Triton Robosub Technical Design Report 2020: *COVID-19* Edition
University of California, San Diego

E. Ansaldi, J. Borja, N. Carniglia, W. Chang, D. Drews, G. Graak, J. Griffin, S. Hollander, R. Ji, R. Johnson, R. Lai, I. Matin, W. McCloud, P. Paxson, C. Qin, A. Rivera, N.B. Rivera, L. Samaan, K. Singla, D. Truong, A. Vizuet, P. Xu, A.T. Yazdi, J. Ye

Abstract

The Triton Robosub team, representing the University of California, San Diego, was excited to return to Robosub in 2020. Our experience in the 2019 competition drove us to develop more accurate and more complex deep learning models for underwater computer vision, and new instruments like a Doppler Velocity Log and hydrophone array led us to rework our controls architecture using a Robotic Operating System core. With these new advances in our ability to see and navigate the environment, we also began implementing a grabber and torpedo system to interface with the props. However, the COVID-19 pandemic put a halt to our planned construction and testing season, so many of the hardware changes we were planning were put on hold. We hope to implement our plans in 2021, and see our fellow competitors next August!

I. Competition Strategy

For our debut year at the 2019 Robosub competition, our only goal was to successfully pass through the gate. We accomplished this goal during the second day of the competition, and turned our attention on the buoy mission. For the rest of the week, we attempted to train a machine learning model capable of discerning the buoys from the surrounding water. Though we did not successfully accomplish the buoy mission before the week ended, even our basic and haphazardly-trained model yielded some promising results. The experience we gained from attempting it helped us develop a more powerful and robust machine learning model in the following several months.

Because of our new and old members' expertise in the field, we made machine learning-aided computer vision our main focus for navigating the competition space. This decision informed the rest of our design at a hardware and software level, and we chose to attempt all of the missions that could take advantage of computer vision; namely the gate, buoy, bins, and torpedo missions. This meant that alongside the machine learning development, we needed interfaces to accomplish the bins and torpedoes, so our mechanical team began developing a grabber and torpedo launcher for their corresponding missions. We also received a sponsorship from Teledyne Marine, which enabled us to obtain a Doppler Velocity Log, prompting the mechanical team to redesign the modified BlueROV frame we were using in order to integrate this new hardware.

In addition to the aforementioned missions, we noticed that many teams were able to score higher point values by attempting the octagon mission at the 2019 competition. Its low risk and high reward prompted our electrical team to begin developing a hydrophone system to detect the pinger marking the octagon's location.

We knew that attempting to accomplish nearly all of the missions was an ambitious goal, but we were confident that our experience from the previous year would make the gate and buoys trivial. The remaining missions did not add a large amount of complexity to the overall design, because components like the torpedo and grabber could remain unimplemented without affecting the robot's overall performance. However, the addition of so many extra sensors prompted us to reconsider our software design, and we decided to migrate to a controls architecture built on Robotic Operating System for more modularity and compartmentalization. This change reduced the complexity of each individual part of the software architecture, enabling us to develop and test individual parts with lower risk.

Our planned integration timeline began with development of the software architecture, electrical schematics, and mechanical designs in Fall, and a planned construction phase in mid-Winter, finally bringing all subteams together for testing in Spring. However, due to the COVID-19 pandemic, our manufacturing source shut down before we could begin construction, and classes moved to a digital format for Spring. Our integration timeline unfortunately fell apart, and we shifted our focus to preparing for 2021 and working on what we could virtually.

II. Vehicle Design

A. Electrical Subteam

The goal of the electrical team this year was to implement pinger detection and direction localization, considering that last year, the team was not able to participate in the tasks directed by pingers. The electrical team acquired 4 H1c piezo-transducer hydrophones, and they attempted to develop a prefilter for the hydrophones to sample data for use with a MicroZed DSP solution as shown in **Figure 1**. The pre-filter was designed with two gain stages, one as an initial stage to capture the signal through high impedance and matching operational amplifiers and a variable one for

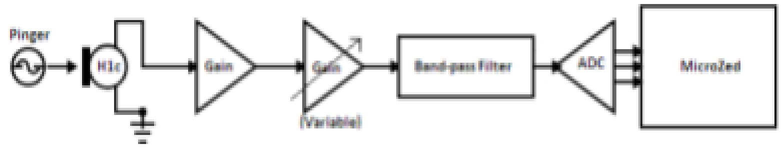

Fig. 1: Schematic for hydrophone preamplifier

dynamic conditions of testing in different environments. The signals went through a 6th-order Chebychev band-pass filter, utilizing the filter's ripple for more attenuation of noise before feeding it through an analog-to-digital converter. Here the team chose the LTC2325, a 16-bit, 5 Msps (mega-samples per second) ADC. Using this setup, it is possible to get 5 million samples per second, per channel using 4 parallel SPI lines. This gives the most crisp signal possible to the processor. To get the information to the processor, a MicroZed FPGA is used. An FPGA is extremely well suited to this application since it can handle the massive amounts of data being delivered in parallel. From here, an AXI bus delivers data to the processor where computations can be applied.

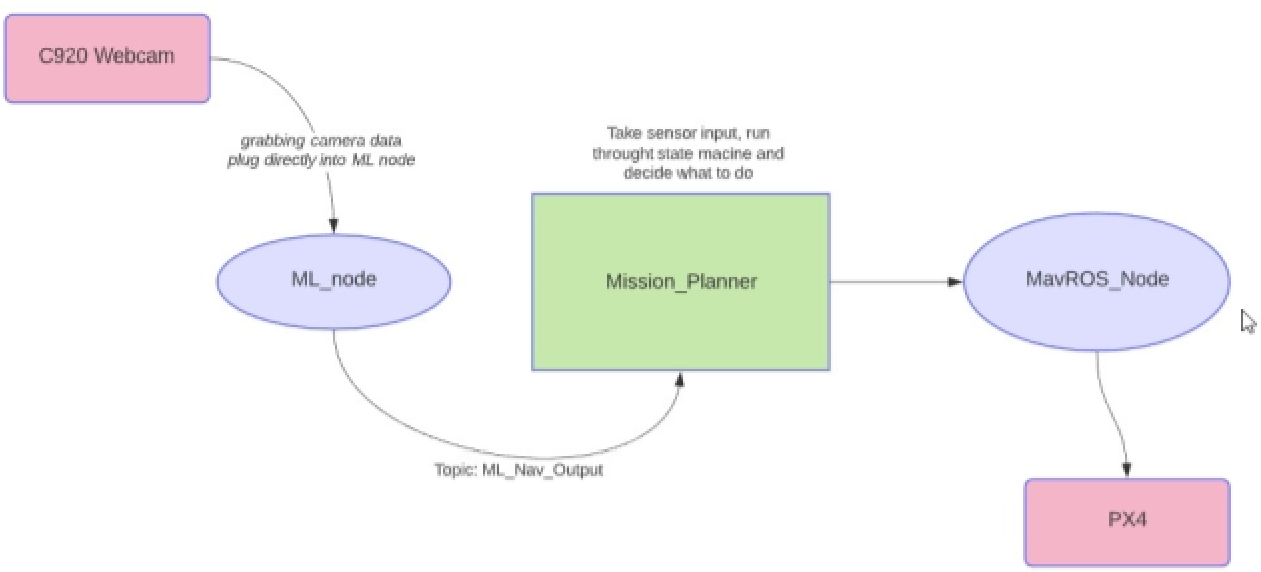

Fig. 2: Simplified overview of the controls flow using ROS.

After the signal has been digitized, the electrical team planned to implement a time-difference of arrival (TDoA) algorithm to deduce the direction of the pinger. First, two moving averages are used for determining the start time of the ping at each hydrophone. Using three time differences between four hydrophones, and assuming the ping is a plane wave, a least-squares optimization determines the most likely direction of the audio source. This direction is then sent over a TCP connection to the main control computer.

B. Software Subteam

The main improvements in vehicle software were seen in the improvement of deep learning models used for complex tasks such as object recognition. The software team researched a multitude of deep learning models to determine the best solution for object detection, and eventually settled on a custom implementation of the popular YOLOv3 network. Using data augmentation techniques in order to bolster the smaller training dataset we had, we were able to create a network that was much more accurate than our network from the previous RoboSub competition. The network was able to determine the location of important competition obstacles, even with test data from the murky waters seen in the competition.

As part of our software strategy for the competition, we decided to pursue simulating the underwater environment of the competition in order to gather testing data for our computer vision and object detection algorithms. We did so by creating the environment in the Unity3D game engine. In doing so, we were able to capture images from the perspective of the AUV of obstacles such as the gate from the start of the competition for object detection testing. The benefits of having a simulated environment is twofold. It allowed the software team to test code in isolation from hardware, meaning code could be tested remotely without having to put an AUV in the water. It also allowed us to experiment with simulated training data for our deep learning networks. The creation of large amounts of pre-labelled simulated data made training much easier, and lessened the burden on those collecting and labeling data.

The controls architecture was changed in order to accommodate extra sensors added this year, such as the Doppler Velocity Log (DVL). The software team utilized the Robot Operating System (ROS) in order to make communication between boards and processes much simpler.

C. Mechanical Subteam

The vehicle design is a modification of the stock BlueROV2 created by Blue Robotics. In order to make the vehicle fully autonomous and to be able to meet our competition strategy we needed to add more electronics boards, more sensors, and more systems that are not a part of the stock BlueROV2. To add these new components a redesign of the vehicle based off the stock chassis was done. To account for the new boards, we substituted the stock

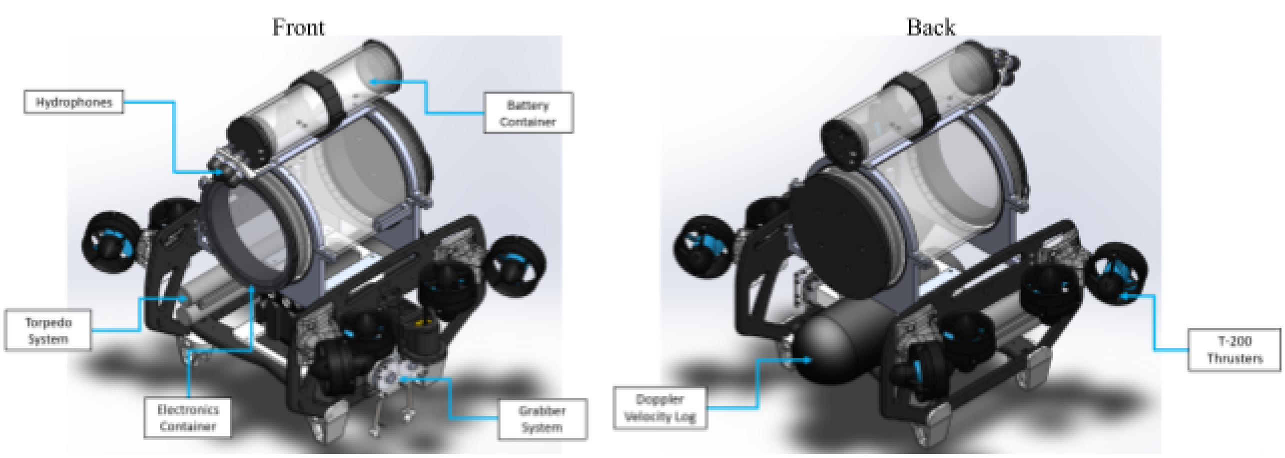

Fig. 3: Labelled 3-dimensional render of planned 2020 vehicle

6in container for a 8in container. A doppler velocity log was added to the bottom of the vehicle to enhance position tracking. The grabber system was added to the left side of the vehicle and the torpedo system was inserted into the center of the vehicle along the right side. All these additions to the vehicle changed the center of mass and required us to move the motor mounts to the outside of the chassis. The motors were also moved up slightly to account for the new center of mass.

The grabber system consists of multiple parts. The two arms have interchangeable 3D printed claws that would have allowed us to grab whatever object needed to be picked up in the competition and it allows for a quick replacement in case of damage to the tips. The arms are then attached to the gears which are then attached to the motor.

The torpedo system uses two compressed springs to independently launch two plastic torpedoes. Using a spring system greatly reduces the space required by the system as it does not need pressurized air tanks as with a pneumatic system. Using a spring system also avoids any potential electrical complications that are caused by an electromagnetic system. In order to further save space a wig wag pinion is used to release the springs with only one motor. This system functions by having three gears: one gear attached to a motor and the other two are attached to the mechanisms that release the compressed springs. When the motor rotates one direction it causes the powered gear to come in contact with one of the release gears and when it rotates in the other direction it causes the powered gear to come into contact with the other release gear.

The final design of the vehicle is a compact and functional design that vastly improves upon the stock design in allowing it to run, navigate, and manipulate things autonomously.

III. Experimental Results

Due to the COVID-19 pandemic, in-water results were limited. The mechanical team was not able to assemble any new components, but simulated stress and buoyancy tests yielded positive results.

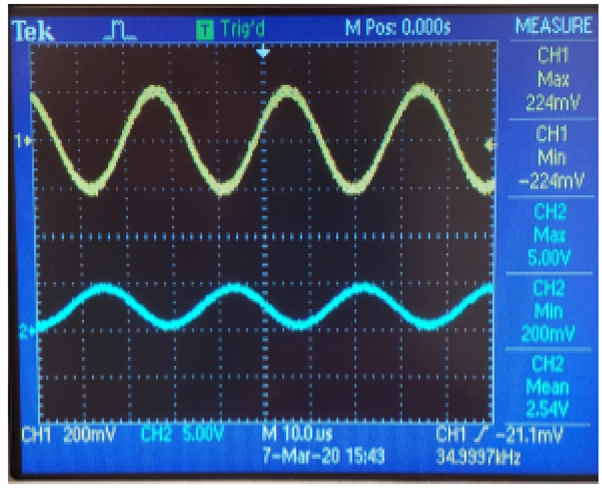

Fig. 4: Hydrophone Circuit Testing

The electrical team prototyped a prefilter for the hydrophones and **Figure 4** shows an example of some testing. A small hydrophone signal of peak-to-peak value of .5 V centered around 0 V was amplified to a signal in the range of 0-5 V for the analog-to-digital converter. It was a success that the electrical team was able to amplify small signals while filtering out the undesired range. During testing, it was observed that the bode plot of the signal was not as accurate as the simulated results, and it was enough to warrant further action. The electrical team sought to implement two separate options for the near future: implementation of the

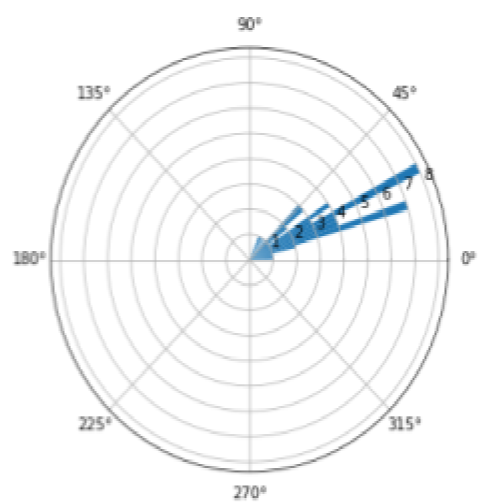

Fig. 5: Simulated Direction Results From Noise on Inputs

preamplifier circuit with a higher order filter or exploration with filtering digitally, ie. FPGA solution. Because of Covid-19, the electrical team lost access to lab space and testing equipment, so the circuit was not able to be fully developed and finely tuned. We look forward to next year improving on our designs.

On the algorithms side, the electrical team simulated and evaluated a variety of approaches for utilizing the digitized signal. Algorithms for determining direction from both phase difference and time difference were simulated and compared. It was determined that the accuracy advantage of the phase-based system did not overcome the mechanical and analog challenges associated. Once TDoA was decided upon, two methods for edge detection were evaluated using MATLAB simulations on both generated and real data. A jupyter notebook was constructed to visualize the response of TDoA to noise introduced into the ping start times. Using this, the electrical team found that up to 200us of error on the recorded times was acceptable, which provided design requirements for the rest of the system.

Deep learning was much more successful this year. By utilizing new data augmentation techniques, we were able to reach high accuracy on test images taken from the 2019 competition, even when objects were in murky water and a fair distance away.

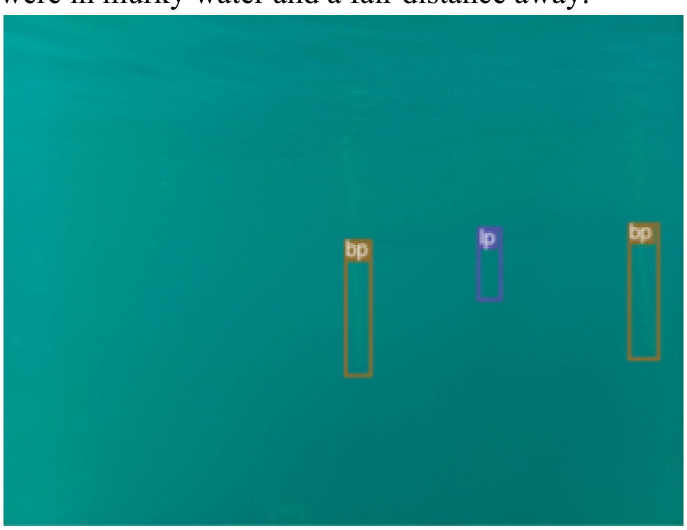

Fig. 6: Test of custom YOLOv3 network trained on competition data.

While experimenting with new controls architectures, we discovered that utilizing the ArduSub framework as we have been is inefficient with the use of custom sensors such as the Doppler Velocity Log (DVL). Because ArduSub is simply a modified fork of the ArduPilot library, many parts of it are specific to airborne drones, and do not function with our application. Next year, we aim to move away from this solution and implement a new controls architecture from scratch that will allow us to better integrate custom sensors.

IV. Acknowledgements

Triton Robosub greatly appreciates the support of our faculty advisors: Ryan Kastner in the CSE department and Curt Schurgers in the ECE department. Their mentorship aided our decision-making and kept our focus on getting results. We would also like to thank Eric Lo and Nathan Hui for their help and advice throughout the year. We would not have been nearly as successful as we have been without their expertise and IMMENSE patience. A special thanks to the Kastner Research Group for providing the base BlueROV2 and a cutting edge laboratory space where we could work pre-pandemic.

We would also like to thank the Scripps Institution of Oceanography for allowing us to perform tests in the Keck pool throughout the year. The data and results gathered from these tests have proved invaluable to us.

Financial support in our sophomore year was tremendous. Thanks to the generous support of the Jacobs School of Engineering IDEA Center, as well as the support of local companies like BrainCorp Inc, we were able to purchase raw materials for our electrical system and mechanical construction, as well as various competition fees. We'd also like to thank Teledyne Marine in particular for the largest donation we've ever received in the form of the Explorer DVL. This donation single-handedly prompted us to push forward with our redesign, and we are very excited to finish integrating it into our system in 2021. We look forward to expanding our reach in our community in the future for even better innovative design.

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APPENDIX A: COMPONENT SPECIFICATIONS

I. HARDWARE

Component	Vendor	Model/Type	Technical Specifications	Cost
Frame	Blue Robotics	BlueROV2	**Material:** High-density polyethylene	$339.00
Waterproof Housing	Blue Robotics	Watertight Enclosure	**Diameter:** 8”	$343.00
Waterproof Connectors	Blue Robotics	M10 Cable Penetrator	**Quantity:** 8 **Diameter:** 6mm	$4.00
	Blue Robotics	M10 Cable Penetrator	**Quantity:** 4 **Diameter:** 8mm	$5.00
Thrusters	Blue Robotics	T-200 Thrusters	**Quantity:** 6 **Operating Voltage:** 7-20 V **Full Throttle Forward Thrust:** 5.25 kg f **Full Throttle Backward Thrust:** 4.1 kg f	$179.00
Electronic Speed Controller	Blue Robotics	Basic ESC	**Quantity:** 6 **Amperage:** 30 amp **Firmware:** BLHeli_S	$27.00
Battery	Blue Robotics	Lithium-ion Battery	**Power:** 14.8V, 18Ah **Weight:** 2.9 lbs	$289.00
Power Converter	Amazon	D-PLANET	**Quantity:** 2 **Power:** 5A at 4-38V to 1.25-36V	$14.00
CPU	Nvidia	TX2	**GPU:** 256-core NVIDIA Pascal™ GPU architecture with 256 NVIDIA CUDA cores **CPU:**Dual-Core NVIDIA Denver 2 64-Bit CPU	$377.32

			Quad-Core ARM® Cortex®-A57 MPCore **Memory:** 8GB 128-bit LPDDR4 Memory 1866 MHx - 59.7 GB/s **Storage:** 32GB eMMC 5.1 **Power:** 7.5W / 15W	
Internal Comm Network	TP-Link	TL-SF1005D	**Number of Ports:** 5 **Speed:** 100Mbps **Power:** 1.9W	$9.99
External Comm Interface	Blue Robotics	Fathom-X Tether Interface	**Speed:** 80 Mbps Ethernet over two wires **Max Length:** 300m+ tether length **Power:** Onboard switching power supply with 7-28V input range	$85.00
Development Board	Avnet	MicroZed	**System on Chip:** XC7Z010-1CLG400C **Memory:** 1 GB DDR3 SDRAM 128 Mb QSPI Flash	$199.00
Flight Controller	Pixhawk	Pixhawk 1	**CPU:** STM32F427 180 MHz ARM® Cortex® M4 with single-precision FPU **RAM:** 256 KB SRAM (L1) **Sensors:** ST Micro L3GD20H 16 bit gyroscope, ST Micro LSM303D 14 bit accelerometer / magnetometer, Invensense MPU 6000 3-axis accelerometer/gyroscope, MEAS MS5611 barometer	$219.90
Doppler Velocity Log	Teledyne	Explorer	**Bottom Tracking Altitude:** 81m **Water Profiling Range:** 35m **Center Frequency:** 614.4kHz	$15,759.00

			Depth Rating: 1000m **Power:** 12W	
Front Camera	Logitech	C920	**Max Resolution:** 1080p	$79.99
Bottom Camera	Teledyne	Camera with waterproof enclosure	**Interface Type:** Analog	Unknown
Hydrophones	Aquarian Hydrophones	H1C	**Quantity:** 4 **Sensitivity:** 1 V/µPa **Range:** 1 Hz-100 kHz	$139.00

II. Software

Control Unit	Language(s)	Tools/Libraries
Computer Vision	Python	ROS LabelImg PyTorch Custom YOLOv3
State Machine	C++	ROS
Motor Control	C++	ROS ArduSub
Simulation Tool	C#	Unity3D

III. Team Information

Team Size	24 people
HW/SW expertise ratio	13:9 (4 electrical, 9 mechanical, 9 software, 1 systems, 1 design)
Testing time: simulation	80 hours
Testing time: in-water	10 hours

Appendix B: Outreach Activities

We love participating in outreach events to further the engineering community around us in San Diego! This past year, we joined our fellow engineers in the Society of Hispanic Professional Engineers to teach children at Logan Elementary School about basic engineering concepts. We also participated in and hosted many on-campus events, such as a Robotic Operating System workshop with our friends at the Association for Computing Machinery, a Reverse Career Fair with the ECE Undergraduate Student Council, and the UCSD Summer Research Conference in 2019. We even made a splash at the Triton Engineering Student Council's Engineering on the Green, setting up a 10 foot wide, 30 inch deep pool to show other students what Robosub is all about!

In addition to working with the general engineering community, we love working with other Robosub teams! After the competition last year, we invited members of the San Diego Robosub teams to join a shared Discord server so that we can trade tips and events. Through this, SD City Robotics from San Diego City College joined us for a tour of BrainCorp, one of our sponsors. We also met with Team Terra from the Federal University of Santa Catarina (UFSC) over Zoom to give them some tips based on our experience at the competition, and working with a BlueROV.

We have many more events planned for the upcoming year, and are excited to connect with even more engineers and get them excited about underwater robotics!

Fig. 7: Triton Robosub members presenting at the Reverse Career Fair

Fig. 8: A group picture with the UCSD Summer Research Conference particpants

Fig. 9: A tour of BrainCorp's testing facility with SD City Robotics

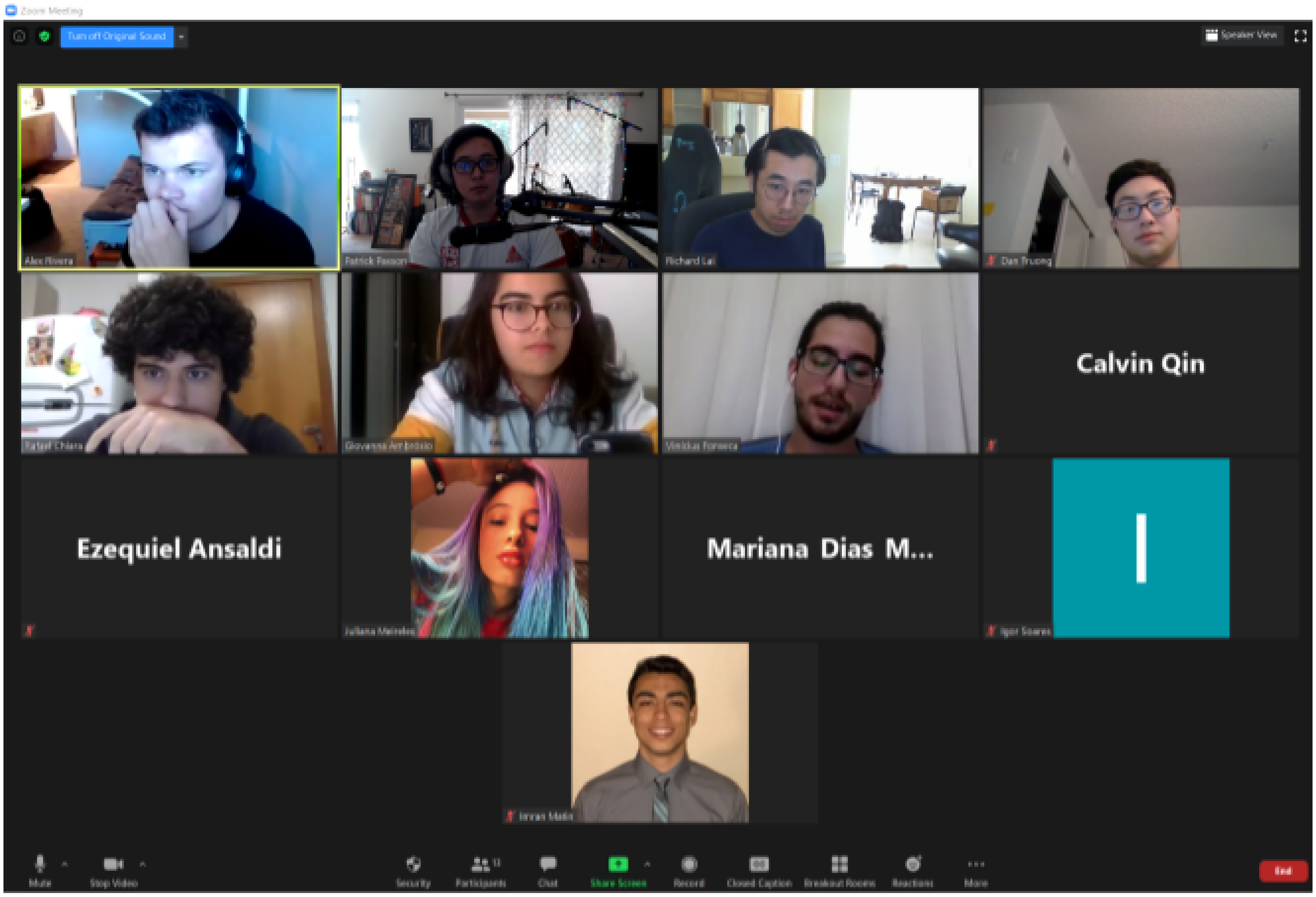

Fig. 10: Collaboration with Team Terra over Zoom