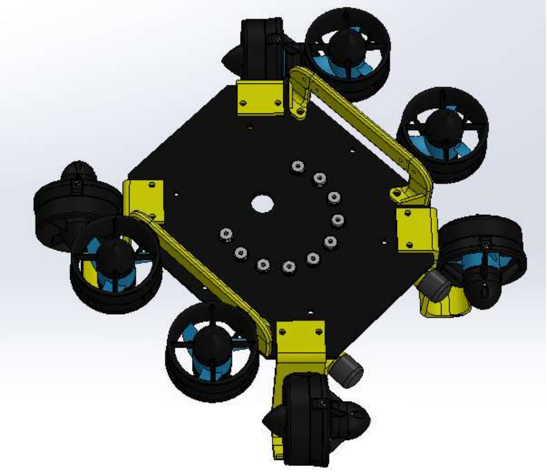


Fig. 2 Propulsion system

After choosing Jelly's propulsion system, we then moved on to designing the electronics bay. The electronics bay of Jelly was designed to ensure that we could access all our electronics easily and quickly to stay on top of a busy competition schedule. In our last sub, the whole electronics bay slid out which required a lot of unwiring and rewiring every time we needed to access the electronics bay. Jelly's electronics bay has a cylindrical top which can be loosened and tightened with 6 double-threaded bolts and allows access to all the electronics without having to disconnect any wiring. The electronics bay has the ESC's for the thrusters on the bottom level, and they are mounted in such a way that makes them easier to remove than the old electronics bay. They are connected to a pair of bus bars that provide power for the whole sub from the battery. The second level houses the voltage regulators and kill switch relays. The Jetson, hydrophone drivers, and other smaller sensor and control boards are housed on the top layer. All the signal cables are routed up through the center of the electronics bay to try to keep cables out of the way. There is also a camera mounted that can view what is in front of Jelly.

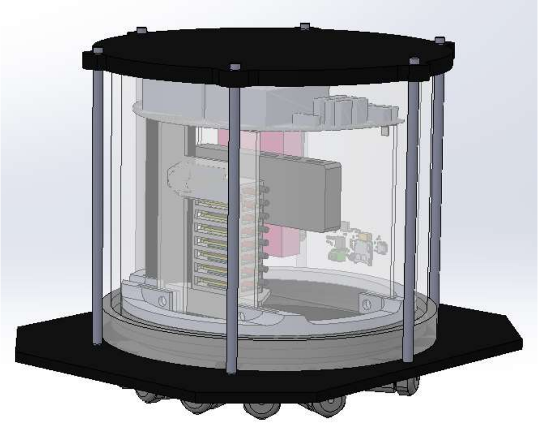


Fig. 3 Electronics Bay

After creating the electronics bay, we wanted to ensure that the battery was close to the electronics but since the battery carries a large amount of Jelly's weight, the placement of the battery shifts the center of gravity significantly. We decided to add a tube under Jelly's main plate to put the battery, lowering Jelly's center of gravity closer to the middle of Jelly's plate. Keeping the center of gravity in the middle of the rotors keeps the robot stable when moving since the rotors won't be applied unwanted torque forces. In addition to holding the battery, Jelly also has a bottom facing camera mounted in the bottom of the battery tube to allow Jelly to track the lines along the bottom of the pool and to be able to precisely drop objects into the drop zone.

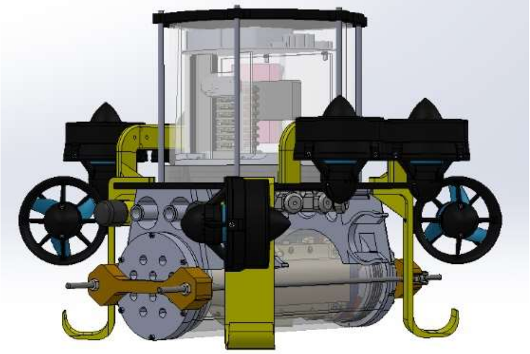
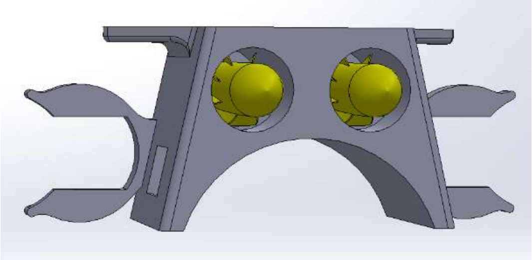


Fig. 4 Battery Tube and Mount

After adding the battery tube and the mounts, we thought we could use the space taken by the battery mount in a more efficient way by fitting it to include 2 independent torpedo shooters. The battery tube mount was right in the middle of the robot on the front so utilizing it as a torpedo shooter creates an accurate torpedo shooter that takes up no extra space. To minimize our space usage for the torpedo shooter we decided to use a pressurized system with independent pneumatic solenoids to shoot the torpedoes.



To complete our torpedo shooter, we needed to add air tanks to the sub. We found small air tanks and mounted them the sides of the battery tube to provide air to the pneumatic torpedo shooter and act as a ballast. Jelly will complete its tasks using whatever air is necessary in the tanks and hold the rest to help decrease Jelly's buoyancy. Once Jelly needs to return to the surface, all the air in the tank will be shot out of the torpedo shooters to increase Jelly's buoyancy and allow Jelly to float to the surface of the water with ease.

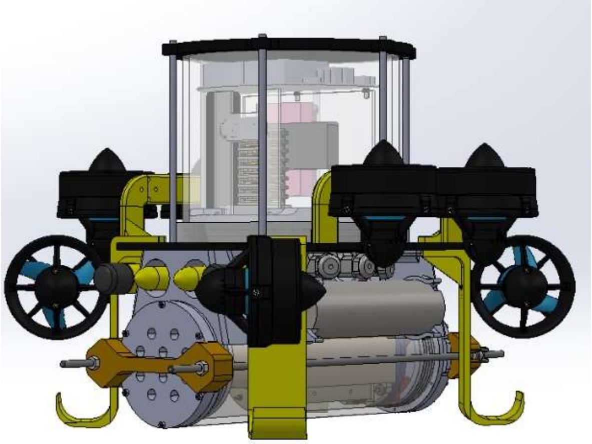


Fig. 5 Torpedoes and Air Tanks

Since we already designed Jelly to have air tanks, we moved forward on a pneumatic gripper mechanism so we can utilize the components that we already have on Jelly more efficiently. Jelly's gripper mechanisms are designed with a double acting hydraulic cylinder. We extended the feet of Jelly to include a mount for the graver mechanism. The claws are designed to stay out of the vision of the camera when they are not clamping anything to allow Jelly to have an unobstructed view of the field and the item it is trying to grab. The clamps will come into the view of the camera when Jelly clamps on the object to ensure Jelly can have view of the object while Jelly is moving to the drop zone. The second hand allows Jelly to complete other tasks when one hand is occupied. This helps our strategy because we can pick up an object and do other tasks along the way to dropping it off, or even holding 2 items at once.

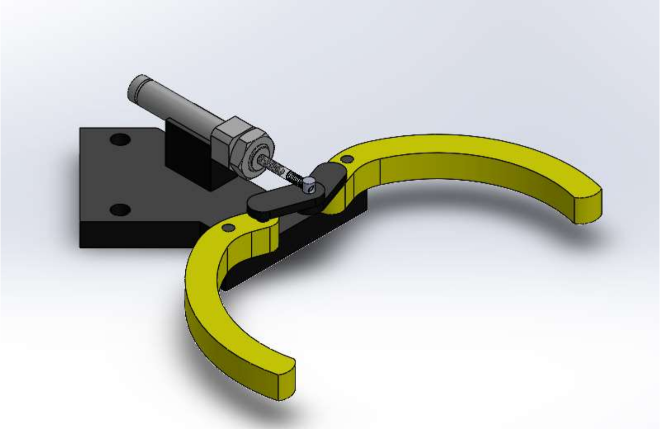


Fig. 6 Gripper Mechanism

Overall, Jelly's hull design is meant to be as compact and lightweight as possible while still having enough equipment onboard to complete tasks. In the end, Jelly came out to weigh 29.6lbs. and have dimensions of 17” (length) 18” (width) and 14.25” (height) for a linear size of 49.25”. We were able to keep Jelly way under the constraints we set and use all of the space possible to create not only a light and small submarine, but an effective one as well.

III. EXPERIMENTAL RESULTS

Although Mizzou SURF had trouble getting our sub to a pool this year, we were able to do some preliminary experimentation. We have an open-air motor test bed consisting of our older T100 Thrusters and a Jetson TX2. This has been very useful in experimenting with motor control algorithms while still being able to implement new design decisions to the actual submarine.

For software, though we originally planned on using Ardusub and a Pixhawk because of their extensive documentation, it was decided that it limited our capacity to read and incorporate data from sensors, such as our hydrophones, into motor movements. Instead, we are experimenting with using an Adafruit PWM servo board. Though this requires much more coding work up-front, in the long-term we expect this will make it much easier to extend Jelly’s capabilities. With this strategy, we were able to implement new strategies for motor control and stability.

For motor control, rather than changing yaw to change directions, we experimented with ‘crab walking’. The placement of the four horizontal motors at 45, 135, 225, and 315 degrees allow Jelly to maneuver along the x-y axis in all directions. In addition, pulse width modulation (pwm) communication allows for a finer control of motor speed. Direction in the x-y plane could be measured in units of degrees increasing counter clockwise from Jelly’s ‘front’, where the claws and torpedoes are positioned. For Jelly to change directions, a series of trigonometry equations would be used to determine how much output each motor would need to provide to go in that direction at a target speed, rather than adding the additional step of turning the sub in the correct direction. We were not able to test our equations completely on the test bed, but we were able to control the motors at various speeds, and create functions to accelerate and deaccelerate them safely.

For stability, we utilized the gyroscope on the Adafruit BNO055. Using Euler angle measurement outputs, we developed and tested a script that would interpret the measurements and run the correct combination of vertical motors to correct the instability. The script was able to correct for instabilities exclusively in pitch and yaw directions. In the future we plan to better handle cases in which a combination of pitch and roll causes the sub to be unsteady. We also plan on implementing sensor fusion algorithms to correct for noise within the accelerometer, gyroscope, and magnetometer.

We designed and wrote the drivers for a custom hydrophone filter, digitally controlled gain stage, and ADC circuit. The 16-bit ADC is currently running at about 865kS/s.

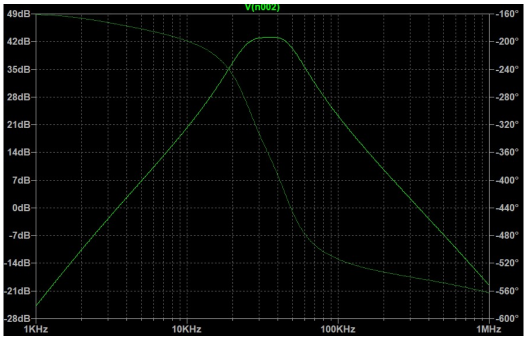


Fig 7. Simulated Filter Response (max gain)

In addition to the electrical and software testing, we were also able to complete some sub part testing out of the water. We have run some simulations in MATLAB for determining the thrust that the rotors are able to create in each yaw direction.

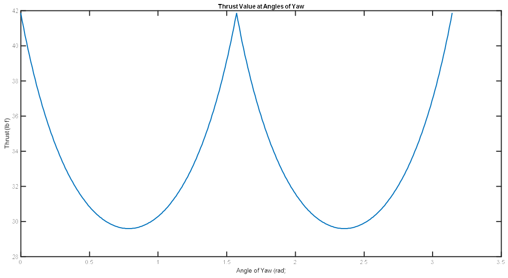


Fig. 8 Thrust in yaw direction

We then ran another simulation that calculates the thrust of the robot at different pitches at a yaw of 0˚ when the buoyancy force is inputted. This allows us to know how much the robot should be pitching to get the most speed going forward while also keeping Jelly at the same depth.

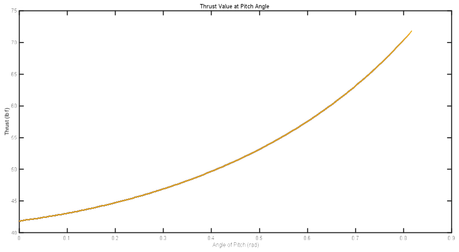


Fig. 9 Thrust in Pitch Direction at 0˚ with a buoyancy force of 10 lb f

Physically, we were also able to test our torpedo shooting mechanism out of the water through pressurizing our tanks and manually opening the solenoid valve to simulate when it is powered. At the end of the season while we were prototyping the grabber mechanism, our 3D printer broke and we were not able to test our hand mechanism, but it is one of the first things we are planning on returning to do.

Although we were able to simulate Jelly on the test bed and through air testing of our subcomponents, we did not have the opportunity to get Jelly to a pool to test Jelly. We hope next year to get Jelly in the pool early in the season and start testing the code that we have ready but have not been able to develop too much due to a lack of test results.

ACKNOWLEDGMENTS

Mizzou SURF would first like to thank our sponsors: Mizzou, SolidWorks, MathWorks, NASA, Blue Robotics, and Nvidia for providing us with the money and materials to create our sub. We are very grateful for our faculty advisor Dr. Josiah Bryan for the help, and he will be greatly missed next year when he is no longer a part of our university. We also want to give a big thank you to the RoboSUB team for organizing this competition and providing our team with the resources and help to create the robot that we did this year.

APPENDIX A: COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Cost (if new)
Frame	Mc Master Carr	Black Acrylic Sheet (Lower)		Not on order sheet
	Mc Master Carr	Black Acrylic Sheet (Upper)		Not on order sheet
	Mc Master Carr	Clear Acrylic Tube		Not on order sheet
	Mc Master Carr	Clear Acrylic Ring		Not on order sheet
Waterproof Housing	Blue Robotics	Watertight Enclosure	11.75x4” Acrylic Tube	$158
Waterproof Connectors				
Thrusters	Blue Robotics	T200		Reused
Motor Control	Adafruit	PCA9685	16 channel, 12-bit PWM controller board	$15
Actuators	Mc Master Carr	6498K322	½” Stroke Length	$18.91
Battery	Turnigy	High Capacity LiPo Pack	20,000mAh 4s 12c	Reused
Converter	(generic)	12V Buck	100W, 12V step-down (buck) converter	reused
Regulator				
CPU	Nvidia	Jetson TX2	Dual-Core NVIDIA Denver 2 64-Bit CPU, Quad-Core ARM Cortex-A57 MPCore, 256-core Nvidia Pascal GPU, 8GB RAM	Donated
MCU	PJRC	Teensy 4.1	NXP iMX RT1062 32-bit ARM Cortex-M7 @720MHz (OC), 1MB RAM	$27
Internal Comm. Network		I2C		
External Comm. Network		Ethernet		
Inertial Measurement Unit (IMU)	Adafruit	BNO055	accelerometer, magnetometer and gyroscope	$35
Vision	Logitech	C270	720p, 30fps	Reused

Hydrophones	Aquarian Audio and Scientific	H1C	Sensitivity: -190dB re: 1V/uPa Useful range: <1 Hz to >100KHz	Reused
Open-Source Software 1	Adafruit	PCA9685 Driver		
Open-Source Software 2	Adafruit	BNO055 Driver		
Programming Language 1		Python 3		
Programming Language 2		C++		
Programming Language 3		MATLAB		
Team Size	5 consistent members: 3 Sophomores, 1 Junior, 1 Senior			
Expertise Ratio	MAE: 2, ECE: 2, CS: 1 (plus help from the ECE's)			
Testing time: simulation	20:00 of subcomponent simulations			
Testing time: in-water	0:30			

APPENDIX B: OUTREACH ACTIVITIES

This year, due to COVID, Mizzou SURF was unable to continue outreach in the same capacity as last year. However, we took this as an opportunity to participate in a virtual opportunity that we had not previously been a part of, Mizzou STEM Cubs. STEM Cubs is an annual event managed by the University of Missouri's College of Engineering to introduce and promote engineering activities to children in K-5th grades from underrepresented backgrounds. Typically, the event takes place in the fall, and elementary school students would come to campus for a day and participate in activities organized by different competition teams and organizations in the College of Engineering. This year however, instead of holding an in-person event, the college has been working on creating a virtual program of how-to videos and take-home kits. SURF created a video targeted to 4th and 5th graders on how to make a propelled submarine out of plastic bottles, paper clips, and rubber bands. The video aimed not only to teach the mechanics of the water bottle sub, but also how key science concepts, such as buoyancy and density, affected the submarine. We also demonstrated how we used the same concepts when considering how to build our submarine. Once we made the video, we collected materials for the kits. The videos will not go out yet for a few months, but SURF is excited to be a part of the college's outreach efforts and looks forward to continuing to participate in-person for years to come.