SDSU Mechatronics 2020 Autonomous Underwater Vehicle (AUV): Scion

Sarah Melissa Gomez, David Pierce Walker-Howell, Eduardo Daniel Campas, Christian Gould, Alexa Becerra

ABSTRACT - Scion is the Mechatronics AUV design created for the 2020 Robosub competition. The design's main goal is to improve on the modularity, performance, and safety of past vehicles, while adhering to the team's competition strategy. This strategy is to focus on a limited selection of obstacles to repeatedly and reliably score points, as opposed to attempting all obstacles with a limited success rate. These decisions yielded a mechanical design with a renovated vision system, modular mechanisms, and redundant water seals to prevent damage to the vehicle's electronics. Our team also developed a generalized electrical system capable of accepting any printed circuit board with a common interface, with ample opportunity for future expansion.

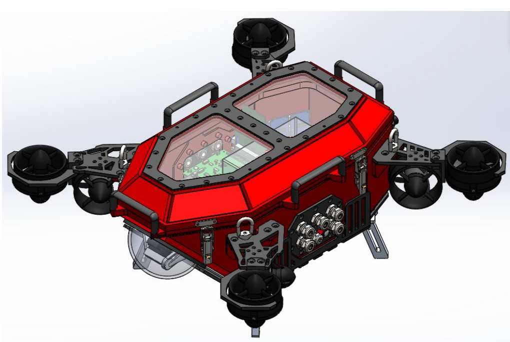

Fig. 1: Solid CAD Model of Scion

I. COMPETITION STRATEGY

Mechatronics' competition strategy for Robosub 2020 is to focus on consistency of completing a few tasks with high confidence rather than attempting to multi-task with low confidence. The tasks that were prioritized were the initial starting gate and the buoy tasks. For the initial starting gate, our team also focused on being able to identify and move through the correct side for the coin flip, as well as be able to spin while moving through the gate for style points. We also wanted to be prepared to attempt the torpedo task and dropper task, which is why our vehicle design included developing a pneumatic system for our payloads. Finally, if successful in these tasks during the competition run, we would attempt to navigate to the octagon and rise to end our run.

To meet this challenge, the Mechatronics software team has focused on perfecting movement and computer vision. By focusing on these two areas, the software team can better monitor performance, and individual contribution metrics from developers.

More detailed and extensive testing was performed on the navigation system to ensure it can maneuver the vehicle accurately. Given the increased performance in the control, higher level design of autonomy can be developed for completing tasks without worrying about the consistency of control. There was also a greater focus on improving the computer vision system.

II. VEHICLE DESIGN

The overall design of Scion focused on maximizing scoring with the aforementioned obstacles while improving on previous designs' modularity and safety. These goals ensured that the resulting vehicle was simple, robust, and confidently able to interact with the selected obstacles. The design also leaves room for future hardware and software additions to expand the AUV's capabilities.

A. Mechanical Systems

The AUV consists of an Aluminum 6061-T6 enclosure, built from panels of 0.25” and 0.5” thickness that are welded together and anodized. A singular lid, located at the top of the enclosure, utilizes an O-ring seal to form the only access point of the enclosure. The purpose of having only one sizable access point is to facilitate access to the internal components and to expedite troubleshooting. It also serves as a safety measure against potential leaks since there is only one seal that is repeatedly removed. The enclosure's geometry provides abundant space for the electrical system. Its symmetric shape facilitates buoyancy control by keeping the center of gravity close to the center.

Scion's design includes replaceable Input-Output panels (I/O Panels), which are flat aluminum plates that attach to the enclosure via O-ring seals. These panels contain cable pass-throughs for all of the connections that travel from the inside to the outside of the AUV. New panels with different pass-throughs can be made to accommodate design changes, eliminating the dangers of performing irreversible milling operations directly on the enclosure. Since this AUV is smaller than previous designs, an I/O Box was included at the rear to increase the available surface area for pass-throughs. This box contains five pass-through surfaces as opposed to one provided by an I/O Panel. Both components are shown in Figure 2.

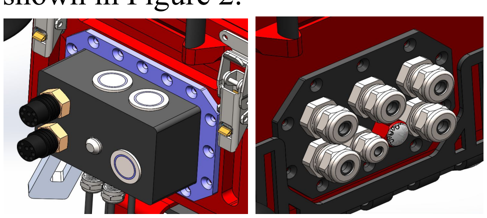

Fig. 2: I/O Panel (Top) and I/O Box (Bottom)

Another inclusion of modularity in Scion's design is the variety of mounting points for payloads and external sensors. The external frame, which spans the belly and the sides of the enclosure, contains various slots with a standard width to provide ample mounting space for mechanisms added in the future (Figure 3). The frame is constructed from 5052 Aluminum to facilitate sheet metal bending.

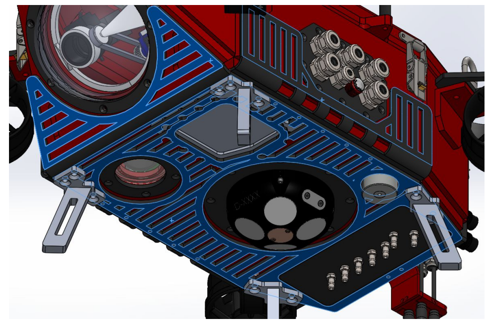

Fig. 3: External Frame (blue) of the AUV

Modularity also extends to the inside of the vehicle. An internal frame provides spots for mounting electrical hardware. This frame is replaceable, similar to the I/O Panels. A new internal frame with different mounting holes can be made in the event that the electrical design changes.

In terms of vision, Mechatronics has utilized camera systems for obstacle tracking in the past. These systems have featured one static forward-facing camera and one static downward-facing camera. However, Scion uses a tilting camera system (Figure 4). This was chosen over the traditional vision method to increase the AUV's field of vision and to eliminate blind spots created by objects traveling in the area between both camera lenses. The new setup consists of a belt-driven pulley system that rotates the camera to face either forward or downward, depending on where the tracked object is located. This subassembly is housed inside of a 6" transparent acrylic dome. The pulleys are driven by a SG90 9G micro servo motor.

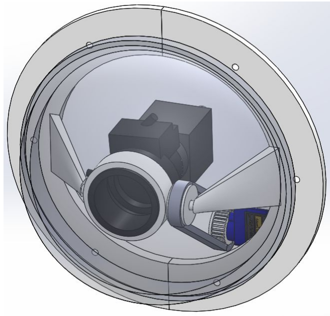

Fig. 4: Tilting Camera System

Safety against water leaks has been proficient in the past, but not perfect. While permanent O-ring seals have never failed, water can penetrate the hull and damage electronics if the removable lid is not properly closed. Therefore, measures have been taken to protect the electronics from water once it has already entered the enclosure. One such measure is to add redundant O-ring seals to the Doppler Velocity Log (DVL). A face seal protects the DVL against water from the outside of the vehicle, while two radial seals protect the device from the inside. These radial seals are formed by compressing two O-rings with a custom-made DVL Cap (Figure 5).

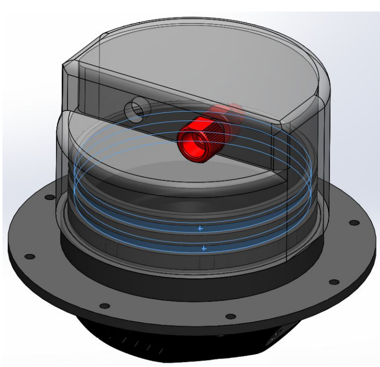

Fig. 5: DVL Cap (transparent) and Radial O-ring seals (blue)

For the same reason, Mechatronics has opted to design and fabricate a custom pneumatics manifold (Figure 6). Customizing this component allows it to be designed such that all pneumatics tubing travels on the outside of the vehicle. This reduces the risk of the pneumatics system causing a water leak in the event of a malfunction. The new manifold rests within the bottom panel of the AUV's enclosure and a plate that contains an O-ring seal.

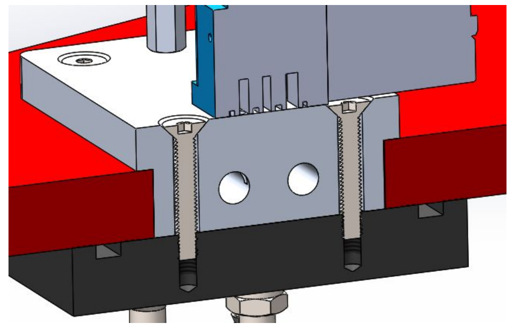

Fig. 6: Cross-Section of Manifold (silver) and O-ring seal plate (black), attached to the Enclosure (red)

B. Electrical Systems

The electrical system was designed with a primary focus of modularity, scalability, and simplicity. The electrical system in the vehicle performs safe power management and reliable command and control of the sensors and actuators.

The power management system (PMS) breaks out 6V, 12V, and 19V power rails from a single 16000 mAh 4s LiPo battery. These voltages are regulated through 3 separate DC-DC converters. Our power distribution board (PDB) contains a variety of XT30, XT60, and XT90 connectors on each of the power rails to provide plug-and-play access to power.

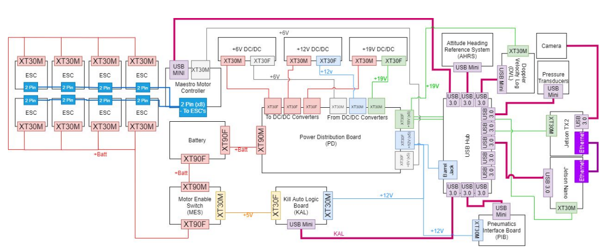

Fig. 7: Electrical System Diagram

The 8 T200 BlueRobotics thrusters are powered directly from the battery due to the high current requirements of the thruster's brushless DC motors. For safety purposes, we designed and implemented a high power MOSFET switch, called the Motor Enable Switch (MES), that can cut power to the thrusters in case of an emergency. The MES is electrically controlled by our Kill Auto Logic (KAL) board via a capacitive button on the rear face of the vehicle or through command of the on-board computer. MES and KAL also have built-in features to autonomously kill the vehicle as it approaches unsafe power conditions.

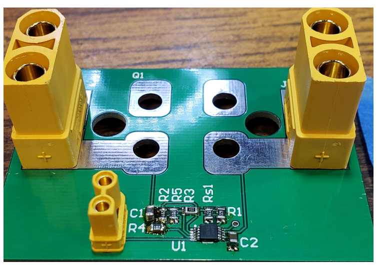

Fig 8: Motor Enable Switch (MES) high power switching MOSFET board.

The various sensors on-board include: Sparton AHRS 6E for vehicle orientation, Nortek DVL1000 for velocity measurements, BlueRobotics I2C pressure transducers for depth measurement, and Point Grey cameras for vision perception. Each of these sensors have interfacing with USB to allow easy connection and communication to the on-board computers.

A Pneumatics Interface Board (PIB) was developed to digitally control the 12V solenoids for our torpedo launchers and dropping mechanism. It communicates to the main computer through USB and can support up to 8 solenoids.

A custom DC brushed motor controller with current sensing feedback was developed for compatible control of the Teledyne SeaBotix Grabber Attachment. This provides the ability for manipulation with tactile feedback.

C. Software Systems

The software system is developed primarily in Python because of its simplicity, ease in learning, and speed of prototyping designs. All lower level and repetitive software is compiled in either C or C++ with Python wrappers for use within higher level code.

The software architecture of the system is divided into multiple separate subsystems that are highly parameterizable and easy to test. These systems run independently of each other, and can be containerized.

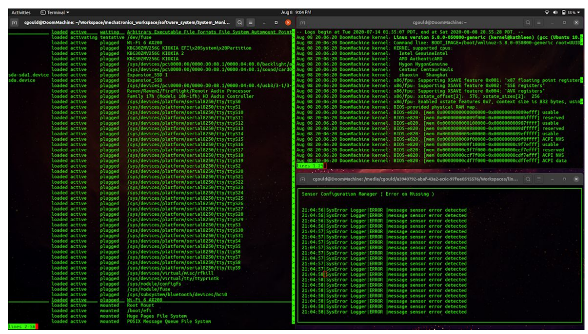

Fig. 9: System monitor display

The primary system is the System Monitor (Fig. 9). This Monitor controls tasks in both computers, and gives telemetry from both. The monitoring system is composed of systemd wrappers and hooks into systemd startup and shutdown systems. This utilizes native features of the linux operating system to control and queue tasks, as well as monitor and kill them if necessary. Using the SLURM workload manager for clustered HPC systems, both computers can be controlled simultaneously, giving a holistic view of the whole system. The system monitor is tightly bound with the systemd init system, and therefore starts at boot and is given the highest authority within each native process queue.

There is also the Data Gathering System, which collects information from each sensor and adds derivation or integration telemetry to consecutive data points. It also responds to real time interrupts and power on-off events. This subsystem was implemented on the NVIDIA Jetson Nano.

The Control System is containerized, and holds the second highest priority after the System Monitor. The Control System is a Proportional-Integral-Derivative (PID) controller with different control modes for each position. By switching between control points, Scion can perform complex movements, such as rotating along multiple axes and traveling in a particular direction simultaneously.

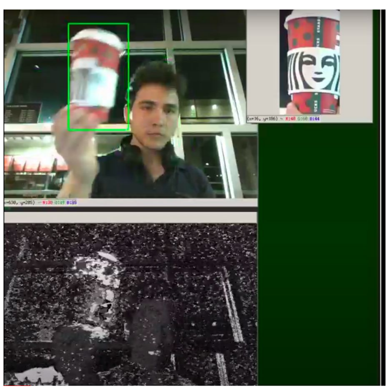

Fig. 10: Computer vision detection system

The Computer Vision System uses OpenCV's tracking module, as well as the Tensorflow MobileNetv3 architecture to capture and track detections. This system is implemented on the NVIDIA Jetson Tegra, and is directly connected to the vehicle's camera system.

IV. EXPERIMENTAL RESULTS

This year, due to challenges set by COVID-19, Mechatronics achieved less testing than desired.

The core electrical components for the power system, actuators, and sensors were successfully dry tested. The testing of the new MES and KAL boards showed significant improvements in safety and reliability in the power management system.

Due to not being able to physically test the mechanical systems, the team relied heavily on simulations and engineering calculations to ensure that the mechanisms are validated. Finite Element Analysis (FEA) was utilized to increase the load capacity of the thruster mounts to prevent yielding or breakage due to impacts. Load calculations were performed on the top lid's O-ring seal to ensure that the latches are strong enough to compress and maintain the seal. Additionally, Solidworks was used to manipulate mass properties and ensure that the AUV is buoyant while keeping the center of gravity below the center of buoyancy.

IV. ACKNOWLEDGMENTS

The Mechatronics team would like to thank the SDSU Engineering Department as well as our corporate sponsors: Northrop Grumman, General Atomics Aeronautical, Mathworks, BrainCorp, McMaster-Carr, and Altium.

We would also like to especially thank our faculty advisor Theresa Garcia, as well as Donovan Geiger for supporting us.

VI. REFERENCES

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[2] Labelbox, "Labelbox," Online, 2019. [Online]. Available: https://labelbox.com

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Cost
Buoyancy Control	PVC Pods			
Frame	Custom 6061 T6 anodized aluminum, 0.25" Thickness			
Waterproof Housing	Custom 6061 T6 anodized aluminum, 0.25" and 0.5" Thickness			
Waterproof Connectors	Seacon	WET-CON		$300
Thrusters	Blue Robotics	T200		$169
Motor Control	Blue Robotics	Basic ESC	30 amp	$27
High Level Control	NVIDIA	Jetson Tegra X2 and Jetson Nano		$599
Actuators	None			
Propellers	Blue Robotics	T200		$169
Battery	Hobby King	Lipo Battery	16000 mAh 4s 10c Multistar	$101
Converter	None			
Regulator	Mini-Box	DCDC-USB		$54
CPU	NVIDIA	Jetson Tegra X2 and Jetson Nano		$599
Internal Comm Network	USB			
External Comm Interface	Seacon	Seacon Cable		$1000
Programming Language 1	Python			
Programming Language 2	C			
Compass	Sparton	AHRS 6E		$1500
Inertial Measurement Unit	Sparton	AHRS 6E		$1500
(IMU)				
Doppler Velocity Log (DVL)	Nortek	DVL1000		$18,000
Cameras	Point Grey	BFLY-U3	808x608 Resolution	$325
Hydrophones	Sparton	PHOD1		$999
Manipulator	Teledyne Seabotix Gripper	TJG300-2I-L-V	Three Jaw, Long, 600mm	$2,995
Algorithms: vision	Tensorflow MobilenetV3			
Algorithms: acoustics	N/A			
Algorithms: localization and mapping	DVL, AHRS			
Algorithms: autonomy	PID			
Open source software	OpenCV, systemd, Tensorflow,			
Team size	20			
HW/SW expertise ratio	1.5			
Testing time: simulation	Not applicable			
Testing time: in-water	Not applicable			

Appendix B: Outreach Activities

Mechatronics is proud to participate in Science, Technology, Engineering, and Math (STEM) outreach, and strives to promote education in STEM in the San Diego community and beyond.

Our team is an active participant in school events where we showcase our vehicles and spread awareness of the RoboSub competition.

Fig. 11: Our RoboSub vehicles on display at the Robotics Showcase Extravaganza.

Mechatronics also volunteered at the Robotics Showcase Extravaganza 2020 in San Carlos Library. In addition, Mechatronics engaged with engineering companies by presenting our RoboSub vehicles to BrainCorp, ABL Space Systems, and SpinLaunch.

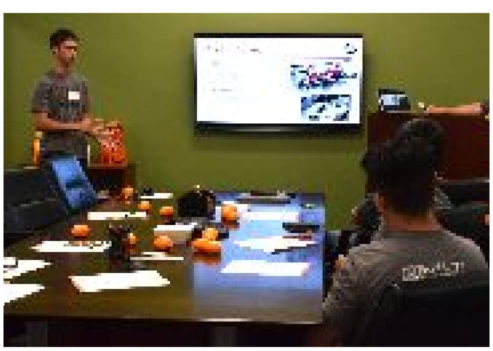

Fig. 12: Vehicle design presentation at BrainCorp facility during a tour.

We were also scheduled to participate in other events in the spring that were cancelled due to COVID-19, but our team is already looking to continue outreach activities virtually as best as we can.