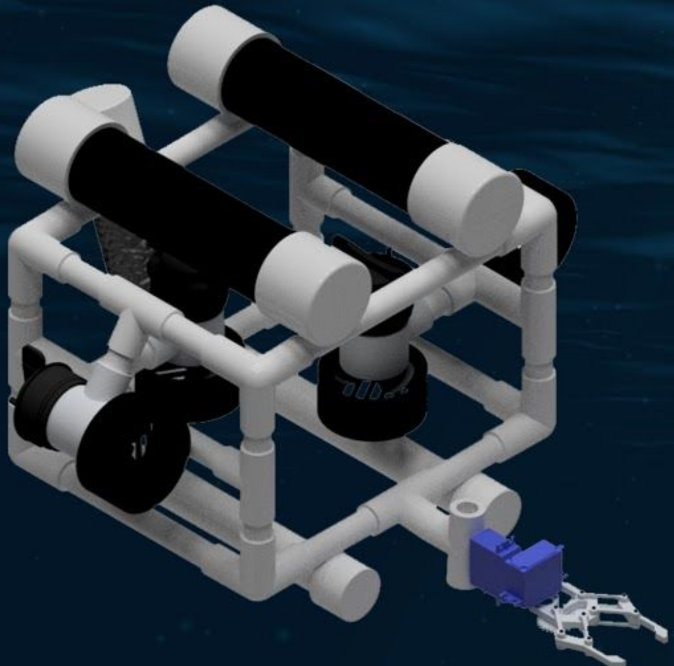
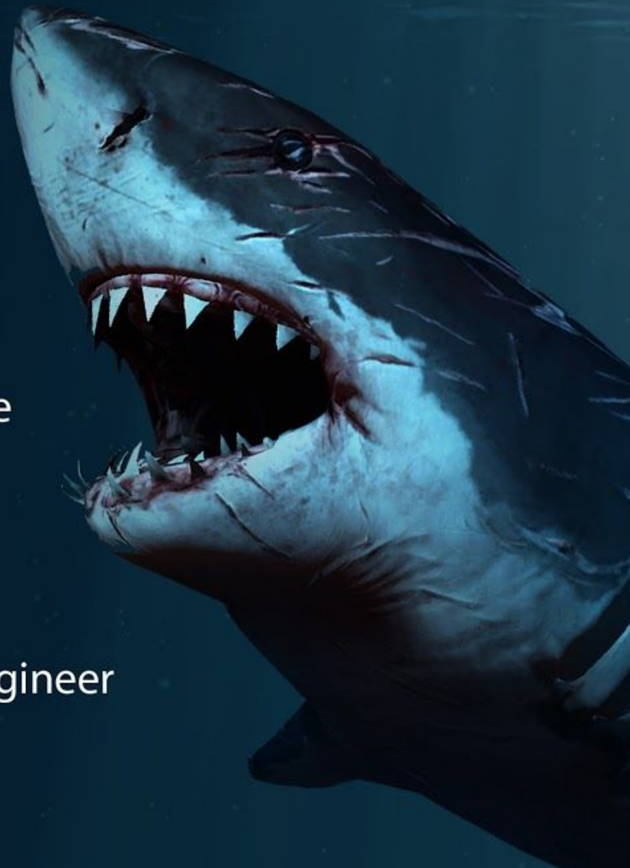
45C ROBOTICS
CAMS ROV ROBOTICS TEAM

TRITON VI

CAMS High School
Carson, CA
MATE 2017





Jiajer Ho '16 - CEO and Electrical Lead
Isaac Neil-Zanoria '15 - Electrical and Software
Ted Lin '15 - Software Development Lead
Brad Biscocho '15 - Mechanical Engineer
Celia Yu '16 - Mechanical Engineer
Isaac Addis '15 - Design Lead and Writer
Kentaro Vadney '16 - Lead CAD Engineer
Jesse Leal '16 - Technical Report Writer and Engineer

Sandra Barnett - Mentor

Table of Contents:

Abstract

45C Robotics has worked endlessly to manufacture *Triton VI*. Our ROV is designed to perform a variety of tasks necessary for the well-being of the Port of Long Beach. *Triton VI* has been developed for underwater usage, and is capable of performing various tasks: (1) assisting the instillation of a Hyperloop system, (2) conducting maintenance on the port's water and light show, (3) identifying and collecting samples of contaminated sediment as well as remediating the area, and (4) identifying contents within containers.

45C Robotics has implemented precise engineering into all aspects of its design, including the robot's electronics and software. 45C utilizes design-oriented programming along with source control management to streamline the software engineering process. Multiple microcontrollers and an off-board main computer are utilized to power and control the system with fluidity for the electronics system.

Triton VI is the result of endless hours of engineering which goes above and beyond the requirements for the 2017 MATE ROV Competition. The robot has been tested in mock situations and the 45C team is proud to present *Triton VI*.

The following technical documentation describes the design rationale and engineering process behind the creation of *Triton VI*.

Figure 1: 45C Robotics Team Picture

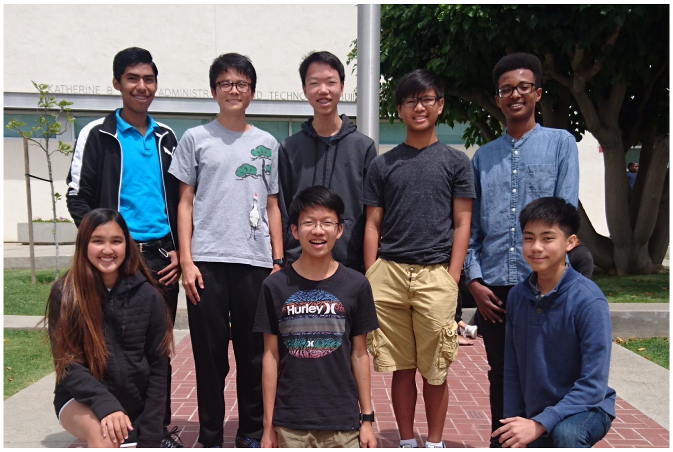
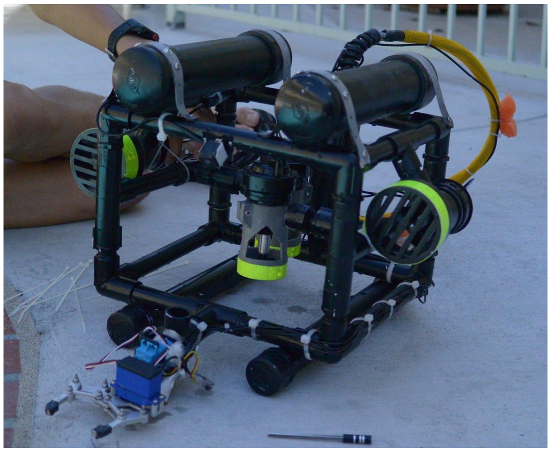


Figure 2: Triton VI during construction



Safety

A. Safety Philosophy

45C Robotics holds safety as its highest priority to ensure the wellbeing of all employees, customers, and robots is preserved. The company always considers safety in all activities and developments of the robot to prevent accidents within the work environment.

B. Safety Guidelines

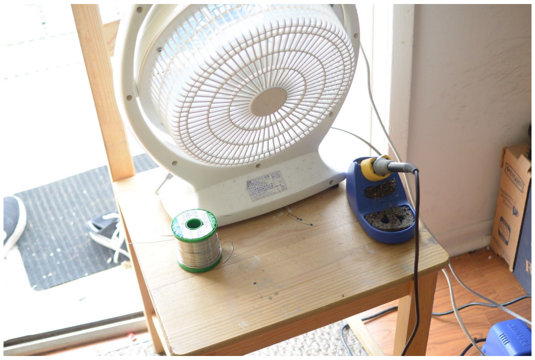
45C enforces various safety measures throughout the manufacturing process of the robot by having all team members conform to clothing requirements and requirements for appropriate equipment application at all times. In addition to the MATE Safety Guidelines, 45C Robotics has adopted an additional safety checklist that is observed before and after each water test of the ROV. Each subteam also has their own safety checklist and procedures.

C. Safety Features

Triton VI has been developed with an emphasis on safety. Throughout *Triton*'s development "dry runs" of the robot were held periodically to ensure the mechanical and electronic components were working properly, before being tested under water.

Any team member programming the ROV is required to save any progress by committing to the project on GitHub instead of overwriting existing files. By doing so, a backup of the program is available if the new code malfunctions. In addition, team members are encouraged to comment on any code they write, so others can easily understand iterations of the code. 45C also incorporates TDD, or Test-Driven Development, by testing each individual function of the code on hardware before porting the code to the main program that runs everything. This way, the engineers can quickly solve any problems and avoid issues that may occur when the central program is ran.

Figure 3: *Soldering Station*



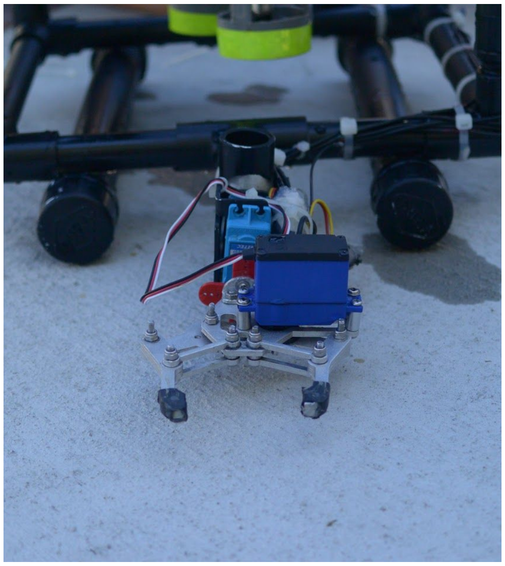
Proper ventilation and protection by way of fans and goggles are required whenever soldering. In addition, team members working on electronics must warn everyone working on the robot before activating/deactivating the power supply to the robot or before testing any moving parts, such as servos and motors attached to the ROV.

Design Rationale

A. Mechanical Design Rationale

During development 45C made use of a step-by-step design process to strive for maximum efficiency. First, members of the team began this process by brainstorming many ideas, with no constraints on any idea. Brainstormed designs were then compared and evaluated through a decision matrix with the following criteria: cost, size, weight, and simplicity.

Figure 4: *Claw Gripper*



Manipulator

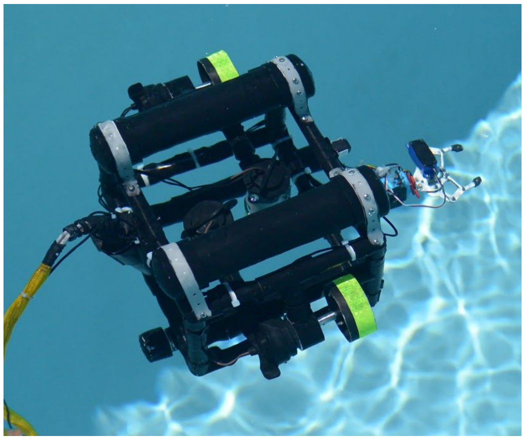
The Triton VI's Claw Gripper consists of 2 servo motors operated by an arduino microcontroller. A dual servo design allows the claw to rotate 180 degrees for optimal vertical and horizontal claw positions. Additionally, the claw's rotation greatly aids on rotating the valve required in task 2. An alternative method to completing this task would be to continuously hit the valve with our ROV until the valve comes loose, which we have deemed as a less efficient and effective technique. The claw's grip has been significantly improved with the addition of rubber heat shrinks on the ends of the claw as depicted in **Figure 4**. The claw's servo motor is manually controlled with a button on the control box system which opens and closes the gripper. The second rotating servo is controlled with a linear potentiometer which can rotate a full 180 degrees, providing the pilot with realistic tactile controls. Our gripper design enables the Triton VI to acquire the objects required to successfully complete the 2017 MATE ROV mission.

To decide the most efficient and effective servo motor, 45C Robotics compared possible models across several criterias that needed to be met.

Decision Matrix: Claw's rotation Servo Motor						
Servo:	**Cost**	**Quality**	**Simplicity**	**Efficiency**	**Rotation**	**Total**
Model 1	+	0	0	-	-	**-1**
Model 2	0	-	-	0	0	**-2**
Model 3	0	+	-	+	0	**1**

Frame

Figure 5: *Structure Design*



The robot was developed to be compact and simple to maneuver for practical use in the Port of Long Beach. The compact frame is most beneficial and effective in task 3 where the ROV must maneuver inside the platform to disengage the locking mechanism. Our compact frame allows our ROV to enter the platform through the smaller opening which saves time. Our previous design had a large frame which increased our total time and difficulty of maneuvering the ROV. Our newly designed frame is constructed mainly of Polyvinyl Chloride (PVC) piping due to the material's strength, cost-efficiency, and malleability. To abide by size constraints, the frame's dimensions are 26.67 cm x 31.75 cm x 21.27 cm.

Figure 6: *Makerbot 3D Printer*

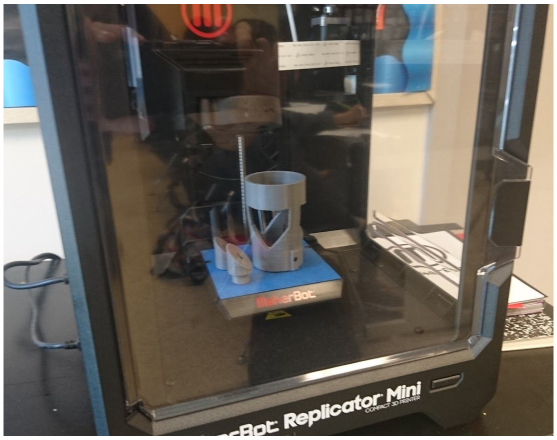


Figure 7: *3D Model of Shrouds*

3D Printed Motor Mounts

The motor mounts of the Triton VI were 3D printed. It was decided that 3D printing would be the best design choice due to the lightweight material of 3D printed PLA plastic. Heat was not transferable through the base of the 3D printer we borrowed, so our only non-heat required material we could use was PLA as well. Also, shrouds used for the forward/backward motors would not have provided a secure fitting. 3D printed shrouds were later reinforced with silicone and resin in order to withstand the force of the thrusters. Silicone is also hydrophobic, which can significantly reduce the risks of water damage to the thrusters.

B. Electronics

Figure 8: *SmartSystem Display*

Smart System

The Triton VI’s Smart System provides a safe protection circuit for the Triton VI’s computer hardware. Smart System constantly monitors the voltage, current, and internal temperature. The system also displays the active position of the claw and the claw’s angular position from its initial position. Aforementioned system was developed to insure a safe environment is maintained when operating the Triton VI.

Control Box

The Triton VI’s control system provides realistic feedback when operating the ROV. Buttons are well located and clearly labeled making piloting Triton VI as simple as possible. Low power LEDs within the buttons are used to indicate which switch is active at a glance. Furthermore, the buttons are also rated IP55 dust and water resistant, making them durable and long lasting.

Figure 9: *Control Box Buttons*

Figure 10: *Joystick Controls*

Joystick Control

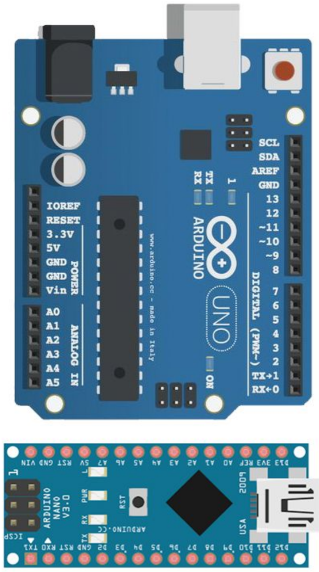
The joystick controls on the Triton VI are separated from the control box by a one meter tether. This allows one operator to pilot the Triton VI while the other operator control the switches on the control box. This design maximizes efficiency of the 2 operators and prevents unwanted interruptions.

Tether Mount System

Triton VI's tether is neatly organized in an ABS fitting to secure crucial wires to the robot into place. This tether system also makes repair simpler and helps organize the wires of the system. The tether mounting system also provide strong strain relief for the Triton VI.

Figure 11: *Tether*

Figure 12: Arduino Uno and Nano



Computing System

The Triton VI utilizes three Arduino microcontrollers to increase processing speed. An Arduino Nano with the ATMega328 chip handles the Smart System and reads inputs from a button and a linear potentiometer which control the two servos of the claw gripper. The Smart System is programmed to check for voltage, current, and temperature changes in the control box every 200 milliseconds. If any changes are detected, the Arduino Nano will notify the pilot with a five volt piezo buzzer and a 1602 display. The display is connected to a serial IC module to reduce the 16 pins of the display to only 4 pins. The Arduino Uno with the ATMega328P chip reads the analog input of the joystick potentiometers and converts it into digital output for the relays to control the thrusters.

C. Software Design

45C emphasizes software functionality and modularity to avoid software-related issues underwater. Important methods in the *Triton VI*'s code are all diagrammed to streamline the debugging process.

Control of motors, claws, and sensors are performed in loops within the Arduino language as such:

Figure 13: Motor Controllers

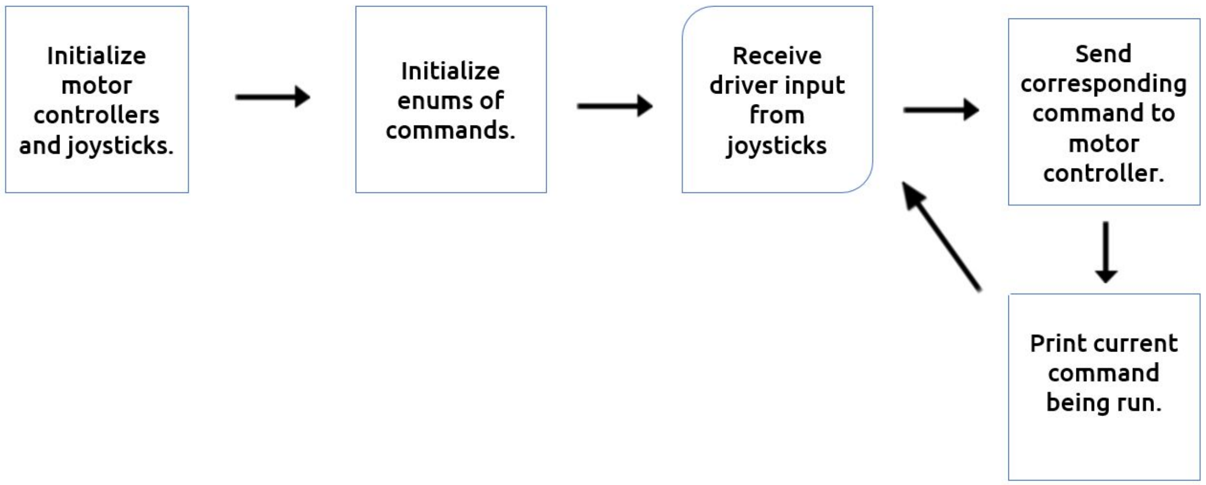


Figure 14: Claw Control

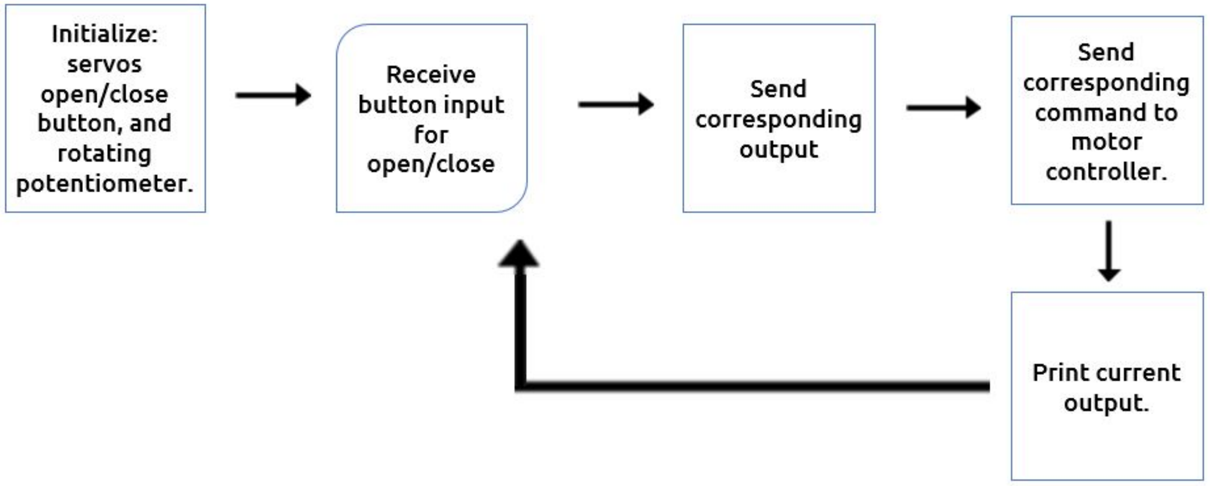
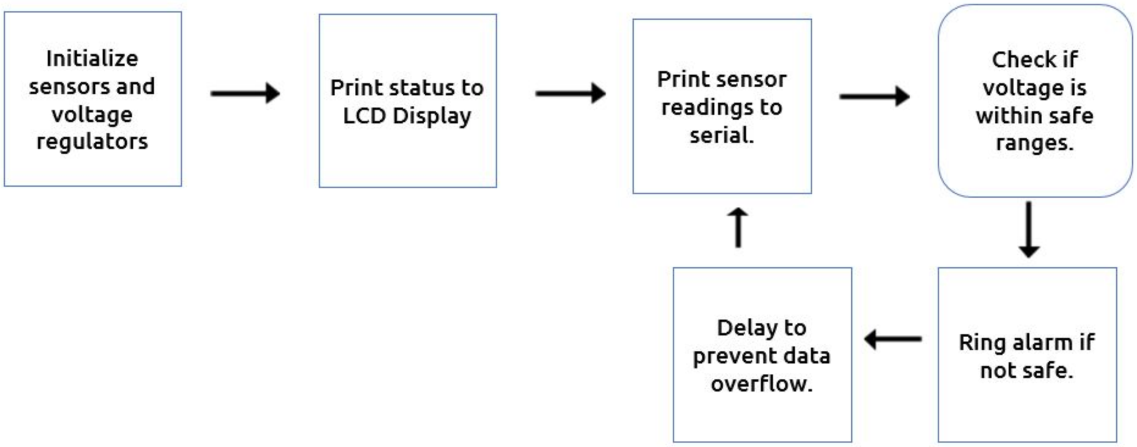
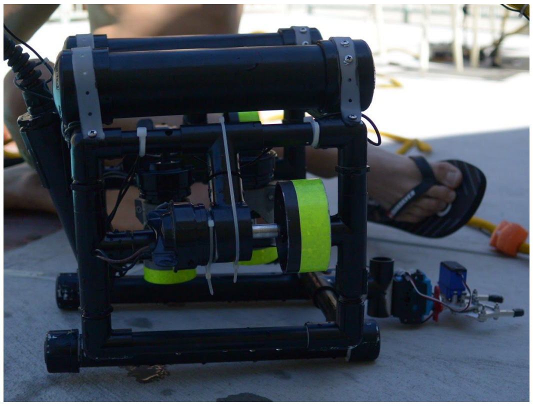


Figure 15: SmartSystem (and sensors)



D. Buoyancy

Figure 16: *Buoyancy Tubes*



Buoyancy

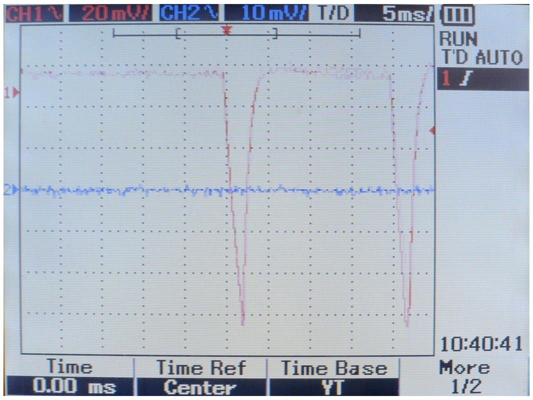
45C Robotics has successfully integrated neutral buoyancy into the *Triton VI*. Neutral Buoyancy is very important in controlling the movement of the ROV. This is especially important at the end of task 2, where the ROV has to disconnect a power cord. Without neutral buoyancy the pilot would have to continually reposition the robot which decreases accuracy and efficiency. Placed above the ROV are PVC/ABS-constructed ballasts. Skids are also located at the bottom of the robot are weights to account for the heavier distribution of weight located primarily at the top of the robot.

E. Troubleshooting

Figure 17: *Testing ROV at Pool Deck*

45C conducts several small-scale tests on different aspects of *Triton VI* to isolate and identify problems with the robot. In debugging the Arduino code, the software team goes through individuals lines of code and identifies its relation with the rest of the program to isolate the bug. The electrical team uses a current limiter and monitor to avoid electrical shorts or component overloads.

Figure 18: *Graph from a Failed Servo*

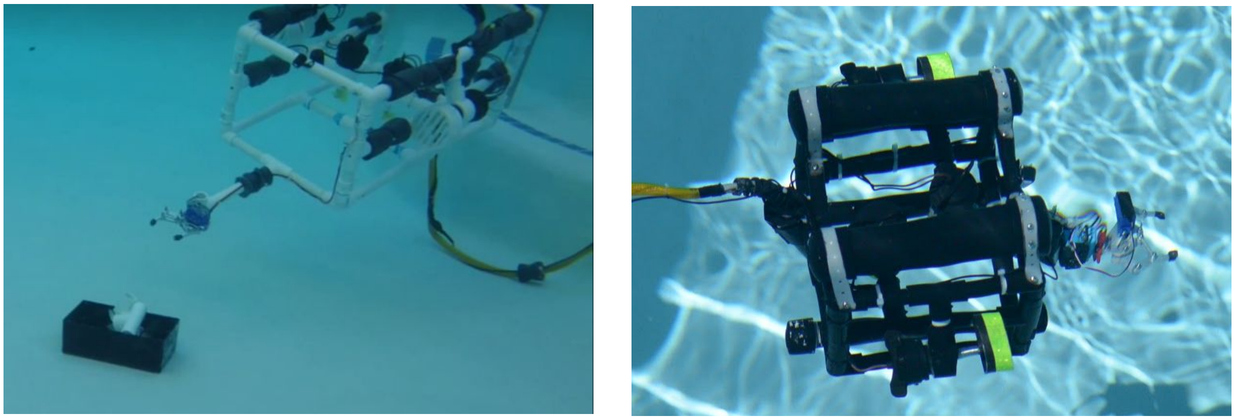


45C Robotics used an oscilloscope to determine the amount of sudden voltage drop of electrical components that have failed. By analyzing the voltage drops, the electrical team can determine the current draw of the components that have failed and decide whether the malfunctioned part needs to be replaced. The spike in voltage can also help determine if the component needs a filtering circuit to reduce the voltage spike.

F. Evolution of the Robot

Since its inception as Triton V at the start of this year's building season, 45C Robotics has refined its robot using test-driven development to maximize performance.

Figure 19, 20: Progression of the robot throughout two phases (from left to right): Triton V (phase one of this year's building season), and the Triton VI (the finalized robot for this year's competition).



Management

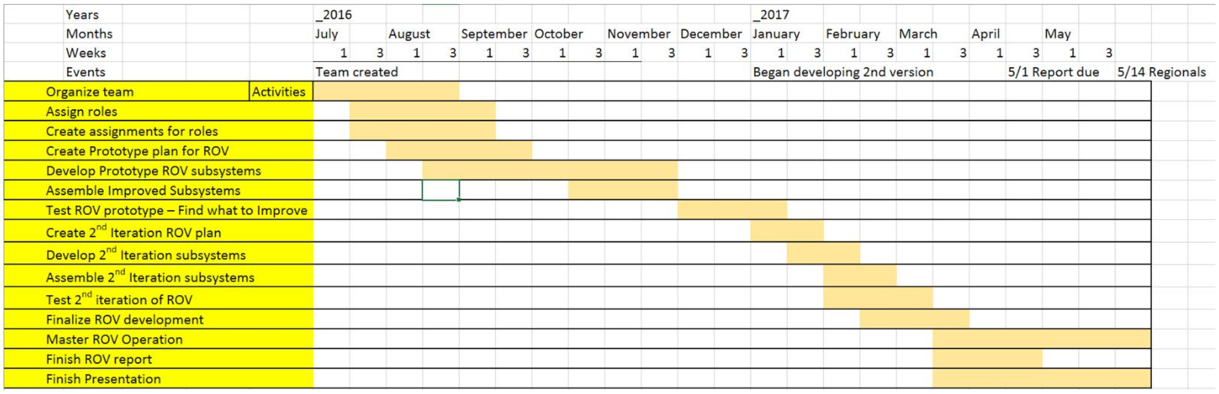
A. Company Organization

45C Robotics compartmentalizes its members into self-chosen subteams for optimize efficiency. Members are divided into: mechanical, electrical, programming, and design subteams. Each team performs specific tasks to develop the robot.

B. Project Management

Work is delegated by the CEO onto subteam leads and reported back according to set deadlines. In order to complete project objectives on time, a Gantt chart was used to enforce guidelines on expectations of task deadlines. Figure 20 shows the Gantt Chart used throughout the year for the robot's production.

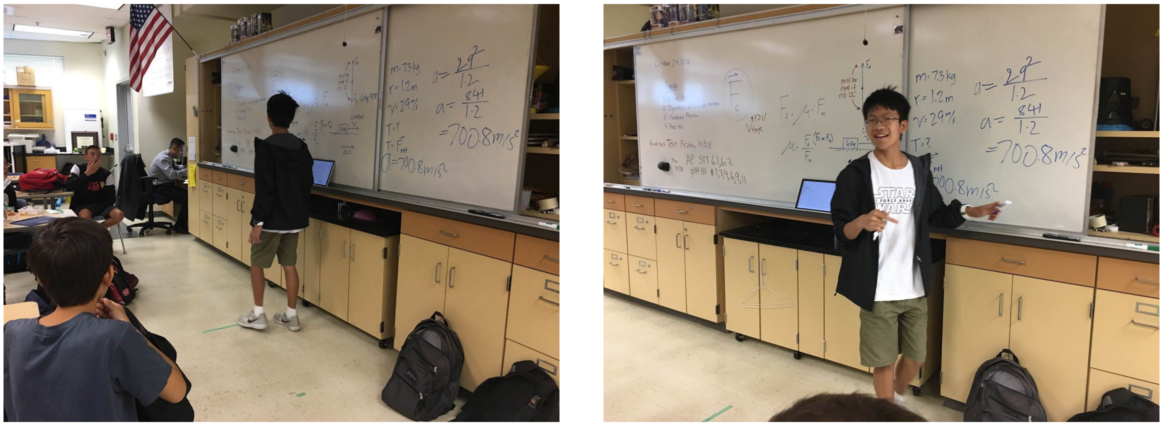
Figure 21: *Gantt Chart*



Years		_2016												_2017										
Months		July		August		September		October		November		December		January		February		March		April		May		
Weeks		1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	
Events		Team created												Began developing 2nd version							5/1 Report due			5/14 Regionals
Organize team	Activities	▨	▨	▨	▨																			
Assign roles			▨	▨	▨	▨																		
Create assignments for roles			▨	▨	▨	▨																		
Create Prototype plan for ROV				▨	▨	▨	▨																	
Develop Prototype ROV subsystems					▨	▨	▨	▨	▨	▨	▨													
Assemble Improved Subsystems									▨	▨	▨													
Test ROV prototype – Find what to Improve												▨	▨	▨										
Create 2nd Iteration ROV plan														▨	▨									
Develop 2nd Iteration subsystems															▨	▨								
Assemble 2nd Iteration subsystems																▨	▨							
Test 2nd iteration of ROV																▨	▨	▨						
Finalize ROV development																	▨	▨	▨					
Master ROV Operation																			▨	▨	▨	▨	▨	▨
Finish ROV report																			▨	▨	▨			
Finish Presentation																			▨	▨	▨	▨	▨	▨

C. Outreach and Community Training

As part of its mission and community values, 45C Robotics also works to empower and educate other students. 45C educates students at the California Academy of Mathematics and Science on important concepts which are not taught in a classroom setting. Such topics include: electronics, mechanical design, and programming.



Figures 22, 23: *Jiajer Ho (CEO) teaching students the basic principles of electricity.*

D. Budget and Project Costing

2017 was 45C Robotics' first year of competition and our team did not have the reputation needed for sponsorships. Therefore the team was required to seek creative methods to control expenditures.

To estimate the amount of money needed to build the robot, the team considered the necessary funding for all components of the competition. The 2017 International Competition is set to take place in a location close to all members of the 45C team, so no money was allocated for travel which reduced budget costs. 45C also chose to forgo machined parts in place of cheaper parts, establishing $1000 as a sufficient budget for the construction of the entire robot.

This year's expenses totalled a mere $65.11 due in part being able to secure reused and donated services as well as parts. A GoFundMe campaign created for the robot generated $155.08, further reducing the out-of-pocket contribution required from each team member. The value of donated and reused parts was $276.40 with a total ROV cost of $500.51, making the Triton VI inexpensive yet effective for completing all of this year's tasks.

Conclusions

A. Challenges

The main challenge 45C Robotics faced was to successfully waterproof the claw gripper servo motor. The Triton VI utilizes 2 servo motors for the claw gripper and each servo needs to withstand the high pressure of water from the depth of the pool. The servo motor 45C Robotics used was designed to have a water resistance rating of IP56. For an ROV, the IP rating must be IP68 or higher for the servos to work properly. 45C Robotics used various methods of waterproofing. However most methods failed or impaired the servo's performance. After many water ingestion tests, 45C Robotics chose to use lithium based marine grease to waterproof the servos due to its highest waterproofing ability along with a cheap cost. When applied to the gasket of the servo motor, the marine grease will repel the water providing the servo motor an IP rating of at least 68.

In order to insure efficiency of Triton VI's smart system, 45C Robotics required a fast computing system that can perform multiple tasks simultaneously. 45C Robotics originally attempted to use an Arduino Mega microcontroller for all of the Triton VI's computing needs, but quickly ran into a few problems.The first problem was the constant delay caused by the Smart System program when checking for errors. This delay inhibited the motor's ability to work efficiently every 200 milliseconds. Additionally, the overloading amounts of data from the sensors increased the delays experienced with the Arduino Mega. After months of testing with a variety of circuit designs, 45C Robotics developed a unique circuit design. The final design consists of 2 different arduino microcontrollers, each responsible for performing a certain task. They are also programed to communicate with each other if errors are detected. The first microcontroller is an Arduino Uno, which is responsible for handling the motor controller and the joystick controls. The second microcontroller is an Arduino Nano, which houses the smart system program and the claw gripper code for the servo motors.

Communication and distribution of tasks also proved to be a critical challenge for the efficiency of the team. 45C Robotics divided itself into subteams to distribute work pertaining to specific aspects of the robot to each of these subgroups. The mechanical subteam is responsible for the assembly and placement of the physical components of the ROV. The electrical subteam developed the electrical system for *Triton VI* and worked to minimize the amount of errors due to wiring. The programming subteam is responsible for programming the code running on the Arduinos. By dividing the members of 45C Robotics into subteams based on their abilities and skills, the production of the robot was manufactured at a more efficient rate.

B. Lessons Learned

Software engineers learned to regularly use and update code onto GitHub to be able to review and restore past versions of the robot code, thereby saving time as of a result of the team being able to access previous versions of the code and improve current code. Electrical engineers learned how to separate the Arduino microcontrollers in order have Triton VI respond faster to commands. Mechanical engineers learned how to 3D print a CAD model and how resin can be used to reinforced the structure of 3D printed objects.

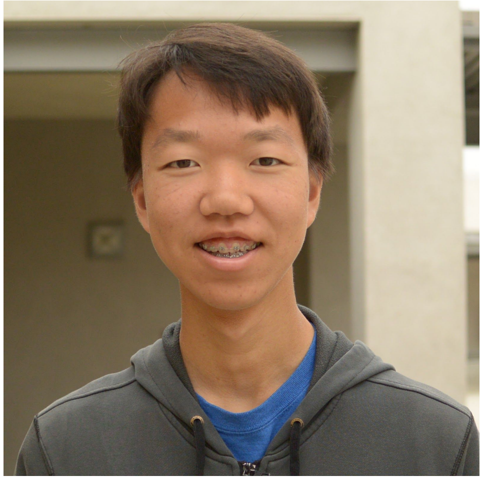
C. Future Improvements

Future improvements of the Triton VI include the use of onboard electronics. By having onboard electronics, the setup of the control box can be much simpler and the amount of the tether wires can be significantly reduced. Furthermore, the design of the frame should be finalized in the beginning instead of changing the design in the middle of the building season. More research should be conducted on motor controllers and various other electronics, saving valuable time that could instead be used for ROV testing.

D. Reflections

“During this past year with 45C Robotics, I've gained skills that I'll use in the real workplace, and made lifelong friends with my teammates. For instance, I've learned the skills I need to become an electrical engineer through the hardware development of our control box. I've learned which sensors to use in specific situations and how to use input signals to control the robot. My experience in ROV has taught me lessons I'll never forget.”

- **Jiajer Ho, CEO and Electrical Lead**

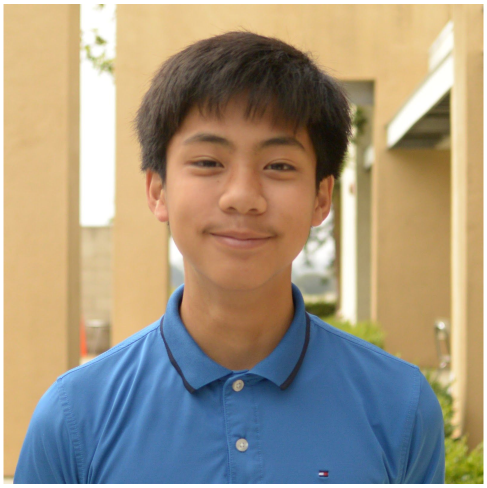


“This is my second year doing ROV and I've learned a lot from my experience, including both technical and life lessons. By being in ROV, some of the technical things I've learned include good software organization, test-driven development, and how to adapt different sensors to underwater use. I've also learned the importance of good teamwork. Everyone has to be on the same page for a team to work efficiently and effectively, and I think our team really showcased that throughout our ROV build season. I'm proud of what our team has accomplished, and will never forget this experience.”

- **Ted Lin, Software Engineer Lead**

“Even though this has been my first year with 45C Robotics, I feel like I’ve grown very close with everyone on the team. The process of building the ROV has been full of ups and downs, and we’ve stuck together through it all. I’ve learned a lot about programming and electronics this year, and I’m so thankful for the experiences, friendships, and skills I’ve been able to build by being a part of this team.”

- **Isaac-Neil Zanoria, Electrical and Software Engineer**



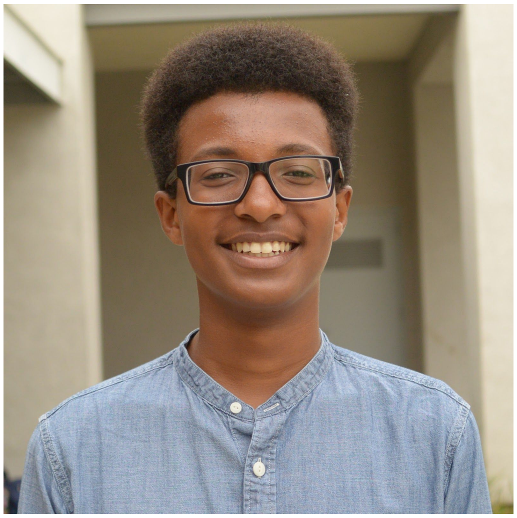
“This has been a great year in participating for the MATE ROV competition. I have learned a lot going from this year. I have learned that the most important part of the competition is practice and confidence. In order to perform well, each task must be practiced many times in order to master it. I have learned that in, order to be able to perform at your full potential, a lot of work must be put into the final product.”

- **Brad Biscocho, Mechanical Engineer**

“I have learned a lot through my experiences in 45C. Being in 45C Robotics has taught me many lessons that I couldn’t have learned outside. Through the struggles I have overcome together with my teammates, I have truly learned to be patient and have confidence in whatever I am doing, whether it be circuit designing or technical debugging. Nevertheless, I am thankful for this experience, regardless of our results at competition.”

- Celia Yu, Mechanical Engineer

“In my past year with 45C Robotics, I have learned equally as much engineering techniques as general techniques which improve the quality of the decision-making process. One of the most important of these that I have learned is the importance of creative thinking in all decisions. The team has directly taught me that: as more ideas are considered for the solution of a particular problem, the better the solution will likely be. In addition, 45C has taught me communication and organizational skills. ROV has taught me how to work efficiently with other members in a team, a skill that I will be able to carry onto other disciplines in life.”’



- **Isaac Addis, Design Lead and Technical Report Writer**

“Teamwork, was an essential lesson that I obtained by working in unison with my team in 45C Robotics. I obtained and further extended my knowledge in robotics electronics and in engineering techniques. We were able to efficiently and effectively execute multiple tasks simultaneously to improve our productivity and create our Triton VI. Personally, I enjoyed this experience with my team more than my previous years in robotics due to the team unity and team support.”**- Jesse Leal, Technical Report Writer and Mechanical Engineer**

“Spending time with my teammates was a both entertaining and educational. I learned how to have fun even under stress and make everyone laugh. Although this was only my first year I learned a lot and I’m glad our team has been performing wonderfully.”
- Kentaro Vadney, Lead CAD Engineer

Appendix

A. System Interconnect Diagrams

Figure 24: *Triton VI System Interconnect Diagrams*

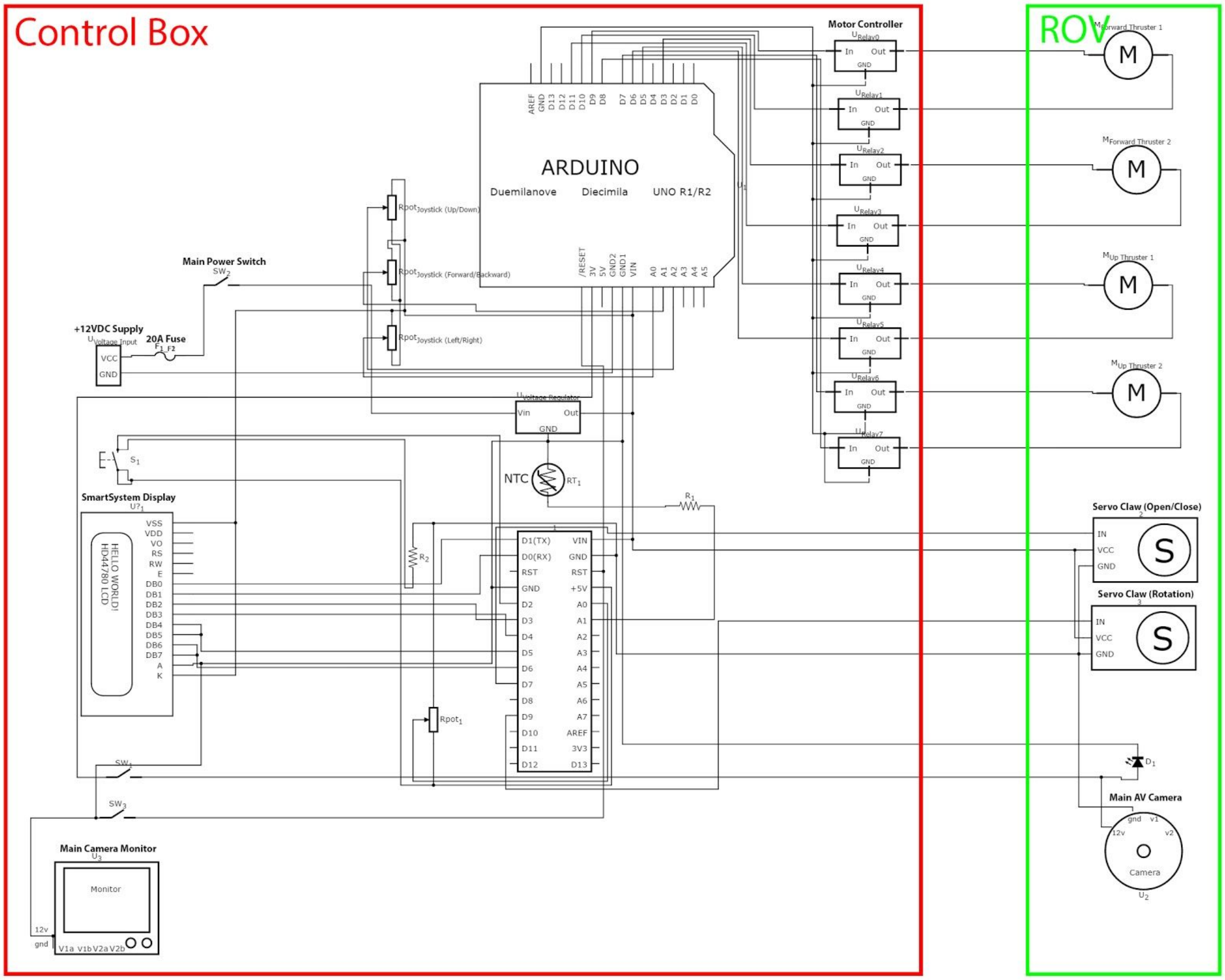
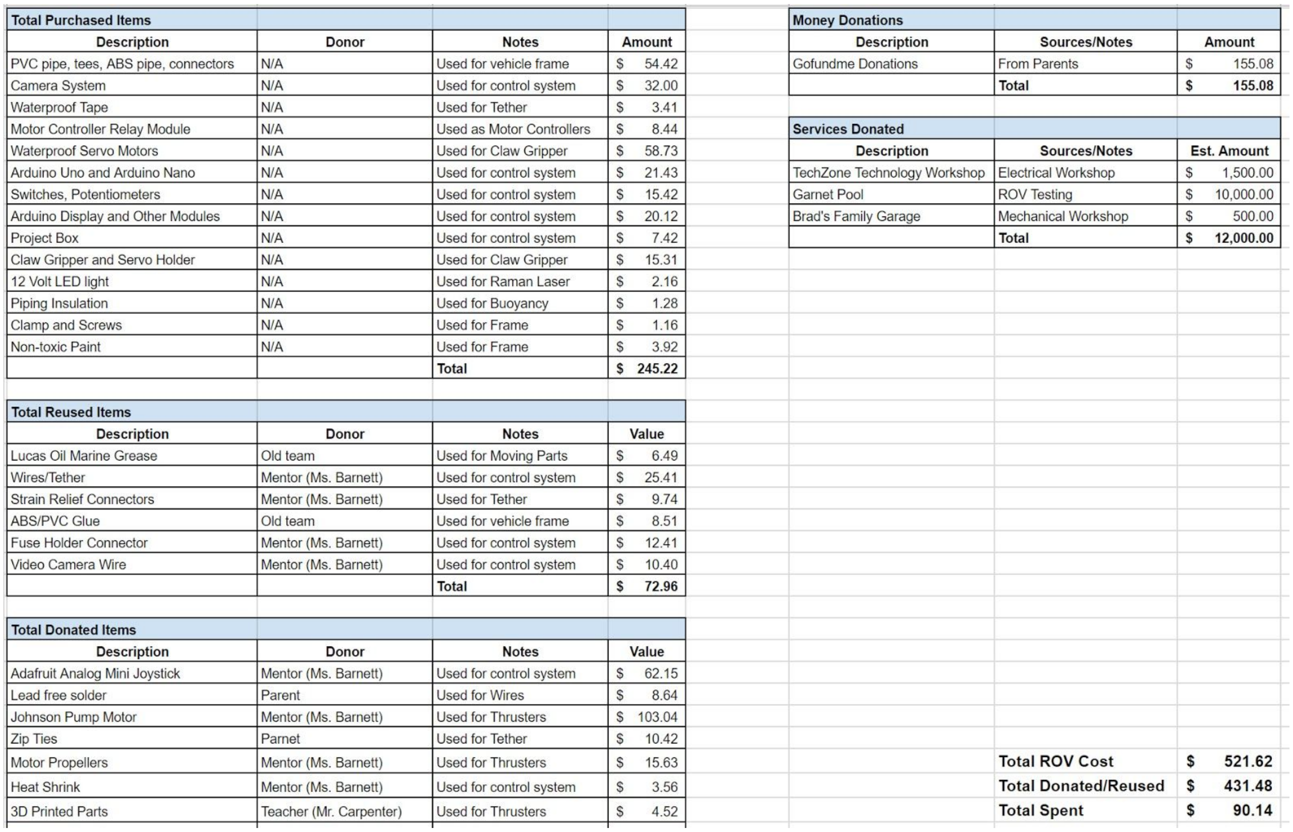


Figure 25: *Fuse Calculations*

Fuse Calculations			
Component	**Current Draw**	**Quanity**	**Total**
Thrusters	2.7	4	10.8
Servo	0.6	2	1.2
Camera	0.12	1	0.12
Monitor	0.15	1	0.15
Relays	0.02	8	0.16
LED Lights	0.02	1	0.02
Arduinos	0.01	2	0.02
Total Current	**12.47**		
Current * 150%	**18.705**		
Fuse Needed	**20 A**		

B. Budget Sheet

Figure 26: *Total expenditures and incomes throughout the production of Triton VI.*



Total Purchased Items			
Description	**Donor**	**Notes**	**Amount**
PVC pipe, tees, ABS pipe, connectors	N/A	Used for vehicle frame	$ 54.42
Camera System	N/A	Used for control system	$ 32.00
Waterproof Tape	N/A	Used for Tether	$ 3.41
Motor Controller Relay Module	N/A	Used as Motor Controllers	$ 8.44
Waterproof Servo Motors	N/A	Used for Claw Gripper	$ 58.73
Arduino Uno and Arduino Nano	N/A	Used for control system	$ 21.43
Switches, Potentiometers	N/A	Used for control system	$ 15.42
Arduino Display and Other Modules	N/A	Used for control system	$ 20.12
Project Box	N/A	Used for control system	$ 7.42
Claw Gripper and Servo Holder	N/A	Used for Claw Gripper	$ 15.31
12 Volt LED light	N/A	Used for Raman Laser	$ 2.16
Piping Insulation	N/A	Used for Buoyancy	$ 1.28
Clamp and Screws	N/A	Used for Frame	$ 1.16
Non-toxic Paint	N/A	Used for Frame	$ 3.92
		Total	**$ 245.22**

Total Reused Items			
Description	**Donor**	**Notes**	**Value**
Lucas Oil Marine Grease	Old team	Used for Moving Parts	$ 6.49
Wires/Tether	Mentor (Ms. Barnett)	Used for control system	$ 25.41
Strain Relief Connectors	Mentor (Ms. Barnett)	Used for Tether	$ 9.74
ABS/PVC Glue	Old team	Used for vehicle frame	$ 8.51
Fuse Holder Connector	Mentor (Ms. Barnett)	Used for control system	$ 12.41
Video Camera Wire	Mentor (Ms. Barnett)	Used for control system	$ 10.40
		Total	**$ 72.96**

Total Donated Items			
Description	**Donor**	**Notes**	**Value**
Adafruit Analog Mini Joystick	Mentor (Ms. Barnett)	Used for control system	$ 62.15
Lead free solder	Parent	Used for Wires	$ 8.64
Johnson Pump Motor	Mentor (Ms. Barnett)	Used for Thrusters	$ 103.04
Zip Ties	Parnet	Used for Tether	$ 10.42
Motor Propellers	Mentor (Ms. Barnett)	Used for Thrusters	$ 15.63
Heat Shrink	Mentor (Ms. Barnett)	Used for control system	$ 3.56
3D Printed Parts	Teacher (Mr. Carpenter)	Used for Thrusters	$ 4.52

Money Donations		
Description	**Sources/Notes**	**Amount**
Gofundme Donations	From Parents	$ 155.08
	Total	**$ 155.08**

Services Donated		
Description	**Sources/Notes**	**Est. Amount**
TechZone Technology Workshop	Electrical Workshop	$ 1,500.00
Garnet Pool	ROV Testing	$ 10,000.00
Brad's Family Garage	Mechanical Workshop	$ 500.00
	Total	**$ 12,000.00**

Total ROV Cost	**$ 521.62**
Total Donated/Reused	**$ 431.48**
Total Spent	**$ 90.14**

C. Safety Checklist

Pre-Start Checklist

Vehicle Inspection:

Inspect for sufficient grease on all moving parts
Inspect/secure all shafts
Tighten all propellers
Insure the frame is securely attached

Tether and Tether Management Subsystem:

Inspect the tether for visible damage
Insure the tether cable is neatly coiled
Insure proper connection from the ROV to the control box

Electrical Subsystem:

Insure all fuses are installed properly
Insure plug connectors are secure
Insure correct polarity are in the plug

Safety Inspection:

Verify the location of first aid kits, fire extinguishers and other safety equipment
Verify that the risk management plan developed earlier has been fully implemented

Start-Up Checklist

Request for start-up clearance

Battery main toggle switch ……………..……………………......…….….………….ON
Alarm test ……………………………....…..………...Press and Hold for 3 seconds
Main camera lights …………………………..………..………….....…...As required
Raman Laser……………………………....…………..………….……………...Checked
Video Signal ………..…………………….………..Checked
Claw servo (OPEN/CLOSE, ROTATE) ….……...…....…………….………..….Checked

Thrusters Start-Up Checklist

Request for main thrusters start-up

Thrusters selector switch ………………………………..…………………….….... ON
Test all main thrusters ....……………….……………………………......…….……Checked
Test all joystick input commands ....…….…..……………......……......……….….Checked

Request for ROV dive

Shutdown Checklist

Request for ROV shutdown

Main camera lights …………………………….…………………………........ OFF
Raman Laser………………………….……………………….….….………...OFF
Claw servo (OPEN/CLOSE) ……………...…………………………………..... Open
Claw servo (ROTATION) ……………......……………………………...….…. Horizontal
Reset button ……………………....…………….………… Press and Hold for 3 seconds
Thrusters selector switch ……………….....………………………………...……… OFF

Go to Recovery Checklist

Recovery Checklist

Request for ROV Recovery

Position ROV close to the deck, then pull the tether slowly recovering the ROV.

Thruster Failure Checklist

Report thruster failure number

Rest button ……………………………………...….…Press and Hold for 5 seconds

*If thruster continues to fail, **request emergency mission abort and follow the checklist below***

Battery main toggle switch ………………………………………...….....………OFF

Go to Emergency Recovery Checklist

Emergency Fire/Alarm Checklist

*If **smoke or spark** is visible on **ROV control box** and/or the “03 OVERHEAT” is displayed on the smart system, please follow the checklist below.*

Battery main toggle switch ……….....……………………………...….....………OFF

If smoke still persists outside of the control box, disconnect battery and place it at least 30 feet away from the control box and the ROV vehicle.

In case of flameover of the control box, use a class C or carbon dioxide fire extinguisher.

*Insure smoke is **significantly reduced** and at least **15 minutes has passed** since emergency battery disconnection. **Go to Emergency Recovery Checklist***

Emergency Recovery Checklist

Request for Emergency ROV recovery

Move the ROV close to the deck and then pull the tether slowly.

Conclusion Sheet

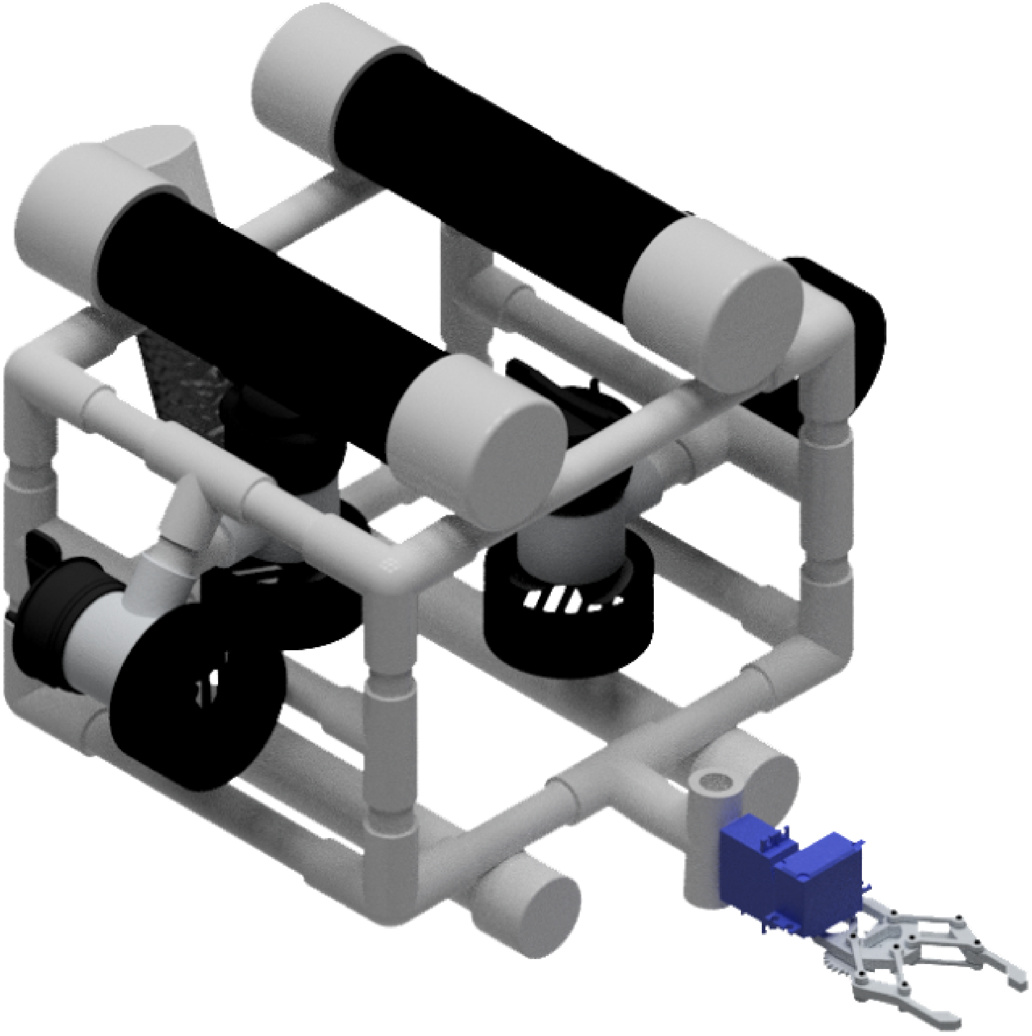


Figure 27: *3D CAD Model of Triton VI.*

Dimensions: 26.67 cm x 31.75 cm x 21.27 cm

Weight: 8.4 Kg

Total Cost: $521.62

Acknowledgments

45C Robotics would like to thank:

- Marine Advanced Technology Education (MATE) for hosting and supporting STEM programs
- The City of Long Beach for hosting the regional competition in Southern California
- Ben Lee and Amar Patel for gofundme donations
- Garnet Pool for ROV testing purposes
- Joseph Carpenter for 3D printing technical expertise
- CAMS for equipment lending and material donations
- Sandra Barnett for material donations and aid in organization
- All the volunteers and staff at the Long Beach Regional event

References

- Thone, Steve. "Homebuilt Rovs". *Homebuiltrovs.com*. N. p., 2017. Web. 23 Apr. 2017.
- "MATE - Marine Advanced Technology Education :: Home". *Marinetech.org*. N. p., 2017. Web. 23 Apr. 2017.
- "Blue Robotics - ROV And Marine Robotics Systems And Components". *Blue Robotics*. N. p., 2017. Web. 23 Apr. 2017.
- "Arduino Forum - Index." *Arduino Forum - Index*. N.p., n.d. Web. 23 May 2017.