Mizzou Student Underwater Robotics Foundation
Robosub 2024 Technical Design Report

Amelia Truong
University of Missouri
Columbia, MO, USA
ajt9zn@umsystem.edu

Kendra Minch
University of Missouri
Columbia, MO, USA
kkmbfc@umsystem.edu

Daniel Hough
University of Missouri
Columbia, MO, USA
dshc3f@umsystem.edu

Henry Bloch
University of Missouri
Columbia, MO, USA
habcpm@umsystem.edu

Nikola Radinovic
University of Missouri
Columbia, MO, USA
nmrrvc@umsystem.edu

Isaac Jensen
University of Missouri
Columbia, MO, USA
imjfh4@umsystem.edu

Luke Deffenbaugh
University of Missouri
Columbia, MO, USA
ltdckd@umsystem.edu

***Abstract* - Coming into the 2024 competition, Mizzou SURF decided it would be best to improve upon the 2022 submarine. Mechanical team designed and tested custom parts to make the sub more neutrally buoyant and easily modifiable. Electrical team condensed the electrical bay by designing a motherboard PCB for power distribution and added a battery monitor as a more reliable safety measure for working with LiPo batteries. Software team used OpenCV and object detection through ML to locate task objects and built a foundation of software knowledge with ROS. Altogether, the individual teams worked alongside each other to achieve navigation based tasks (passing through the gate, visual tracking of markers on the pool floor, and touching buoys) to improve on the achievements of past competitions.**

I. COMPETITION STRATEGY

A. Introduction

For this competition we have opted to focus our efforts on navigation based tasks, specifically passing through the gate and visual tracking of the markers on the floor of the pool. After this, we will move on to the Hydrothermal Vent - Buoy task and if time allows, we will work to achieve some more tasks in the challenge.

SURF has decided to pursue the coin flip toss to decide which direction the robot will be positioned in upon the beginning of the run. After being placed in the water, the sub will first submerge and pivot around its vertical axis until the cameras detect the gate. Once the gate has been located, the sub's position and orientation relative to the gate will be determined and it will head that direction. As the sub approaches the gate, it will search for the red rotation image and proceed to that side of the gate. The sub will complete a full rotation in both the pitch and roll axis to obtain the extra points. Upon passing the gate it will activate its next task, locating the path markers on the floor below. It will map this as a line in space and follow that line forward until the cameras can detect the third task, the buoy. Using the same methods as finding the gate, the sub will calculate its position relative to the buoy and head towards it. This will be the end of the competition based tasks.

Completing the tasks described above will be a significant achievement for the team. SURF's previous model of submarine "Jelly 1.0" could not adequately demonstrate autonomy. In particular, our goals as a team this year is to build a solid software foundation by utilizing tools such as Robot Operating System (ROS), OpenCV, and object detection through machine learning, make improvements mechanically based on our previous submarine, and integrate hydrophone sensors to improve position and orientation estimation and prepare for future competition tasks requiring pingers.

B. Mechanical Strategy

In previous years there were issues with the submarine being overly buoyant, too difficult to modify, and having interference between the hydrophones and motors. The goal of this year's robot, Jelly 2.0 (Fig. 1), was to build a new submarine that fixed these issues, giving the team a base to build off of in the coming years.

To address the buoyancy issue, Jelly 2.0 was designed with an aluminum base plate rather than an acrylic plate to increase the weight of the robot, countering the buoyancy force. This route was chosen over decreasing the volume of the electronics bay due to the bay already being small. Additionally, the acrylic ring that seals the main electronics bay was thickened both to create a mounting point that can support the load from the latches and to increase the weight of the component to further counter the buoyancy force applied to the robot.

With the goal of making Jelly 2.0 more modifiable, the main electronics bay was built to attach to the base with latches rather than threaded rods to provide easier access to the electronics. An effort was made to avoid the use of epoxy to have non-permanent connections between components. Jelly 2.0 was designed with a shorter, wider electronics bay to fit a custom circuit board, with a slightly larger battery tube that can accommodate the electronics for future systems like torpedoes and an arm for sample collection.

To address the noise interference the motors had on the hydrophones, the hydrophones were moved lower. Consequently, this made it easier to add a third hydrophone, as it decreased the height of the mount for the third hydrophone. Furthermore, the motors were moved to be inline with the theoretical center of mass of the robot to allow for accurate movements without having to account for induced rotations caused by adding thrust on planes that are not inline.

C. Software Strategy

Object detection is used heavily for the bot during competition because it allows for an easy way to make the sub dynamically react to changes in its environment. The software team has implemented this object detection through machine learning [1] and deep learning [4] to avoid tweaking gradients with limited data sources. For instance, object detection will be used to have the sub navigate towards and through the gate by looking for the red image [2], indicating the side of the gate the robot should pass through. To locate the path task after the gate, OpenCV and NumPy are used when capturing and processing video frames from a webcam to detect and indicate the direction of the path in real-time. Through multiple operations including flipping the frame, changing the color space, and performing mathematical operations, the algorithm will create a mask that highlights the orange region [3]. After detecting the largest contour and drawing a fitted line to this contour, the robot will be able to identify the visualized line, following the path with ease. Similar constraints for the gate can be used for the buoys.

Due to COVID, SURF has had difficulty keeping software membership high enough to retain information year after year. To address this, special emphasis has been put on recruitment and streamlining the transfer of knowledge to new members.

This season it was decided to focus on laying a strong foundation for the software team, despite the limits this would impose on the number of tasks that the sub could achieve. In particular, the focus is working with tools such as ROS, Gazebo Simulation, and OpenCV while working to create internal documentation for future reference. By achieving the simpler tasks with these tools, it will establish a base to create future design improvements and accelerate the iteration process when designing future algorithms. This will help SURF achieve more complicated tasks in future competitions.

D. Electrical Strategy

In order to ensure the most safe and efficient experience for those swimming with the robot, time was put into designing a battery monitor and battery cutoff PCB (Fig. 6). Though Jelly 1.0 was already equipped with an emergency shut off switch, this PCB was designed to monitor the battery while the sub is in use and can switch off the power if the battery voltage is too low. This is accomplished through feeding the battery cell values into comparator circuits. Each comparator circuit outputs a high or low signal depending on if the battery cells are above the minimum safe threshold. The output signals then go to a four-input AND gate that gives the final cut-off signal. Furthermore, this battery monitor is able to be detached from the motherboard and can be overridden for times when the battery monitor needs to be fixed and software needs to use the motherboard for code testing.

II. DESIGN STRATEGY

A. Introduction

SURF opted to redesign and improve the internal part design and optimize the external design of our 2022 RoboSub submission. By using the well-designed structure of our previous sub as a template and revising the parts that needed improvement, SURF significantly enhanced its sub design. We focused on reworking the positioning of the motors, redesigning our ROS strategy, consolidating the electronics bay, and increasing the size of the battery tube. SURF has continued its part manufacturing, allowing us to rapidly prototype our designed parts, make adjustments, and refine them as needed. By continuing the design process we excel at and revising the aspects we identified for improvement, SURF is confident that we are returning to the competition with a superior product.

B. Propulsion Systems

The propulsion system is a vectored ROV with four vertical thrusters and four horizontal thrusters. (Fig. 3) The thrusters were mounted in this configuration attached to eight legs, allowing Jelly 2.0 to sit flat on any surface. This configuration provides the submarine with the power needed to move quickly from task to task, the precision to perform the tasks, and is easily integrated into ROS.

C. Electronics Bay

The electronics bay (e-bay) of Jelly 2.0 was redesigned to functionally remain the same, but improved in its organization and space efficiency. This was done by converting the three tier design into a power distribution PCB (Fig. 5) to cut back on the amount of loose wires floating around the e-bay. Additionally, the PCB was designed to include spaces for other custom PCBs including the buck converter (Fig. 7), hydrophone stack (Fig. 8), and battery monitor (Fig. 6). By doing this, not only was the e-bay more compact, but it was easier to maintain and diagnose issues. Compared to the last version of the e-bay which required us to take apart multiple layers of circuitry to access all of the electronics, the new power distribution PCB allows for easy access to all electrical components by just removing the e-bay lid. Furthermore, the PCB was designed with multiple holes through the board to allow wiring up from the battery tube and to attach waterproof bulkhead connectors leading to motors and other electronics outside of the e-bay.

D. Battery

In order to keep a stable and low center of mass, the battery is mounted in its own acrylic tube below the electronics bay. The close proximity to the electronics bay allowed us to easily route power to all of the essential electronic components of our sub. Due to the weight of the LiPo battery, it has a great effect on the center of mass of the system. This inspired the decision to mount the battery below the electronics bay to bring the center of mass down to the level of the thrusters. Within the acrylic tube is also a downward facing camera to allow tracking of lines along the bottom of the pool.

E. ROS Software Structure

ROS is utilized for code structure and pre-built libraries, this allows for the code to be written in simple modules that allow for easy debugging while allowing complex behavior to arise through interactions. Figure 4 shown below illustrates the planned software structure, with each block representing either a physical sensor or a node of code. Nodes are connected by topics, which stipulate what kinds of information are passed between them. The software design strategy was influenced by the lack of ability to have in situ pool tests; and so ROS allows for the code to be highly modular and failure resistant. The structure is initiated with the blue sensor boxes, which input data into the submarine's Jetson Xavier. The green boxes take data from the sensors and publish pertinent data onto ROS topics while providing simple smoothing and offset functions to be tuned at a later date. The camera system is unique to other sensors because much more processing power is spent to utilize it for object detection and reference in the state machine [4] . The pink "state estimator" block combines sensor data to estimate the orientation of the bot. The "main" node in yellow monitors the vehicle's progress through each task and determines which task should be accomplished at any given time, controlling the "desired state selector."

The six nodes representing the states all perform path planning calculations for their individual tasks. This allows the main program to quickly choose a new task upon completion by switching to instructions that are being generated without firing up a new system. The task nodes feed desired positions as quaternions into the "PID" node, which commands the submarine to the desired positions and attitude by changing the target point, the outputs are then set to the "Motor Command" node which translates to PWM signals that the ESC can read and run the motors with.

III. EXPERIMENTAL RESULTS

A. Software testing

Our testbench includes test motors in the same configuration as the sub itself, which allows us to experiment and test nodes related to motor control before the electronics of the sub are fully implemented. Nodes for sending PWM outputs to the motors have been validated, as well as nodes for reading and smoothing sensor inputs. The sub has been simulated in unity to test and calibrate the PID controller. This allows us to simulate the interaction of the simple components and observe the complex resulting behaviors. Gazebo will also allow for junior members of the team to assist with testing different implementations of algorithms while not needing the resources of a full system test. This will save time instead of needing to test in pool facilities, which we have limited access to.

B. Electrical Testing

Simple pin monitoring scripts were used to test each hydrophones' ability to detect different frequencies within the desired range. The method of adjusting which frequencies were detected is to vary the resistance of a potentiometer which then determines the voltage applied to the filtering operational amplifier located on each individual hydrophone board. Tests were unsuccessful at detecting frequencies of the desired range with regularity. Though the potentiometer was found to be set correctly, the monitored pins on the Teensy seemed to cycle between 3 voltage values instead of the 14-bit resolution it was designed for. The problem was isolated to the code running the ADC. The ADC is a 4 channel, simultaneous-sampling MAXIM MAX11057. Due to the nature of monitoring multiple channels, the original code for the ADC was unlike previous ADC code the team had experience with. The team was able to set all setting pins correctly and determine the digital to analog equations, but were not able to test this code in conjunction with the hydrophones before the Spring semester finished. The project is currently ongoing.

C. Mechanical Testing

After manufacture, all parts are immediately tested for tolerancing and meshing with the existing parts. If parts do not fit, they are tweaked until they do. Using 3D prints greatly sped up this process. For waterproof testing, all electronics were removed and replaced with coffee filters to ensure all of the seals were tight. Once this is ensured, electronics will be added back to test the required buoyancy. From there, motor movement will be tested, first using remote control of the sub. This also provided the opportunity to test both the physical and remote kill switches. After these tests, autonomous tests for each task will gradually be implemented.

ACKNOWLEDGEMENTS

Mizzou SURF would first like to thank our sponsors and contributors: Mizzou College of Engineering, SolidWorks, MathWorks, Blue Robotics, and Nvidia for providing us with the money and materials to create our sub. We are very grateful for our faculty advisor Kristofferson Culmer for his guidance and advice. We also want to give a big thank you to the RoboSub organizers, judges, and the rest of their team for creating and running this amazing competition.

REFERENCES

[1] K. He, X. Zhang, S. Ren, and J. Sun, "Deep Residual Learning for Image Recognition," 2015. Available: https://arxiv.org/pdf/1512.03385

[2] S. Ren, K. He, R. Girshick, and J. Sun, "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks," arXiv.org, 2015. https://arxiv.org/abs/1506.01497

[3] "Types of Morphological Operations - MATLAB & Simulink." https://www.mathworks.com/help/images/morphological-dilation-and-erosion.html

[4] K. Liu, L. Peng, and S. Tang, "Underwater Object Detection Using TC-YOLO with Attention Mechanisms," Sensors, vol. 23, no. 5, p. 2567, Jan. 2023, doi: https://doi.org/10.3390/s23052567.

APPENDIX A: COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Custom / Purchased	Cost	Year of Purchase
Hull Plate	Midwest Steel Supply	6061 Aluminum Plate	0.250" x 16" x 16" with holes drilled for bulkhead connectors and leg attachments	Custom	$108	2022
Main Tube	Custom	Custom	10" Acrylic Tube salvaged from old robot	Custom	No Data	2017
Battery Tube	Custom	Custom	6" Polycarbonate Tube with custom made end caps	Custom	$160	2023
Propulsion	Blue Robotics	T200	(8x) Full throttle FWD/REV thrust @ 12V - 8.2/6.4 lbf	Purchased	Awarded	2022
Power System	Custom	Custom	Custom 8" battery distribution PCB	Custom	$124	2022
Battery	Turnigy	High Capacity LiPo Pack	16,000mAh 4S 12C	Purchased	$120	2024
Motor Controls	Skystars	BLHeli_32	(2x) 4 channel ESC with current and voltage sense	Purchased	$41	2023
CPU	Nvidia	Jetson Xavier NX	Jetson Xavier NX Modules in a Seed Studio A203 v2 Carrier board with 512GB NVMe SSD	Purchased	$860	2022
Teleoperation	N/A	N/A	N/A	N/A	N/A	N/A
Compass	N/A	N/A	See IMU	N/A	N/A	N/A
Inertial Measurement Unit (IMU)	Adafruit	BNO055	accelerometer, magnetometer, and gyroscope	Purchased	$35	2022

Doppler Velocity Logger (DVL)	N/A	N/A	See IMU	N/A	N/A	N/A
Camera(s)	Logitech	C270	(2x) 720p, 30fps	Purchased	$50	2018
Hydrophones	Aquarian Audio and Scientific	H1C	(3x) hydrophones and custom driver/filter/ADC circuitry	Custom	$500	2020
Algorithms	N/A	N/A	Custom Algorithm	Custom	N/A	2023/2024
Vision	N/A	N/A	See Camera(s)	N/A	N/A	N/A
Localization and Mapping	N/A	N/A	Custom Algorithm	Custom	N/A	2024
Autonomy	N/A	N/A	Custom Algorithm	Custom	N/A	2024

APPENDIX B: FIGURES

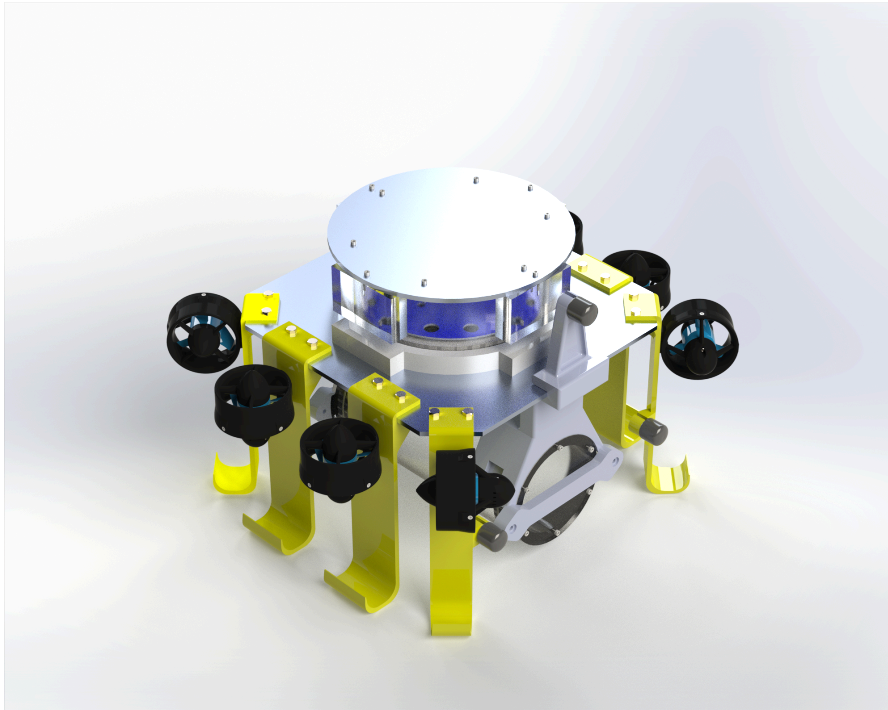

Fig. 1: Jelly 2.0

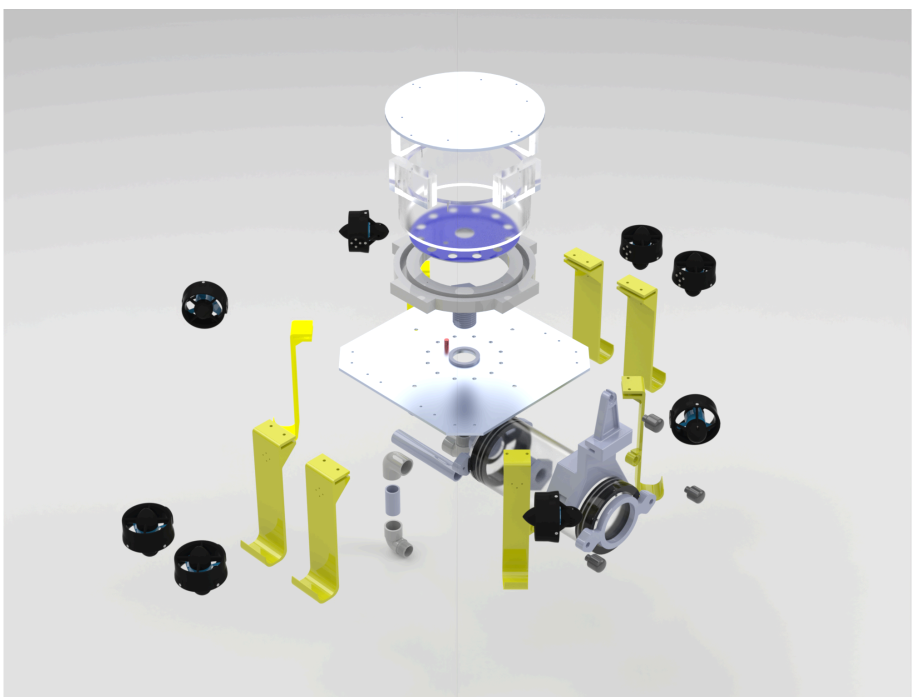

Fig. 2: Jelly 2.0 Component model

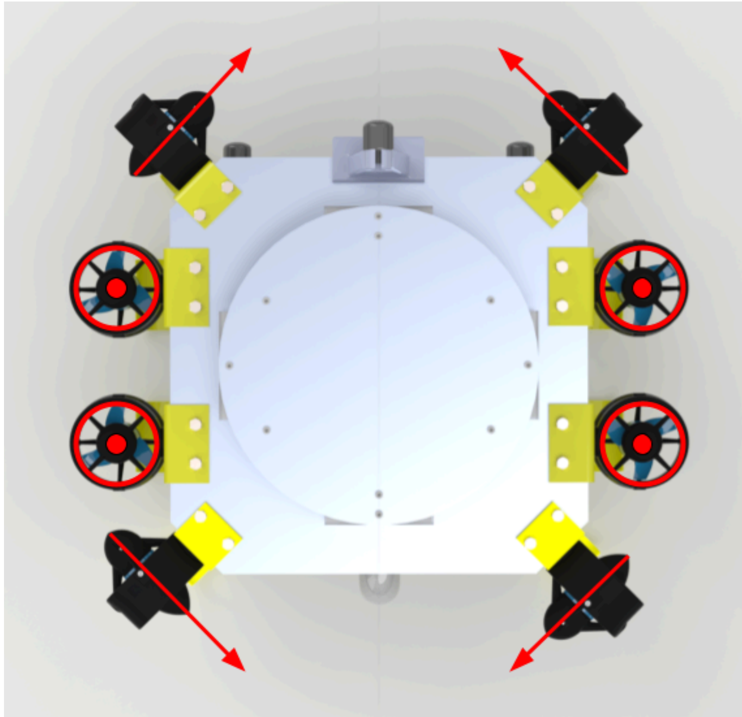

Fig. 3: Jelly 2.0 Propulsion System

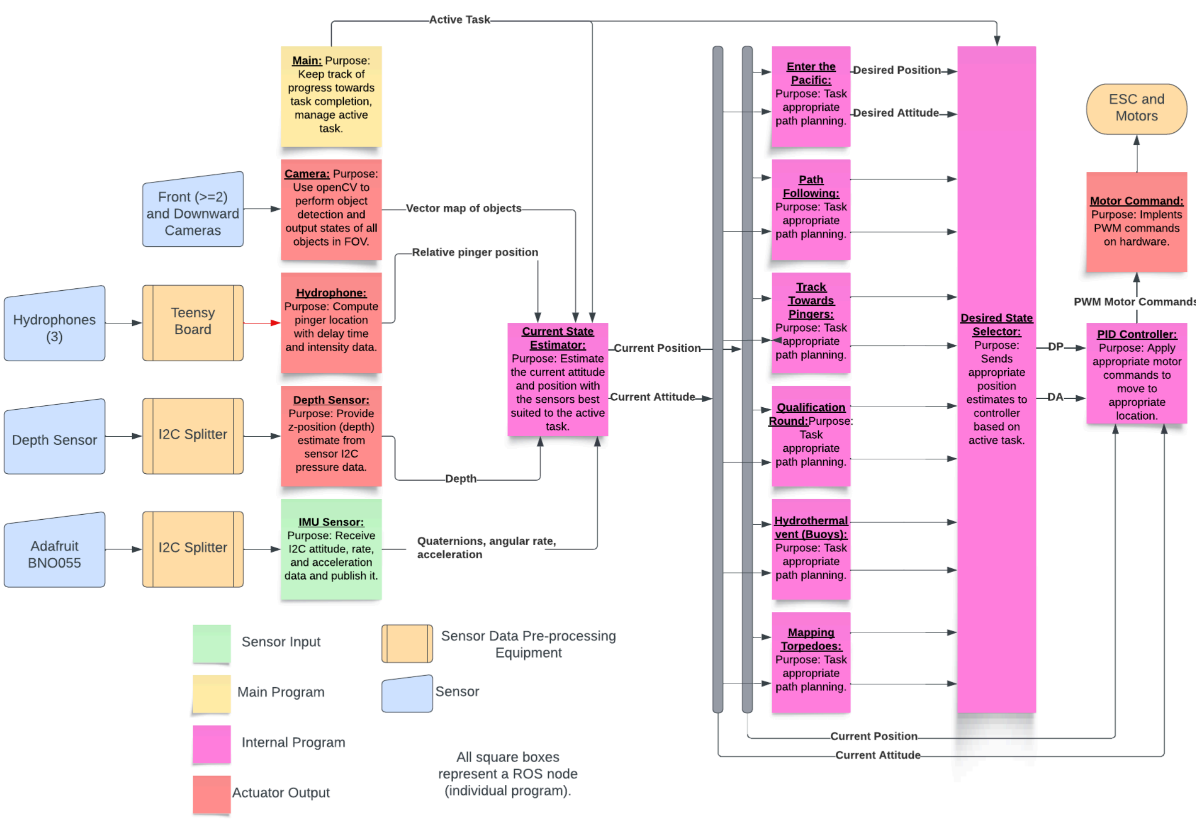

Fig. 4: System engineering design of submarine operation

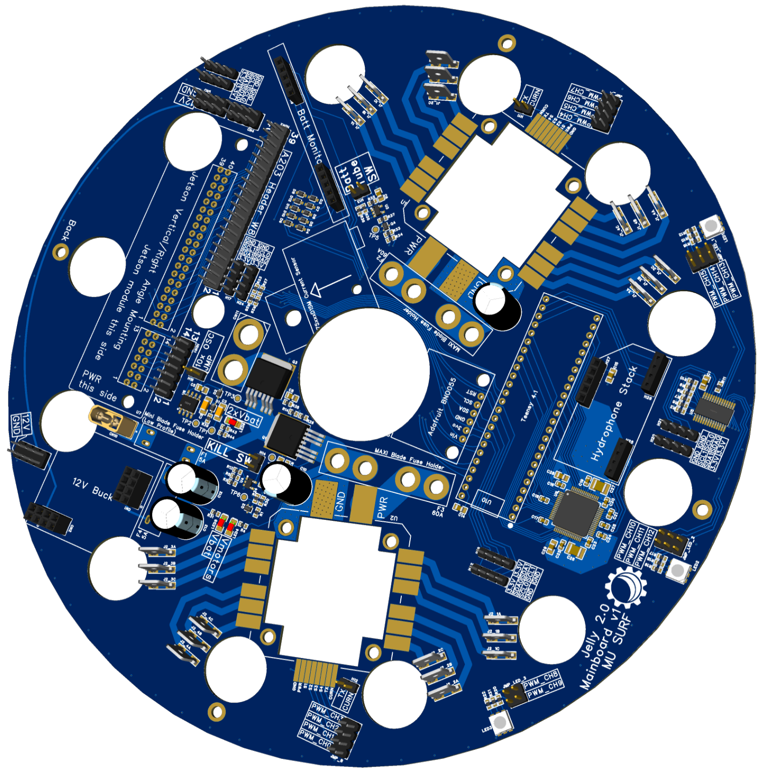

Fig. 5: Power distribution PCB (also referenced as "motherboard")

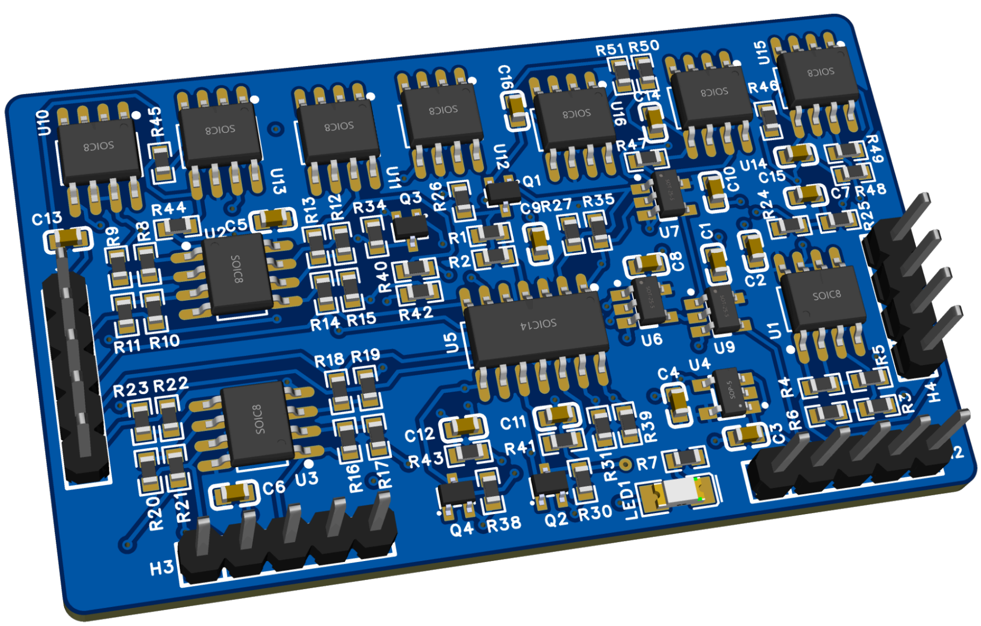

Fig. 6: Battery monitor PCB

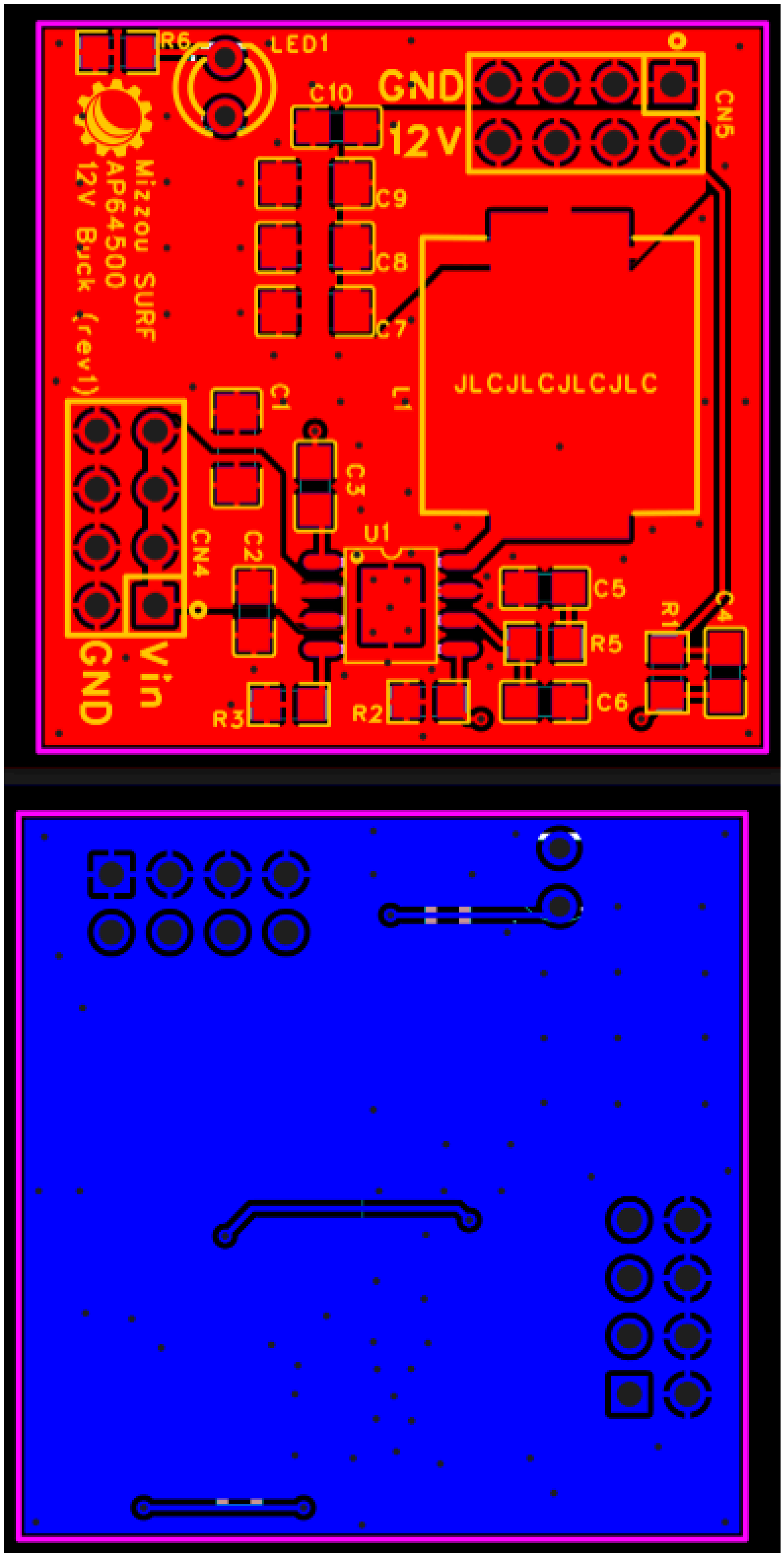

Fig. 7: Buck converter PCB

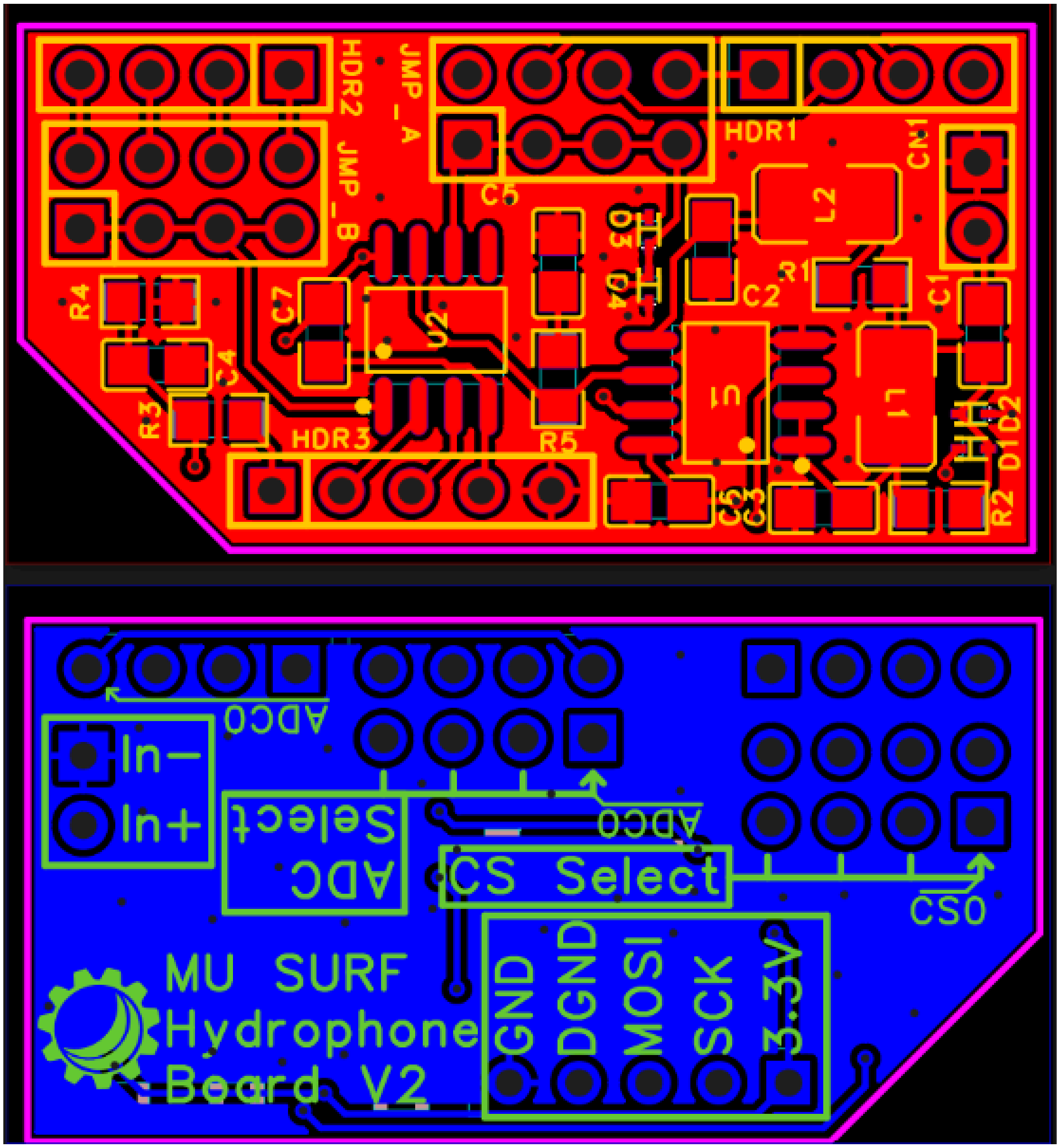

Fig. 8: Hydrophone stack PCB